Study of Mouthguard Design for Endurance and Air-Flow Intake

I Zaman1,a, S A M Rozlan1, B Manshoor1, M Z Ngali1, A Khalid2, N A M Amin3

1Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia.
2Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia.
3School of Mechatronic Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia.

Corresponding author: izzuddin@uthm.edu.my

Abstract. Mouthguard is one of the important device for athletes. 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 mouthguard, in term of stress distribution and air flow path by improving the pressure difference between ambient and the oral cavity pressure. 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 0.20 mm to 0.16 mm for the exerted external forces ranging from 50–500 N, whereas, for internal forces ranging from 100–600 N have reduced deformation from 0.24 mm to 1.44 mm. The simulation process is then followed by the air flow study in the oral cavity with an open mouth about 0.5 mm when the athlete is doing exercise with speed 4.43 m/s of air flow into a mouth. The finding indicates that the modified mouthguard has large value of velocity streamline compared to the preliminary design which is supported by significant pressure difference of 401.86 Pa, compared to 140.09 Pa of the preliminary design. Velocity streamline also shows that the higher speeds occur in the near mouthguard, that is, between the bottom surfaces of the mouthguard and the lower teeth. The results demonstrated that the thicker the mouthguard, the better it is for prevention but less in air flow distribution into the oral cavity.

1. Introduction

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 [1,2]. 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 [3]. 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 [4] 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 [5]. 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 wear 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 [6].

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 [7,8]. 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.

2. Mouthguard Protection

The design of a mouthguard is very important in order to minimize the impact and pressure when force was applied to it. There was two design made in this study to compare the properties in term of stress distribution and air flow pressure effects. Figure 1 shows the dimension of the first mouthguard in this study which was using Autodesk Inventor 2015.

![Figure 1. The dimension of the first design of mouthguard (a) rear view and (b) front view](image)

The next stage of this study is to investigate the critical part of stress deformation in term if Von Mises Stress by using ANSYS 15.0 Workbench for the first mouthguard design. The force given for the external part is between 50 to 500 N with the increasing of 50 N while for the internal part is...
between 100 to 600 N with the increasing of 100 N. The critical area for design 1 when given 100 N force is shown in Figure 2 for both external and internal part.

![Figure 2. The critical area of the design 1 for 100N force when (a) external force exerted and (b) internal force exerted](image)

Design of mouthguard which have different thickness is made as for the second mouthguard as illustrated in Figure 3. The second design modification is made according to the critical point of the first mouthguard design. The data gain from the first design will determine the new thickness of second design which had been increased to 5.9 mm at the covering of the upper molar teeth where the maximum deformation occur at that point.

![Figure 3. Design 2 of mouthguard](image)

3. Result and Discussion
After the modification is made at the second design of mouthguard, both design are compared in term of total deformation for each given force as in Table 1 for external forces and Table 2 for internal forces. The total deformation and equivalent (Von Mises) stress analysis were done to see the changes in the shape of the mouthguard caused by the application of a forces. It is proportional to the stress applied within the mouthguard’s elastic limits to deform – it returns to its original shape when the applied stress is detached.
Table 1. Different length of total deformation between design 1 and 2 for the external forces

| Force (N) | Maximum Deformation (mm) | Different length of deformation (mm) |
|-----------|--------------------------|-------------------------------------|
|           | Design 1 | Design 2 |                              |
| 50        | 0.06     | 0.04     | 0.016                          |
| 100       | 0.11     | 0.08     | 0.032                          |
| 150       | 0.17     | 0.12     | 0.047                          |
| 200       | 0.22     | 0.16     | 0.063                          |
| 250       | 0.28     | 0.20     | 0.079                          |
| 300       | 0.33     | 0.24     | 0.095                          |
| 350       | 0.39     | 0.28     | 0.110                          |
| 400       | 0.45     | 0.32     | 0.126                          |
| 450       | 0.50     | 0.36     | 0.142                          |
| 500       | 0.56     | 0.40     | 0.158                          |

Table 2. Different length of total deformation between design 1 and 2 for the internal forces

| Force (N) | Maximum Deformation (mm) | Different length of deformation (mm) |
|-----------|--------------------------|-------------------------------------|
|           | Design 1 | Design 2 |                              |
| 50        | 0.06     | 0.04     | 0.016                          |
| 100       | 0.11     | 0.08     | 0.032                          |
| 150       | 0.17     | 0.12     | 0.047                          |
| 200       | 0.22     | 0.16     | 0.063                          |
| 250       | 0.28     | 0.20     | 0.079                          |
| 300       | 0.33     | 0.24     | 0.095                          |
| 350       | 0.39     | 0.28     | 0.110                          |
| 400       | 0.45     | 0.32     | 0.126                          |
| 450       | 0.50     | 0.36     | 0.142                          |
| 500       | 0.56     | 0.40     | 0.158                          |

