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A Supplement to

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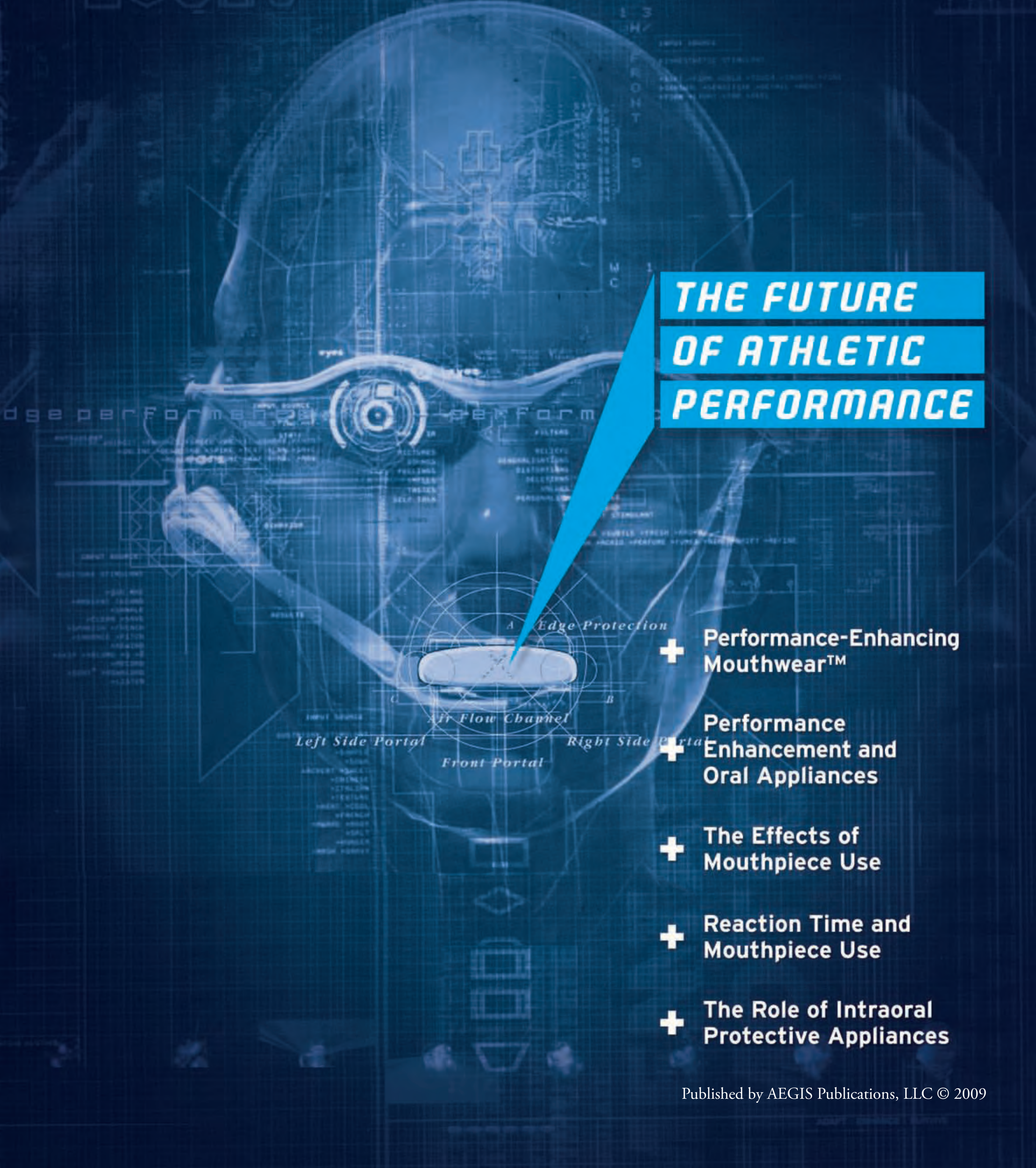

THE FUTURE OF ATHLETIC PERFORMANCE

- Performance-Enhancing Mouthwear™
- Performance Enhancement and Oral Appliances
- The Effects of Mouthpiece Use
- Reaction Time and Mouthpiece Use
- The Role of Intraoral Protective Appliances

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A Supplement to
Compendium
of Continuing Education in Dentistry®

The Future of Athletic Performance

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AEGIS COMMUNICATIONS

Dear Readers,

In 1961, I had a sound reason to become involved with the understanding and treatment modalities of a TMD (temporomandibular dysfunction). I was the patient!

A doctor gains additional understanding of a disease or illness when the patient is oneself. The associated physiologic manifestations brought about by temporomandibular joint (TMJ) problems are difficult to understand. How can the articulation of two bones cause such problems? While localized joint pain makes intuitive sense, associated anatomic pain away from the joint space and violent bouts of vertigo are harder to rationalize. I desperately needed to engage in a commonsense self-evaluation and splint design to solve my problem. That is why over 40 years ago I began the lifelong process of understanding mandibular positioning through occlusal interception.

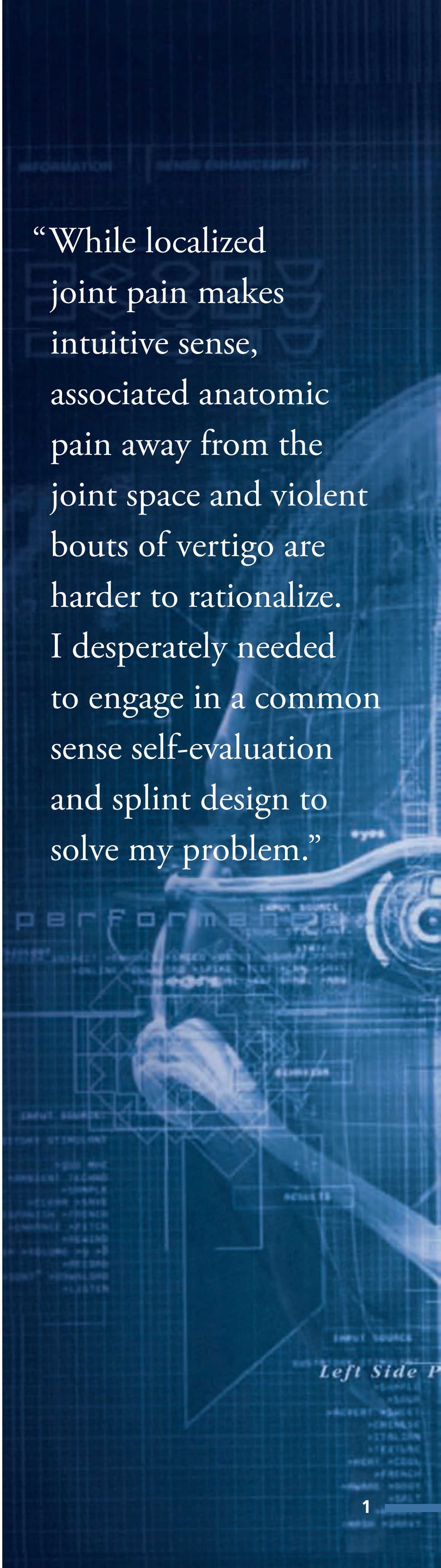
My journey began with a three-unit gold onlay bridge replacing tooth No. 19. The bridge fit the teeth but the occlusion caused problems, and my TMD started then. I sought the advice of dentists and medical doctors, but no one could give me relief. In their defense, they were working with TMJ treatment modalities that were in their genesis back then. Many different mandibular positioning devices were created for my problem, including upper and lower appliances of all shapes and sizes. Some were made from acrylic and others from cast metal. Every conceivable functioning design was fabricated until the condylar pressure that led to inflammation and pain in the joint, surrounding tissues, and structures could be eliminated.

The knowledge gained from personal evaluation of mandibular repositioning devices led to the creation of what is today known as “the reverse wedge”—a simple yet effective device through which a predictable increase in the distal portion of the posterior teeth and a lesser dimension in the premolar area positions the mandible to bring the head of the condyle slightly out of the fossa. By relieving abnormal and/or over-pressures in the TMJ, I became pain-free.

