STUDY OF MOUTHGUARD DESIGN FOR ENDURANCE AND AIR-FLOW ENHANCEMENT

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ABSTRACT

Recently, mouthguard is one of the important device to the athletes during sports and exercise. Wearing a mouthguard is a must to prevent them from any orofacial injuries occurs during their sport activities. Therefore, to make sure it is safe and comfort, a study on the mouthguard design is carried out to investigate the performance of the mouthguards, in term of stress distribution and air flow path by improving the pressure difference between the ambient (outside) and the oral cavity pressure (inside). A preliminary design has been study to simulate its total deformation and stress, in terms of Von Mises Stress by using ANSYS 15.0 Workbench. From the results, the critical parts are identified on the preliminary design and later being used to improve the design to the new one. By increasing the thickness of the preliminary design, the total deformation has been decreased for about 0.2 mm to 0.16 mm for the exerted forces of 50 N to 500 N for external forces comes from outside, whereas, for internal forces from 100 N to 600 N has decreased about 0.24 mm to 1.44 mm. The simulation process is then followed by the air flow study in the oral cavity with the open mouth about 0.5 mm when the athlete is doing the exercise with 4.43 m/s speed of flowing air entering the mouth. The finding indicates that the modified mouthguard has large value of velocity streamline compared with the preliminary design because it is thicker than the first design. The difference pressure between both of the designs are, 140.09 Pa for the preliminary design and 401.86 Pa for the modified design. Velocity stream line also showed that higher speeds occur in the near mouth guards, that is, between the bottom surfaces of the mouthguard and the lower teeth. The results show that, the thicker the mouthguard design, the better it is for prevention but less in air flow distribution into the oral cavity.

ABSTRAK

Pada masa kini, pengawal mulut adalah alat yang penting kepada atlet dalam sukan dan senaman. Dengan memakai pengawal mulut dapat menghalang mereka daripada sebarang kecederaan oro-wajah semasa aktiviti sukan. Oleh itu, untuk memastikannya selamat dan selesa, kajian mengenai reka bentuk pengawal mulut telah dilakukan untuk mengkaji prestasi pelindung gigi, dari segi taburan tekanan dan menentukan tekanan aliran udara pada pelindung gigi untuk mendapatkan perbezaan tekanan antara ambien (di luar) dan tekanan rongga oral (di dalam). Reka bentuk awal telah dikaji untuk mensimulasikan jumlah perubahan bentuk, dan tekanan dari aspek Von Mises dengan menggunakan ANSYS 15.0. Daripada keputusan yang diperoleh, bahagian-bahagian kritikal telah dikenalpasti pada reka bentuk awal dan kemudian digunakan untuk menambah baik reka bentuk kepada yang baru. Dengan menambah ketebalan pada reka bentuk awal, jumlah perubahan bentuk telah menurun sebanyak 0.2 mm hingga 0.16 mm untuk daya yang bertindak sebanyak 50 N ke 500 N, untuk daya luaran yang bersentuh dari luar muka, manakala, bagi daya dalaman sebanyak 100 N hingga 600 N telah menunjukkan penurunan sebanyak 0.24 mm hingga 1.44 mm. Proses simulasi kemudian diikuti oleh kajian aliran udara dalam rongga mulut dengan mulut terbuka seluas 0.5 mm apabila atlet melakukan latihan dengan 4.43 m/s kelajuan aliran udara. Dapatan kajian menunjukkan bahawa pengawal mulut yang diubah suai mempunyai nilai yang besar bagi halaju arus berbanding dengan reka bentuk awal kerana ketebalan yang bertambah. Perbezaan tekanan antara kedua-dua reka bentuk adalah, 140.09 Pa bagi reka bentuk awal dan 401.86 Pa untuk reka bentuk yang diubah suai. Halaju garis arus juga menunjukkan kelajuan yang lebih tinggi berlaku berhampiran dengan pengawal mulut, iaitu, antara permukaan bawah pengawal mulut dan gigi. Keputusan menunjukkan bahawa, lebih tebal reka bentuk pengawal mulut, lebih baik untuk perlindungan, tetapi kurang dalam pengagihan aliran udara ke dalam rongga mulut.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Mouthguards are a device that made of a specialized rubber-like. It is typically used to fit over the upper teeth and help to prevent injury at the teeth, lips, cheeks and tongue. Mouthguards usually being used during sports by an athlete to prevent tooth loss and may reduce the risk and severity of jaw fractures and concussions because of the body contact while doing these sports activities.

The use of mouthguard had been started in a boxing sport back to about the turn of the 20th century. At that time, a primitive mouthguard or known as a mouth piece is use and made up by cotton, tape, sponge and even small pieces of wood (Keystoneind, 2013). The first mouthguard or ‘gum shield’ was developed by a dentist from London in 1890 to protect boxers from debilitating lip lacerations whereas, it is a common injuries in boxing competition during that time. It is made from gutta percha and was held in place by clenching the teeth. Starting in 1927, mouthguards become a common use during a boxing match.