As for the pressure volume result, the maximum value for design 1 as shown in the Figure 4 is 98.10 Pa which is occurring at the front of the mouthguard, while the minimum value is -41.99 Pa which is occurring at the part of the inner cavity. The different pressure value for the highest and the lowest pressure is 140.09 Pa. Figure 4 shows the contour of pressure volume rendering from the simulation starting from inlet to the outlet of the enclosure. In this study, the mouthguard was set to be in an enclosure of the rectangular box in order to make it looks like in an oral cavity of the human. The air had flowed under the mouthguard which is the part between the mouthguard and the lower teeth which was about 5 mm. For meshing analysis, the air flowing into the model was meshed using tetrahedral element in terms of grid independent test. Overall, there were 65909 nodes and 343147 elements of this meshing process.
However, by referring to Figure 5, it is the pressure volume rendering contour for design 2. The maximum pressure volume is 254.56 Pa, while the minimum pressure volume shows it is -147.3 Pa. The different pressure value for the highest and lowest pressure for this modified mouthguard is bigger than the design 1 which is 401.86 Pa.

A thick mouthguard may have better protection than the thinner mouthguard. However, it will increased the pressure differences from the outside cavity to the inside cavity which will give less comfort to the athletes during wearing the mouthguard [9]. According to Boyle’s law, the more pressure in the oral cavity will give more oxygen intake to the lungs. This happen when the pressure in the mouth and thoracic is larger than the lungs pressure. When the air in the lungs increase, there will be more oxygen intake needed by the athletes during their exercises. Due to increased lung capacity, the alveolar surface area will increased and increased the blood pressure from muscle pumping.

4. Conclusion
The objective of this paper is to investigate the performance of the mouthguards, in term of stress distribution and 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). The real mouthguard is from design 1 and for design 2 is modified to make the comparison on the stress distribution and pressure difference. The simulation method is used to get the results to be analysed. The second design give long lasting mouthguard and better protection to the user where it exhibited less deformation than the preliminary mouthguard. On the other hand, when it comes to the simulation of the air flow from ambient to the oral cavity pressure, the modified mouthguard has a large number of pressure different than the preliminary mouthguard. So, it is important to make sure there are just a small different of thickness to be added to design 1 where the pressure different will be smaller.

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References
[1] Abdullah D, Wee CLF, Ahmad WNW, Robin R, Tiong SP and Khoo S 2013 Knowledge and Use of Mouthguards among University Athletes in Malaysia. Movement, Health & Exercise 2
[2] Mantri SS, Mantri SP, Deogade S and Bhasin AS 2014 Intra-Oral Mouth-Guard in Sport Related Oro-Facial Injuries: Prevention Is Better Than Cure! Journal of clinical and diagnostic research: JCDR 8 299
[3] Knapik JJ, Marshall SW, Lee RB, Darakjy SS, Jones SB and Mitchener TA 2007 Mouthguards in Sport Activities History, Physical Properties and Injury Prevention Effectiveness. Sports Medicine 37 117-14
[4] Al-Kahtani AM 2013 Carrier-Based Root Canal Filling Materials: A Literature Review. The journal of contemporary dental practice 14 777
[5] Dhillon BS, Sood N, Sood N, Sah N, Arora D and Mahendra A 2014 Guarding the Precious Smile: Incidence and Prevention of Injury in Sports:: A Review. Journal of international oral health 6 10
[6] Association AD 2004 The Importance of Using Mouthguards: Tips for Keeping Your Smile Safe. The Journal of the American Dental Association 135 1061
[7] Clemente MC, Silva A, Sousa A, Gabriel J and Pinho J 2011 Sports-Related Oro-Facial Injuries: Which Kind of Mouthguard Will Be the Most Suitable to Play Safe? ISBS-Conference Proceedi
[8] Martinez F 2013 New Mouthguard Design with Intermediate Nickel-Titanium and Foam
[9] Park JB, Shaull KL, Overton B and Donly KJ 1994 Improving Mouth Guards. The Journal of prosthetic dentistry 72 373-80