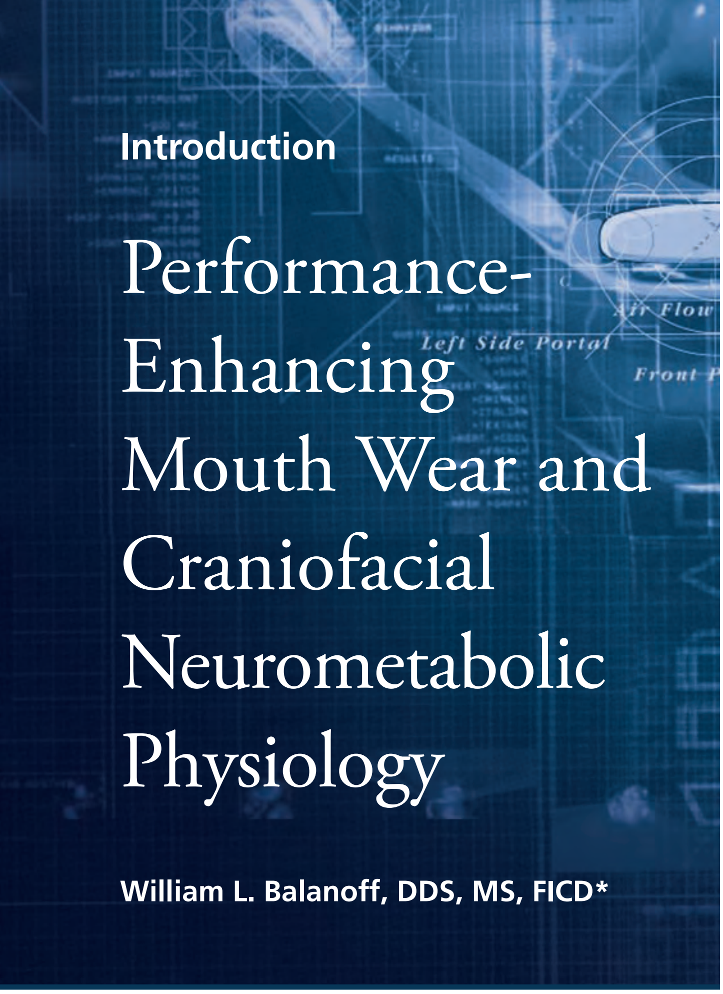
I could not predict 40 years ago that my suffering would lead to performance-enhancing mouth wear. I invite you to enjoy this very special supplement to *Compendium of Continuing Education in Dentistry* introducing this new field of dentistry.

Respectfully,

Paul Belvedere, DDS
Private Practice
Minneapolis, Minnesota



“While localized joint pain makes intuitive sense, associated anatomic pain away from the joint space and violent bouts of vertigo are harder to rationalize. I desperately needed to engage in a common sense self-evaluation and splint design to solve my problem.”



Introduction

Performance-Enhancing Mouth Wear and Craniofacial Neurometabolic Physiology

William L. Balanoff, DDS, MS, FICD*

In this special supplemental issue of *Compendium*, readers will be introduced to a new retail category—performance-enhancing mouth wear and its effect on the body. The literature and science presented in this issue will encourage new reflections on an old idea that has been anecdotally and qualitatively described in the past, but is now being supported by a number of scientific studies.

The role of neuroreceptors, neurotransmission, activation or suppression of neuropathways, the mechanism of neuropathways, stress, cortisol, lactate, concussion causation, and the craniofacial musculoskeletal system is beginning to be unraveled and comprehended in different ways. Scientists are reviewing known phenomena and applying double blind studies with remarkable results. Their conclusions are forging a new branch of science: craniofacial neurometabolic physiology.

Numerous published papers, as well as much anecdotal evidence, support the contention that a mandibular orthodontic repositioning appliance provides some beneficial physiological effect. Even two tongue depressors held between the molars seem to permit some degree of bodily strength enhancement. Of course, responsible dental professionals do not make decisions based on anecdotal evidence: treatment protocols are based on science. The gold standard is a double blind study with a large population of participants. When professionals can separate blatant commercialism from science and prescribe objective solutions, patients receive appropriate, current therapy that will create a better quality of life.

THE STRESS RESPONSE

Stress is a normal physiologic response and can be beneficial, maintaining alertness, focus, and efficiency. However, when stress becomes excessive (such as the "fight or flight response"), the body is overloaded, and both performance and health are adversely affected. Teeth clench in response to elevated stress levels. This clenching mechanism completes a circuit, as it were, and signals the brain to begin a complex series of responses in the hypothalamic-pituitary-adrenal (HPA) axis.

The HPA axis is a feedback loop signaling the release of hormones[1] and affects various parts of the body. When someone is faced with a stressful situation, the hypothalamus releases the corticotropin-releasing hormone (CRH), which activates the pituitary gland to release adrenocorticotropin into the bloodstream.[1] This triggers the adrenal glands to release epinephrine (adrenaline), norepinephrine (noradrenaline), and cortisol, all enabling the body's stress response.[1] Epinephrine increases blood pressure, reaction time, and heart rate, and sends blood to the muscles. Cortisol releases glucose to supply the brain and muscles with immediate energy.[1]

The HPA axis communicates with regions of the brain, including the limbic system, which controls motivation and mood.[1] It also communicates with the hippocampus, which has a vital role in memory formation, mood, and motivation.[1] Other affected areas include body temperature, appetite, and pain control. Stress will also shut down hormonal systems, which affects growth, metabolism, and immunity.[1] This serves as a useful short-term solution when the body must marshal its energies to confront or run from

*Private Practice, Fort Lauderdale, Florida

the source of stress.[1] However, stress's interference outlives its usefulness and becomes detrimental when chronic.

Cortisol, the "stress hormone," is essentially the trigger for adrenaline. Cortisol belongs to a class of hormones called glucocorticoids, which affect almost every organ and tissue in the body.[1] Scientists believe cortisol has hundreds of positive effects in the body but its most important job is to help the body respond properly to stress. Cortisol helps maintain blood pressure and cardiovascular function and is essential to normal functioning but needs to remain in proper balance.[1] At excessively high levels, particularly for long periods, the whole endocrine system is affected negatively. High cortisol levels limit peripheral vision, decrease metabolism, cause fatigue, reduce muscle-building, and suppress the immune system.[1]

The results of tests showing, among other benefits, a significant increase in endurance as well as a marked reduction in cortisol during stress, indicate that a properly designed oral appliance can interrupt the fight-or-flight signal by preventing the completion of the clenching mechanism.

SCIENTISTS ARE REVIEWING KNOWN PHENOMENA AND APPLYING DOUBLE BLIND STUDIES WITH REMARKABLE RESULTS. THEIR CONCLUSIONS ARE FORGING A NEW BRANCH OF SCIENCE: CRANIOFACIAL NEUROMETABOLIC PHYSIOLOGY.

CURRENT TECHNOLOGY

Various companies throughout the years have sought to deliver the "power position" through mouthguards; however, no studies to substantiate their claims have appeared in peer-reviewed journals. The products employed uniform-thickness bite plates that essentially locked or fixed the position of the jaw. All were bulky, uncomfortable, and hard to retain, and none proved successful.

What was needed was a device that would effectively "short circuit" the HPA process by preventing the completion of the clenching mechanism, thereby interrupting the fight-or-flight signal. This then clears the channels for enhanced performance and prevents the negative effects of stress from overloading the system. In simple terms, a person needs an oral appliance that prevents teeth from occluding or clenching under stress and halts the body's preconditioned flight-or-fight reflex.

Researchers have studied a unique oral device that unlocks the body's true potential and delivers performance enhancement without drugs. A simple wedge was the solution. Properly placed in the mouth, it enhances athletic performance in multiple ways and reduces stress.

The wedge is a multicomposite (elastomer, polymer) bioengineered intraoral device that relieves pressure on the temporomandibular joint that occurs each time the jaw clenches during stress. The wedge relieves this pressure by causing the lower jaw to be moved into the "optimal safety power position." The desired movement of the jaw is achieved by positioning a "reverse wedge" bite plate over both sets of rear molars. Subsequently, when the teeth are clenched—exerting pressure—the twin wedges provide the necessary pivot points that induce the mandible (lower jaw) to move downward in a slight arc.

This supplemental issue of *Compendium* includes a number of reports on the various effects of these devices, including a literature review of research focusing on stress control, cortisol production, and a mechanism to interrupt a complex neuropathway that is being massively overworked in modern society.

DISCLOSURE

The author is an employee of Bite Tech Inc.

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Performance Enhancement and Oral Appliances

Mark Roettger, DDS*

Abstract: **The use of some type of oral appliance to enhance human performance, decrease stress or improve strength, has occurred throughout human history, from ancient soldiers to modern athletes. To date, the science describing this phenomenon has been poorly understood, and the research has been limited. The goal of this paper is to review the efforts to improve human performance with oral appliances, and the research exploring the science behind these efforts.**

For the past 40 years, it has been suggested that mandibular position could affect upper body strength and, hence, athletic performance. In the 1980s, this concept seemed to have little scientific support and was highly criticized.[1,2] More recently, research suggests mandibular position and oral appliances positively affect not only upper body strength, but also endurance, recovery after athletic competition, concentration, and stress response.[3] This information could revolutionize the practice of dentistry. This paper reviews the literature and details the early research regarding mandibular position, clenching, and oral appliances and their effects on physiology and human performance.