In 1947, a dentist in Los Angeles, Rodney O. Lilyquist used transparent acrylic resin to make a mouthguard. It is moulded to fit over the upper and lower teeth and made for a much more unobtrusive object. Since then, many athletes who involved in basketball use to wear this type of mouthguard to prevent dental injuries. During 1950s, the research on mouthguard is increasing in American Dental Association (ADA) and they started to promote the benefits of mouthguard to the public. By 1960, latex mouthguards are being recommended by ADA in all contact sports and all high school football players in the U.S. Since the promotion of mouthguards, the number of dental injuries had been decreased dramatically.

Presently, wearing mouthguards are required in many sports. There are 29 sports have being recommended by ADA to wearing mouthguards which are acrobatic, basketball, bicycling, boxing, equestrian, football, gymnastics, handball, ice hockey, inline skating, lacrosse, martial arts, racquetball, rugby, shot putting, skateboarding, skiing, skydiving, soccer, softball, squash, surfing, volleyball, water polo, weightlifting, and wrestling (JADA, 2004).

However, there are still increased in orofacial injuries even when the athletes are wearing the mouthguard. Therefore, many researches have been done to come out with the results of, which parts of mouthguard can protect the orofacial injuries. The researches have cover on mouthguard's materials, the designs, and the ability of mouthguard to protect athletes from orofacial injuries. Hence, this study is part of collaboration with National Sport Institute (ISN) to investigate the performance of two designs of mouthguard in order to find out which of those designs can prevent athletes especially junior athletes from orofacial injuries.

1.2 Problem statement

The tremendous popularity of organized youth sports and the high level of competitiveness have resulted in a significant number of dental and facial injuries.
Over the past decade, approximately 46 million youths in the United States were involved in some form of sports. In Malaysia, sports among youth have being started since in their primary school. It is compulsory to each student to play at least a sport to claim that they are active in the school.

However, all sporting activities have an associated risk of orofacial injuries due to falls, collisions, contact with hard surfaces, and contact from sports-related equipment. Sports accidents reportedly account for 10 to 39 percent of all dental injuries in children. The Lucille Packard Children's Hospital reports that more than 775,000 children aged 14 and under are treated in hospital emergency rooms (ER) each year, often from falls, collision, or overexertion during unorganized or informal sports activities. Most organized sports injuries (62%) occur during practices, not games. According to Miller (2012), 25% to 30% of youth sports injuries occur in organized sports, and another 40% occur in unorganized sports.

Oral Health Division, Ministry of Health Malaysia, MOH (2011), has reported that, injuries to anterior teeth are on the rise in 12- and 16-year-old schoolchildren. This is related to increased participation in sports and recreational activities associated with active lifestyles and ignorance of or disregard for wearing injury-prevention devices.

Abdullah et al (2013) has claimed that, there are dental injuries while playing sports among athletes who were university students over 18 years and under 30 years of age. The injuries occurred more frequently in hockey (65.3%), basketball (60%) and soccer (45.2%). This occurs due to the lack of knowledge about using the mouthguards during sports activities.

Children are most susceptible to sports-related oral injury between the ages of seven and 11 years. The administrators of youth, high school, and college football, lacrosse, and ice hockey have demonstrated that dental and facial injuries can be reduced significantly by introducing mandatory protective equipment such as mouthguard. Therefore, it is important to design the proper mouthguard and to study its comfort when wearing among the junior athletes.

1.3 Objectives

The objectives of this study are as following:

i. To investigate the performance of the mouthguards, in term of stress distribution.
ii. To determine the air-flow pressure effects on the applied mouthguards for improving the pressure difference between the ambient (outside) and the oral cavity pressure (inside).

1.4 Scope of study

The scopes of this project are lists below:

i. Two designs are used for the comparison
ii. The Autodesk Inventor is used to design the mouthguard.
iii. The material used for the mouthguard is Ethylene Vinyl Acetate (EVA) with density of 930 Kg/m3, young's modulus, 1.379x107 Pa, poisson's ratio, 0.3, bulk modulus, 1.1491x107 Pa, shear modulus, 5.3037x106 Pa, and specific heat of 1400 J/kg.
iv. The stress that is determined is Von Mises stress.
v. Force exerted is from 50 N to 600 N.
vi. The mouth-guard designed for junior athletes
vii. Computational Fluid Dynamics (CFD) Software - ANSYS 15.0 is used to investigate the stress and fluid flow test.
viii. The study of airflow is conducted during the open mouth condition by 5 mm between the mouthguard and the lower teeth with air velocity 4.43 m/s.

