Oral Appliances and Athletic Performance

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13.1 Introduction

This chapter will include a comprehensive literature review and history of oral appliances used to improve physical performance. This will be helpful in obvious ways in the sports arena but may also have additional medical implications. Discussion of the literature will be complete and thorough. Then theories of possible mechanisms will be discussed, and the chapter concludes with a discussion of potential future research areas to be explored.

13.1.1 History of Crude Oral Appliances

The history of oral appliances to improve breathing may be dated back to Pierre Robin who developed a device to improve breathing in those individuals diagnosed with Pierre Robin syndrome [1]. This syndrome has characteristics of a cleft palate, glossoptosis, and a retrusive mandible [2]. In the early 1900s, Robin developed two devices first treat glossoptosis and then later a device that was purported to change the position of the mandible [1]. Yet even before oral appliances emerged in the early 1900s, it has been cited that both soldiers in battle and women during childbirth were given leather straps and sticks to bite on during the pain of surgery or child delivery to alleviate and endure physical stress [3]. Although the history of oral appliances has been long, there is limited understanding of the physiological impact of such devices on the individual during *physical* stress. Thus, the purpose of this chapter is to point to potential physiological mechanisms occurring during the stress of exercise while using a mouthguard/mouthpiece.

13.1.2 Use of Oral Appliances for Protection

Recent research on oral appliances, in the form of mouthguards, have been used in a variety of sports to prevent oral-facial injury (see ▶ Chap. 7) [4]. In a review of dental trauma literature, Glendor noted that participation in sports resulted in the greatest cause of dental injury [5]. A review by Newsome cited that early research estimated that players in contact sports such as American football and rugby had a one in ten chance of receiving a dental injury during a year of play, with a one in two chance in one's lifetime of playing such a sport [6] as cited in [7]. Injuries without mouthguard protection range from crown fractures via high-velocity objects, root fractures, mandibular fractures, and tooth fractures to luxations from low-velocity trauma [8]. Of these injuries, the American Dental Association (ADA) cites that close to 80% of these oral injuries occur with the maxillary incisors [9]. Thus, due to the correlation between dental injuries and sport participation, the ADA recommends that athletes use a mouthguard during contact sports [9]. In addition, other governing bodies such as the National Federation of High Schools and the National Collegiate Athletic Association mandate mouthguard use for athletes in a variety of contact sports such as football, field hockey, ice hockey, and lacrosse in order to minimize dental trauma during sport participation [10, 11].

There is substantial evidence that mouthguard use reduces dental injury for individuals during contact sports/activities [12, 13]. Early research in the field of mouthguard use and prevention of injury cited a significant reduction in injury as it related to mouth protections for high school football players [14]. In a more recent review of mouthguard use and injuries, Knapik and colleagues cited 69 quantitative studies on mouthguard use and prevention of injury [15]. Although there were difficulties in analyzing the data from the studies due to the methodology used, Knapik and colleagues concluded that there is a significant reduction in overall risk of orofacial injury with mouthguard use. They cited a 1.6–1.9 times higher risk of injury without mouthguard protection [15]. De la Cruz and colleagues supported this finding in their research with military individuals, specifically finding an overall risk of orofacial injury being 1.7 times greater during a period without mandated mouthguard use for all training events versus during periods when mouthguards were required for all training events [12].

Although the use of mouthguards in protecting the athlete cannot be refuted, compliance by the athlete is an issue. While the use of mouthguards during contact sports is of utmost importance to the dental health of the athlete, adherence to the use of the mouthguard should continually be monitored based on studies citing a range between 16 and 46% of athletes who do not wear the appliance [16–18]. Hawn and colleagues examined the enforcement and use of mouthguards in a men's collegiate ice hockey season. Of the 127 NCAA-affiliated institutions, it was cited that while a 93% of athletic trainers believe that mouthguards reduce dental injury, only 63% of the athletes actually wear the appliance. Interestingly, the study found that athletes in Division I were less likely to wear a mouthguard than to not wear a mouthguard ($N = 462$ reported wearing mouthguard, while $N = 481$ reported that they did not wear mouthguard) as compared to athletes in Division II and III [18]. Similar outcomes were found with players in the Rugby World Cup, with an average of 16% of the players from Ireland, Scotland, Wales, and Australia citing that they do not wear a mouthguard, while 100% of the players from all countries believe a mouthguard decreases injuries [17]. Berry and colleagues noted an overall negative attitude toward mouthguards in collegiate ice hockey players due to the bulkiness, uncomfortableness, and decreased ability to talk and breathe [19]. Thus, the question that continues to plague dental professionals and others associated with contact sports is how to encourage the athlete to wear a mouthguard during play.

13.2 Literature Review on Oral Appliances and Performance

13.2.1 Early Research on the Effect of Mouthguard Use on Performance

To potentially answer this question and to encourage athletes to wear a mouthguard, dental professionals in the late 1970s and early 1980s began to practice a new type of dentistry called "sports dentistry" [20]. Sports dentistry involved fitting athletes with mouthguards to correct malocclusions and temporomandibular joint (TMJ), while touting an improvement performance along with protection of the teeth, being named as physiologic dentistry by Fonder [21] and Moore [20]. However the idea of properly fitting mouthguards to improve TMJ issues was not without its critics. Smith, a physical anthropologist, cited that there was no theory to support a complex interaction between the TMJ and other parts of the body [20]. Yet, subjective data associated with use of a mandibular orthopedic repositioning appliance (MORA) stated athletes improved performance in sports such as football, luge, and running. Garabee cited improvements in endurance, leg strength, and resiliency in long-distance runners [22]. Kaufman, in utilizing the MORA with Olympic luge athletes, found that the device prevented headaches and resulted in greater endurance in their training runs [23]. Yet as intimated earlier, much of the purported benefits of mouthguard use were subjective in nature; thus, the credibility of these findings was seen as controversial [24].

To aid to the understanding of these subjective claims, dentists and researchers sought to quantify any increases or improvements in strength and performance with the use of a MORA device [23, 25–27]. Smith cited significant increases in strength in the isometric deltoid press in NFL football players (*N* = 25) when wearing a wax bite versus during a teeth together condition while completing an isolated muscle movement [25]. In a later study, Smith supported these findings citing a 66% significant improvement in strength using a custom vinyl mouthguard in professional football players [26]. In addition, Grunwaldt found in 41 members of the Green Bay Packers an 8–11% improvement in Cybex muscle testing in using corrective mouthguards [20]. However, comparing a MORA device, with no mouthguard, and a mouthguard condition, Yates et al. did not cite any significant differences in the isometric dead lift in college football players using whole-body movement [28]. In addition, in testing isolated muscle groups, Welch and colleagues found no differences in strength when measuring strength outcomes; specifically there were no differences in the maximal grip strength and knee extension and flexion [29]. However, problems of small sample sizes (the Welch study sample was small, *N* = 9), lack of control subjects, potential influence of the placebo effect, and the types of athletes (female volleyball players, NFL football players) studied makes it difficult to compare results. In addition, although Smith used an isolated relatively smaller muscle group (deltoids) and Yates studied a whole-body movement, critics could argue that differences may lie in the resistance training techniques and the impact of a mouthguard/mouthpiece on these movements. Forgione and colleagues suggest mouthguards with diverse designs could result in varied strength outcomes based on the construction of the mouthguard which is difficult to compare between studies [30, 31].

The design of the mouthguards in early research studying the effect of mouthguards on athletic performance primarily utilized what was labeled as a MORA device. Jackush cites the MORA device (also known as the Gelb appliance) derived from Dr. Harold Gelb [32] (Fig. 13.1). The MORA device was intended to cover the occlusal surfaces of the posterior teeth of the mandible with an appropriate vertical thickness. In addition, splints which cover the occlusal surfaces were often made of acrylic resin but may be lesser durometer if used in a mouthguard for the maxilla [32]. Yet, the issue with describing these appliances was the technique employed by the researcher to determine proper vertical dimensions which typically involved subjective methodology. For example, Welch and colleagues set the ideal vertical dimension based on the subject's manual resistance of the deltoid muscle. This technique is similar in other studies utilizing the MORA, in which the researcher(s) manually applied opposing force and measured the associated vertical dimension of occlusion during the greatest force production by the subject [25, 29]. The subject is then said to be in a state of optimal mandibular position that could then positively affect other parts of the body [27, 32]. Thus, in many of the studies in the late 1980s, vertical displacement and its varying degrees of displacement was often used as a gauge to measure if differences in performance occurred with the MORA device.

