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Sports mouthguards: a review

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Abstract

Mouthguards are resilient intraoral devices, which aim to minimise the risk of damage to oral structures, particularly the teeth and periodontium. While mouthguards have been shown to prevent sports-related dental injuries, their benefit in enhancing athletic performance or preventing concussion is inconclusive. Awareness of their protective effects and a history of dental injury motivates athletes to wear mouthguards. 'Smart' mouthguards may be the future of the mouthguard industry, combining physical protection and live-tracking technology. Our aim is to provide an overview of the scientific literature on mouthguards for design features, physical properties, performance, efficacy, and compliance.

Introduction

Athletic mouthguards, previously known as "gum shields", first emerged in boxing in 1890 to protect athletes from lip lacerations. The first mouthguard was fabricated from gutta-percha and then later replaced by vella rubber (McCrory 2001). Research conducted by the American Dental Association (ADAa) in the 1950s led to the use of mouthguards in other sports. In 1962, mouthguards became mandatory in all high school and college American football games (BDHE 1963).

Currently the New Zealand Dental Association (NZDA) recommends wearing a custom-fit mouthguard for all contact sports, and several sporting associations in New Zealand have created their own regulations and guidelines (NZDA). The use of mouthguards in rugby has been mandatory for all levels of play since 1998 (NZPA 2003). Hockey New Zealand Safety Policies states that Hockey NZ youth tournaments require all players to wear mouthguard. All other players are strongly recommended to wear mouthguards but this is to be controlled by the team managers, not the umpire (HNZ 2018). Basketball New Zealand's mouthguard policy requires all individuals 19 years and under at any level of play to wear a mouthguard. (BBNZ 2016). The use of mouthguards in New Zealand boxing is strictly compulsory (BNZ 2014). Several reviews on sports mouthguards have been published in the international literature recently (Knapik *et al*. 2007; Lloyd *et al.* 2017; Parker *et al*. 2017); but despite widespread use of mouthguards and a culture of sport participation in New Zealand, no review of the literature on mouthguards has been published in the New Zealand context.

Understanding the science behind mouthguards can lead to better education of oral health care providers and coaches, and in turn provide better protection for athletes from sporting injuries. The aim of this review is to provide an overview of the scientific literature on mouthguard designs, physical properties, performance, protection and compliance, and to identify gaps in this field in the international and New Zealand context.

Mouthguard types, design and fabrication

The ideal mouthguard is one that is protective, comfortable, durable, without taste or odour, affordable, easy to clean, simple to fabricate, and does not interfere with breathing and speech during use (Scott *et al.* 1994; Tuna and Ozel 2014; Piccininni *et al.* 2017). Three main types of mouthguards used by athletes are pre-fabricated, mouth-formed and custom-fit (Maeda *et al*. 2009; Parker *et al.* 2017). Each of these types come with different fabrication steps, physical characteristics and costs.

Types

Pre-fabricated mouthguards are used without further modification and are held in by continual biting, due to the lack of retention (Newsome *et al.* 2001; Piccininni *et al.* 2017). While being the most affordable type of mouthguard, the bulk of this mouthguard has been found to interfere with speech and breathing (Tuna and Ozel 2014; Piccininni *et al.* 2017). Mouth-formed (boil-and-bite) mouthguards are fabricated from a thermoplastic material that moulds by finger, tongue, or biting pressure after being heated, and can be re-moulded when required. The extension and thickness of mouth-formed mouthguards cannot be standardized, and they are retained by continuous biting pressure (Newsome *et al.* 2001; Piccininni *et al.* 2017). Due to a relatively poor anatomical fit, there is a risk of dislodgement, which may cause airway obstruction (Jagger 1996; ADAb 2016; Lloyd *et* al. 2017). While most mouth-formed mouthguards are rigid, dual-layer mouth-formed mouthguards are available, featuring a less rigid inner layer. However, limited research was found regarding these mouthguards. Custom-fit mouthguards are fabricated from an impression, most commonly of the athlete's maxillary arch (ADAa 2006; Parker *et al.* 2017). Custom-fit mouthguards can achieve adequate retention and reduced bulk to make breathing and speech more natural (Newsome *et al.* 2001; ADAa 2006; Tuna and Ozel 2014). The dentist and technician can consider patient-level factors in the design–dental age, occlusal relationships, orthodontic treatment, history of trauma and sport being played (Tuna and Ozel 2014; Piccininni *et al.* 2017; ADAb 2016). The greater expense allows custom fabrication for each mouthguard and a much higher degree of protection (Tuna and Ozel 2014, Parker *et al.*

2017). Custom-fit mouthguards are viewed as the most acceptable type of sports mouthguard (ADAb 2016).