1.5 Significant of study

An appropriate mouthguard design gives comfort to the wearer, especially among junior athletes to prevent facial and dental injuries. To produce a suitable design, studies need to be done into all important aspects of mouthguard to avoid unfitted design.

CHAPTER 2

LITERATURE REVIEW

2.1 Mouthguard

A mouthguard is a plastic shield and a flexible custom fitted device which held in the mouth by an athlete to protect their teeth and gums from damage because of their athletic and recreational activities. It is also known as a mouth protector because of its function. The mouthguard, also defined as a resilient device or appliance placed inside the mouth to reduce oral injuries, particularly to teeth and surrounding structures (Mantri, 2014). Generally, mouthguards will cover the upper teeth only. However, in some cases, where there are a user wear braces or another fixed dental appliance on their lower jaw, the dentist will make a mouthguard for the lower teeth as well. Figure 2.1 shown the picture of mouthguard that have being used by an athletes.

Figure 2.1: Mouthguard use by an athlete (JADA, 2004)

The use of mouthguard should help the user to buffer damage to the teeth, the brackets and any other fixed appliances from blows and physical contact during their activities. By wearing a mouthguard, the risk of soft tissue damage will be lessen because it can act as a barrier between teeth and the cheeks and also, between the lips and tongue. An effective mouthguard should provide a high degree of comfort, resist tears, be durable and easy to clean, odourless, tasteless, can stay firmly in place during action and should not restrict your breathing or speech. Figure 2.2 shown an illustration of a human orofacial side view with a mouthguard wearied at the upper teeth. The red point shows the parts where mouthguard could prevent from damage when one have being wearing the mouthguard.

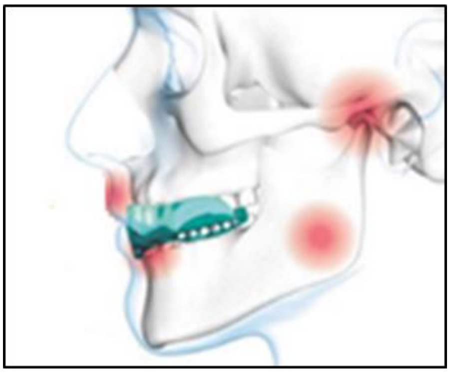

Figure 2.2: How a mouthguard should be wear (ADA, 2014)

There are three categories of mouthguard that use to protect the athletes' teeth according The American Society for Testing and Materials. Each categories of mouthguard are differences in their qualities such as their artificial ways, price, and the ability to protect the user's mouth or teeth.

2.1.1 Stock mouthguard

Stock Mouthguard (SM) is one of the cheapest mouthguards among the other two categories. Stock mouthguard can be found easily at any department stores or sporting goods stores. It comes pre-formed and ready to wear. However, most of the dentist does not recommend stock mouthguard to be used because it the worst fitting, least comfortable and less protective mouthguard. It can be bulky to the users, increase the tendency to gag, and make the user hard to breath and talk because they required the jaw to be closed to hold the mouthguard in place. Usually, it is made of rubber or polyvinyl. Figure 2.3 shown the stock mouthguard that can be found in the department stores or sporting goods stores.

Figure 2.3: Stock mouthguard (ADA, 2014)

2.1.2 Boil-and-bite mouthguard

The second category of mouthguard is Mouth-formed mouthguard which also known as, Boil –and-Bite mouthguards (BBM). This category of mouthguard is including all the mouthguards that are formed directly in the mouth. User can bought it directly at sporting goods stores, inexpensive and may offer a better fit than stock mouthguard. There are two types of mouth-formed mouthguard which are; shell liner type and thermoplastic type.

The shell liner mouthguard usually consists of an outer polyvinyl chloride shell that is filled with a soft liner made from plasticized acrylic resin gel or silicone rubber. However, there are some disadvantages of this type which are decreased retention because of repeated biting into the soft lining material, hardening of the soft liner, increased occlusal vertical dimension, discomfort, and bulkiness. The thermoplastic mouthguard is made up by soften it in hot or boiling water and then, placed in user mouth and will be moulded to the contours of the teeth using the fingers, lips, tongue and biting pressure. The mouthguard can be refitted if it is not properly made at the initial fitting. The example of boil-and-bite mouthguard has shown in Figure 2.4.

Figure 2.4: Boil-and-bite mouthguard (ADA, 2014)

2.1.3 Custom made mouthguard

The greatest fit, comfort and protection of mouthguard category are the Custom- made mouthguard (CMM). Because it is the better one, it becomes more expensive than other types of mouthguards. Custom-made mouthguard is made from a cast to precisely fit the user's teeth. The dentist will makes an impression of one individual's teeth and then, it is moulded over a model using special material. The mouthguard will be constructed under dentist's instruction at dental laboratory or in the dentist's office. Because of this, custom- made mouthguard will need some time to be done and wear by the user. There are two types of custom mouthguards which are the out dated Vacuum mouthguard and the modern Pressure Laminated mouthguard.

