The Significance of Oral Inflammation in Elite Sports: A Narrative Review

Authors

Cordula Leonie Merle[1, 2], Jan C. Wuestenfeld[3, 4], Fabian Fenkse[5], Bernd Wolfarth[3, 4, 5], Rainer Haak[2], Gerhard Schmalz[2], Dirk Ziebolz[2]

Affiliations

1 Department of Prosthetic Dentistry, Universitätsklinikum Regensburg, Regensburg, Germany
2 Department of Cariology, Endodontology and Periodontology, University of Leipzig Faculty of Medicine, Leipzig, Germany
3 Department of Sports Medicine, Institute for Applied Scientific Training, Leipzig, Germany
4 Department of Sports Medicine, Charité University Medicine, Berlin, Germany
5 Department of Oral, Craniomaxillofacial and Facial Plastic Surgery, University of Leipzig Faculty of Medicine, Leipzig, Germany

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70469 Stuttgart, Germany

Correspondence

Dr. Cordula Leonie Merle
Universitätsklinikum Regensburg, Department of Prosthetic Dentistry, Franz-Josef-Strauss-Allee 11
93053 Regensburg
Germany
Tel.: +4994194411910
cordula.merle@klinik.uni-regensburg.de

ABSTRACT

Recently, there has been intense discussion about sports dentistry and potential interactions between oral health and athletes' performance. This narrative review aims to provide a comprehensive overview of the available literature about oral inflammation in sports. For this purpose, it presents the most common types of oral inflammation (gingivitis, periodontitis, pericoronitis, apical periodontitis), and their prevalence in athletes. Both the impact of oral inflammation on performance and causes for oral inflammation in athletes are discussed by presenting current literature. Finally, international recommendations for dental care in sports are presented. Several studies stated a high prevalence of oral inflammation in athletes, especially of gingivitis (58–97 %) and periodontitis (41 %). Also, many athletes report oral pain (17–30 %) and a negative impact of oral health on training (3–9 %). Besides this, a systemic impact of oral inflammation is discussed: In periodontitis patients, blood parameters and physical fitness are changed. In athletes, associations between muscle injuries and poor oral health are reported. There are deficits in oral health behavior. Furthermore, systemic changes due to physical stress could influence oral tissues. Overall, complex bidirectional interactions between competitive sports and oral inflammation are possible. Regular dental examinations and prevention strategies should be implemented in sports.

Introduction

The negative influence of acute toothache on top athletic performance is considered generally obvious and has been described in sporadic publications [1]. Moreover, oral diseases can interact with the entire body system. Although the relevance for professional sports must still be determined, there is a potential risk of a negative influence on performance [2]. Accordingly, oral health should play a role in professional sports. However, a high prevalence of oral inflammation was stated in elite athletes [1, 3, 4]. Based on existing data, neither Olympic athletes [3, 5] nor athletes in well-sponsored sports, e. g., soccer [6], seem to receive adequate dental care [6].

▶ **Table 1** Survey of the most frequent types of oral inflammation including symptoms, potential influence on performance, and approaches for therapy and prevention.

	Gingivitis	Periodontitis	Pulpitis/Periodontitis apicalis	Pericoronitis
Symptoms	Bleeding, swelling, pseudo pockets	Pocket formation, bone loss	Toothache	Pain, swelling, sometimes fever
Systemic influence (performance or regeneration)	+	+ + +	+ +	+ +
Possible causes for missing training/ competition	–	(+)	+ +	+ +
Therapy	Prophylaxis, antiseptic mouth wash, improved intense individual oral hygiene	Repeated prophylaxis, periodontal therapy with subgingival cleaning	Root canal treatment, pain medication if applicable	If applicable, pain medication, local anti-inflammatory therapy, recess removal by removal of soft tissue or wisdom tooth
Prevention	Adequate oral hygiene, individual preventive dental care	Regular screening, individual preventive dental care	Regular dental examinations, especially presentation after traumata	Regular clinical and radiological evaluation of the situation, removal of wisdom teeth if applicable

+ The number of plus signs presents the probability from + for possible up to + + + for very likely. – A minus sign signifies unlikelihood.

Up to now, the reasons for the deficiencies in oral health in elite athletes have not been fully understood. On the one hand, physical stress and accompanying parameters could influence oral health behavior leading to effects on oral health status. On the other hand, physical stress itself could have direct effects on oral tissues. Owing to their prevalence and potential systemic interactions, inflammatory oral diseases have special importance in this respect [7].

The aim of the present review is an overview of the most common types of oral inflammation, their prevalence, significance for performance, and causes in elite athletes. Possible mechanisms of bidirectional interaction between competitive sports and oral health will be presented.