Design

Mouthguard design can vary depending on the sport being played. Sports involving a collision of a soft object, such as a softball or tennis ball, to the orofacial structures causes deformation of the soft object. Athletes in these sports may benefit from the use of a mouthguard constructed from rigid material that allows for force redistribution. Where a collision between a hard object and the orofacial structures occur, such as from bats and racquets, it is desirable to increase the contact time of the collision, thus decreasing the maximum force of impact. This can be done by fabricating mouthguards from a softer material that deforms on impact (Knapik *et al.* 2007). A bimaxillary mouthguard may be recommended when an athlete is at higher risk of orofacial injury or the consequences of such injury may have more severe consequences; for instance boxing, contact martial arts, higher levels of competitive sport, a history of mandibular fracture (Chapman 1989; ADAb 2016).

Various features of mouthguard design have been suggested. The occlusion between the mouthguard and the opposing dentition should feature uniform contact, allowing for even force distribution to the maxilla upon forceful closure of the mandible. Superficial indents on the occlusal surface are preferable, as deep indents may lead to 'bite-through' of the mouthguard surface (Chapman 1989; ADAb 2016; Lloyd *et al*. 2017). A material thickness of three-four millimetres has been recommended for optimal comfort and protection (Westermann *et al.* 2002; Yamada *et al.* 2006; Verissimo *et al.* 2015). Two-three millimetres is considered appropriate on the labial and palatal aspects (ADAb 2016; Lloyd *et*. 2017). The mouthguard should extend to the second molars if present, although first molars are generally accepted, within two millimetres of the sulcus depth labially and ten millimetres above the gingival margin palatally or lingually (Tuna and Ozel 2014, ADAb 2016).

Fabrication

The ideal material for a mouthguard is easily manipulated, sufficiently elastic, rigid and tough to reduce stress, distribute force and resist splitting, respectively, resistant to fluid or heat distortion, biocompatible, tasteless and odourless (ADAb 2016). Thermoplastic materials, typically ethyl vinyl acetate (EVA), are the current materials of choice for custom-fit laminated mouthguards (Maeda *et al*. 2009; Parker *et al.* 2017). Laminated mouthguards offer the best protection against dental and orofacial injuries (Lloyd *et al*. 2017). EVA adequately meets the biological, physical, and mechanical requirements and has superior tensile strength, durability and shock absorption compared to other materials, such as latex rubber (Tuna and Ozel 2014). EVA can also be easily manipulated and is readily available at a low cost. To the best of the author's knowledge, there have been no recorded instances of mouthguard-induced EVA allergy, which could be found in national and international literature (Parker *et al.* 2017). A disadvantage of EVA is its reduced capacity for elastic memory that contributes to decreased mouthguard retention over time. This can be overcome by pressure lamination techniques as it minimizes the effect of EVA's elastic memory and allows for equal distribution of the material on all surfaces (Newsome et al. 2001; ADAa 2006). EVA has some limitations in regard to shock absorption and rigidity (Maeda *et al*. 2009).

Custom-fit mouthguards are fabricated after an impression has been taken of the patient's maxillary arch or both arches and models poured. A laminated mouthguard uses two layers of three-four millimetres thickness EVA. The material is moulded to the model using either vacuum or, ideally, pressure lamination techniques. The first layer is reduced and roughened, and a second three-millimetre EVA layer is laminated on top of the first The mouthguard is coooled before being trimmed to appropriate dimensions and making occlusal adjustments. Where possible, two sheets of EVA at three millimetres thickness should be selected to produce the adequate three millimetres final thickness after thermoforming (Maeda *et al*. 2009).

Biomechanics

The protective benefit of mouthguards comes from their ability to absorb some energy from the contact at the impact site and redistribute the remaining energy throughout the mouthguard. Over a larger surface area, this impact has less intensity and transmits less force to the teeth and alveolar bone. Overall, this reduces the potential for deformation of the oral structures (Chapman 1989; Verissimo *et al.* 2015). A mouthguard that is thicker than three millimetres can reduce compressive forces on buccal enamel and tensional forces on palatal enamel. This in turn reduces the incidence of dental injuries, such as crown fractures (Verissimo *et al.* 2015). A historical study, performed on a cadaver, showed that mouthguards absorbed the pressure from impact that would have otherwise transmitted through the cranial bones and increased intracranial pressure (Hickey *et al.* 1967). It is important to remember that these findings are relevant to a simulated experiment on a cadaver, rather than the complex impacts experienced by athletes in a sporting context. While experiments on cadavers cannot be repeated due to ethical constraints, laboratory studies have been conducted since. It has been demonstrated that mouthguards reduce mandibular distortion and decrease acceleration of the head that result from a direct impact to the mandible on an artificial skull model (Takeda *et al.* 2005).