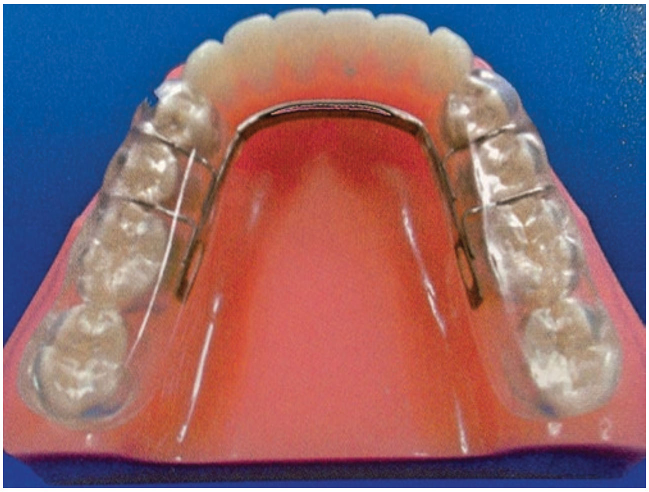


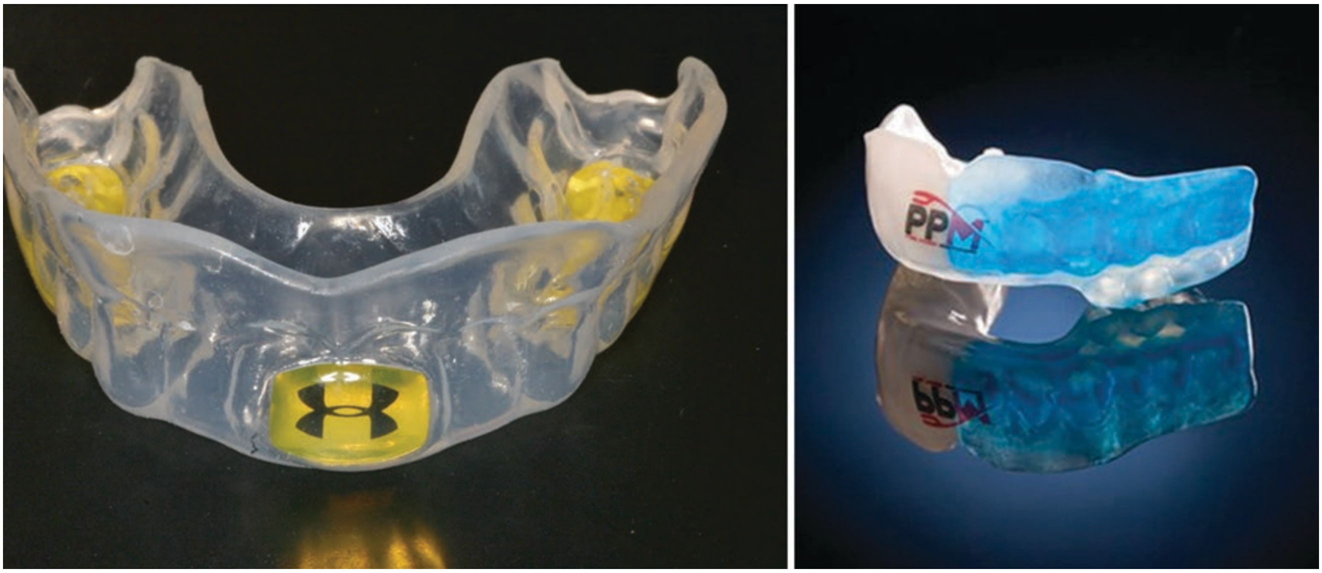
Fig. 13.1 MORA appliance. MORA (mandibular orthopedic repositioning appliance) appliance with hard acrylic covering the posterior teeth designed to reposition the mandible in the anterior direction

Consequently, in order to assess differing impacts of vertical dimensions and subsequent effects on performance, researchers employed various methods to measure impact on performance. Greenberg and colleagues conducted a study by creating a placebo appliance (no vertical dimension) versus a MORA/Gelb device, testing strength differences in a university basketball team ($N = 14$). The authors were not clear on how much vertical dimension the appliance provided but did cite that the placebo appliance did not provide any resin on the occlusal services, resulting in no change in vertical dimension for this appliance. In testing shoulder abduction and adduction on the dynamometer, there were no differences between the placebo appliance, the no appliance, and the MORA device [33, 34]. However, the sample size was small, no vertical dimensions were reported, and the authors noted that these athletes were not involved in any strengthening program at the time of testing. Therefore, in order to address some of these issues, Yates and colleagues set the vertical dimensions to a specific 2–3 mm for 14 college football player subjects studying the effect of the MORA on isokinetic and isokinetic upright rower, isometric deadlift, or isometric two-arm pull. They too found no significant positive or negative outcomes in muscular strength with this position at 2–3 mm vertical dimension [28]. However, more recently, Lee et al. [35] utilized a MORA device which was designed using a precise protocol (see paper for all aspects of the protocol) that provided 3 mm vertical dimension at the centric occlusion and adjusted such that all teeth would come in contact evenly with the MORA device [35]. Their findings revealed significant EMG outcomes with isometric improvements in the following muscle groups: sternocleidomastoid muscles, cervical and lumbar erector spinae, upper trapezius, biceps, triceps, rectus abdominis, and internal and external oblique [35].

It is evident in many of the earlier studies that a few methodological issues were apparent as it relates to the vertical dimensions, sample size, types of athletes and sports studied, and design of the mouthguards. However, despite these issues, each study added valuable knowledge to the understanding of the effect of MORA and/or mouthguard use during exercise performance. Yet the question still remained on how the MORA and/or mouthguard use during exercise performance elicited performance outcomes, if any. Were any positive performance outcomes due to the placebo effect, or was there a link to whole-body physiology with the use of such a device as described by Stenger and Kaufman [23, 27]? Thus, due to the complexities of the issues, the difficulties involved for practicing dental professionals in conducting research, and the lack of interest by researchers in the field of exercise physiology, investigation of this issue remained stagnant for several years.

13.2.2 Recent Research on the Effect of Mouthguard Use on Performance

However, in the early 2000s, research interest in the use of custom-fit mouthpieces regained momentum, and this is partly due to the subjective feedback provided by athletes wearing mouthpieces designed by Shock Doctor, Bite Tech, and Makkar Athletics, mouthguard companies that marketed the effectiveness of mouthguard use during exercise performance (◘ Fig. 13.2). For example, Shock Doctor's website stated that "Performance mouthguards, mouthpieces and mouthwear that advertise increased strength and performance are typically called MORA (Mandibular Oral Repositioning Appliance) mouthguards. MORA technology provides optimum positioning and 'bracing' of the lower jaw, neck and shoulders so that the muscles work more



◘ **Fig. 13.2** Performance-enhancing mouthguards. Two styles of performance mouthguards Under Armour MG that relies on wedges to move the mandible in an anterior inferior direction. The pure power MG utilizes neuromuscular dentistry to locate the desired bite to build into the appliance efficiently, thus conserving energy for the muscles controlling the arms and legs, which may increase strength" [36]. However, such claims are based on subjective data by athletes. Therefore, with the increased use of mouthguards as a performance-enhancing device, researchers have taken up the mantle left by their predecessors to determine if there are effects on performance and then to link these effects to more objective measures. Mouthguards tested from the 2000s to present can be classified into three categories: stock mouthguards, boil and bite mouthguards, and custom-made mouthguards [9]. Yet, these vary greatly between study to study, including suppositions of forward mandibular placement, optimal temporomandibular placement, and lower mouthpieces versus upper mouthguards. Thus, in critically examining if any effects are physiological or placebo, a review of the studies is needed with a description of the mouthguard(s) used, the testing procedures, and the differences in performance as it relates to anaerobic and aerobic activity with use of the mouthguard. With all this information, plausible theories will be suggested to explain potential physiological effects in order to encourage future research to clarify the mouthguard effect.