Types of oral inflammation (▶ Table 1, ▶ Fig. 1)

Inflammation of tissues around teeth, e. g., gingivitis, is common, affecting more than 90 % of the global population [8, 9]. The most common type is dental plaque biofilm-induced gingivitis (▶ **Fig. 1a–c**), which affects the gingiva only. This non-specific inflammatory condition is caused by accumulated plaque biofilm at and below the gingival margin [10]. The typical clinical signs are erythema, edema, bleeding (especially during tooth brushing), and enlargement, but usually no pain [10]. This disease is fully reversible after biofilm removal [11]. It is known that systemic conditions such as pregnancy and micronutrient deficiencies can favor this type of oral inflammation [11].

Gingivitis is a prerequisite for periodontitis [11]. Persistent gingivitis can progress into inflammation of the entire periodontium (the tooth-supporting tissues) (▶ **Fig. 1d–f**) [12–14]. While approximately only 1.7 % of the population aged up to 25 years is affected [15], more than 50 % of the population aged 35 to 44 and 90 % of older adults experience periodontitis [16]. Severe developments are estimated to affect 5 to 15 % of the global population [8]. Today, periodontitis is considered a multifactorial and primarily polybacterial opportunistic infectious disease of the periodontium [17, 18]. The clinical manifestation of the disease covers a depth proliferation of the gingival pockets and ulceration of the dental epithelium, resulting in a reduction of periodontium and bone (so-called attachment loss). Chronologically, periodontitis is accompanied by an increasing accumulation of potentially periodontopathic bacteria (subgingival biofilms). The versatile interactions between biofilms and hosts play a key role. The transition from periodontal health to periodontitis is marked by imbalances in the biofilm (ecologic shift, dysbiosis) and subsequent between the host and biofilm (immunological disbalance) [17]. The dysbiotic state includes an increase in gram-negative, obligatory anaerobic microorganisms such as *Porphyromonas gingivalis*, *Tanerella forsythia,* and *Treponema denticola* [19]. They undermine the immune defense of the host by different virulence factors and cause inflammatory reactions [20]. The induced (partly overactive) immune reaction influences connective tissue metabolism and bone metabolism [20]. Alveolar bone degradation with the formation of gingival pockets leads to the typical clinical picture of periodontitis. In cases with continuing progression, tooth mobility and tooth loss may occur. Usually, the disease is free of pain. Nevertheless, the resulting inflammatory surface can reach a considerable surface of more than 2,000 mm^2 [21].

Another type of oral inflammation that may occur around partially erupted teeth is pericoronitis (▶ **Fig. 1g–j**). Plaque retention and food impact favor the inflammation of the tissue around the tooth crown [22]. The breakthrough of wisdom teeth is expected in their late teens or early 20s. In many people, there is not enough space for wisdom teeth, or they are dislocated and thus cannot grow in the normal dentition. Therefore, approximately 25 % of the adult population is diagnosed with impacted wisdom teeth [23]. Approximately 5 % experience pericoronitis, especially at ages 21 to 25 [24]. While chronic pericoronitis (83 %) generally has a subclinical development, subjects with acute pericoronitis (12 %) suffer severe pain, distinct swelling, and general symptoms such as fever or even spreading of the inflammation, e. g., abscesses. Symptomatic pericoronitis can affect oral functions such as nutrition as well as lifestyle and sleep [25].

▶ **Fig. 1** Clinical and radiographic impressions of different types of oral inflammation: Gingivitis (**a**–**c**), (marginal) periodontitis (**d**–**f**), pericoronitis (**g**–**j**), apical periodontitis (**k**–**n**). **a**–**c**) Gingivitis: Redness and swelling (S) of the gingiva indicate acute inflammation and probing or even toothbrushing often results in bleeding (**b**, **c**). Note the causal dental plaque-biofilm (B) at the gingival margin and the dental calculus (C). **d**–**f**) (Marginal) Periodontitis: The inflammation of the tooth-supporting tissues (periodontium) leads to its destruction. The resulting attachment loss is clinically visible as resulting recessions (R) with exposed root surfaces (**d**, **f**). The corresponding radiography (**e**) allows the evaluation of the extent of the interdental bone loss. **g**–**j**) Pericoronitis: Remaining tissue partially covers the wisdom tooth (W) and leads to a niche (**g**). The corresponding radiography (**h**) shows a correct vertical position but an anatomic position in the ascending part of the mandibula. Also, a clinical unerupted wisdom tooth (W) can lead to niche and subsequent inflammation (**i**). The radiography (**j**) shows the connection to the oral cavity and an angular dislocation that inhibits the eruption. **k**–**n**) Apical periodontitis: The typical radiographic manifestation of chronic apical periodontitis (**k**) shows a clearly visible periapical bone lesion (L). After dental trauma, apical resorption (D) can occur (**l**). An intraoral visible fistulae (F) drainages pus from an exacerbated apical inflammatory process (**m**). The radiography (**n**) shows resorption (D) of the root apex of the tooth with insufficient root canal treatment. Source for ▶ **Fig 1d**: Dr. Elena Günther. Source for ▶ **Fig 1g** and ▶ **Fig 1m**: Tilman Riemer.