2.1.3.1 Vacuum-formed mouthguard

The vacuum-formed mouthguard is made up of single layer thermoplastic material that is adapted over the mould with a vacuum machine. The vacuum machine will form a mouthguard using a wet model. However, the wet model make it difficult to fit, so there are some researchers recommend to use a dry model cast with its surface temperature is elevated. Therefore, a better fit mouthguard will be obtained. However, there are some defects with vacuum mouthguard which are, the incisal edges can become thin, and occlusal, labial and lingual aspects of the mouthguard can shrink. Figure 2.5 shown a vacuum-formed mouthguard that has been made by Australia Dental Association (ADA).

Figure 2.5: Vacuum-formed mouthguard (ADA, 2014)

2.1.3.2 Pressure laminated mouthguard

Compare with all types of mouthguard, the pressure-laminated mouthguard have a greater fit, comfort and protection, with little deformation when it is worn for a period of time. The process of pressure lamination has more advantages than the single layer vacuum-formed design. The material will be layered to a specific thickness to suit the specific sport and can provide more protection to certain exposed areas in the mouth as needed.

Both Australian Dental Association and The American Dental Association (ADA, 2014) had strongly recommended to wearing a custom-made mouthguard to ensure a very maximum protection. Because of the dental injuries can be very costly and it might be permanent for the rest of one live, so, it is worthwhile for investing in a custom-fitted mouthguard especially for the athletes who are the one who always facing the physical contact’s activities. Example of pressure laminated mouthguard made by Australian Dental Association has shown in Figure 2.6.

Figure 2.6: Pressure laminated mouthguard (ADA, 2014)

Clemente et al. (2011) reported that, the custom-made mouthguard has the best characteristics in order to prevent orofacial trauma among the other types of mouthguard and it should be informed to all the athletes. The characteristics that the custom-made mouthguard has respect the quality criteria which are comfort, fit, retention, easy of speech, resistance to tearing, ease of breathing, as well as, good protection of the teeth, gingiva and lips, essential for successful prevention of orofacial and dental injuries.

Agron & Behlul (2013) has studied the functional efficiency of mouthguards in martial arts sports and has been conclude that, the custom-made PlaySafe maxillary and maxillary boil-and-bite mouthguards do not significantly reduce airflow dynamics of oral breathing when compared with the bi-maxillary boil-and-bite. However, these two types of mouthguards were found to positively affect aerobic capacity.

2.2 Mouthguard material

To form a good mouthguard for sports activities, mouthguard need to be made by using an appropriate material which it can be constructed and prevent any arofacial injuries to the athletes. Material used is one of the important things to take into account. Mouthguard materials should have an optimal consistency, energy absorption, and strength in order to cushion the traumatic impact.

The materials used to make the mouthguard have begun with cotton, tape, sponge and small pieces of wood. Then, the natural rubber or ‘gum shield’ was used to make a mouthguard by Woolf Krause (Keystoneind, 2013). It is originally made from gutta percha, a resin from the lsonandra Cutta tree, which is contain approximately 20% gutta-percha (matrix), 66% zinc oxide (filler), 11% heavy metal sulphates, and 3% waxes or resins which consist of plasticizer. The mechanical properties of gutta percha were indicative of a partially crystalline viscoelastic polymeric material (Friedman, 2013). Then, the mouthguard was modified and made from vella rubber, vinyl resin, and acrylic resin. All of these materials used have the same function which is to prevent athlete’s oral injury during sports.

Recently, many researchers have studied several types of materials suitable for making a mouthguard to make it works well and give the comfort to the athletes during the games. The most materials commonly used today is by many of the mouthguard manufacturer is thermoplastic copolymer. Thermoplastic materials are those materials that are made of polymers. These polymers are linked by intermolecular interactions or van der Waals forces, which then forming linear or branch structures.

There are several types of thermoplastic materials which are differing in properties and applications. The most common type of thermoplastic material that uses to make a mouthguard is Ethylene Vinyl Acetate (EVA). EVA has a flexible property like rubber, good low temperature flexibility and chemical resistance, transparent, tough at low and moderate temperatures, resilient, soft and extremely elastic, good clarity and gloss with little or no odour and high friction coefficient.

Other than one of the thermoplastic groups, EVA has being grouped in an Ethylene Copolymer. Besides forming as mouthguards, the typical applications of EVA are; footwear components, flexible hose, automobile bumpers, toys and other athletic goods, moulded automotive parts, flexible packaging, and films. Table 2.1 shows the physical and mechanical properties of EVA.