13.2.3 Mouthguard Effect on Anaerobic Performance

There have been a number of current studies published which cite improvements with mouthguard use during anaerobic performance which includes varying mouthguards and methodology [37–41]. Ebben and colleagues using a vinyl mouthpiece found significant improvements during knee extensions, with an 11% increased average torque and 10% increase in peak torque with subjects clenching on a mouthpiece versus no-mouthpiece condition [40]. Dunn-Lewis and colleagues also cited improvements with a Pure Balance mouthguard made of an EVA material which incorporates pronounced bite pads on both sides of the maxillary mouthguard. Among their findings, they cited a significant increase in bench throw power and force, increased rate of power production in the vertical jump for the Pure Balance mouthguard versus no mouthguard and an over-the-counter mouthguard. Yet no differences were seen in the Pure Balance mouthguard between conditions as it related to 10 m sprint time, sit and reach distance, a visual reaction test, and balance [38]. Utilizing a TMJ repositioning mouthguard, Arnet and colleagues gauged the effect on physical performance parameters in collegiate and professional athletes using neuromuscular dentistry (a method in which TENS surface electromyography is applied to the jaw to facilitate muscular relaxation resulting in a neuromuscular optimal bite position, with a mouthguard fabricated based on this position). They found that when subjects wore a TMJ repositioning device, there was a 3% improvement in vertical jump and average mean power for the Wingate anaerobic test versus a standard custom-fit mouthpiece designed to protect the teeth [37]. These findings as it relates to the Wingate protocol were later substantiated using a maxillary mouthguard (CleverBite®, CleverBite SL, Terrassa, Spain) fabricated using digital scans of the maxillary and mandibular dental arches as well as a recording of the interocclusal relation of the rest position of the mandible. They found a 4% improvement in peak power and a 1% improvement with mean power during the Wingate anaerobic test in the mouthguard condition, these being the same findings (4% and 1%, respectively) by Arnet and colleagues using the same protocol [37, 41]. In addition, researchers cited an 8% improvement in lactate measures with the mouthguard use and significant improvements in all variables associated with anaerobic testing with mouthguard use compared to no-mouthguard condition [41]. Durante-Pereira and colleagues also cited significant improvements with a maxillary custom mouthguard (described as pressure laminated with gum shield consisting of ethylene vinyl acetate) in testing countermovement jumps (CMJ) in 10 rugby players. Yet they found no differences in a 15 second rebound jump nor in the spirometer data with each of these tests. Yet, the improvement in the CMJ test should be viewed with caution due to the small sample size [39]. Using the same CMJ test, Busca and colleagues utilized a larger sample size ($N = 28$) and measured vertical CMJ and found significant improvements in mean power and height in the mouthguard condition versus a clenching no-mouthguard condition and a no-clenching no-mouthguard condition. The mouthguard used in this study was the CleverBite (as described earlier in this review) which relies on digital scans of the maxilla and mandible with a resultant maxillary mouthguard of 1.4 mm EVA overlaid with 4 mm polyethylenterephthalat-1. In addition, they cited significant improvements during the hand-grip test and the back-row isometric force test (force development and peak force) in the mouthguard condition versus the other two conditions (clenching no mouthguard and no clenching no mouthguard) [42].

While there are many studies which have cited improvements in performance with mouthguard use during exercise, there are numerous others which have cited no difference in anaerobic performance with mouthguard use. A study by Allen and colleagues examined recreationally trained individuals and found no differences in countermovement vertical jump (CMJ) using a force plate and Vertec device, one-repetition bench press, and measurements of peak force or rate of force development. However, the caveat of this study was that the authors admitted they had not informed the subjects to clench or not to clench but to try to perform each exercise as "normally as possible" [43]. Thus, the difference between those articles finding improvements with mouthpiece use and those which did not cite differences may be due to the clenching effect. Goelm and Arent also found no differences with a maxillary mouthpiece in assessing measures of vertical jump and power output, balance, flexibility, range of motion, strength (though trended to significance with $p = 0.06$), and agility. They cited that this lack of evidence in any of these parameters may be due to the fact that they used a basic custom mouthpiece that may not have provided optimal jaw-repositioning versus a custom dental appliance used in a previous study done in their lab which found differences using a jaw-repositioning mouthpiece [37, 44]. Drum and colleagues also noted no differences in anaerobic, aerobic, reaction time, and flexibility measures between a custom-fit maxillary mouthguard, boil and bite mouthguard, and a no-mouthguard condition. Their study utilized a collegiate football team, highly conditioned athletes, yet sample size ($N = 10$) was small and would be an impetus for more studies with a larger sample size [45].

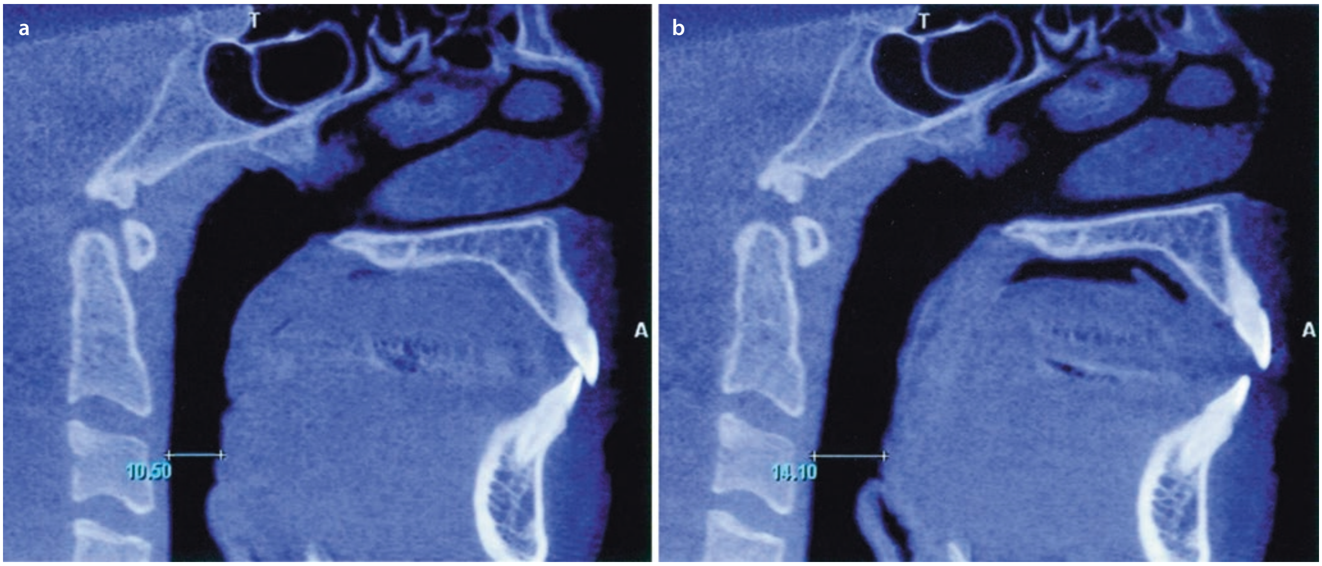
13.2.4 Oxygen Uptake and Ventilation

While much of the research has focused on anaerobic performance outcomes with mouthguard use, other research has focused on objective measures assessing differences in oxygen uptake, heart rate, and ventilation and mouthguard use [46–55]. In a study examining impact of exercise between no-mouthguard condition, commercially available maxillary mouthguard, and custom maxillary mouthguard in 19 trained males, Bourdin and colleagues cited no differences in respiratory parameters as well as no differences in visual reaction time and explosive power at rest and during exercise [47]. Yet interestingly, as it relates to respiratory parameters, the commercially available mouthguard showed differences in respiratory rate during stages of incremental exercise on the cycle ergometer. The use of this mouthguard resulted in a 9% decrease in respiratory rate during stage 1 of the incremental protocol using the commercially available mouthguard as compared to the no-mouthguard condition. These appear important in light of later research by Garner and colleagues which found significantly lowered respiratory rates with various mouthpieces utilized in their studies [47–50]. Gebauer and colleagues also found no differences in respiratory function (ventilation, oxygen uptake, and heart rate) during a graded exercise test (two 5 min stages at 6.2 and 7.5 mph) between no mouthguard, normal-palate maxillary mouthguard, and an open-palate maxillary mouthguard, with $N = 27$ [53]. However, they cited a 3.9% change between no-mouthguard condition and palate-free condition and a 2.1% change between no mouthguard and normal-palate mouthguard in comparing maximum oxygen uptake (ml/kg/min) during each stage [53]. During an incremental exercise protocol in which the workload was increased each minute by 30 W, von Arx and colleagues showed that subjects experienced no difference between no mouthguard and custom mouthguard as it relates to peak oxygen uptake, breathing frequency, and peak minute ventilation. However, von Arx and colleagues did note a 5% improvement in workload scores with the mouthguard versus no mouthguard [55]. In another graded exercise protocol in which subjects were asked to cycle for 5 min during four stages which increased by 50 W for each stage, Bailey and colleagues cited a significant difference in ventilation in the vented moldable maxillary mouthguard versus the no mouthguard and standard boil and bite maxillary mouthguard. Specifically, the vented mouthguard ventilation was 9% lowered at maximum workload as compared to the no-mouthguard condition and was 6% lower at 200 W in vented versus no mouthguard. In addition, they cited a significant reduction in blood lactate levels with the vented mouthguard as compared to the no mouthguard and standard boil and bite mouthguard at both the 200 W and maximum workloads [46]. Finally, while most studies cited involve males, Rapisura and colleagues using an all-female population ($N = 11$) cited no significant differences in heart rate, oxygen consumption, and minute ventilation between women with a self-adapted mandibular mouthguard, boil and bite maxillary mouthguard, and no-mouthguard condition during 2 min incremental exercise on the cycle ergometer [54]. Yet issues with this study were small sample size and potential differences in the use of the maxillary versus mandibular mouthguard as well as inability to compare respiratory parameters due to the duration of incremental exercise chosen for this study (2 min stages). While these studies have utilized various sample sizes and protocols, what appears to be apparent is that a trend or a significant difference occurs with respiratory parameters with mouthguard use during higher-intensity exercise. Yet why would such changes in respiratory parameters during exercise be important to individuals during exercise?