▶ **Table 2** State of oral inflammation in elite athletes including prevalences according to published contemporary data (time of evaluation not before the year 2003). Data from dental clinics during competitions were excluded due to high selection bias.

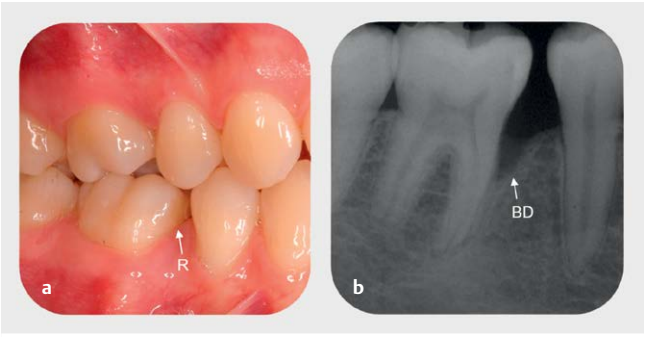
State of oral inflammation in elite athletes			
Oral inflammation	**Prevalence**	**Cohort**	**References**
Gingivitis			
Gingival bleeding (self-reported)	30–60 %	Professional soccer players, elite athletes in Great Britain, endurance athletes from German perspective, and youth squads	Gay-Escoda 2011 [6], Gallagher et al. 2018 [29], Merle et al. 2022 [31]
Signs of gingivitis (PSI score 1 or 2)[a]	60–97 %	Elite athletes in Great Britain, Dutch candidates for the Olympic Games 2016, endurance athletes from German perspective, and youth squads	Needleman et al. 2016 [30], Gallagher et al. 2018 [29], Kragt et al. 2019 [3], Merle et al. 2022 [31]
Gingivitis (no detailed definition)	58–64 %	Professional rugby players, Dutch candidates for the Olympic Games 2016, endurance athletes from German perspective, and youth squads	Minty et al. 2018 [41], Kragt et al. 2019 [3], Merle et al. 2022 [31]
Periodontitis			
Signs of periodontitis (PSI score 3 or 4)[a]	5–40 %	Elite athletes in Great Britain, Dutch candidates for the Olympic Games 2016, endurance athletes from German perspective, and youth squads	Needleman et al. 2016 [30], Gallagher et al. 2018 [29], Kragt et al. 2019 [3], Merle et al. 2022 [31]
Periodontitis[b] • Stage I • Stage II • Stage III	41 % • 32 % • 5 % • 5 %	Professional soccer players	Botelho et al. 2021 [4]
Pericoronitis			
Problems with wisdom teeth (self-reported)	14–23 %	Elite athletes in Great Britain	Needleman et al. 2016 [30], Gallagher et al. 2018 [29]
Acute pericoronitis	1–3 %	Elite athletes in Great Britain	Needleman et al. 2016 [30], Gallagher et al. 2018 [29]
Recommendation for removal of at least one wisdom tooth	22 %	Dutch candidates for the Olympic Games 2016	Kragt et al. 2019 [3]
Other inflammation			
Need for root canal treatment	2–24 %	Athletes in the Middle East (Qatar), Dutch candidates for the Olympic Games 2016	Knight et al. 2019 [34], Kragt et al. 2019 [3],
Open pulp, ulceration, fistula, or abscess	3–8 %	Elite athletes in Great Britain	Needleman et al. 2016 [30], Gallagher et al. 2018 [29]

[a] PSI: screening examination for periodontitis (periodontal screening index, basic periodontal examination, or Dutch periodontal screening index), score 1–2: signs of gingivitis with periodontal probing depths ≤ 3.5 mm, and bleeding on probing and/or calculus, score 3–4: signs of periodontitis with periodontal probing depths > 3.5 mm); [b] According to the case definition of the American Academy of Periodontology (AAP) and the European Federation of Periodontology (EFP) periodontitis case definition of 2018 [100].

Moreover, pulpitis (inflammation of the tooth nerve), and apical periodontitis (inflammation around the root apex of a tooth) must be mentioned (▶ **Fig. 1k–n**). Pulpitis and acute apical periodontitis can cause severe pain. Chronic apical periodontitis can involve no or only minor symptoms. In cases with exacerbation, abscesses may lead to spreading with accompanying general symptoms. Irreversible pulpitis is described in approximately 1 % of teeth [26], apical periodontitis is an issue in approximately 50 % of the adult population [27], and acute exacerbation is only present in less than 5 % [28]. Root canal treatment of the affected tooth is required to treat these conditions. These inflammations may originate from extended carious lesions but also from tooth trauma.