THE QUEST TO IMPROVE HUMAN PERFORMANCE

Legend and history provide a glimpse of the beginnings of performance enhancement and oral appliances. Roman soldiers were said to use leather straps between their teeth to improve their prowess in battle. Native American women would bite on sticks during childbirth to ease delivery. Perhaps the most dramatic example of this phenomenon is from the US Civil War. Surgical options for devastating wounds from heavy lead bullets were limited. As a result, the treatment of choice for many of these wounds in the extremities was amputation. At that time, general anesthesia was in its infancy (in 1844, Horace Wells, a dentist, was the first to use nitrous oxide to induce the loss of consciousness for surgery). Therefore, soldiers were given bullets to bite on during these procedures to help them endure the agony, and the phrase "bite the bullet" was born. What was it about the action of biting a bullet that could help these soldiers deal with the incredible stress created by these crude operations?

Although there were early forays into these concepts of occlusion, oral appliances, and human performance, the quest for optimal jaw position and its relationship to performance began in earnest in 1958 under Stenger et al at the University of Notre Dame.[4] A starter on the football team, Jim Schaaf, suffered a concussion and subsequently Ménière's disease, a recurrent prostrating vertigo associated with generalized dilation of the membranous labyrinth of the inner ear, was diagnosed. The serious nature of the disease prevented Schaaf from competing. The researchers believed he had a temporomandibular joint (TMJ) problem, contributing to his equilibrium issues, and received permission from the coaches to examine him. The researchers placed cotton rolls over the player's back teeth and instructed him to swallow; the patient stated that his ears had cleared for the first time in weeks. It was determined that a splint and special mouthguard would be made: the patient wore the splint continuously and used the mouthguard during practice. In 2 weeks, the patient's equilibrium returned to normal and he resumed his starting role

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with the football team. Stenger and his dental colleagues at Notre Dame documented other cases in which jaw position was able to enhance or enable football players' abilities. However, these case reports are anecdotal, rendering them scientifically suspect although the results appear impressive.

Approximately 10 years later, Stephen Smith performed a sample study of professional football players, examining jaw position and muscle strength.[5] Smith's test position was obtained by bringing the player's lower jaw from physiologic rest position toward the closest speaking space, with evenly aligned midlines. He measured the player's strength, using a Cybex II Dynamometer (Cybex International, Inc, Medway, MA). When he reviewed the data, Smith failed to use statistical analysis and was criticized for poor science, although he did observe improvement in strength when participants' jaws were placed into the test position.

In 1980, Kaufman[6] fabricated bite-altering splints for the US Olympic bobsled and luge teams. He discovered that a number of the luge athletes who had reported headaches during and after runs found relief by wearing the dental splints. Some athletes also perceived increased strength when pushing off at the start of their runs. Again, these results were discounted as unscientific and anecdotal.

Kaufman followed up his Olympics findings with a double blind study to observe the effects of a mandibular orthopedic repositioning appliance (MORA) on football players.[7] The overall results were positive: among players using the MORA, there were fewer severe injuries, such as knee injuries. The athletes reported greater strength.

In the early 1980s, a double blind study was conducted at the University of Illinois with 20 students who were randomly selected.[8] The participants were examined, and two appliances were fabricated for each person: a MORA, which repositioned the mandible as described by Gelb, and a placebo appliance that did not affect the occlusion. Three bite conditions were tested for each participant: centric occlusion, centric occlusion with the placebo splint in place, and the Gelb position using the active MORA appliance. Data were collected using a Cybex II Dynamometer. Statistically significant differences were recorded between the MORA and normal centric occlusion when measuring shoulder strength. No significant differences were noted between the placebo and centric occlusion.

In 1996, Dr. Harold Gelb retrospectively reviewed many of the claims and counterclaims published in the area of jaw posture and strength throughout the decades of the 1970s though the 1990s.[1] Gelb noted not only that many of the studies that found improved performance while using oral appliances were flawed, but that those studies refuting claims of improved performance were also flawed. In some of the older studies, he observed that if proper statistical analysis were applied, there were actual statistical improvements in performance within the studies. Gelb's explanation of the critical charges and countercharges during this controversial period was based on the training of researchers: clinical scientists spend most of their training in patient care, while basic scientists spend much of their training learning experimental design. He called on the two sides to work more closely together for the sake of science and the benefit of the patients. Afterwards, research in the area of jaw position and strength proceeded in a positive direction. The next few years produced some particularly strong work in this area from Tufts University College of Dental Medicine in Boston. A series of well-designed, well-controlled studies examining jaw position and strength under a number of different conditions were published; these studies showed significant improvements in strength while using well-designed oral appliances.[9-12]

Efforts have been made throughout the years to improve the science in designing studies to collect data on the correlation between jaw position and strength. Historically, opinion among dentists is divided as to whether jaw position positively affects athletic performance. Research will remove opinion and anecdote from evaluation of this phenomenon, and provide clinicians with important knowledge for prescribing effective appliances. The quest continues, using technology and advances in biology to help evaluate how oral appliances may enhance human performance.

CNS EFFECTS OF CLENCHING AND MANDIBULAR POSITION

Brain mapping using functional magnetic resonance imaging (fMRI) has offered an opportunity to study neurobiology safely and noninvasively and has presented an unprecedented view of the brain's inner workings. Blood oxygenation level-dependent (BOLD) fMRI is the most popular form of functional brain imaging. BOLD fMRI contrast arises from the consequence of a higher ratio of oxyhemoglobin to deoxyhemoglobin that accompanies neuronal activation.[13] Areas of brain activation during a task or procedure actually "light up" when imaged by fMRI.

Researchers have begun mapping brain activity during clenching and chewing. These early studies indicate jaw activity in the form of clenching or chewing stimulates not only the sensorimotor cortex of the brain but also results in activation of the brain's autonomic area, such as the insula and hypothalamus.[14] Further research needs to be performed to determine which areas are involved in clenching and if the mandibular position affects the neurophysiology of clenching. Stimulation of the hypothalamus would indicate a connection between clenching and the masticatory and autonomic nervous systems (ANS). The hypothalamus is considered to be the "master control" of the ANS, mediating a variety of functions, such as fluid and electrolyte balance, temperature regulation, stress regulation, and energy metabolism. The insula is considered to be the "coordinator" of the ANS.[14]

Additional evidence that the masticatory system is intimately related to the autonomic nervous system has been published in several journals. Gomez[15] in 1999 showed a possible attenuation of stress-induced dopamine metabolism by nonfunctional masticatory activity. The conclusion of this study was that this activity decreased the effects of stress on central cholinergic neurotransmission.

A 2004 study by Hori et al[16] clearly showed that nonfunctional biting could suppress stress-induced activation of the hypothalamic-pituitary-adrenal (HPA) axis and consequently the expression of corticotropin-releasing factor (CRF) in the rat hypothalamus. Corticotropin-releasing factor is a 41 amino acid hypophysiotropic peptide secreted from neurons in the paraventricular nucleus (PVN) of the hypothalamus. CRF activates the anterior lobe of the pituitary gland, releasing adrenocorticotropic hormone (ACTH), which in turn stimulates release of cortisol from the adrenal gland into the plasma. Cortisol is a steroidal hormone that helps the body cope with stress by increasing gluconeogenesis, providing antiinflammatory effects, and by influencing many other bodily functions responsible for homeostasis. Acute stress also activates noradrenergic neurons in the locus ceruleus, confirming involvement of the sympathetic nervous system as well as the HPA-axis in the stress-induced physiologic responses. This study showed that rats who were allowed to bite on a wooden stick during stress exhibited a significant reduction in CRF in the paraventricular nucleus (PVN) of the hypothalamus compared with rats that were not allowed to bite a stick. These observations suggest a possible antistress effect of biting and an important role of nonfunctional masticatory activity in coping. Attenuation of stress by stick-biting in rats suggests oral appliances may help control stress in humans and thereby improve performance.

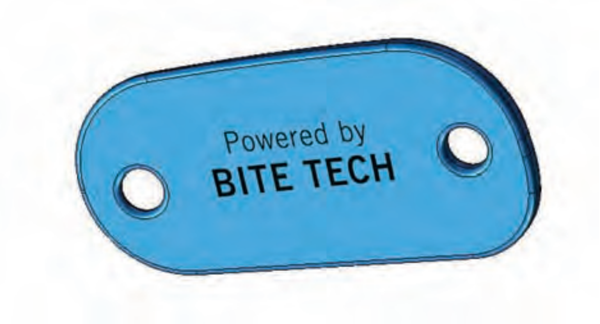

Figure 1 Schematic drawing of the Bite Tech wedge used in appliances to reposition the mandible, designed to help decrease stress and improve human performance when worn in a properly designed oral appliance.