Table 2.1: The physical and mechanical properties of Ethylene Vinyl Acetate (EVA) (Berins, 2000)

Properties	Values
Density, ρ	0.93 to 0.96 Mg/m^3
Dielectric Constant (Relative Permittivity)	2.8
Dielectric Strength (Breakdown Potential)	21 kV/mm (0.8 V/mil)
Elastic (Young's, Tensile) Modulus, *E*	0.0015 to 0.08 GPa (0.002 to 0.01×10^6 psi)
Elongation at Break	300 to 800%
Melting Onset (Solidus)	55 to 95°C (130 to 200 °F)
Specific Heat Capacity	1400 J/kg-K
Tensile Strength: Ultimate (UTS)	3 to 35 MPa (0.4 to 5.1×10^3 psi)
Thermal Conductivity	0.34 W/m-K
Vicat Softening Temperature, T_m	45 to 80°C (110 to 180°F)
Thermal Coefficient of Expansion	160 – 200×10^{-6}
Notched Impact Strength	No break Kj/m^2

2.3 Mouthguard designs

Other than material used to construct a mouthguard, a specific design of mouthguard also plays an important role for a better usage. A good design of mouthguard can make the athletes feel comfort during their games. There are many different types of mouthguard designs available in the market. Every design has many functions designed by the manufacturer to improve the ability mouthguard to protect and provide comfort to the athletes when they wear it.

Figure 2.7 shows one of the stock mouthguard design which is courtesy of Specialty Orthodontics of Chicago, Illinois. It is well constructed with solid materials. From this figure of mouthguard, we can see that, there are a substantial opening at the front surface of mouthguard to allow the athletes easier to breath and speech.

Figure 2.7: Mouthguard of Specialty Orthodontics Chicago, IIllinois (Board Certified Orthodontist, 2014)

The mouthguard is mostly designed to protect the upper and lower teeth from grinding or hitting one another as shown in Figure 2.8, where the perspective visual of the mouthguard intraoral cavity. It shows that, both the upper and lower teeth are non-contact to each other when there is a mouthguard between them. However, these types of design does not fitted properly because if there are lots of movements, the mouthguard will lose and will become useful for the athletes who wear it. Therefore, it is not suitable for all types of sports especially boxing and martial arts.

Figure 2.8: The perspective visual of the mouthguard intraoral cavity (Board Certified Orthodontist, 2014)

Mekayarajjananonth (1999) had design a custom made mouthguard as shown in Figure 2.9 which a front view of completed mouthguard without pigmented resins while Figure 2.10 shown a lateral view of completed mouthguard with pink-pigmented resins. He had said that, this mouthguard design with a suitable material and procedure is soft and comfortable which is it can prevent any traumatic impact during the game. The design will not have any interfere with breathing. But in the same time, the researchers said, to increase comfort to the athletes the breathing holes between the mouthguard and the mandibular extension can be made.

Figure 2.9: A completed mouthguard without pigmented resins (T. Mekayarajjananonth, 1999)

Figure 2.10: A completed mouthguard with pink-pigmented resins (T. Mekayarajjananonth, 1999)

Jung, Chae, & Lee (2013) has studied on partial and full coverage of mouthguard. It is shows that, the partial coverage of mouthguard is more convenient for the athletes' muscular to work on than the full coverage of mouthguard. However, in their study, there is no significantly difference on the air-flowing between ambient air and oral cavity air through these two types of mouthguard design. Therefore, to complete this study, we will find that, how the ambient air flow through the mouthguard into the oral cavity of the athletes.

2.3.1 Design of mouthguard by thickness

In 1999, there was a research on 5 designs of mouthguards which are difference by thickness and materials attached to each designs. There were also differences in clinical stresses and conditions of mouthguards in the mouth of patients were compared on their efficiency. The purpose of this study was to develop a device and method to test and quantify the potential of mouthguards to absorb shock and evaluated by the comparison of 5 different designs of mouthguards. The results were shows that, all 5 types of mouthguards have provided some measure of protection and were better than unprotecting from other materials or thickness.

Figure 2.11: Three types of shock absorption mouthguards (Francois, 1999)

Martinez, (2013), had study on a mouthguard design with intermediate Nickel-Titanium and Foam Layer to improve the capability of shock absorption beyond the protection that an EVA mouthguard. Seven configurations were fabricated at three different thickness which consisted of an intermediate layer composed of NiTi, foam, or NiRi/foam. A drop tower was used for two different test methods which are first, samples were placed on a flat plate attached to a force sensor to record the transmitted peak force, and second method wasinvolved a simply supported aluminum plate that allowed some deflection which is then allowing the calculation of energy absorption using transmitted peak force and strain energy data. The results shows that, configurations with a NiTi intermediate layer in the three thickness groups performed significantly worse than the control in both the flat plate test and thesimply supported beam test.