State of oral inflammation in athletes (▶ Table 2)

Oral health in athletes has not yet been sufficiently evaluated. Existing studies on oral inflammation in elite athletes generally show a high prevalence of gingivitis (58–97 %) [3, 5, 29, 30]. The stated prevalence of periodontitis is lower (5–41 %) [3, 5, 29–32]. When interpreting these data, it must be considered that these studies often indicate the prevalence of periodontitis, but usually used the surrogate marker necessity of periodontal treatment. The examinations were screenings (Periodontal Screening Index [33], PSI, basic periodontal examination, or Dutch periodontal screening index, score 3 or 4) that can only state the presence of increased periodontal probing depths (PPDs) and the resulting necessity of individual preventive care and periodontitis therapy where appropriate. A diagnosis of periodontitis is not possible with the collected data. Only one study provides a detailed examination of the periodontal situation: In soccer players with a mean age of 28 years, periodontitis was diagnosed in 41 % of the subjects, mainly as initial forms (32 %) (stage I with attachment loss up to max. of 2 mm) with only one case of moderate (stage II, 3–4 mm) and one of severe periodontitis (stage III, ≥ 5 mm) [4]. Clinical experience shows pronounced findings of oral inflammation even in young, generally healthy, sport-active patients (▶ **Fig. 2**). A study comparing competitive and amateur athletes allow the assumption of an increased periodontitis prevalence in young adult elite athletes [31].



▶ **Fig. 2** **a** and **b** Example of periodontal damage in young years: This young, systemically healthy, active sporting woman showed localized severe periodontitis in her early 20s. (**a**) Clinical situation with only slight signs of recession (R) mesial of 46. The external appearance may seem healthy at the first glance. A screening by probing revealed the periodontal pocket. (**b**) The radiograph shows the extent of periodontal damage: The vertical bone defect (BD) mesial of 46 reaches up to the middle of the root.

Regarding wisdom teeth-related inflammation, a total of 14 to 23 % of the athletes reported corresponding discomfort [29, 30]; up to 3 % showed clinical signs of pericoronitis, and in 22 % removal of at least one wisdom tooth was recommended [3].

Moreover, pronounced acute oral inflammation such as open pulp, ulcerations, fistulas, or abscesses were found in 3 to 8 % of elite athletes [29, 30]. Periapical infections were recorded in 12 % of athletes in the Middle East [34]. In general, they are a frequent reason for dental consultations in the Olympic Games [35–38].

For interpretation of these data, it must be considered that (partially small) cohorts in different types of sports and different countries have been evaluated. Sport disciplines show a high variety of resulting influence factors and behaviors. Differences include for example body composition and nutrition behavior [39]. The categorization in endurance, strength, contact, and team sport might provide an initial estimation. Oral health behavior, socioeconomic status, [40] and the health care system, which depend on the athlete's country of origin and the country of investigation, might have a further impact. These points limit comparability and transferability of the available studies, especially as only very few studies provide non-athletic persons or recreational athletes as a control group [31, 41, 42]. Moreover, no systematic data for older athletes (> 30 years) are available. Thus, the possible long-term consequences of competitive sports on the periodontal conditions remain unclear. Further studies in representative samples of different ages should consider different sport types and risk factors in comparison to a control group. Detailed periodontal examination should include exact diagnosis, treatment need, and periodontal inflamed surface area to allow quantification of inflammatory burden.

Impact of oral inflammation on general health

Gingival inflammation is marked by only a small area and the extent of inflammation. Therefore, an impact on general health is not expected. Nevertheless, increased values of C-reactive protein (CRP) have been detected in experimental gingivitis [43].

However, periodontal inflammation is known to be involved in numerous systemic diseases. The extent of inflammation, i. e., the resulting inflamed area, seems to presuppose the extent of the effect [44]. The interrelation appears complex and is explained by a combination of different mechanisms of direct and/or indirect causality. On the one hand, the chronic bacterial load in in presence of inflamed tissue with impaired integrity and permeability (here, the periodontium) can result in recurring bacteremia and thus have a direct bacterial impact. On the other hand, systemic inflammatory reactions can be caused by inflammation mediators that are released in the periodontium and distributed via the blood. Further biological mechanisms are cross-reactions caused by bacterial or inflammatory dysregulations of the immune defense with resulting autoaggression, and the swallowing and aspiration of bacteria [45, 46] are further biological mechanisms. Some studies found respective differences in blood parameters for patients with periodontitis, while others did not [47, 48]. However, changes in circulating blood cell profiles [32] and increasing CRP values [49] are reported by recent systematic reviews and seem to reflect the systemic inflammatory reaction. Furthermore, periodontal treatment leading to a reduction of the oral inflammation results also in improvement of these systemic effects [50, 51]. Additionally, the interrelation between periodontal inflammation and numerous general diseases is still under discussion [52].