An earlier study by Francis and Brasher helps shed light on possible mechanisms and impact on exercise performance with mouthguard use [56]. In this study, they had subjects perform 20 min of continuous exercise with varying intensities with the following conditions: no mouthguard (No), unfitted upper mouthguard (MG1), unfitted bimaxillary mouthguard (MG2), and a bimaxillary guard with a breathing hole (MG3). In comparing all conditions for the subjects with conditions randomly assigned, they found that during heavy-intensity exercise, subjects had significantly lower ventilation with the mouthguard conditions as compared to the no-mouthguard condition, with expired volume of gas being higher in the mouthguard condition. They then concluded that the use of the mouthguard may actually result in an improved breathing pattern that would enhance alveolar ventilation. They cited that this could be due to a type of pursed-lip breathing that would enable subjects to take in less air with a given amount of oxygen thereby affecting ventilation and expired gas [56]. In their protocol they examined effects during both light and maximum exercise on a cycle ergometer, with only the maximum exercise demonstrating differences. Similar to this protocol, Garner and colleagues utilized mandibular mouthpieces against a no-mouthpiece condition in assessing effects on respiratory parameters [48–50]. In one study, they found significant decreases in respiratory rate with both the boil and bite and the custom mouthpiece, specifically a 3% reduction in respiratory rate during the first 5 min of moderate-intensity activity [49, 50]. Then in comparing the boil and bite to the custom, the boil and bite had lowered respiratory rate versus the custom, with a 9% reduction in the respiratory rate with the mandibular boil and bite mouthpiece [48–50]. As noted earlier, comparing these outcomes is difficult to relate to other studies as none have provided steady-state exercise parameters. However, the study by Bourdin and colleagues was the most similar with an incremental exercise protocol of 4 min. Bourdin and colleagues found a 2% difference in ventilation (L/min) with the custom upper mouthpiece versus the no-mouthguard condition during the first 4 min of the exercise, with Garner finding 1.4% difference in ventilation between their custom lower mouthpiece and the no-mouthpiece condition during the first 5 minutes of steady-state exercise [49, 50]. In addition, Bourdin and colleagues found a 5% difference in breaths per minute between the boil and bite mouthguard and no-mouthguard condition, while Garner found a 5% decrease in respiratory rate (similar to breaths per minute) between custom mouthpiece and no mouthpiece and a 9.7% decrease in respiratory rate between a boil and bite and the no-mouthpiece condition during 10 min of steady-state exercise [47–50]. Although the protocols are different, cycling versus running and steady state versus graded, they are the most similar and enable a greater understanding the effect of various mouthguards/mouthpieces versus a no-mouthguard/no-mouthpiece condition. A potential explanation on the differences may be due to the amount of material with boil and bite mouthguards/mouthpieces versus the custom devices as it relates to the tongue placement (to be discussed in a later section). Thus in these studies, the objective measures of respiratory function demonstrated trending or significant improvements in ventilation and or breathing rate with mouthguard use during maximal exercise. This is critical as it shows that breathing rate and ventilation is slower while taking in the required oxygen needed for exercise with mouthguard use, potentially resulting in improved alveolar ventilation and reduced workload as seen in the study by Bailey and von Arx studies [46, 55, 56].

13.2.5 Lactate and Cortisol

While understanding the effect of mouthguard use during exercise on respiratory physiology provides more objective measures of identifying the mouthguard effect, Garner and colleagues and Dudgeon and colleagues have sought to add to the body of objective measures by assessing the effect of mouthpiece use during exercise on lactate and cortisol [49–51, 57–59] . Thus based on the differences cited in respiratory physiology and the potential mechanisms to explain the mouthguard effect, Garner and McDivitt measured the width and diameter of the oropharynx with and without a mouthpiece using cone beam computed tomography (CBCT) scans. They cited a 9% increase in both diameter and width for subjects using a mouthpiece but found no difference in lactate levels during an exercise protocol, yet the sample was small ($N = 10$) [51] (◘ Fig. 13.3). Thus, based on the changes in the airway parameters, they conducted a study with a larger population ($N = 24$) and found that lactate levels were significantly improved after 30 min of running at moderate-intensity exercise, noting a 23% change of lowered lactate levels with mouthpiece use versus a no-mouthpiece condition [59]. In addition to differences in lactate during running, researchers also studied effects of mouthpiece use during exercise on cortisol levels, citing a trend toward lowered cortisol levels with mouthpiece after 30 min of running [58]. Yet, the exercise intensity may not have been substantial enough to elicit significant changes in cortisol. Thus, to test this theory, researchers utilized a more intense protocol of 1 hour with resistance exercise. In this protocol a Division I football team completed a routine resistance training session while cortisol was measured before, during, and after the session. With mandibular mouthpieces being randomly assigned, they found a 51% reduction in cortisol levels 10



◘ **Fig. 13.3** CBCT scans airway. CBCT scans of subject airways with and without oral appliance. Appliance used was Under Armour mouthpiece (lower arch) seen in ◘ Fig. 13.4. **a** shows the no appliance airway and **b** shows the airway while wearing the appliance. There was consistent significant improvement in airway volume while wearing the appliances minutes post exercise (*N* = 28). This is significant for a few reasons. Firstly, cortisol with mouthpiece use had not been measured in humans, though a similar measure had been assessed in rats under stress while biting on a stick [60, 61]. Secondly, research in resistance exercise without a mouthpiece shows that cortisol levels increase significantly from baseline to post-intensive resistance exercise, and this was the case in the no-mouthpiece condition, thus corresponding with the literature [49, 50, 62, 63]. Thirdly, it is well understood that elevated cortisol affects protein synthesis and immunity [64, 65], thus these findings link mouthpiece use with a potential recovery aspect of exercise. Supporting these findings by Garner et al. [49, 50] was a follow-up study by Dudgeon and colleagues in which they had subjects complete a highly intensive protocol of ten sets of six repetitions of back squats at 80% of the individual's one-repetition maximum with and without a mandibular mouthpiece. They cited significant reductions in cortisol and lactate, finding a 39% reduction in cortisol and 22% reduction in lactate 30 min post exercise with mouthpiece use [57]. In conclusion, the studies by Garner and colleagues and Dudgeon and colleagues cite credible results and potential mechanisms that would support the mouthguard effect and be difficult to link to a placebo effect.

In conclusion, although these recent studies have cited improvements, of importance is understanding if there is an impact of the placebo effect with any of these studies, i.e., if a person is told he/she will or won't improve performance outcomes with an appliance, this is likely to affect results. It is unclear whether researchers informed subjects of a potential effect in studies that found improvements. In studies within the Garner laboratory, subjects were not told whether the mouthpiece would or would not affect their performance [59]. However, due to the popularity of such products, it still may be a factor in influencing subjects. Thus, research which is less subjective is needed to support or refute the positive physiological findings with mouthpiece use. Much of the evidence citing positive physiological performance effects leads this author to believe that there is a physiological mechanism resulting from mouthguard use during exercise. Thus, the next sections of this review will delve into these theories of the mouthguard effect which have been substantiated in other fields of research, thus providing a greater understanding and knowledge of how to better study this area of sport dentistry.

13.3 Literature Review of Theories to Support Performance Enhancement

13.3.1 Genioglossus and Tongue Position

It has been cited that the "the tongue is a small member and has dominion" (James 3:5, Aramaic Bible in Plain English). Although this statement was not in reference to the tongue being a physiologic marvel, it cannot be overstated the importance and involvement of the tongue within several physiologic functions. The complexity of the organ can be found in studying its involvement in respiration, swallowing, speech, and mastication [66–72]. The tongue muscle, specifically the genioglossus, is the main protruding muscle. The genioglossus is innervated by the hypoglossal (cranial nerve XII) which, along with the hypoglossus, causes a pressing down of the tongue base [66, 69]. The importance of the genioglossus is its role in increasing muscular tone during the inspiratory phase of breathing [73, 74] which in turn is important for dilating of the pharyngeal area. The importance of the genioglossus' role in dilating the airway has been extensively researched in the area of sleep apnea and will be discussed later in this chapter [75–79].