Park et al. (1994) in their research had reported that, a mouthguard with a stiffer insert is more protective, which means that, the thicker the material is, the greater the resulting energy absorptions. However, they also said that, the thinner mouthguards are more comfortable than the thicker one. Therefore, the modification they had used was to minimum the thickness of the modified mouthguard. In this study, they were use ethylene-vinyl acetate copolymer materials but varying in thickness and stiffness. The materials were tested for their mechanical, thermal, and water absorption properties.

Tensile test was used upon a standard tensile specimen whereas, each thickness of the sheet was examined about five times in a hydraulically controlled materials testing machine. Stress-strain curves for each specimen were plotted from the recorded force versus elongation data. While for the energy absorption test was done by doing the impact test which provided information on peak impact forces and the amount of energy lost on impact.

2.4 Human oral cavity and teeth

To understand more about mouthguard design, we need to know about human mouth and teeth because the athletes will wear the mouthguard on their mouth to prevent their teeth from any injuries.

Oral cavity also known as mouth is the hollow cavity that allows food and air to enter the body. There are many other organs inside the mouth, such as the teeth, tongue, and the ducts of the salivary glands which are work together to aid in the ingestion and digestion of food. The temperature inside the mouth is about 37 ^oC (Swenson, 2008). Mouth-to-mouth and mouth-to-nose are the important systems of artificial respiration in human body. Figure 2.12 shows a human upper airway system diagram with the important parts.

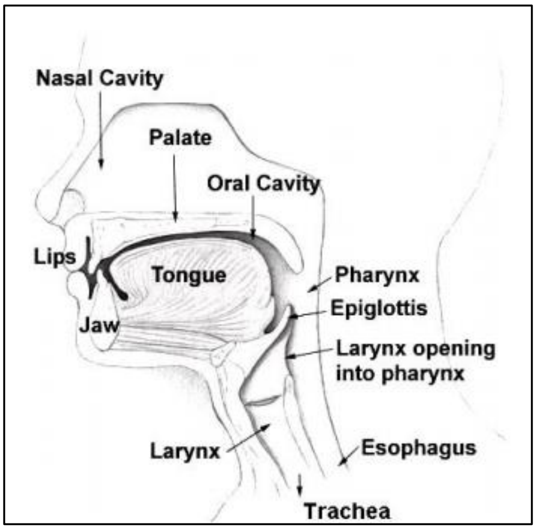

Figure 2.12: Human upper airway system (Deun, 2011)

The mouth also plays a major role in the production of speech through the movements of the tongue, lips and cheeks. Therefore, mouth is one of the most important organs to the human being. Besides, it is placed at the skull which is nearly to the brain that controls all of human body to functions well. For the athletes who always contributes to any hard body contact games, it is important for them to wear the mouthguard, so that, they can prevent any injuries on their head. Figure 2.13 shows the illustration of upper and lower teeth of a human being. These parts of teeth is important to know to make sure that, the proper design mouthguard has been made.

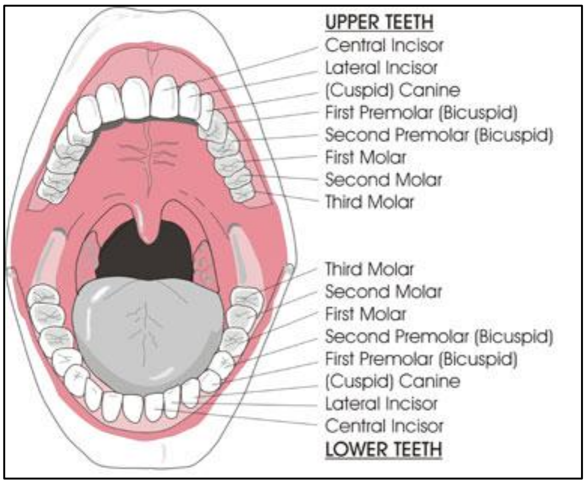

Figure 2.13: Illustration of upper and lower teeth in a human mouth (Swenson, 2008)

2.4.1 Dimension of the mouth

To design a mouthguard, it is important to know the dimension of the mouth. However, it is hard to state any standard measurement for human mouth because each person has difference size of mouth. The dimension of mouth also depends on the age level of the person where Sachdeva et al. (2012) had state that, with the increasing of age, there are an increasing of 0.7 mm wide of the smile index, whether transversely or vertically. For this study, only 15 to 20 age group sizes have been taken for the design of mouthguard. It is shows that, the average lips' length for this group of ages is about 19 mm to 25 mm.

2.5 Stress distribution on mouthguard

In this study, the stress distribution on mouthguard has been simulate on the design 1 before improving into design 2. There are several studies have been made to preview for further understanding and proper research.

2.5.1 How a mouthguard help to protect athletes

Mouthguards are designed to absorb and distribute the forces of impact received during athletic activities. There are at least six points to be considered of the serious injuries during games.