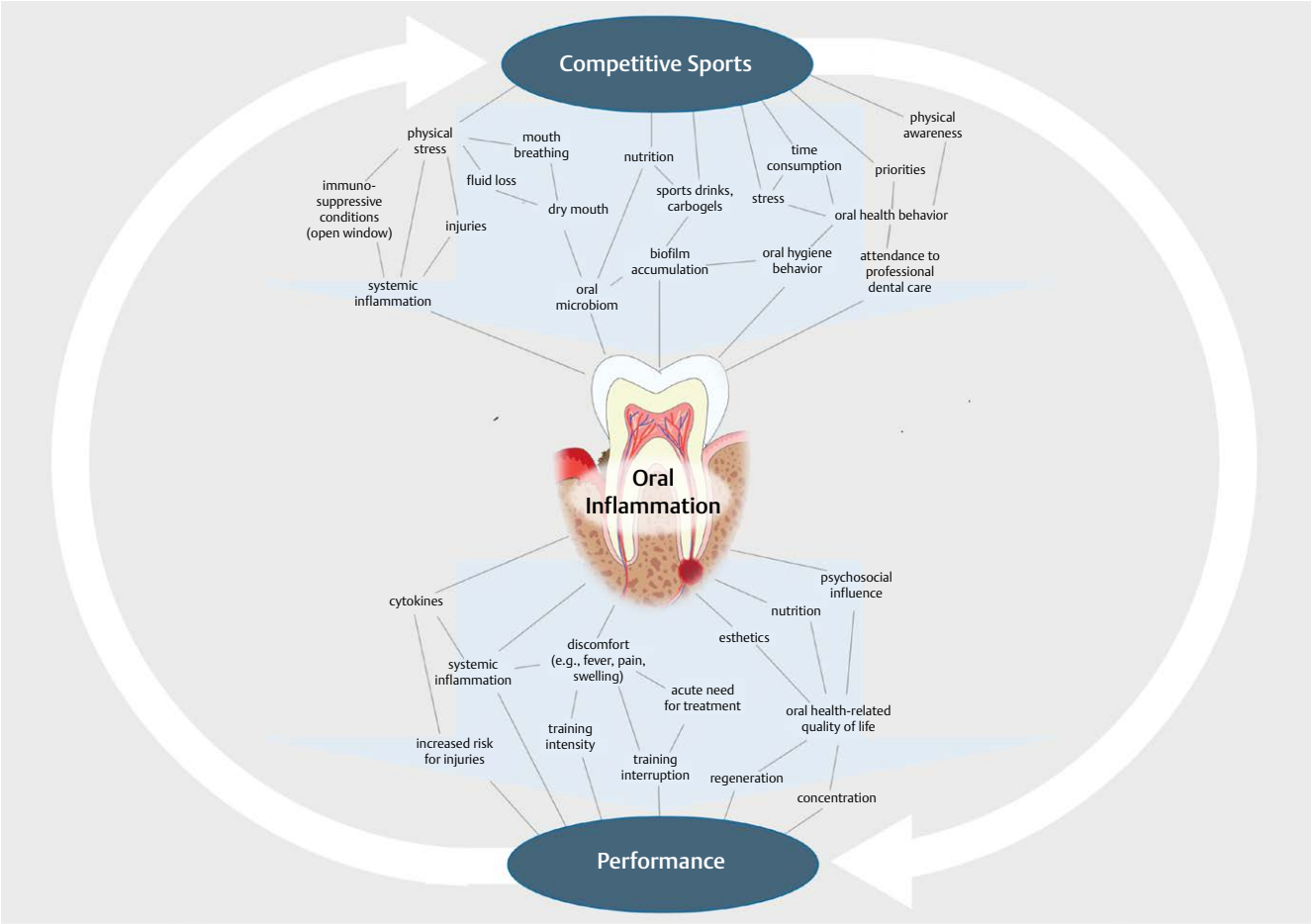
However, due to common factors of predisposition (e. g., smoking, obesity, genetic predisposition), the causality remains difficult to prove. Such systemic influences are also discussed for apical periodontal diseases regarding both systemic diseases [53] and several blood parameters such as CRP, interleukin (IL-) 1, 2, 6, and immunoglobulin (Ig) A, G, and M [54, 55].

Impact of oral inflammation on performance (▶ Fig. 3)

Limitations and reduced quality of life due to (acute) oral discomfort

A loss of performance and efficiency is most obvious in cases with acute pain due to oral health conditions. These are relatively common: 17 % [6] to 30 % [29] of athletes in various sports report pain in the oral region. A total of 4 % [5] to 8 % [29] declared that they suffered from acute discomfort at the time of evaluation. Three percent of all athletes in the 2004 Olympic Games visited the dental clinic in the Olympic Village [38]. An equally frequent impact on performance was documented: 3 % [3] to 4 % [29] of athletes reported reduced training, and 9 % reported difficulties participating in regular training or competitions [29]. In general, 7 % to 18 % of the interviewed athletes believed that their oral health conditions had a negative influence on their training or their performance over the last 3 and 12 months, respectively [3, 5, 29, 30]. More than 40 % of elite athletes feel a generally negative impact on sports caused by their oral health situation [5, 30], whereas 20 % to 50 % also report a negative impact on their daily life [3, 5, 29, 30]. Thirty-five percent reported limitations in food intake, 15 % in relaxation, and 17 % in smiling [29]. This negative influence on the regeneration and psychosocial well-being of athletes could indeed reduce their performance, even if they do not seem to be aware of this context.