Perceived benefits of mouthguards

Dental and orofacial trauma

Mouthguards cover the teeth and surrounding gingiva and provide protection by dissipating and absorbing traumatic forces. This may reduce the deflection of teeth, hereby lowering the risk of tooth fracture, luxation, or avulsion, provided that the mouthguard remains in position at impact. Soft tissue injuries, such as lacerations or contusion, may also be reduced where the soft tissue is covered by the mouthguard (Tuna and Ozel 2014; ADAb 2016). Avulsed or fractured teeth may be retained in the mouthguard to prevent inhalation, ingestion, or expulsion from the oral cavity (Newsome *et al.* 2001).

Analysing dental and orofacial trauma statistics can prove challenging due to inconsistent or incomplete data collection methods. While New Zealand has an acceptable trauma data collection system through the Accident Compensation Corporation (ACC), few countries have a similar system. ACC is a New Zealand public sector entity that provides financial compensation and support on a no-fault basis to individuals who have been injured. Illness and ageing-related conditions are not covered, and a co-payment is often required (Quarrie *et al.* 2005). ACC does not collect data regarding mouthguard use at the time of a dental and orofacial injury. The incidence of dental trauma reported to ACC has increased between 2013-2018. Sport-related injuries contributed 24% of the approximately 34,600 dental injury events reported from mid-2017 to mid-2018. During this period, 70% of the sport-related dental injury claims to ACC were from males (ACC 2018). This is greater than the 60% reported by Welch *et al.* (2010) based on ACC data from 1999-2005. In the same period, 61% of sport-related dental injuries were reported to ACC by under twenty-year-old athletes (ACC 2018), similar to the 60% reported by Welch *et al.* (2010).

In New Zealand, data were compiled and assessed, reviewing data on injury claims obtained from ACC, data on numbers of players in the rugby union obtained from NZRU, and self-reported data on mouthguard obtained from the 1993 New Zealand Rugby Injury and Performance Project and 2002-2003 Rugby Injury Surveillance Projects (Quarrie *et al.* 2005). The rate of injury claims to ACC during 1995-2003 was 4.6 times higher for non-wearers versus wearers of mouthguards. In 1998, mouthguards became compulsory at all levels of rugby in New Zealand. Despite an increase in rugby participation, the recorded number of dental injury claims made in 2003 was 43% lower than in 1995. It can be speculated that this decrease in dental injury claims could be attributed to the protective effect of mouthguard use. However, other potential reasons for the decrease in injury claims could be a change in the nature of rugby over time, and difficulties obtaining accurate records on the number of players in the rugby union before 1998 (Quarrie *et al.* 2005). Further evidence was found in a meta-analysis compiling 14 studies and nearly 300,000 participants, over half from the United States (Knapik *et al.* 2007). The risk of orofacial injury was shown to be 1.86 times as likely when a mouthguard was not worn during sport, with 95% confidence intervals from 1.76-1.96. It should be noted that compliance was not measured in this meta-analysis, therefore the risk estimates may not be accurate (Knapik *et al.* 2007).

Financial Implications

The costs of traumatic dental injuries are high because the teeth involved may require care over an individual's entire lifetime and are not always covered fully by ACC or other compensation or insurance funds (Piccininni *et al.* 2017; ACC 2017). Concomitant presence of oral disease may preclude cover by ACC, and even if cover if provided by ACC, co-payments may be required by the individual (ACC 2017). Long-term treatment of tooth avulsions can lead to a cost of up to $15,000 USD, along with many hours of treatment (Newsome *et al.* 2001). ACC provided $6.5 million NZD towards 14, 700 dental injury claims from sport in the 2017 claims cycle, an average of $440 per claim (ACC 2019). The reduction in ACC payouts between 1995-2003, after mouthguards became compulsory in rugby, has been estimated to total approximately $1.87 million NZD (Quarrie *et al.* 2005). However, it must be emphasized that other factors may have contributed to this.

Mandibular Injury

It has also been suggested that the use of mouthguards can protect the structures in the temporomandibular joint region, mandibular condyles and the body of the mandible (ADAb 2016). A Japanese laboratory study assessed the influence of occlusal support from various types of mouthguards in relation to head acceleration and mandibular distortion from a single impact to the chin of an artificial skull. Overall, the use of a mouthguard significantly reduced the distortion of the mandible from this impact (Takeda *et* al. 2005). However, it was found that decreased occlusal support from mouthguards increased the amount of mandibular distortion compared to those with increased occlusal support. It is essential for the sports person to make the right choice about mouthguards. The recommendation is that multilayered pressure laminated custom fit mouthguards are the mouthguards of choice and that poorly manufactured single layered custom built or mouth formed mouthguards will not reduce the risk of injury (Takeda *et al*. 2004).