Corticotropin-releasing factor (CRF) is the subject of intense research as it becomes clear that it is involved in many physiologic processes in the nervous system and beyond. Research is identifying CRF receptors not only in additional areas of the brain but also in smooth, skeletal, and cardiac muscles.[17] This would indicate that CRF is active in many areas of human physiology. Considerable evidence suggests excessive activity in CRF systems is associated with depressive illness and anxiety disorders.[18] Overproduction of CRF and the resultant anxiety has been implicated in diminished performance in animal models.[18] CRF is also implicated in pregnancy and postpartum morbidity and physiology.[19] There is high-level neuropharmacologic research to find antagonists to CRF to be used as orally active agents against a number of neurologic disorders. Oral appliances that could help control the CRF production could be extremely important both in dentistry and medicine.

The link between teeth, clenching, oral appliances, and the autonomic nervous system is poorly understood and deserves thorough study to fully describe the connection. Basic science has suggested a relationship between the masticatory system, hypothalamus, and autonomic nervous system, which may explain how "biting the bullet" could positively affect those under intense stress. Can this basic research be translated into clinical studies to understand more completely the influence of oral appliances on human performance?

CLINICAL RESEARCH: EFFECTS OF SPECIALIZED ORAL APPLIANCES ON HUMAN PERFORMANCE

A wedge-shaped component (Figure 1) has been designed to reposition the human mandible (simulating the use of bullet, sticks, and leather straps) to improve human performance. This wedge can be imported into numerous oral appliances (Figure 2), making them useful in athletic sports and in many other applications. The wedge has spawned experiments designed to test its effectiveness in enhancing human performance.

The first test was conducted at the University of Tennessee in 1999.[20] This study examined how the wedge affects strength and endurance, measuring grip strength as well as heart rate and blood pressure during aerobic exercise. The grip strength portion of the study involved 123 males and females. Results indicated 93% of the women and 67% of the men displayed increased grip strength when wearing an oral appliance with the wedge. Data from these individuals indicate a 96% confidence level that appliances containing the wedge would increase strength as compared with a placebo. The aerobic endurance section was smaller, with 17 participants. Fifty percent of the participants wearing the wedge appliances showed an increase in endurance as evidenced by lower heart rates. This study raised the question as to how an oral appliance could affect strength and endurance.

Previously cited research has indicated that physical stress increases blood pressure and activates the HPA axis as indicated by hormonal changes with the ultimate production of cortisol.[18] There are also indications that a modest increase in cortisol during exercise is beneficial, while extreme elevations have been associated with suppressing testosterone and increasing anxiety,[21] thereby adversely affecting performance and endurance. Animal models, such as those done by Hori, studied the CRF levels in the rat as a result of stress, which required sacrifice of the animal and immunohistochemical analysis of neural tissue to measure CRF. Human studies required a new design to safely measure the stress response: measuring cortisol levels to see if specially designed oral appliances could have similar anti-stress effects in humans as stick biting did in rats. Cortisol can be easily and safely measured by salivary assay. Using salivary assay analysis, Garner and McDivitt[3] investigated the correlation between cortisol levels when wearing and not wearing an oral appliance with the Bite Tech wedge (Bite Tech, Minneapolis, MN) during exercise protocols. A definite trend for lowered cortisol levels was noted with use of the wedge appliance (mean value with appliance .2921 mgs/dL vs mean value without appliance .3229 mgs/dL, $P = .389$. In fact, cortisol levels were lower in 11 of 18 participants. Those who were helped by the appliance had a 49% decrease in cortisol.

Figure 2 Some of the Bite Tech oral appliances that incorporate the wedge to improve human performance, different designs are used for different sports and other applications

Muscular activity is an integral part of the "fight or flight" response. The HPA axis and its hormones play a leading role in the preservation of homeostasis during intense exercise. Physical training and conditioning appears to lead to a reduction in the stress response to a given workload[22] just as the EDGE appliance did in many of the test participants. The fact that more than half of the participants experienced a significant decrease in cortisol is quite promising and justifies further research to clarify results and to examine the relationship of stress, performance, and oral appliances. The function of this modulation of the stress response in the improved performance of athletes is intriguing and will continue to be studied.

A link between cortisol and lactic acid has been described by Luger.[22] Because the EDGE appliance had some effect on cortisol levels, researchers studied the relationship of the EDGE appliance and lactic acid levels during exercise. Significant reductions in lactic acid were found in those wearing the EDGE appliance (see Garner page 9). This is another promising finding that could help explain the ability of oral appliances to affect human performance during exercise and stressful conditions.

CONCLUSION

The concept of oral appliances affecting human performance is not new. Crude appliances have been used for hundreds of years to help humans cope with difficult times and procedures. The mechanisms of this performance enhancement are complex and have been poorly understood. Recently, science has begun to explain more thoroughly the links between oral appliances and enhancement of human performance. Eventually, dentistry, medicine, the military, industry, athletics, and education may be positively impacted by this knowledge.

DISCLOSURE

The author is Executive Director of the Bite Tech Research Institute and a consultant for Bite Tech, Inc.

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RESEARCH UPDATE

Effects of Mouthpiece Use on Airway Openings and Lactate Levels in Healthy College Males

Dena P. Garner, PhD;[1] and Erica McDivitt, MS[2]

Abstract: **Research has described the use of mouthpieces not only in preventing oral-facial injuries, but linking use to improvements in muscular strength and endurance. However, the mechanisms by which these improvements occur have not been elucidated. The purpose of this study was to understand possible physiological explanations for improvements in exercise performance with the use of a mouthpiece. Specifically, this study focused on differences in lactate levels after 30 minutes of endurance exercise with and without a mouthpiece. In addition, computed tomography (CT) scans were taken of the cross-sectional area of the oropharynx in each participant (N = 10) with and without a mouthpiece. CT scans showed a significant difference in mean width (28.27 mm with the mouthpiece vs 25.93 mm without the mouthpiece, *P* = .029) and an increase in mean diameter with a mouthpiece (12.17 mm vs 11.21 mm, *P* = .096). Lactate levels were lowered with the mouthpiece at 1.86 mmol/L vs 2.72 mmol/L without mouthpiece. This research suggests that there is an improvement in endurance performance that may be linked to improved airway openings resulting from the use of a mouthpiece. Future studies should continue to clarify the possible mechanisms for these exercise outcomes as well as to understand the optimal mandibular advancement to elicit these exercise improvements.**

Mouthpieces have been used for a variety of contact sports to prevent oral-facial injury.[1] In a review of dental trauma literature, Glendor[2] noted that participation in sports is the greatest cause of dental injuries. To minimize injury associated with contact sport participation, the American Dental Association (ADA) recommends the use of mouthguards to protect against dental trauma during contact sports.[3] In addition to the recommendation of the ADA, such sport-governing bodies as the National Alliance of Football Rules Committee have mandated mouthguards for use in high school football in the United States.[4] The 2008-2009 National Athletic Association (NCAA) Sports Medicine Handbook mandates mouthguards for athletes involved with football, field hockey, lacrosse, and ice hockey in order to minimize dental trauma during these sports.[5]

While there is compelling research to support the use of mouthguards to protect against oral-facial injuries during contact sports, there is also research to suggest that mouthpieces may enhance performance. Smith[6,7] noted that professional football players exhibited greater arm strength with properly fitted mouthguards that resulted in changes in bite patterns. Smith also noted that those players with the most extreme overbite corrected with a mouthguard experienced the greatest increase in strength. Specifically, he observed that with a properly adjusted mouthguard, 66% of the players exhibited significant strength improvements on the isometric deltoid press.[7] He stated that the increase in strength with a properly fitted mouthguard was because of decreased pressure in the temporomandibular joint (TMJ).

Not only has improvement in strength been noted, but Garabee[8] described improvement in 7 runners' endurance

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and recovery with use of a mouthpiece to promote proper occlusion. He observed that when runners wore a wax bite mouthpiece, there was an increase in mileage: 64 to 100 miles per week in one runner, and 50 to 80-100 miles per week in another. He also noted quicker recovery times and decreased perceived exertion with use of the mouthpiece vs without the mouthpiece. Garabee hypothesized that this improvement was because of decreased stress with mouthpiece use that reduced clenching and grinding of teeth during exercise.

As the research evolved, the possible reasons for improvements in performance were elucidated by Francis and Brasher.[9] In a study of 10 men and 7 women, they found that wearing a mouthpiece during 20 minutes of high intensity cycling resulted in improvements in ventilation (average of 43.13 l/min with mouthpiece vs 50.98 l/min without mouthpiece). They noted that this improvement may be from pursed lips breathing which results in greater oxygen saturation. Ugalde and colleagues[10] confirmed that pursed lips breathing resulted in increased oxygen saturation in myotonic muscular dystrophy patients, while Tiep[11] stated that such breathing results in increased tidal volume, carbon dioxide removal, and oxygen saturation.