For interpreting these data, several points should be considered. First, all reports from the dental clinic in the Olympic Village [5]



▶ **Fig. 3** The complex network of possible mechanisms of a bidirectional interaction of competitive sports and oral inflammation

have a high selection bias as the included athletes sought dental treatment. In general, the available data were not part of routine diagnostic service but a voluntary additional service [3, 6, 29, 30]. Consequently, there is also a possible selection bias as the participants could have had both a higher level of oral health consciousness in general or of dental complaints. This applies particularly for a small sample [6] and a low response rate [3]. In contrast, Needleman 2016 [30] and Gallagher 2018 [29] could achieve representative samples of elite athletes in the United Kingdom of eleven sports. Regarding the impact on quality of life and performance, all data are based on retrospective self-reported impressions. Furthermore, no data of control groups are available for comparison.

For future research, longitudinal studies in representative samples should investigate oral discomforts and resulting restrictions in daily activity in comparison to non-athletic controls.

Systemic influence on performance.

In this context, a negative influence of periodontitis on performance has been documented [2]. The increased extent of periodontal findings (parameters such as PPD, attachment loss, and bleeding on probing) is related to reduced physical fitness (manual force and fitness score, respectively) [56, 57]. Moreover, periodontal disease severity [58] as well as increased PPD values (PSI code 3 or 4) [59], were inversely associated with the maximum oxygen intake capacity (VO_{2max}) as a degree of cardiovascular fitness, whereas another study did not confirm these findings [60]. To date, this connection with physical fitness has not been confirmed for other types of oral inflammation. However, it is at least assumed for multiple apical sources of infection [56]. The methodological quality of these studies was high including clear reporting of the study settings, reliable measurement of the periodontal conditions by meaningful parameters and standardized physical fitness tests. In part, the evaluations were part of large population-based studies with over a thousand participants [57, 59, 60]. Furthermore, potential confounders as age, body mass index (BMI), smoking, and frequency of exercise were considered [56–60].

In competitive athletes, the influence of oral inflammation on performance has not yet been examined. According to the above-mentioned findings, a negative impact on performance for athletes experiencing periodontitis would be expected, at least in cases with severe findings. However, transferability of the data reported above on elite athletes is limited: The cohorts had mainly a higher mean age than the cohorts of young elite athletes that were examined to date. Furthermore, some of the participants explicitly had a sedentary lifestyle. Furthermore, the revealed differences refer to a higher extent of periodontal inflammation [56–59]. In contrast, in

athletes mainly gingivitis and or initial stages of periodontitis were reported (▶ **Table 2**). Interestingly, the one study that could not reveal differences in cardiorespiratory fitness between the groups with different periodontal inflammation had low mean PPD and attachment loss and resulting small group differences of periodontal inflammation [60]. Nevertheless, it must be considered that VO_{2max} was only estimated based on heart rate during exercise. Potentially, in well trained athletes and measured by spiroergometry small differences in periodontal inflammation could also show an effect. Therefore, studies in athletes of various age groups with a detailed periodontal examination should investigate the influence of oral inflammation (periodontal, gingival, periapical) on performance. Performance should be measured by a standardized physical fitness test including VO_{2max} by spiroergometry or strength tests adapted to the respective disciplines. The periodontal inflammation burden could be quantified by periodontal inflamed surface area.

Increased risk of muscle injuries

Another potential correlation was described between oral health and muscle injuries in soccer players. One study showed a (weak) correlation between increased PPD, plaque index, and muscle injuries [6]. This is especially interesting as the injuries were documented by the team physician during a one-year follow-up, and oral health status was assessed clinically. However, periodontal evaluation was only based on some index teeth. No periodontitis was reported, hence the detailed periodontal status remains unclear. A further study documented more non-traumatic muscle and joint injuries in athletes with periodontitis (according to a detailed full-mouth periodontal evaluation). However, this effect was not significant in this cohort with mostly mild periodontal disease severity regarding self-reported injuries [4]. Nevertheless, it must be taken in account that the lack of statistical significance could also be caused by the small cohort size (22 participants). Furthermore, two surveys indicated poor oral health as a risk factor for injuries [61], respectively reinjuries [62]. However, these surveys were only based on the self-reported status by the athletes [61, 62]. It remains unclear if the self-reported surrogate marker "gum problems (bleeding, swelling, recession)" reflects the oral inflammation burden in athletes. In particular, gum problems were cited in one survey as well as not removed wisdom teeth [62]. Even though third molars are a risk factor in periodontitis, their presence does not indicate periodontal inflammation in general.