Lip, cheek, tongue and gums are the soft tissue in human mouth that needs to be protected from laceration of the sharp teeth. It can be preventing when there is properly fitted mouthguard covering the sharp surface of teeth where it usually are located on the front of the mouth. It also can prevent any mouth impact that can cause any damage to the teeth and upper jaw. Direct jaw impact and under chin impact are another impact that can cause orofacial damage to the teeth, Temporomandibular Joint (TMJ) and jaw (Garry, 2010).

TMJ is a hinge that connects the human jaw to the temporal bones of the skull, which are in front of each ear. It lets the jaw to move up and down and side to side. Therefore, it is one of the factors that allow us to talk, chew and yawn. A properly fitted mouthguard can reduce the potential for jaw joint fracture and displacement by cushioning against the impact.

From Figure 2.14 below, a mouthguard helps to absorps and deflects the impacts from outsides or inside the cavity that can cause any tooth injuries, brain concussions and protects the TMJ from dislocation and any others related injuries. It also helps to prevent jaw fracture caused by side and bottom jaw impacts. Moreover, a mouthguard is a very useful device to protect an athlete against internal oral lacerations causing intentionally or unintentionally.

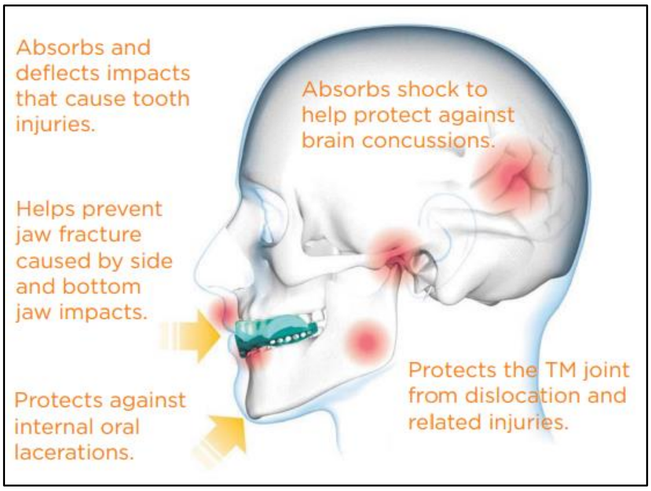

Figure 2.14: Ways mouthguard protects athletes from injuries (ADA, 2014)

2.5.2 Literature on mouthguard impacts

Viano, Whithnall & Wonnacottet (2011) has study on effect of mouthguard on head responses and mandible forces in football helmet impacts. Boil and bite mouthguard with EVA laminated was used in this testing. The mandible force and displacement have been validated against cadaver impacts to the chin. It was showed that, the mouthguard significantly reduced forces on the upper dentition by 40.8% to 63.9% and only the thickest mouthguard may influence head responses in the facemask impacts.

Noh et al. (2012) in their research on finite element analysis of the effects of a mouthguard on stress distribution of facial bone and skull under mandibular impacts had state that, when the mouthguard was wore on a model, the stress was low as it was dispersed to the teeth, the facial bone, and the skull when the oblique (45^o) and horizontal impact were occurred. However, when the vertical impact was added, the mouthguard was less effective at shock absorbing.

Most of the literature review on the mouthguard impacts must have relations on the thickness of the mouthguard. Therefore, in this current study, the von mises stress is used to determine on which part of the design may have weakness when any impacts occur. Then, a new design have been come out to modify and improve the current design. The stress distribution analysis has been done by using Computational Fluid Dynamics.

2.5.3 Force of the human bite

The analysis of the stress deformation had been studied when there has occur some internal force by the lower teeth of the athletes who are wearing the mouthguard. To do this research, some study has made by review a few of papers on the bite force in the human oral cavity that involve between lower teeth and the upper teeth.

Rosa, Bataglion & Siessere (2012) had studied on the maximum bite force and masticatory efficiency of adult individuals rehabilitated with difference type of dentures. The experiment has been done and maximal bite forces were recorded on the first molar regions, whereas the masticator efficiency rates were recorded on the right, left and habitual sides. The results shows that, the individual who were rehabilitated with implants and single crowns showed the greater bite force values and masticator efficiency rates compared to the other normal individuals. They have conclude that, the force of bites and masticator was depends on the types of oral rehabilitation. The maximum force that has been recorded for the molar region right and left was between 200N to 400N.

The variability of bite force measurement between sessions in different position within the dental arch had been studied by Tortopidis et al. (1998). Three transducer positions with a different pattern of transducer were used. The highest force measured was 580 N with the bilateral posterior transducer.

2.6 Study of respiratory response to exercise

Breathing is define as the movement of air into and out of the pulmonary system. It is describe as the manner of oxygen and carbon dioxide were exchanged in the lungs when breathing and ventilation whereas, at this time, these two terms are known as respiration. In other side, Hurst had stated that, ventilation is the breathing of air into and out of the pulmonary system which are including, nose, mouth, trachea and lungs (Hurst, 2004).