In addition to the genioglossus's role in dilating the airway, there has been a body of literature which states the tongue's role in temporomandibular (TMJ) disorders, serving as a way to mediate or reduce the severity of the disorder. Schmidt and colleagues cite the use of the tongue as a treatment option as minimizing muscle activity and thereby reducing pain in the orofacial area; specifically by placing the tongue in a position of "rest" will maximize relaxation and subsequently reduce muscle-related pain in the TMJ [80]. Optimal tongue placement providing a "rest" position suggests that it should be positioned on the floor of the mouth. Evidence of this optimal tongue "rest" position cites decreased EMG activity in the right masseter, suprahyoid, right temporalis, and left temporalis with the tongue on the floor of the mouth versus against the hard palate [80]. To a degree, others have supported this, finding decreased activity in the anterior temporalis and suprahyoid with the tongue on the floor of the mouth versus on the hard palate yet with an increase in masseter EMG activity with the tongue on the floor versus the hard palate [81]. Yet, before the research of how the genioglossus elicits effects in the body, there must be an understanding of mechanisms involved with innervating the tongue muscle and its reflex response.

Miller [69] states that the tongue, in order to operate optimally, receives complex somatosensory input via the central nervous system, resulting in both complex and simple reflex actions [69]. Initial animal and human research to more recent research supports this hypothesis [69, 82–87]. With the animal model, Lowe and Sessle cite the interaction between the jaw and tongue when they opened the cat jaw as little as 4 mm, resulting in genioglossus activity. This outcome led to their conclusion that the temporomandibular joint significantly affects the activity of the tongue due to reflexes originating in orofacial regions [88]. In earlier human research, Weber and Smith [87] stated a reflex exists between the jaw, tongue, and lip by demonstrating increased EMG activity of the masseter, orbicularis oris inferior, and the genioglossus with mechanical stimulation [87]. In the human model, Takata and colleagues found genioglossus and orbicularis oris EMG activity increased with jaw opening and ceased with jaw closing during gum chewing, suggesting the link between the tongue, lip, and jaw [89]. Hiyama's laboratory also found similar outcomes with EMG activity of the genioglossus, with EMG increasing during jaw opening. Yet, they also found increases during jaw closing. They state that this may be due to the hypoglossal nerve which innervates the tongue protruding muscle, thus resulting in EMG activity in both the opening and closing phases of the jaw. They hypothesize that this collaboration of activity between the jaw and tongue would not be explained by a sequential reflex response but possibly preset into the central nervous system within the lower brain stem [67]. Miller [69] explains these complex oral reflexes as it relates to the genioglossus, stating that either via the lingual nerve or mechanical stimulation of the tongue will result in a potential excitation or inhibition in various tongue muscles [69]. In addition, Miller cites that this interaction between the tongue and jaw plays a critical role in the function of the pharyngeal pathway during respiration; specifically that protrusion of the tongue muscle will function to open in the pharyngeal airway [69].

The importance of tongue muscle placement has been cited as playing a key role in the opening of the pharyngeal area, with sleep apneic studies citing a forward shift of the mandible and subsequent forward protrusion of the tongue using sleep apneic mouthpieces designed to promote enhanced breathing mechanics [75, 76, 90, 91]. These devices have been shown to increase the pharyngeal area, with Kyung and colleagues citing a 19% improvement in cross-sectional area of the retroglossal (defined as the back of the tongue to the wall of the pharynx) area of the pharynx using a 75% mandibular advancement mouthpiece [91]. Mann and colleagues cited increases in the diameter of the hypopharyngeal area with genioglossal stimulation, resulting in a mean 133% increase from baseline [68]. Earlier research cited that contracting the genioglossus results in pulling the base of the tongue down and forward, with later researcher citing that this occurs with the help of the protruder muscles, which will subsequently open the pharyngeal area [92, 93]. To clarify how this occurs, Saboisky et al. [71] cited a complexity of networks linking the hypoglossal motoneurons which innervate the genioglossus. They cite increased genioglossus discharge rates during both inspiration and expiration thereby leading to tongue protrusion [71]. In addition, research has shown that the number of hypoglossal motoneurons will also be affected by exercise, citing an increased number of these motoneurons activated with increased exercise intensity, resulting in increased EMG activity of the genioglossus [94].

13.3.2 Role of Clenching

In addition to the important role the genioglossus plays in dilating the airway as innervated by the hypoglossal motoneurons, research has also examined the effect that clenching has on the EMG activity of this muscle. Firstly, researchers have cited an increase in EMG activity in the genioglossus with mild to maximal clenching during non-exercise protocols [86, 95]. Valdés and colleagues cite a link between the masseter while clenching and its effect on the tongue, noting the interaction using 30 healthy subjects with no current or past pain in the TMJ, mouth, or tongue. In measuring the EMG activity of the masseter and temporalis during clenching and swallowing, they cited significantly lower EMG activity in the masseter during clenching with the tongue on the floor of the mouth versus on the hard palate, this being explained by the effect the tongue creates when placed on the floor of the mouth, against the mandibular, lingual side of the incisors, which consequently linked to the masticatory muscles [86]. Igarashi then demonstrated outcomes in the genioglossus during clenching, finding an increase in EMG activity of the genioglossus during clenching [96]. Finally, as it relates to force production, placement of the tongue has also been cited as an important factor. Saboisky et al. [97] found that optimal position for the tongue resulting in the greatest tongue force production is when it is retracted between 12 and 32 mm, with the mean maximal force being 28.3 N at 24 mm and the lowest forces (14.9 N) produced with tongue protrusion at 12 mm [97]. Not only did they find increased force production but also cited in a significant decrease in breathing rate with the tongue on the floor of the mouth (15.47 BPM) versus the tongue on the roof of the mouth (16.15 BPM, $p = 0.023$). These findings support observational studies in our laboratory with various mouthguard/mouthpieces utilized during exercise (versus at rest as in the Saboisky et al. study) and will be discussed later in this chapter.

Not only has clenching been cited to effect genioglossus activity and masticatory muscles, clenching has also been shown to affect cerebral activity in activation of the cortical areas in the brain, thereby affecting the hormone response [60, 61, 98–100]. As cited earlier, studies have cited decreases in cortisol levels with both clenching and chewing, with and without physical activity [49, 50, 100]. Yet what mechanism can explain the purported improvements in hormone levels with clenching? A rat model may explain the potential mechanisms that occur with a reduced stress response during clenching. Researchers have cited that restrained and stressed rats, when biting on a stick, had reductions in corticotrophin releasing factor and c-Fos in the hypothalamus which may be modulated by suppression of extracellular signal-regulated protein kinase 1/2 (pERK 1/2) in the paraventricular nucleus [60, 61, 101]. This link between the hypothalamus and the involvement in the jaw muscle via clenching may be explained by neuronal projections from the lateral hypothalamic connecting to the trigeminal motor nucleus in the rat model [102]. In addition, it was observed that the trigeminal motor nucleus is innervated by corticotropin-releasing factor-immunoreactive fibers within the amygdala, providing another explanation of effects on hormonal response during clenching [102].