In this context, an increased risk of soft tissue injuries and muscle protein damage in cases with increased circulating inflammatory cytokines was observed [63, 64]. An increase of these cytokines is also discussed in the context of periodontitis requiring treatment [47].

All in all, a potential increased risk of muscle injuries in case of increased oral inflammation is an interesting point in sports medicine. A detailed periodontal examination including the periodontal inflammation surface area would allow quantification of inflammatory burden. Injuries should be assessed longitudinally over at least one season.

Possible causes of increased oral inflammation in athletes

There are many possible causes for an increased presence of inflammatory oral diseases in (competitive) athletes (▶ **Fig. 3**). On the one hand, modified oral health behavior and physical stress have a strong impact, which will be discussed here. Moreover, the very time-consuming activity [3], increased stress [41], physical constitution [41], nutrition (mainly so-called "sports nutrition" consumed during training, such as carbohydrate gels and bars) [39, 41], and repeated episodes of dry mouth (due to mouth breathing and fluid loss during training) play a role. In this context, important individual- and sports-specific differences occur. Moreover, complex interactions such as common risk factors must be considered. For example, psychosocial stress is described as a promoting factor both for gingival inflammation [65, 66] and staleness [67].

Oral health behavior

Insufficient oral health behavior is a common reason for increased oral inflammation [68]. Respective deficiencies were documented, especially for elite athletes (▶ **Table 3**). Regular dental maintenance appointments [3, 6, 30, 41] and individual oral hygiene are frequently insufficient, e. g., regarding interdental care and fluoride supply [31, 39]. In addition, a dependency on the duration of training was noted: 97 % of the athletes who train up to 20 hours per week brush their teeth twice a day. If training exceeds 20 hours per week, the number drops to 77 % [3]. Furthermore, known differences between competitive and amateur sports [42] and between different teams [30] suggest an influence of coaches and advisors. Again, available data must be interpreted with caution due to limited comparability and transferability. The different disciplines [39] and the country of investigation and socioeconomic status might be influence factors.

Influence of physical activity on inflammation

Physical stress influences the inflammation load. Generally, regular physical activities are described as promoting health: Physical activity leads to fewer proinflammatory cytokines in the blood and therefore has a positive influence on numerous diseases [69, 70]. Regarding oral inflammation, physically active subjects report less gingival bleeding and tooth mobility than physically inactive subjects [71]. Actually periodontitis is less diagnosed in physically active subjects, especially those who perform 3 to 5 training units per week [72]. Here, the reduction of the immunomarkers CRP and IL-1ß, which are increased in numerous diseases, including periodontitis, seems to play a role [73]. While regular moderate physical activities have a positive influence on oral health, this effect cannot be completely transferred to elite sports. Training stimuli activate inflammatory-like processes: Up to 72 hours after loading, systemic (pro-inflammatory) markers such as CRP, IL-1β, IL-6, IL-8, IL-10, and tumor necrosis factor alpha (TNF-α) [74–76] as well as the stress hormones cortisol and adrenaline [77] increase significantly in the blood, while immunoglobulin A in the saliva decreases [78]. As these (pro-)inflammatory markers circulate in the blood, are expressed in saliva and play a pathogenic role in oral inflammatory processes [79, 80], they could affect the oral tissues. Nevertheless, changes in interleukins depend on extend of physical activity and were described especially for long-distance running [74, 76]. Furthermore, the causality of elevated periodontal destruction due to elevated systemic inflammation has not been proven despite various assumptions in the interrelationship of systemic conditions and periodontitis [81, 82]. In addition, cellular defense is temporarily

▶ **Table 3** Oral health behavior of elite athletes.

Oral health behavior	Prevalence	Cohort	References
Dental appointments in the last year	21–81 %	Professional soccer players, treated athletes in the Olympic dental clinic 2012, professional rugby players, Dutch candidates for the Olympic Games 2016	Gay-Escoda et al. 2011 [6], Needleman et al. 2013 [5], Minty et al. 2018 [41], Kragt et al. 2019 [3]
Tooth brushing (daily)	100 %	Elite triathletes, Dutch candidates for the Olympic Games 2016, endurance athletes from German perspective, and youth squads	Bryant et al. 2011 [101], Kragt et al. 2019 [3], Merle et al. 2022 [31]
Tooth brushing (at least twice daily)	60–94 %	Elite triathletes, professional soccer players, elite athletes in Great Britain, Dutch candidates for the Olympic Games 2016	Bryant et al. 2011 [101], Gay-Escoda et al. 2011 [6], Gallagher et al. 2019 [39], Kragt et al. 2019 [3]
Interdental care	44 %	Elite athletes in Great Britain, endurance athletes from German perspective, and youth squads	Gallagher et al. 2019 [39], Merle et al. 2022 [31]
Use of fluoride mouthwash	41–49 %	Elite athletes in Great Britain	Gallagher et al. 2019 [39]
Use of fluoride gels	11 %	Endurance athletes from German perspective, and youth squads	Merle et al. 2022 [31]

reduced [83]. This could favor infections after intensive physical exercise ("open window theory") [84, 85]. How far these factors influence oral health in athletes has not yet been evaluated.