Usually, ventilation at rest occurs primarily via nasal route. However, as a person begins to exercise, the oxygen demands are increasing for the body, hence changes the breathing process from a strictly nasal route to an oro-nasal route. As stated in O’Kroy (2001) in his research, 80% of the breathing during exercise occurs via the oro-nasal route with intensities of 40 L/min.

Overand et al. (2000) had done a research on the effect of the Breathe Right (BR) external nasal dilator strip on treadmill exercise performed while wearing an upper maxillary mouthguard. The subjects were performed two random assigned bouts of incremental treadmill exercise with and without the BR strip while wearing upper maxillary mouthguards. The results show that patency of subjective nasal was significantly increased with the strip, repeated-measures analyses of variance revealed a significant main effect of the BR strip on dyspnea ratings during exercise, but there was no effect of the strip on test duration, heart rate, or running speed during the tests. Therefore, they conclude that the BR nasal dilator strip does not affect treadmill exercise performance in subjects of wearing mouthguards.

2.7 Computational Fluid Dynamics (CFD)

Computational fluid dynamics (CFD) is a branch of fluid mechanics that use to solve and analyze problems which has involve of fluid flow by using numerical methods and algorithms. In this study, ANSYS CFD simulation has been used to predict the impact of air flow on the mouthguard design.

In this study, CFD is used to validate the airways pressure of the mouthguard design trough human mouth. Many researchers have studied the human upper airway flow simulation using CFD. However, there are none of them had study about how the air flow though the various types of mouthguard design.

Zhao et al. (2013) has used CFD simulation to study the performance at the maximum air-flow rate during inspiration to treatment a patient who has obstruct of sleep apnea. A model of physical upper airway of a patient is validating against the pressure profile of a physical model of mouth appliance by using CFD method. The result shows that, the pressure was low when the soft palate and the base of the tongue were close to each other. They also come out with pressure contour of the airway before and after treatment in the oropharynx to see the pressure difference between both conditions as shown in Figure 2.15 below.

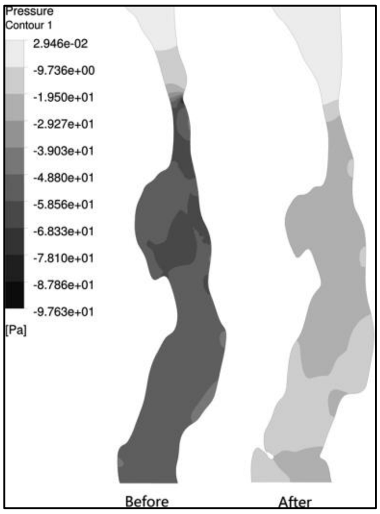

Figure 2.15: Pressure contour of the airway in the oropharynx (Zhao, 2013)

Mylavarapu et al. (2009) had made an anatomically accurate human upper airway model to conduct detailed in CFD FLUENT simulations during expiration. The obstruction occurs during the fluid flow in the airway regions has been investigated. Pressure and velocity measurement were conducted in the physical model with peak expiratory flow rate of 200 L/min. Unsteady Large Eddy Simulation (LES), steady Reynolds-Averaged Navier-Stokes (RANS) with two equations of turbulence models such as k-epsilon, standard k-omega, and k-kl-omega, Shear Stress Transport (SST) and one equation Spalart-Allmaras model. Among all these approaches, the best agreement with the static pressure measurements, with an average error of ~20% over all ports was standard k- turbulence model. At the tip of the soft palate, there was a larger pressure drop had been observed, whereas, it has the smallest cross section of the airway. They were suggested that, CFD simulation can be used to accurately compute the characteristic of aerodynamic flow at the human upper airway system.

CHAPTER 3

METHODOLOGY

This chapter is about the methodology on how this study is conducted. In order to complete this study, a planning need to be done to make sure the project follow the flow of each part of methodology. The plan is divided into two parts, which include methodology in semester one and methodology in semester two.

3.1 Finding parameters

The first part of methodology is focused on finding and understanding the additional information about mouthguard. The study includes types of mouthguard, the benefits for athletes when wearing a mouthguard, the materials use to make a mouthguard, and the design the manufacturers and other researchers always use to make a good mouthguard in order to prevent any orofacial injuries to the athletes.

After all the understanding of mouthguard, as state in the objective, this first part of methodology has come out with a design of mouthguard as a benchmark to the next part of methodology.

The methodology is then are followed by the second master project 2 on semester 2. From all task done in Master Project 1, it has been stated that, the Autodesk Inventor has been used to design the mouthguard. All the designs then are transfered to the Computational Fluid Dynamics (CFD) ANSYS 15.0 Software to study all the scopes state in Chapter 1.

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