Yet rat models cannot completely explain the stress response mechanisms involved in humans during chewing and clenching; thus, researchers use functional magnetic resonance imaging or positron-emission tomography to assess cortical activity and blood flow dynamics during clenching and chewing which have been cited to be a valid measures of assessing these tasks [98, 99, 103–106]. Momose et al. [105] demonstrated mastication increased cerebral blood flow in the sensorimotor cortex by approximately 26.5% during clenching [105]. Later studies cited significantly increased middle cerebral blood flow and significant activation of the sensorimotor cortex with clenching versus other tasks such as gum chewing and a hand motor task [98, 103]. Research also cites that activation within the dorsolateral prefrontal cortex (DLPFC, an area in the cerebral cortex) is most likely dependent on continuous teeth contact as occurs during clenching, and that intensity of the clenching most likely influences that magnitude of the cerebral activity within the sensorimotor cortex (area in cerebral cortex responsible for motor function) [99, 107]. Qin et al. [108] cited that the function of the DLPFC is likely affected by the HPA axis by decreasing levels of the catecholamines [108]. These findings are significant as it relates to mouthpiece use during exercise as they provide potential explanations for the cited decreases in cortisol and lactate with mouthpiece use during exercise [49–51, 58, 59]. Thus, enhanced cerebral blood flow may be a key piece in understanding these effects, with researchers citing improved cerebral blood flow rate when subjects are in a mandibular physiologic rest position [109]. Research by Otsuka and colleagues demonstrated how an experimentally induced retrusive mandibular position using a splint (defined as placing the mandible in a more backward position) resulted in an activation of the hypothalamus during clenching in two of eight subjects [110]. Though this evidence is not sufficient to make any definitive links between malocclusion and activation of the hypothalamus and subsequent stress response, it is another step in understanding a mechanism that could explain the cortisol response during exercise with a mouthpiece, a mouthpiece which has been cited as placing the mandible in a more forward mandibular position [48–50, 58]. In closing, more recent research aims to elucidate how increased cerebral blood flow could affect the hypothalamic response from stress with subsequent hormonal production such as cortisol. Miyake et al. [104] demonstrate that biting during stress and its effect on the hypothalamic response appears to be mediated by nitric oxide levels, specifically with biting resulting in decreased levels of nitric oxide versus not biting which leads to elevated nitric oxide levels [104]. They surmise that masticatory activity (biting down) during physiological stress results in an anti-stress response that may be facilitated by nitric oxide in the brain in which nitric oxide acts as an amplifier or feedback mechanism for neuronal activity during stress [104].

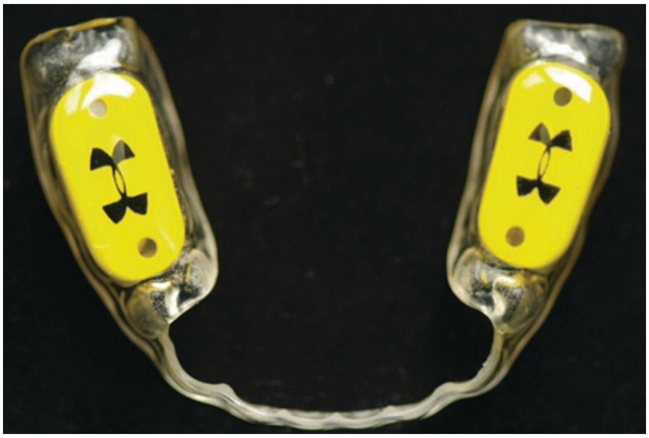
Although the interaction between the mandible and tongue has been clearly established in the literature, the relationship between such a reflex and effect on whole-body movement is sparsely cited. However, some research suggests that concurrent activation potentiation is the result of the jaw-repositioning and subsequent mandibular muscle contraction which thereby affect neuromuscular outcomes during exercise [42, 91]. Ebben first defined this phenomenon in his review of concurrent activation potentiation which he defined as an interaction between the Jendrassik maneuver, a type of remote voluntary contraction, in which individuals can increase the strength of reflexes by clenching their teeth and motor overflow, referring to communication between cortical areas through various parts of the brain [111]. In essence, Ebben cites literature suggesting that remote voluntary contractions acting through the H reflex will positively affect lower body musculature [111]. Examples of this phenomenon can be found in studies that show an increase in the soleus H reflex, which is described as a measure of the excitation of the spinal monosynaptic reflex in humans, during clenching, with a strong correlation in the increase of EMG activity of the masseter [112, 113]. The conclusion is that such a clenching response would be beneficial during stabilizing posture and improving fluidity of movement during muscular contraction, this being due to enhanced H reflex of the leg muscles with a concurrent reduction of the reciprocal Ia inhibition [113].

13.3.3 Genioglossus and Clenching and Involvement of the Mouthguard

Although there is substantial evidence of the importance of the genioglossus, as well as the effect of clenching, how does this relate to mouthguard use during exercise? Firstly, an appliance provides some type of stimulus to the tongue muscle as well as an increased opportunity for the individual to clench during exercise. Hidaka and colleagues found that with increased clenching, there was a resulting shift on the bite force such that there was a more balanced bite force (with balance bite force being defined as force placed on all occlusal contacts). They hypothesized that this outcome may be a mechanism which prevents damage to teeth and to the temporomandibular joint [114]. Thus, using a mouthguard may improve clenching capacity thereby resulting in changes of cerebral blood flow and hypothalamic response as noted earlier. Secondly, the design of the mouthguard is important to understand in light of its potential effect on the tongue muscle, i.e., a mandibular mouthguard versus a maxillary mouthguard differs in its impact on the tongue and may thereby affect outcomes associated with the genioglossus.

Accordingly, reviewing what is known will enable researchers to clarify the precise mechanism(s) that may be occurring with mouthguard/mouthpiece use during exercise. With research as it relates to the genioglossus and clenching effect, there is compelling evidence that a few aspects of mouthguard/mouthpiece use should be more carefully studied. Firstly, understanding the types of oral appliances used in previous and current studies should be evaluated for potential effect on vertical displacement, then understanding how the angle of the bite created by the mouthpieces affects vertical displacement as it relates to the TMJ should be reviewed. Murakami and colleagues who used magnetic resonance imaging (MRI) with and without a mouthguard made of a EVA material (Erkosoft Erkodent, Pfalzgrafenweiler, Germany) studied 26 healthy subjects wearing two different EVA mouthguards; MG1 created a 3 mm vertical displacement, while MG2 created a 6 mm vertical displacement [115]. It was cited in both mouthguard conditions that the condyle moved backward and upward in all subjects during clenching yet to a lesser extent than the non-clenching condition. During the non-clenching, MG1 condition, the condyle moved 1.15 mm downward and 2.10 mm forward, with MG2 moving 2.10 mm downward and 2.33 forward, a statistical difference between MG1 and MG2 [115]. Thus vertical displacement alone seems to create varying degrees of condylar distance from the mandibular fossa. A case study assessing the positioning of the temporomandibular joint between the boil and bite UA mouthguard, the custom mouthguard, and no-mouthpiece condition showed that the boil and bite provided greater distance between the condyle and the mandibular fossa, the custom provided lesser distance, and the no-mouthpiece condition resulted in the least distance created between the condyle and fossa, which may be due to the type of vertical displacement created by the two mouthpieces and no-mouthpiece conditions (unpublished data).

In addition to vertical displacement affecting the TMJ, the degrees of vertical displacement created by the different mouthpieces may also have an effect on the genioglossus. Appliances used in the 1970s and 1980s were defined as the MORA devices (▫ Fig. 13.1). These devices are narrowly described in the literature but appear to all have a hard resin which results in increased vertical displacement and subsequent effect on the tongue. In viewing a model of a mouthguard in an article by Stenger, the subject has a substantial vertical displacement, with the tongue visibly elevated to the roof of the mouth and the tongue tip touching the interior teeth. However, it is unclear from the photo the degree of mandibular or vertical displacement [27]. Welch and colleagues state that “the appliances (MORA) were designed to maintain this programmed centric relation/occlusion at the previously determined increased vertical dimension” [29]. Thus, in most cases, this vertical dimension, though vaguely described, involves manually manipulating the patient to find increased muscle force production and citing the position of the mandible along with the increased vertical displacement that coincides with the optimal force production and thereby temporomandibular repositioning [32]. However, it was doubtful that tongue placement was considered in any of these studies. In addition to the potential effect vertical displacement can create on the tongue, some of the appliances studied cited increased mandibular forward placement when utilized in the mouth of the wearer, yet this was never confirmed with CBCT scans which were not available during the time of these studies [26, 29, 33, 116]. As stated earlier in this review, it is well researched within sleep apneic research that forward mandibular placement devices are utilized to open the airway and improve breathing for this population [75–77]. Consequently, due to findings in the sleep apneic literature, Garner and McDivitt studied a mandibular forward placement mouthpiece (as advertised by the company, Bite Tech, Inc.) (▫ Fig. 13.4) Utilizing CBCT scans they studied the effects of mouthguard use on exercise performance and found a significant 9% increase in width and an increase in diameter of the oropharynx with mouthpiece use versus a no-mouthpiece condition [51] (▫ Fig. 13.3). They surmised that the enhanced airway openings as seen in the CBCT scans with mouthpiece use signified forward mandibular placement and thereby explained improvements in lactate [51]. In addition they suggested a link between the mandibular placement of this mouthpiece and effect on the genioglossus, citing increased activation of the genioglossus in a case study referred to in a published study [48]. Thus, understanding the degree of mandibular advancement and vertical displacement and subsequent effect on the genioglossus in future mouthguard/mouthpiece studies should further clarify our understanding of the mouthpiece effect.