In the same way, elevated cortisol, and catecholamine values due to physical activity could play a role: Increased values have been detected in patients with periodontitis [86]. However, many confounders could have led to a meaningful bias [86]. Furthermore, catecholamines promote the expression of virulence factors in periodontopathogenic bacteria such as *Porphyromonas gingivalis* [87].

Such mechanisms should also be discussed for the potential connection between oral health and muscle injuries: Among others, creatine kinase and IL-6 are released due to exercise [75] and are reported to negatively influence periodontal disease burden [88]. Even tough sex, age, and smoking behaviors were consideres as confounders, the results of this singular study must be interpreted with caution: Further factors such as muscular injuries and resulting stress might have an influence.

Prospective studies with measurement of both systemic parameters such as interleukins and oral inflammation before and after physical exercise should be conducted.

Implementation of dental care in (elite) athletes

The increased risk for oral diseases and their possibly severe consequences in the individual athlete demonstrate the relevance of adequate dental care in professional sports.

Protecting the health of athletes is one priority of the international sports federations [89]. Therefore, both the International Olympic Committee (IOC) and the Union of European Football Associations (UEFA) have explicitly included oral health in their statements [90, 91] and recommend regular dental examinations [90].

Key issues are comprehensive examination, education, appropriate treatment, and prevention. The first point requires regular dental screenings. Consequently, annual dental examinations for example as part of the regular preseason sports medical check [92–94], and for elite athletes, a second dental check-up per year [93] is recommended. To this end, uniform examination criteria are demanded [92]. The World Dental Federation (FDI) recommends including dental status (DMFT index and erosion), periodontal condition (PPD, plaque, and gingival index), dental occlusion, the temporomandibular joint, saliva, facial muscles, third molars, nutritional habits, inflammation, and medical history. Indication-based radiologic examinations or other further investigations can be conducted [93]. In particular, examination directly at the training venue is well accepted by the athletes [92].

Besides screening and individual treatment, risk- and individual-based strategies for prevention are essential [95]. Particularly, education of athletes on sports-related risk factors, motivation, and instruction for individual oral hygiene should be included. The increasing interest of athletes and coaches indicates potential: More than 80 % of athletes stated being willing to change certain behaviors to improve their oral health [39]. Actually a prevention strategy combining general and personalized advice could improve both knowledge and oral health behavior of athletes [96]. This proves the effectiveness of such measures. However, repetition seems necessary to maintain the effects, e. g., regarding gingival inflammation [96]. Short (10 min) educational interventions are well accepted and implementable in high-performance sports [96]. Furthermore, the athletes' team of coaches and trainers should also receive structured information for improving oral health in sports. Standard recommendations for individual oral hygiene include toothbrushing with fluoride toothpaste at least twice a day for two minutes, flosses/interdental brushes, and rinsing with water, or chewing sugar-free gum after meals and snacks when brushing is not possible [97].

Overall, establishing a specially trained "team dentist" or sports dentist" is reasonable [92, 94, 98]. These experts would be able to provide sport-specific advice in close coordination with the athlete's support team [92]. So, special prevention strategies such as the application of protective substances inside of mouthguards [99] could be established by these experts. This could be the setting for an adequate interdisciplinary sports dental care concept. In addition, this would also facilitate the work of general dentists by providing a link to the support team of the athletes. Furthermore, such integration of sports dentistry into sports medicine would improve research in this field [94].

Conclusion

The current state of research documents a high prevalence of inflammatory oral diseases in elite athletes, especially gingivitis and periodontitis. Various impacts on performance are reported: High proportions of athletes stated oral pain as well as a negative impact on training. Oral inflammation could influence blood parameters and physical fitness as already described in periodontitis patients. In athletes, associations between muscle injuries and poor oral health are reported. Besides frequent deficits in oral health behavior, systemic changes due to intensive physical stress could influence oral tissues. Overall, there seem to be complex bidirectional interactions of elite sports and oral inflammation. Despite the need for further research, dental examinations and prevention programs should be implemented in the athletes' routine health care. Further longitudinal studies in representative samples of different sport types and ages with detailed periodontal and endodontic examination are necessary. Present oral inflammation status, impact on performance as well as potential causes of increased oral inflammation in athletes are of interest.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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