Drawing from the research by Frances and Brasher,[9] the possible reasons for improvements in endurance performance while wearing a mouthpiece provide insight into the physiological mechanisms that may be occurring. In order to first understand if there were improvements in performance, the authors' laboratory conducted a series of pilot studies primarily to determine if lactate levels were affected by the use of a mouthpiece. If, as Frances and Brasher[9] suggested, there was improvement in ventilation (ie, increased oxygen saturation and removal of carbon dioxide), then there could consequently be an improvement in lactate levels. The authors found that with 24 participants, there was improvement in lactate levels after 30 minutes of running on a treadmill at 85% of maximal heart rate (4.01 mmol/L with mouthpiece vs 4.92 mmol/L without mouthpiece).[12]

THIS PRESENT STUDY SUGGESTS MECHANISMS BY WHICH LACTATE PRODUCTION MAY BE IMPROVED WITH INCREASED AIRWAY OPENINGS, THEREBY IMPROVING OXYGEN KINETICS SUCH AS LOWERED OXYGEN DEFICIT AND/OR IMPROVED BREATHING WORK RATES.

With this data suggesting a physiological improvement when a mouthpiece is used, the next step was to clarify further the possible reasons for this improvement. Trenouth and Timms[13] found a positive association between the orpharyngeal airway opening and mandibular length, with a narrower opening associated with a shorter mandibular length. They cited previous research that suggested repositioning the mandible in an anterior position, thereby opening airways and promoting respiratory gas exchange to and from the lungs. In the literature associated with sleep apnea (where airway openings are diminished during sleep) and mouthpieces, it can be noted that there is significant improvement in airway openings for patients wearing a mouthpiece (a device that fits like a retainer and forces the lower teeth to relax in a forward position). Kyung and colleagues[14] advanced the mandible forward with an oral appliance in 12 sleep apnea patients and found a reduction of the apnea-hypopnea index from 44.9 (without appliance) to 10.9 (with appliance). Gale and colleagues[15] also found a significant improvement in mean airway opening with an anterior mandibular device while patients were supine in a conscious state. Specifically, Gale et al[15] found that in 32 participants, the mean minimal pharyngeal cross-sectional area was increased 28 mm^2 with the mouthpiece vs without the mouthpiece. Gao and collegues[16] stated that for their participants, the mandibular advancement was 7.5% with a mouthpiece. They specifically found a significant opening of the oropharynx (P = .0258) and velopharynx areas (P = .006). Zhao et al[17] also found that the velopharynx opening increased significantly with an adjustable mandibular custom mouthpiece, from 3.27 mm^2 at 0 mm, to 8.45 mm^2 at 2 mm, 17.73 mm^2 at 4 mm, 24.45 mm^2 at 6 mm, and 35.82 mm^2 at 8 mm. This research suggests that the positioning of the mouthpiece will impact the degree of airway opening, with greater movement of mandible in a forward position resulting in a greater opening of the velopharynx. With the findings of previous studies as well as those in the authors' laboratory, the hypothesis of this study is that there will be increased airway opening and a decrease in lactate levels with the use of a mouthpiece.

METHODS

For this pilot study the authors recruited 10 participants to determine if there were differences in airway openings with the use of a mouthpiece and if there were differences in lactate levels after 30 minutes of running. The mouthpiece used was a boil and bite upper mouthpiece which had a greater bite opening distal vs proximal (EDGE, Bite Tech Inc, Minneapolis, MN). Participants were 18–21 years old, male, and from The Citadel. Each participant completed a computed tomography scan (i-CAT 3D Dental Imaging System, Imaging Sciences International, Hatfield, PA) with and without a mouthpiece, and the mean oropharynx area was measured in each. Participants then completed two 30 minute runs on the treadmill at 75%–85% of their maximum heart rate, and lactate levels were assessed at 0, 15, and 30 minutes of the run (Accutrend Lactate Analyzer, Sports Resource Group, Inc, Minneapolis, MN). Participants were randomly assigned a mouthpiece during each running trial and were required to refrain from exercising the day before and the day of testing. If participants failed to cooperate, they were asked to return on a subsequent day when compliance was met.

RESULTS

The results of this study displayed a significant increase in mean width value of the oropharynx at 28.27 mm with the mouthpiece vs 25.93 mm without the mouthpiece ($P = .029$) (Figure 1). In addition, the mean value of the diameter was increased with a mouthpiece vs without a mouthpiece (12.17 mm vs 11.21 mm, $P = .096$) (Figure 1). As previous studies had suggested, the difference in lactate levels from pre- to post-exercise was lowered with the mouthpiece vs without the mouthpiece, though not at the level of significance (1.86 mmol/L with mouthpiece vs 2.72 mmol/L without mouthpiece) (Figure 2).

DISCUSSION

There is a plethora of research to suggest that the upper airway of patients with sleep apnea is improved with a custom-fit oral device, due specifically to the forward movement of the mandible.[13-18] Ryan and colleagues[18] found improvement in the cross-sectional area of the velopharynx and in the apnea index with the use of a mandibular advancement

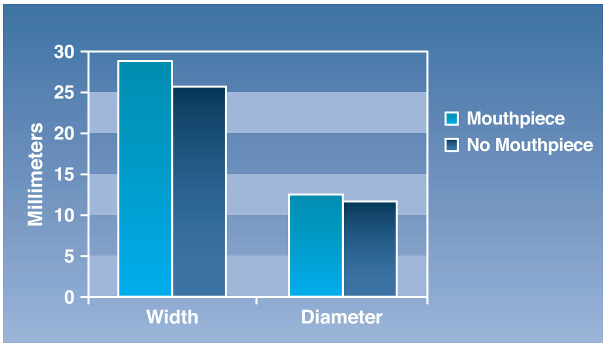

Figure 1 Mean values of oropharynx width and diameter with and without a mouthpiece.

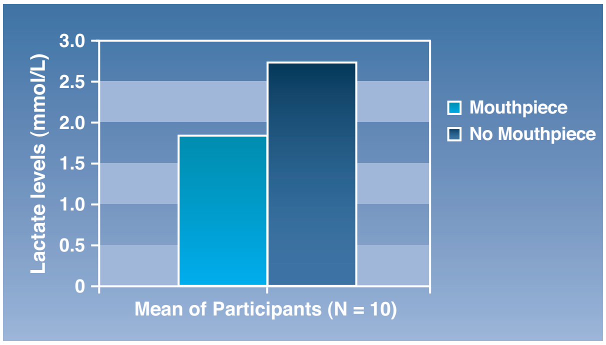

Figure 2 Mean lactate levels after 30 minutes of running at 75%–85% of maximum heart rate.

oral appliance. Kyung et al[14] also found reduced apnea-hypopnea indices, reducing the average index from 44.9 to 10.9 with an oral appliance.

Research continues to elucidate the degree of forward movement which would be most beneficial. In the research by Zhao and colleagues[17] there was a range of improvement in the airway opening for participants: as the mandible was moved to a more forward position, the opening of the airway increased. It should also be noted that a specific mouthpiece was used for this present study. This particular mouthpiece offered minimal obstruction for the participants as they ran, yet was also designed to bring the mandible to a forward position. The mouthpiece was easy to use and mold to participants, who noticed no impairment in their breathing patterns during use. Further research to understand how different mouthpieces could affect the airway openings is warranted. Such studies should focus on measuring the movement of the mandible with the use of a mouthpiece and how this may affect airway openings in healthy participants.

The results of the study suggest that the use of a mouthpiece increases airway openings in these healthy participants and that the use of a mouthpiece while exercising may improve lactate levels. While previous studies with sleep apnea populations indicated improvements in airway openings with the use of a mouthpiece, there were limited data on a younger, healthy population (age 21 +/- 1.1 years). This study, however, is similar in a study by Gao and colleagues[16] which took magnetic images of 14 healthy Japanese men (age 27.7 +/- 1.9 years). Gao et al[16] saw improvements in airway opening with a custom-fit oral device that was specifically designed to move the mandible in a more forward position. Their study found significant improvements in the velopharynx (P = .0006) and the oropharynx (P = .0258), while the current study noted a significant improvement in the oropharynx width (P = .029).

Because of the financial costs of obtaining 2 CT scans for each participant, this study was limited in the number of participants. In addition, this was designed as a pilot study to determine: 1) if there were changes in airway openings with a mouthpiece in healthy participants; and 2) if this could translate into lowered lactate levels. The results suggest there may be a link, which could be one possible physiological explanation for performance improvement with a mouthpiece.