▫ **Fig. 13.4** Appliance used in airway study. Under Armour performance mouthpiece used in the CT studies of airway. Lower appliance used when protection is not required

Finally the design of the mouthpiece and how it affects tongue placement may be of importance understanding outcome differences within these studies. Francis and Brasher [56] cited that in comparing their three mouthguards, that the one which resulted in the most significant improved ventilation was a bimaxillary mouthguard with a small breathing hole. Bailey and colleagues also noted significantly lowered lactate levels and ventilation at 200 W and maximum workloads with a vented mouthguard versus no-mouthguard condition and a traditional boil and bite maxillary mouthguard [46]. While Francis and Basher cited that the improvements in ventilation in their study may be due to a type of pursed-lip breathing, Bailey and colleagues stated that plausible differences in ventilation could be due to the construction of the mouthguard [46, 56]. Garner and colleagues also hypothesized that a type of pursed-lip breathing could be occurring with their lower mouthpieces as a potential explanation in the decreased respiratory rate noted in the lower custom and boil and bite mouthpieces [48–50]. As mentioned earlier, this type of breathing leads to improved ventilation in COPD patients both at rest and during exercise [117, 118], and this being may be linked to displacement of the tongue. However, Garrod and colleagues stated that they were unable to explain the mechanisms for the improvements in respiratory parameters with pursed-lip breathing [117]. Garner hypothesized that the decreased vertical displacement created by the mouthpiece used in the study may have resulted in less space to allow air in and out of the mouth, causing subjects to contract the tongue, thereby opening the airway and in turn explaining the respiratory improvements in this study [48]. Nevertheless, studies to confirm a potential link between pursed-lip breathing and tongue placement as well as other mechanisms to explain respiratory improvements with pursed-lip breathing should be explored.

In addition to understanding the effects of the mouthguard design on tongue placement and activity, the degree of even occlusal contact and subsequent effect on clenching may be of importance in studying effect on exercise performance. Murakami and colleagues stated that the surface of the mouthguards was adjusted such that there was an even bite surface between the mouthguard and the opposing occlusal surface [115]. This is supported by Pae and colleagues who noted that in creating their mouthguard, "all teeth contacted equally at maximal intercuspal positions" a study in which they cited significant improvements in club head speed and driving distance in professional golfers [119]. Similar to these findings was a study by Lee and colleagues in which they utilized a MORA device but noted that the fit of the appliance required that all teeth have even contact [35]. Their findings revealed significant EMG measurements in isometric improvements with the following muscle groups: sternocleidomastoid muscles, cervical and lumbar erector spinae, upper trapezius, biceps, triceps, rectus abdominis, and internal and external oblique [35]. Furthermore, the studies by Garner and colleagues primarily used a mandibular device (Bite Tech mouthpiece, later branded as the Under Armour Mouthguard Performance Mouthwear) which incorporated bite pads that varied between the custom mouthpiece and the boil and bite mouthpiece. Both mouthpieces had a 2 mm posterior to 1 mm anterior wedge; however, the custom mouthpieces did not have a slope, while the boil and bite mouthpieces utilized a bite surface that was continuous and provided even contact with the occlusal surfaces [48]. That study cited that two of the mouthpieces tested had elevated pads which would have prevented even contact between all teeth and could have negatively affected the performance parameters [48]. Thus, more research should focus on the impact of vertical displacement with a continuous and noncontinuous bite surface between the mouthguard and the opposing occlusal surface and its impact clenching intensity.

In understanding both the degree of vertical displacement and occlusal contact, the types of materials used in the various mouthguards should also be considered within those earlier studies. Smith provided a photograph and description of the devices (described as a wax bite that "locks the jaws" into their ideal position) used in his study which found significant improvements in strength measures in professional football players with the wax bite [26, 120]. Yet he also cited that his MORA mouthguards actually transferred the bite pressures, placing more pressure on the molars versus the incisors [26]. This is important as evaluation of the mouthguard research reveals that differences may be in even contact between all teeth.

Oral Conditions that May Improve Performance

- Jaw position
  - Vertical
  - Anteroposterior (anterior)
- Tongue position
  - Anterior/inferior
- Clenching: balanced and complete occlusion
  - Increased cerebral blood flow
  - Decreased cortisol

Jakush concedes that there were differences between the lower MORA devices and the maxillary MORA devices, with the maxillary mouthguard MORA devices using a softer material than the typically hard acrylic resin in the mandibular MORA devices [32]. In revisiting the photo by Stenger, the type of material typically used for these mandibular MORA devices (hard acrylic resin), it is apparent that the vertical displacement (greater jaw opening) is accentuated [27].

In more recent research, the materials used in the basic three types of mouthguards, custom mouthguard, boil and bite mouthguard(s), and placebo condition, vary among researchers and may affect vertical displacement and occlusal contact. For example, Francis and Basher used moldable over-the-counter upper and lower mouthguards [56]. The difference with these and the MORA appliances is the contact between the upper and lower teeth would be less rigid, due to the nature of the rubberized material in the moldable mouthguards. However, it is unclear, how much vertical dimension is created with these. Yet it may be surmised, due to the hinge component of the bimaxillary mouthguard, that this mouthguard would create an increase in vertical dimension. The mouthguards, as described by both Arent and colleagues and Pae and colleagues, consisted of an ethylene vinyl acetate (EVA) polymer [37, 119].

MG Design Considerations for Performance Enhancement

- Mandibular or bimaxillary
  - Optimize tongue position
  - Pursed-lip breathing
- Balanced occlusal contacts
  - Enhances clenching ability
- Thickness
- Materials used
  - Hard vs soft

While the Under Armour custom-fit lower mouthpiece incorporates a polypropylene material versus the more common ethylene vinyl acetate used as a comparison mouthpiece in Garner study [48]. Gould and colleagues cited that the use of EVA is most common within mouthguards due to the fact that EVA is accessible, is easy to work with, and has the appropriate mechanical properties to meet the needs of the product [121]. Gould found that EVA materials in mouthguards ranged from 67.6 to 81.4 on the Shore A hardness factor at 37 °C [121]. Polyurethane bite pads have not been tested in the Under Armour mouthpieces for durometer values, but these plastics typically have lower durometers than the acrylics and EVA materials utilized in much of the mouthguard research [122]. Thus, due to the different outcomes for many of the studies as noted previously, the durometer of the material may be one area of future study to clarify its effect on outcomes during exercise performance. It should be noted that those outcomes in the Francis and Basher study were similar to those in the Garner studies, with these two groups of researchers using lower durometer materials which this author hypothesizes as creating less vertical dimension with a subsequent forward placement of the tongue.

13.3.4 Exercise Physiology and Practical Applications of the Science

Although there has been a great deal of research presented in this review to suggest the importance of tongue placement and the clenching effect, it is important to link the science to the application of exercise and use of the mouthpiece. Firstly, fatigue during exercise has many causes ranging from peripheral to central nervous system fatigue. Yet, one site of fatigue with high-intensity exercise relates to the production of lactic acid. Lactic acid is produced during higher-intensity exercise in which the glycolytic pathway is heavily called upon to produce energy at a high rate (see Fig. 13.5). An end product of this glycolytic pathway is the production of lactic acid. Lactic acid then dissociates into lactate and hydrogen ions. The increased production of hydrogen is one of the fatiguing aspects of higher-intensity exercise as hydrogens cause the blood to become more acidic.

Why Lactate Matters to Athletes

- *Pyruvate* is converted to *lactate* in the absence of *oxygen*.
- When exercise intensity increases, the body is less able to obtain the needed oxygen to exercise. Thus, it relies on the glycolytic pathway to produce energy. This pathway does not require oxygen but does produce a greater amount of lactate.
- The breakdown products:
  - Lactic acid → Lactate + H^+ ions
- Lactate production must equal lactate clearance; if not, the results are fatigue (OBLA = 4 mmol/L).
- *The H^+ ions are considered by many to be the cause of fatigue*:
  - It binds with troponin to inhibit muscle contraction.
  - It inhibits phosphofructokinase, important enzyme in glycolysis.