Concussion

Claims have been made regarding the protective benefits of mouthguard use in reducing the incidence of concussion. Theories include the way mouthguards separate the teeth to reduce the force of impact to the skull where the condyle compresses into the glenoid fossa, force dissipation through the mouthguard, and increased stability of the head during axial rotation from impact (Winters and DeMont 2014; Piccininni *et al.* 2017). A study conducted in the United States demonstrated a reduction of 50% of the concussion incidence in those who wore custom-fit mouthguards compared to those who wore stock mouthguards during a season of soccer. Some 412 athletes participated, with 23 concussions identified during the season (Winters and DeMont 2014). A meta-analysis assessed four studies measuring incidence of concussion in mouthguard wearers versus non-wearers and found evidence for a four-fold reduction in concussion incidence in wearers.

However, when a study based on retrospective recall was removed, the concussion was 0.82 times as likely in mouthguard wearers, with 95% confidence intervals from 0.43-1.58. The authors' conclusion was that there was a lack of evidence that mouthguard use lowers risk of concussion in sport (Knapik *et al.* 2007). A biomechanical impact study showed that of 100 concussion cases video analysed from a sample of Australian rugby and football games, the majority of head impacts resulting in medically verified concussion was due to impacts to the temporal region (63%) of the head. Only 9% resulted from impact to the face or mandibular region (McIntosh *et al*. 2000). This could suggest why few prospective studies have been able to demonstrate the efficacy of mouthguards in preventing concussion (ADAb 2016). The use of a mouthguard may significantly reduce the acceleration of the head compared to not wearing a mouthguard in laboratory studies, however, only a relatively small portion of energy from impact to the underside of the mandible was found to be transferred to the head overall (Takeda *et al.* 2004). More well-designed prospective studies are needed, but ethical difficulties restrict methods of assessing the effectiveness of mouthguards preventing concussion and mandibular fractures (Takeda *et al*. 2005).

Athletic performance

Theories on how mouthguards may enhance athletic performance include an anterior shift of the mandible allowing greater airway opening, the harmonious repositioning of the mandible and condylar region to improve effectiveness of associated structures, and the encouragement of tooth clenching to activate the muscles of mastication for beneficial cortisol release (Hori *et al.* 2004; Tahara *et al.* 2007; Picininni *et al.* 2017).

However, various studies found no difference between mouthguard-wearing groups and non-mouthguard groups for aerobic performance measures such as maximum oxygen uptake (Collares *et al.* 2014; Golem *et al.* 2017), time to run 1600 metres (Duddy *et al.* 2012), or respiratory measures during submaximal exercise (Golem *et al.* 2017). No significant differences in anaerobic measures such as peak power, average power, minimum power and power drop during the Wingate anaerobic test were found (Fischer *et al.* 2017). In a study investigating the anaerobic performance of Taekwondo athletes, no significant differences were found between the mouthguard and non-mouthguard groups for all of these tests except for the hamstring peak torque test whereby there was a significant increase in peak and average power. This study claimed the improvement may be due to the change in vertical dimension with mouthguard wearing, but concluded that more research is needed to support this hypothesis (Cetin *et al.* 2009). There is some evidence that voluntary teeth clenching is associated with facilitating H reflexes in the lower limb (Brooke *et al.* 1997). Currently there is inconclusive evidence to support performance-enhancing claims while wearing a mouthguard (Piccininni *et al.* 2017).

Compliance

Reasons for compliance include social influences by the media, coaches, teammates and family, awareness of protective effects, and a history of dental injury (Cornwell *et al.* 2003). Compliance is associated with regulation, as shown by a decrease in the incidence of dental injuries in New Zealand when mouthguards became compulsory for all levels of rugby in 1998 (Welch *et al.* 2010).

Non-compliance to mouthguard wearing is often influenced by factors such as poor fit and retention, discomfort, difficulty speaking and breathing, peer pressure, costs, negative attitudes towards protective appliances, and the presence of orthodontic appliance (Cornwell *et al.* 2003; Parker *et al.* 2016; Parker *et al.* 2017). One study found a key reason for non-compliance was attributed to a lack of awareness of their importance (Parker *et al.* 2016). Caregivers' attitudes also weigh heavily on a young athlete's decision to wear a mouthguard or not (AAPD 2018), and caregivers are more likely to buy mouthguards for male children and children with previous dental injuries (Diab and Mourino 1997).