It may be surmised that the lack of significant differences in lactate levels in this study may be because of the low number of subjects, even though the trend was lower lactate levels with the mouthpiece vs no mouthpiece. As the authors' previous study suggested (N = 24), lactate levels were significantly lower with a mouthpiece vs without a mouthpiece after 30 minutes of running on a treadmill (4.01 mmol/L mouthpiece vs 4.92 mmol/L no mouthpiece) (Figure 3).

Research has consistently noted the correlation between exercise fatigue and higher lactate levels. As one increases exercise intensity, the glycolytic pathway is highly utilized to meet energy needs. The end product of this pathway is the production of lactic acid. Lactic acid is broken down into lactate and hydrogen ions, and it is this increase of hydrogen ions that is negatively associated with metabolic processes, leading to fatigue.[19-20] Thus, any mechanism which elicits lowered hydrogen levels resulting from lactic acid should increase an athlete's time to fatigue. For example, if the pathways used during exercise rely more on oxygen, then lactate levels will be lowered. Yet understanding this link between lowered lactate levels and increased airway openings is a complex issue needing further investigation.[12]

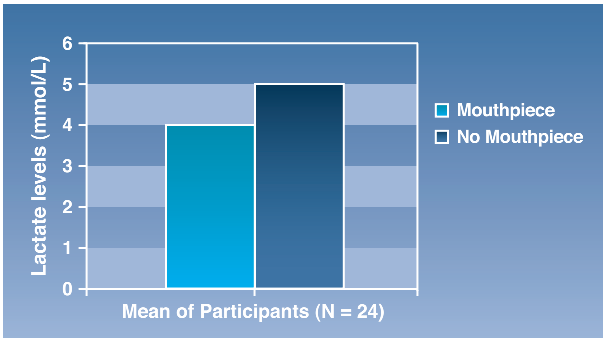

Figure 3 Mean lactate levels after 30 minutes of running at 85% of maximum heart rate.

Previous studies have noted that an improvement in breathing work rates leads to improved exercise time because of reduced oxygen uptake and ventilation.[21-22] Specifically, if breathing mechanics are improved, then there is a decreased need for oxygen and blood flow by the respiratory muscles which typically require approximately 10% of the oxygen needs during strenuous exercise. Less blood flow to the respiratory muscles suggests an increase of blood flow to the exercising skeletal muscles, which would prolong time to fatigue. Specifically, Harms and colleagues found that when respiratory muscle work was decreased (via a proportional-assist ventilator), time to exercise exhaustion was increased in 76% of the trials by an average of 1.3 minutes (+/-0.4 minutes).[22]

Improvement in respiratory muscle function may not be the only mechanism that occurs during mouthpiece use. An interesting study by Kilding and colleagues[23] examined response time of oxygen kinetics in endurance runners (N = 36) to understand its possible effect on a 5 kilometer time trial. An important finding from their study was that a faster phase II oxygen uptake kinetic response at the onset of moderate intensity exercise resulted in faster 5 kilometer performance. Thus, they concluded that those runners who had a shorter oxygen deficit at the onset of exercise (as indicated by shortened phase II response) could increase time to exhaustion, as indicated by the better 5 kilometer performance. Kilding cited previous work by Casaburi and colleagues[24] stating a decrease in oxygen deficit at the onset of exercise could result in decreased lactate production, which could potentially improve endurance performance. This present study suggests mechanisms by which lactate production may be improved with increased airway openings, thereby improving oxygen kinetics such as lowered oxygen deficit and/or improved breathing work rates.

CONCLUSION

This study found that the use of a mouthpiece significantly improves airway openings in participants as compared with these same participants who do not wear the mouthpiece. In addition, lactate levels are improved when participants wear the mouthpiece vs when they do not wear the mouthpiece. One explanation for the decrease in lactate levels may be an improvement in oxygen kinetics at the onset of exercise or improvement in breathing work rates which may be prompted by enhanced airway openings with the use of a mouthpiece. Previous research in the field of mouthpiece use and its effect on human performance suggests that mouthpieces improve performance. However, these studies have been unable to elucidate the possible physiological mechanisms for this improvement. This research is novel in the area of human movement because it suggests a possible physiological explanation for the improvement in performance as noted by athletes. Further studies should focus on the reasons for these improvements, noting differences in jaw morphology and airway dynamics for individuals who may benefit from a mouthpiece during exercise and sport.

DISCLOSURE

Dr. Garner has received an honorarium from Bite Tech Inc.

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Effects of Mouthpiece Use on Auditory and Visual Reaction Time in College Males and Females

Dena P. Garner, PhD;[1] and Jenni Miskimin, MS[2]

Abstract: **Studies in exercise science have suggested that the use of a mouthpiece can improve performance, and these improvements may be linked to an enhancement in temporomandibular joint (TMJ) positioning. Studies have suggested that by improving TMJ positioning, there is improved blood flow in the area of the TMJ. Changes in TMJ positioning may be improved with an oral device. The purpose of this study was to determine if there were improvements in auditory and visual reaction time with the use of a boil and bite mouthpiece. Using a BIOPAC system, study participants (N = 34) were asked to respond to an auditory signal during 40 trials. In the visual reaction time test, participants (N = 13) were assessed on how quickly they responded to a computer cue for a total of 30 trials. Auditory results showed a significant improvement with the use of a mouthpiece (241.44 ms) vs without a mouthpiece (249.94 ms). Visual results showed that participants performed slightly better with the mouthpiece (285.55 ms) vs without the mouthpiece (287.55 ms). These findings suggest that the use of mouthpiece positively affects visual and auditory reaction time, which is a vital aspect to optimal sport and exercise performance. Future studies should continue to shed light on possible reasons for the improvements in auditory and visual reaction time with the use of a mouthpeice. In addition, future studies should further illuminate what, if any, connection these improvements have with enhanced TMJ positioning.**

Reaction time is the period that occurs between a stimulus and the initiation of muscle response[1] and can be assessed as simple reaction time, choice reaction time, and discriminate reaction time.[1] Signals to any sensory system in a variety of populations can be ascertained in any of the above situations. For example, Borysiuk[2] evaluated reaction and movement time with tactile, acoustic, and visual stimuli in advanced and novice fencers. He found that the advanced fencers had a significantly improved reaction time with the visual ($P < .057$) and the tactile ($P < .029$) stimuli, with no significant differences in the acoustic stimuli between novice and advanced fencers. However, the mean reaction and movement times with all three stimuli were lower in experienced fencers vs the beginners. Borysiuk found fencing training improved reaction times in people with advanced fencing skills, thereby explaining improved performance.[2]

Many studies in exercise science have suggested that the use of a mouthpiece can improve performance, which may be related to an enhancement in temporomandibular joint positioning. Without proper temporomandibular joint positioning, nerves and arteries within the joint may become occluded, resulting in strain in nearby tissues, thereby reducing blood flow.[3-7] By neutralizing the temporomandibular joint with a mouthpiece, patients have reported to their dentists reduced pain in the jaw, head, and neck areas, along with increased physical strength. This improvement in strength may be linked to improved blood flow and oxygen kinetics associated with reduced stress in the temporomandibular joint, thereby producing improved blood flow to the exercising skeletal muscles.[8-10]

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Several studies have shown that mouthpieces result in improved strength and endurance.[11-14] Specifically, Fuchs[7] found the isometric strength of the upper and lower body in 40 females was improved when participants wore a wax bite between the upper and lower teeth, resulting in a 3-mm vertical dimension. The greatest improvement with the wax bite was in isometric strength, with an increase of 8% in the left arm, 4.5% in the right arm, 6.3% in the left foot, and 11% in the left foot. Alexander[15] confirmed this finding when she tested the EDGE mouthpiece (Bite Tech Inc, Minneapolis, MN) in 61 male and female participants and found 74% had improved grip strength when using the mouthpiece.

BY NEUTRALIZING THE TEMPOROMANDIBULAR JOINT WITH A MOUTHPIECE, PATIENTS HAVE REPORTED TO THEIR DENTISTS REDUCED PAIN IN THE JAW, HEAD, AND NECK AREAS, ALONG WITH INCREASED PHYSICAL STRENGTH.

The authors found that muscular endurance improved significantly with the use of the mouthpiece vs not using one. Specifically, they determined mean bench press repetitions increased 11% while preacher curl repetitions increased 17% when participants used the mouthpiece compared with nonuse ($P = .03$ bench press; $P = .004$ preacher curl). Thus, based on the indicative data that a mouthpiece improves exercise outcomes, this study's goal was to further elucidate the possible benefits of wearing a mouthpiece in regard to athletic performance, specifically improved reaction time.

METHODS

The research involved assessments of visual and auditory reaction times. There were 34 participants for the auditory arm and 13 for the visual. Ages ranged from 18 years to 21 years, with participants recruited from The Citadel's student body. The study was approved by the school's internal review board, and all participants signed consent forms.