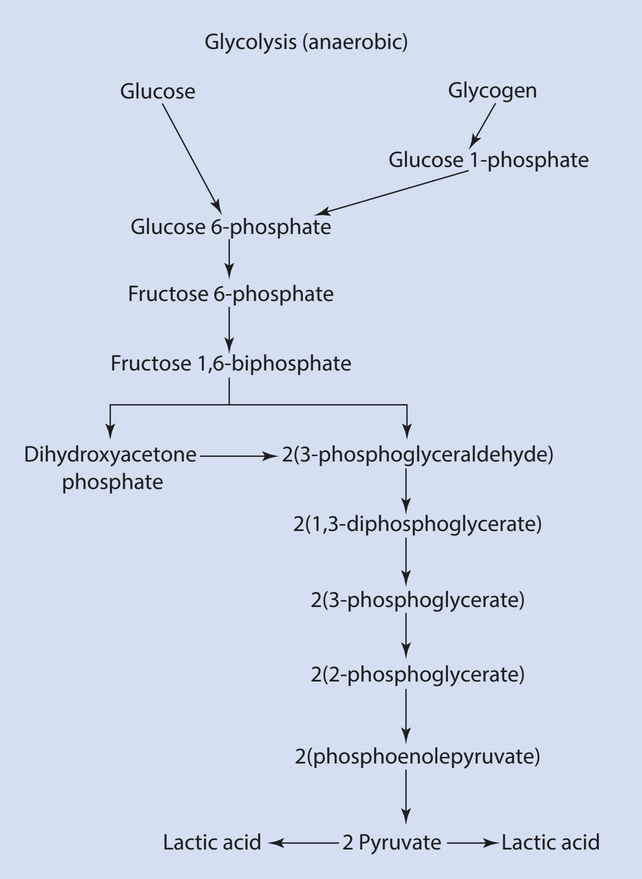


Fig. 13.5 Glycolysis. Glycolysis is a catabolic pathway in the cytoplasm of cells where glucose is broken down into two molecules of pyruvate+ 2 ATP molecules and 2 NADH+ H^+. In times of depleted oxygen, glycolysis becomes the main pathway for energy production and pyruvate is converted to lactic acid

The acid-base balance is thus tightly regulated by mechanisms in the body in order to keep the pH in a tolerable range. One mechanism to regulate the acidity of the blood is the bicarbonate ion, which is formed when carbon dioxide combines with water forming carbonic acid that then quickly loses a hydrogen becoming bicarbonate. It has been cited that increased exhalation of carbon dioxide leads to decreased lactate acid which is precisely what was found in the studies by Garner and colleagues with the use of a mouthpiece during exercise. They cited that the improved breathing patterns created by the mouthpiece resulted in the increased carbon dioxide production noted in their study [49, 50]. In this study, they linked the improved carbon dioxide response to the decreased lactate cited in an earlier study [49–51]. Thus, the mouthpiece effect has been associated with changes in breathing patterns which in turn affect exercise outcomes such as lactate.

Another aspect of the mouthpiece effect is the decrease in cortisol during intense resistance exercise. During exercise, particularly during intense resistance exercise for approximately an hour, there is an increase in cortisol [62, 65, 123]. Cortisol is the product of the hypothalamic-pituitary axis (see Fig. 13.6),

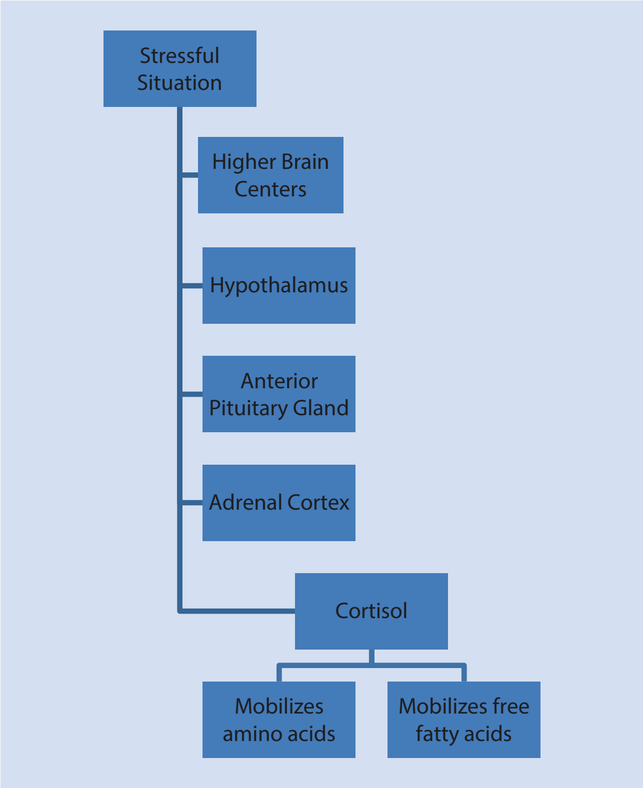


Fig. 13.6 HPA axis. HPA axis schematic shows how stress stimulates the release of cortisol

with prolonged elevated levels being linked to a decreased protein repair and increased protein breakdown, negatively affecting the function and condition of the muscle [65].

Effects on the Body from Excess Cortisol or Stress

- Gluconeogenesis at the expense of muscle proteins
- Decreased immune function
- Decreased metabolism
- Depression
- Hypertension
- Chronic fatigue
- Sleep deprivation
- Migraines
- Tunnel vision

Thus, the findings by Garner and colleagues and Dudgeon and colleagues that the mouthpiece has a significant reduction in cortisol after intensive resistance exercise are critical to examine and seek to replicate [49, 50, 57]. Their findings support those found in the literature with the rat model as it relates to a reduction of stress parameters when biting on a stick and may be linked to increased cerebral blood flow when clenching [60, 61, 99, 100]. Thus interventions such as the use of a mouthpiece during exercise may affect both breathing mechanisms, thereby affecting fatigue pathways as well as potentially affecting the hormone response due to clenching during exercise.

13.4 Conclusions

Findings during this review reveal that there are a variety of acute outcomes with mouthguard/mouthpiece use during exercise. Yet, it is meaningful to understand that making comparisons between studies is difficult due to the complexities of the issues which include the type of mouthguard/mouthpiece used, exercise protocol, sufficient sample size, and techniques utilized to assess differences. Instead of making conclusive remarks about the use of a mouthguard, it is the goal of this review to raise appropriate questions to enable researchers to illuminate appropriate avenues to explore as it relates to mouthguard use during exercise. Finally, in noting the acute improvements cited in many of these studies, results denote seemingly minimal improvements, i.e., on average ranging from 3 to 10%. Thus dental professionals should examine if these improvements are meaningful for the client in fitting the individual with an appliance. However, it is the belief of the author that research in this area may be more promising in understanding the consistent use of mouthpiece/mouthguards during and post exercise in light of the research related to lactate and cortisol. Research should focus on impact on recovery and subsequent training sessions. If, as the research suggests, there are reductions in lactate and cortisol post-training sessions as indicated in the studies, then the impact on physiological recovery is remarkable. We know that elevated cortisol impairs muscle recovery and immune function, while elevated lactate impedes training by prolonging post-oxygen exercise consumption enabling the body to rid itself of elevated hydrogen ions associated with lactate [124]. Thus research should explore use of mouthguards/mouthpieces during and after exercise to determine training impact on the individual over a longer period of time. In addition, as practitioners, many of the common complaints of nonuse of the mouthguard are attributed to the negative effect athletes feel it has on their performance, as it relates to breathing patterns. The research has clearly cited that there appears to be no negative impact on performance, with some of the research citing an improvement in breathing parameters. Thus, as dental professionals, the research can be referred to as it relates to these common complaints made by the athlete and therefore encourage mouthguard use during play.

13.5 Future Research

The question remains, “Where do we go from here?” As intimated with this short review of the mouthguards, tongue placement, cortical communication via clenching, and resultant effect on hormones, the human body during rest and exercise involves a complexity of interactions which are not yet fully understood. As Chakfa and colleagues stated in establishing a link between increased isometric strength with application of increased vertical dimension using bite plates, "as data increase, the physiological mechanism underlying this phenomenon will become clear" [125]. Indeed the goal of this chapter was to summarize the research in the area of mouthguard/mouthpiece use with exercise and subsequently provide potential physiological mechanisms to explain these outcomes. With evidence in various disciplines, it is difficult to refute the mouthpiece effect during exercise. Therefore, researchers should be encouraged to investigate to what extent the mouthpiece plays during different types of sports, studying a variety of athletes, ranging from recreational to elite, male and female, and the types of mouthpieces utilized to create the effect. Specific areas to study include assessing the effect of clenching during exercise and its effect on cerebral blood flow while including an assessment of endocrine functions with and without a mouthpiece. In addition, using biological markers connecting to the response of clenching with mouthguard use appears to be a promising avenue, unlocking the mystery of the mouthguard effect which has eluded researchers over the years. Using biological markers helps minimize bias or the placebo effect that may accompany the use of a mouthguard during exercise performance. Thus, gaining clarity in this area of science would enable researchers to further elucidate the mouthguard effect during performance. As researchers take into account the interactions of these various factors, then the answers may become clearer for the practitioner to prescribe the correct mouthguard/mouthpiece which offers protection, as well as performance improvements.

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