The level of compliance of New Zealand rugby players was measured in self-reported data collected by the Rugby Injury and Performance Project in 1993, before mouthguards became mandatory. Mouthguards were used in 65% of weeks that rugby was played. Further research into compliance rates and penalty enacting in New Zealand is needed, as regulation has changed over time and penalties differ between sports.

Clinical implications for oral health professionals

Dentists have a unique opportunity to educate their athletic patients about the use and replacement of mouthguards, especially for those taking part in contact sports such rugby, basketball, football and hockey (Dorney 1998; Salam and Caldwell 2008). Dental professionals have the necessary skills and knowledge to assess dental trauma risks individually and educate accordingly. Questioning patients about any previous dental injuries can help to determine the risk of future injuries as it has been found that a previous dental injury increases the risk of future injuries (Bourguinon and Sigurdsson 2009). NZDA guidelines recommend the use of a properly fitted, custom-fit mouthguard while playing contact sports (NZDA). Few studies have discussed recommendations for the ideal replacement frequency of mouthguards, but it has been suggested that adults replace their mouthguard every two years to overcome the loss of resilience (Chalmers 1998) and children every year to allow for growth and development of the jaw (Jennings 1990). There is a need for further research on the durability of mouthguards to inform athletes on the ideal replacement timeframes. Individuals can regularly inspect the state of their mouthguard and should take it with them to their dental check ups. Where there are signs of deterioration, splitting or change in the fit or occlusion, a replacement should be arranged (ADAb 2016).

Orthodontic treatment

Patients undergoing orthodontic treatment require special consideration when it comes to preventing dental trauma. Orthodontic treatment is most often carried out before or during adolescence, when a greater proportion of sports-related dental injuries occur (Love and Shane 1998 in Salam and Caldwell 2008). Damage to affected appliances can lead to loosening of the brackets and bending of archwires (Salam and Caldwell 2008). It is recommended that marginal space is left between the fixed appliance and mouthguard to reduce the risk of brackets debonding or archwires distorting (Chapman 1989). Patients undergoing orthodontic treatment should be using custom-fit mouthguards (ADAb 2016) with regular modification or replacement which could be included in their treatment fee.

Mouthguard hygiene

A variety of microorganisms have been found on mouthguards that may be associated with negative health outcomes (Glass *et al.* 2007). One study found that sanitizing mouthguards after wearing them with the agent NitrAdine® reduced the microbial count significantly (Glass *et al.* 2011). Limited research is available for this topic and there are currently no protocols regarding the cleansing of mouthguards. The most recent Australian Dental Association guidelines recommend that mouthguards are rinsed with cold water before and after use and washed with cold or lukewarm water between uses. A small brush can be used on the inner surfaces and then the mouthguard stored in a clean, rigid and ventilated container (ADAb 2016).

Future implications

With technology increasingly incorporated into items of daily use, it is no surprise that there is a future for "smart" mouthguards. These are being developed with embedded microchips to measure impact and acceleration of the head during play and allowing coaches to assess concussion risk. The most commonly available "smart" mouthguards are the mouth-formed type. X2 Biosystems® mouthguards have been trialled in amateur rugby in New Zealand to better understand patterns of impact but research has not progressed further than this to date (King *et al.* 2015). To improve our understanding of their efficacy, "smart" mouthguards may be used to collect large sets of cloud-based data for future research and meta-analyses.

There is a need for increased awareness regarding sports injury prevention to minimize the physiological, psychological, and financial cost of trauma. Understanding around these issues could be increased by collaboration between the New Zealand Dental Association and various sporting unions by raising awareness of their guidelines on custom-fit mouthguards for contact sports. Athletes, coaches and their families should be aware of the importance of wearing a custom-fit mouthguard to reduce the risk of dental trauma. Reducing the cost barrier to accessing custom-fit mouthguards by partial or full funding could be considered in lowering the number of injuries and the financial burden in New Zealand and other countries.

Conclusion

Mouthguards play an important role in reducing the risk of dental injury in sport. While there is no conclusive evidence to support prevention of concussion or an improvement in performance while wearing a mouthguard, theories for these mechanisms do exist and should be explored further. Variations in mouthguard design can be applied to the fabrication process to create desired physical and comfort properties for different sports and occlusal relationships. While numerous factors motivate or deter athletes from wearing mouthguards, social influences can be both positive or negative. There is a need to explore the areas of mouthguard hygiene, durability, and "smart" mouthguards further.

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