BIOPAC Systems (BIOPAC Systems Inc, Goleta, CA) equipment was used to gauge auditory reaction time. The BSL-SS10L push button hand switch (BIOPAC Systems Inc), BSL-OUT1 headphones (BIOPAC Systems Inc), and Windows 95/98/NT 4.0/2000 (Microsoft® Corp, Redmond, WA) were employed. Each participant sat in a relaxed position with closed eyes and held the hand switch with the dominant hand, with the thumb in position to press the button. They were instructed to press this button when the headphones emitted a sound. Everyone underwent four segments, with 10 trials each. Segments one and two included a stimulus at pseudo-random intervals (1 to 10 seconds) while segments three and four used a stimulus at fixed intervals (every 4 seconds).

The visual test used a MS-DOS-based Motor Learning Activity Software System developed at Texas A&M University. This system uses Hick's Law, which states that reaction time increases as a function of a binary logarithm (log2 n), in which "n" is the number of equally likely possibilities. Specifically, the participant was asked to place his or her fingers on letters on a computer keyboard that corresponded to the same letters that were displayed on the computer screen. Above each letter on the computer screen were four large circles. The program proceeded through three sets of 10 trials. During the first trial, a line would appear over one circle with the letter beneath it. After a pseudo-random amount of time (1-10 seconds), the circle became white, at which point participants were to respond as quickly as possible by striking the corresponding letter on the keyboard. During the second set of 10 trials, the line would appear over two circles,

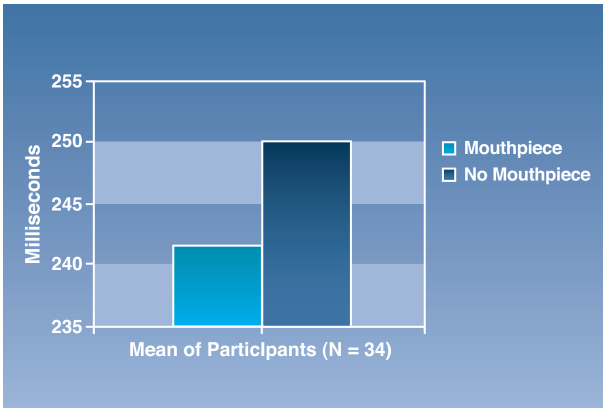

Figure 1 Mean values of auditory reaction time with and without mouthpiece.

but only one circle became white, and participants were to strike as quickly as possible the corresponding letter on the keyboard. For the final set of 10 trials, a line appeared over all four circles, one circle turned white after a pseudo-random amount of time, and participants were to respond as quickly as possible by striking the corresponding key on the keyboard. Participants completed two sets of the outlined Hick's Law test for a total of 60 trials.

For both arms of the study, participants completed the trials with and without a mouthpiece (the EDGE boil and bite). This mouthpiece was designed specifically to create a greater bite opening distal vs proximal in the mouth. Assignment of the mouthpiece was random, and participants were not told if any effect, either positive or negative, would result from its use.

RESULTS

Results of the auditory test showed participants (N = 34) performed significantly better with the mouthpiece than without ($P = .004$). The mean values with the mouthpiece were 241.44 ms vs 249.94 ms without the mouthpiece (Figure 1). Sixty percent were more successful with the mouthpiece. For the visual test, participants (N = 13) performed slightly better with the mouthpiece ($P = .681$). The mean values with the mouthpiece were 285.55 ms vs 287.55 ms without the mouthpiece. Sixty-two percent of participants were more successful with the mouthpiece (Figure 2).

DISCUSSION

This study indicates the use of a mouthpiece results in improvements in auditory and visual reaction times. The significance found in the auditory assessment suggests that the outcomes were not coincidental. The lack of significance in the visual test may be because of the small number of participants. If more participants were recruited, a trend of a lowered visual reaction time with the mouthpiece may be established.

The question, however, is how the mouthpiece provides such a benefit. Reaction time, specifically with visual and auditory stimuli, is a complicated series of events that begins with the stimulus and ends with the initiation of the movement. For example, reaction time associated with visual stimuli begins with the primary visual cortex from which two processing streams emerge. The first stream entails recognition of objects, while the second involves guiding actions and originates from the posterior parietal cortex. The oculomotor system involves three loops starting from the frontal cortex. The first loop goes through the brainstem, then the thalamus, returning to the cortex. The second loop travels through the caudate nucleus, substantia nigra, and thalamus, back to the cortex. The final loop proceeds through the superior colliculus and thalamus, returning to the cortex, with all three loops cross-communicating.[16] Auditory reaction time is associated with efficient spiral organ receptors in the middle ear, which transfer sound to the temporal lobes of the cerebral cortex via sensory neurons. It is well known that visual stimulus results in slower reaction times vs auditory stimulus because of the increased number of sensory neurons involved in the visual pathway.[2] Thus, the mechanisms by which a mouthpiece could affect these pathways may be complicated and worthy of further research.

Research claiming a reduction of stress in the temporomandibular joint area with the use of a mouthpiece may be one explanation for the improvement in reaction time.[8-10] If there is improved blood flow and neural transmission with the use of a mouthpiece that properly aligns

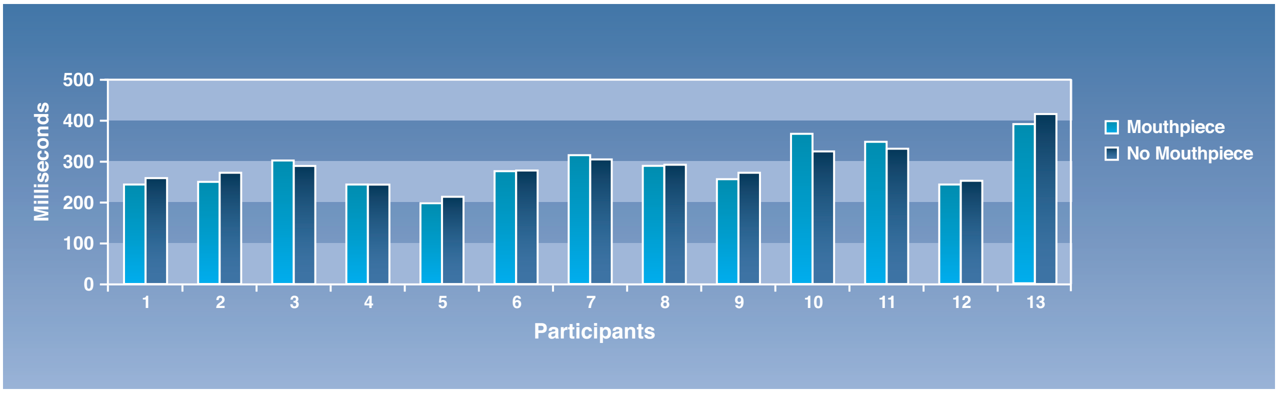

Figure 2 Mean values of visual reaction time with and without mouthpiece.

THUS, THE MECHANISMS BY WHICH A MOUTHPIECE COULD AFFECT THESE PATHWAYS MAY BE COMPLICATED AND WORTHY OF FURTHER RESEARCH. RESEARCH CLAIMING A REDUCTION OF STRESS IN THE TEMPOROMANDIBULAR JOINT AREA WITH THE USE OF A MOUTHPIECE MAY BE ONE EXPLANATION FOR THE IMPROVEMENT IN REACTION TIME.

the temporomandibular joint, then blood flow with increased oxygen unloading could be enhanced in other areas of the head and neck, leading to improvements in such events as reaction time. Reaction time with both the auditory and visual cues is a complicated series of events that may in some way be modulated with improved blood flow. Further studies should ascertain whether the physiologic mechanism within each of these systems is affected by proper temporomandibular alignment that occurs with the use of a mouthpiece.

CONCLUSION

This study explored auditory and visual reaction times with and without the use of a mouthpiece. Many sports engage the use of auditory and visual cues and depend on improved reaction times to obtain positive performance outcomes. If these findings are correct, it can be hypothesized that a number of athletes may be able to enhance performance when using a mouthpiece. Further studies are needed for a greater understanding of how mouthpieces affect performance physiologically.

DISCLOSURE

Dr. Garner has received an honorarium from Bite Tech Inc.

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The Role of Intraoral Protective Appliances in the Reduction of Mild Traumatic Brain Injury

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Abstract: Intraoral appliances (mouthguards) have long been used and mandated for several sports, with good results on the reduction of dentition injury. Recently claims have arisen that mouthguards prevent brain injury. This article reviews the data on such claims, the basic science that has been conducted, and how an intraoral appliance may in the future become part of an engineered system to reduce transfer of energy from impacts to specific locations on the head, in an effort to mitigate some types of mild traumatic brain injury.

Intraoral appliances, or mouthguards, designed to protect the dentition have been in use for many years and mandated in most collision sports for some time.[1] These devices have demonstrated some degree of effectiveness in limiting certain types of dental injuries.[2] Recently, research has attempted to demonstrate that mouthguards prevent mild traumatic brain injury (MTBI). This interest stems from growing emphasis on the causes, incidents, and identification of MTBI, as well as potential preventive interventions associated with MTBI. Some of this science is based on acceleration measurements of the empty skull, while some is ascertained from field data.[3] While skull measurement research is of interest, the magnitude of the impact and thus the impulse is necessarily low. Although the data show some attenuation of energy, it is insufficient to make any claims. The field data also fall short of providing proof of any meaningful reduction in MTBI. A more recent controlled study of neurologic impairment and recovery showed no change in outcome with the use of mouthguards.[4]

This lack of data is not unexpected: to understand these issues, the mechanics of MTBI and the use of the term "mouthguard" should be examined. The term "mouthguard" seems to refer to anything from a "buy them by the hundreds" boil and bite device that has little to no functional effect on occlusion, to professionally made custom appliances, which may offer functional occlusion limits with a wide variety of possible mandible positions and which can be made from different materials. While many of these custom appliances have a good track record of dental injury reduction, there is no standard for determining the function of these appliances in MTBI, and they are functionally useless in MTBI prevention.[5] The construction and fit of these custom appliances is as variable as the practitioners and laboratories that create them. In addition, other "in between" devices, which make various safety claims and offer insurance plans, can be purchased at retail and sporting goods stores and are sold by the millions. These devices sometimes use the word "brain" in the product name or include illustrated claims of MTBI reduction or even prevention.[6,7] Scientific data show these claims to be misleading at best, and fraudulent at worst.

The previously mentioned studies often lack a description of the actual devices employed at the time of data collection; this is particularly true of retrospective cohort studies in which athletes are polled after the fact to see if they were wearing an appliance. The data is of little value, except that it offers no evidence of mitigation in the MTBI event. Other recent data suggest that some appliances may even increase the transferred energy of an impact.[5] In this author's opinion, medically trained individuals should not believe that a device

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placed between the mandible and the maxilla will somehow mitigate the energy from blows to any location on the head that result in MTBI. At best, placing a simple "boil and bite" appliance in the space between the mandible and maxilla may effectively prevent interdigitation, but it could also provide a slippery surface for the dentition of the mandible.

Consider typical athletes in contact sports: they are given a helmet, a face protector, a chin cup, and a "boil and bite" mouthguard. They are told repeatedly to "keep their head up" or "hit with the face." What happens when athletes follow these rules? The energy from an impact is transferred from the face protector to the chin cup, then to the mandible, the dentition of which is on that slippery surface. The mandible is then allowed to transfer to the rear with considerable force. The mechanics of this event, while not likely to cause MTBI or dentition injuries, will probably cause mandibular injury. This type of event can also endanger the delicate areas of the intercondylar space, perhaps leading to basilar skull fractures or penetration of the glenoid fossa. As this is not a typical consideration for which the athlete is examined, and the problem may not present clinically for years, the claim for the successful prevention of dentition injury persists. From an engineering or biomechanics point of view, one of the basics of any intervention is to understand how it will impact the surrounding tissues and structures. In this case, the simple mechanics of the above impact scenario makes the potential for injury obvious.

MECHANICS OF THE MTBI

To understand MTBI, and any role a mouthguard may play in the prevention of such injury, the mechanics of the MTBI should be examined. While the pathophysiology is only now being understood, the mechanism of tissue distortion that triggers these cascades is better comprehended.[8] The basic mechanical properties of the brain, while a very complex issue, are outlined here for the purposes of this discussion. The brain—within the confines of the cranial vault and protected by the dura mater, pia mater and arachnoid sheath, bathed in cerebral spinal fluid—is divided into approximate halves separated by the falx, a very tough layer that limits the motion of the brain as a unit. Interspersed with the functional grey and white matter is the blood supply. If one could hold the blood supply of the brain intact in one hand, and the grey and white matter with the falx in the other, one would appear to be holding two brains. This intimate and complex system of tissues is at times very different in the way it reacts to impacts and impulses that demand a response from this viscous system.

As the system is combined of materials with different mechanical properties, the issue of tissue distortion becomes apparent. Imagine shaking this complex, and visualize the neuronal axons of the grey and white matter distorting around the more rigid materials of the falx and blood supply. One can see how tissue distortion can be highly variable based on several factors, not the least of which is the magnitude and direction of the impact or force vector. It also becomes clear that rotational or angular forces are the most likely to invoke problems at low levels. These kinds of insults do not require an actual impact to the head itself but can be the result of rapid non-impact motion.[9] More likely, there is an impact component at either the beginning or the end of the event.[9] Therefore, both linear and rotational forces are at work in almost all events that result in MTBI. For this reason, helmets demonstrate mixed and limited usefulness in the prevention of MTBI and diffuse axonal injury (DAI).

While somewhat over-simplified, the following two scenarios are examples of the complexity of these injuries. In the first, a head relatively *not* in motion is struck with an object. The impact results in a linear acceleration followed by a rotation, as the head is tethered to the torso and can translate only a short distance. In this case, without a helmet, the person is likely, depending on the impact magnitude, to have a point load, perhaps a skull fracture and significant linear injury prior to the onset of any rotational acceleration. In this kind of event a helmet is indispensible, as it will spread the load area, which reduces the point load, thereby reducing the translation and rotational impulse as well. For this reason helmets have a stellar record of injury reduction and prevention of events such as skull fracture, subdural hematoma, and sudden death.

In the second scenario, the head is in motion: for example when a person falls from a bike, and the head hits the pavement after the shoulder lands. In this case, there is a very high rotational impulse prior to head strike because the linear portion of this event is after the rotational event. Even if a helmet is worn, serious brain damage occurs, limited to the diffuse axonal damage, which is the result of the rotation. The helmet prevents the linear impact from causing immediate death by preventing skull fracture and tissue-destroying linear impact. Although the helmet proved life-saving, the person is seriously injured. The helmet could not protect the brain; the energy that injured the brain is the result of the brain's motion, while the helmet is on the skull.[9]

These events are only two possible examples: there are many other incidents with varying degrees of magnitude. For example, if the helmet is too stiff, the impulse at the end of the rotation may exacerbate the rotational acceleration. A softer helmet may limit the rotational rebound inside the head but may have allowed the point load to take place, still resulting in serious injury, but now more from the linear rather than rotational impact. In the first scenario, a too-soft helmet can result in death.

As a final step in this introduction to MTBI, imagine these scenarios, and others, occurring at much lower impulses, so that the damage is limited to a smaller number of axons (typically farther from the center of rotation). In the case of lower magnitude insult, MTBI can occur. There are standards for the thresholds of more serious brain injuries, but not yet for MTBI.[10,11] As some MTBIs can occur without head impact, no helmet, and thus no mouthguard, can prevent them.

PREVENTING INJURY

However, there are measures that can be taken to prevent MTBI. There is a point where the right mouthguard can limit some of the forces that might cause MTBI. Based on the above explanation, it is clear that the possibility is limited to blows that occur to or are transferred to the mandible—and only the mandible. A device that 1) interdigitates the upper and lower dentition so the mandible is fixed, 2) separates the upper and lower dentition by providing a physical barrier of deformable material with the appropriate mechanical properties, and 3) wears comfortably, will limit the acceleration of the head in impacts where the mandible is a primary point of load to the head. This device will protect the dentition and the mandible, and will limit the acceleration translated to the head, thus reducing both linear and rotational forces that result from the impact impulse.

While this is all good, it is neither a panacea or a simple process. The mechanical properties of such a device must allow it to work, via deformation, at the right time, for the maximum amount of displacement, while still maintaining interdigitation and remaining comfortable. This is not a small task. A standard must be developed to test various compounds and approaches to determine if this device could perform as needed and further to determine the range of function given the limits of materials and space. However, this author believes, based on ongoing testing, that there is a balance of mechanical properties that will result in a device that, when impacted with reasonable forces, either directly or via a chin cup, will limit head acceleration to a degree that makes this of value.[5] This device will work best when coupled with other devices that limit the impulse, such as deformable face protector systems and chin anchor systems with carefully designed properties, resulting in a system that works in harmony to limit the widest range of impulses while transferring the least amount of acceleration to the head.

CONCLUSION

Should such devices exist, they will be important in the tool box used to limit MTBI; however they will not be the critical component. Broad claims that such devices prevent concussion remain unsupported, and any claim that the device has some function even when the mandible is not the point of load should be discounted by the knowledgeable practitioner.

DISCLOSURE

Bite Tech Inc. has provided graduate student support in the past.

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