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ANALYSIS OF AIR FLOW IN THE MOUTHGUARD DESIGN BY USING CFD APPROACH

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ABSTRACT

Many athletes use mouth guard to protect their teeth, gums and soft tissues of cheek and mouth during the game as a protection but at the same time they feel problem to breathe improperly which leads to reduction in their stamina, this is because of the design error and improper ventilation space in it for the athletes. This study was conducted to highlight these problems and analyze the effect of air flow in the design of mouthguard. Three different designs of cavity model of air flow channel were analyzed by using computational fluid dynamic (CFD) approach. In this case, an ANSYS software was used to observe the air flow characteristic for ventilation purpose and determined the parameter related to it such as velocity, pressure and type of air inside and outside of the athlete's mouth. The minimum and the maximum value of velocity profile and pressure has been obtained for further design consideration. The design, shape and number of channel on the mouthguard slightly influence the outcome result of analysis.

Keywords: mouth guard, sports, computational fluid dynamic.

INTRODUCTION

A mouthguard is a protective device which functioning as a buffer from trauma and provide the level of protection based to the type of protection. For example, its provide protection to the oral soft tissues (lips, gums, tongue) and hard tissues (teeth and alveolar bone) and protection from brain injuries (Knapik *et al* 2007). The ability of mouthguard to protect the mouth is very dependent on the ability of mouthguard to act as shock absorber and absorb force transmitted through the teeth (Craig *et al.*, 2008). However, if the applied force is too high, adverse effect can be reduced. Figure-1 shows the injuries occur to the teeth while not using the mouth guard.

Figure-1. Type of injuries in sport.

Mouthguard has been long used as a method to reduce injuries during sports and recreational activities. There are several types of mouthguard. The simplest one is the stock mouthguard, which available and can be purchased from the store sports equipment. The second type is the mouths formed or boils and bite guards, usually used by who were healed and immediately used by athletes to allow some adjustment to the applicable dentition. The most complex mouthguard is custom made and come in several types, but all require a cast impression of the patient's teeth as a first step and mouthguard is made on this cast. Figure-2 shows the available mouthguard on the market.

Figure-2. Available mouthguard on the market.

The issues of the current mouthguard design to the athletes is breathing difficulties due to poor ventilation channel and uncomfortable. Athlete's performance improvement in muscular strength and endurance during games or training are depends on airways opening (between mandibular and temporal bone skull).

Mouthguard was made of from a piece of natural rubber that has been hollowed out and trimmed so that it would fit over the maxillary teeth and was weary to prevent broken or chipped teeth that's resulting from blows upon the head. As it is not in accordance with the teeth, jaw clenched to hold the mouthguard in place, so it's making difficult for the wearer to breathe normally.

There are three types of mouthguard that generally available on the market: stock mouthguard, mouth formed mouthguard, and custom-made mouthguard. Theoretically, a proper fitted mouthguard should be comfortably protective, resilient, tear resistance, odorless, tasteless, inexpensive, and easy to be fabricate and do not interfere with speech but most importance things is airways channel for breathing which play an important role.

Stock mouthguard are preformed and come ready to wear in various sizes but with nearly no adjustment to fit the user mouth. These mouthguards are mostly made from either polyvinyl chloride, polyurethane, or a co-polymer of vinyl acetate or ethylene. Mouth formed mouthguard are known as “boil and bite” mouth guard, where it’s made from thermoplastic material. These mouthguard are placed in boiling water then formed and molded to the contours of the teeth using fingers, lips, tongue, and biting pressure. Custom-made mouthguard are the mouthguard that’s has been made in dental laboratory based on the cast taken from an impression as a mold to create the custom-fitted mouthguard supplied by dentist. These type of mouthguard are made by using multiple sheets that are laminated upon one another over a cast of the athlete’s teeth using heat and high pressure.

Finite element analysis of mouthguard design

Finite element analysis (FEA) is knows as a numerical method to analyze the statics and dynamics properties of the mechanical part such as deformation, stress of the structure, flow of gases using CFD techniques and many more to solve complex structure in engineering and aviation. The significance of CFD analysis in engineering and aviation industries encompasses seamlessly calculating the fluid / gas forces and understanding the impact of gas or liquid on the performance of a product.

In the field of dentistry, finite element analysis was used to stimulate the process of bone remodeling, to examine the internal pressure acting on the teeth, different type of dental material and to optimize the shape of the recovery. Borcic and Braut (2012) conducted an analysis of mouthguard using finite element (FE) technique to determine the behavior of air flow as shown in Figure-3. However, due to complexity of subject structure, conventional methods and morphology due to mechanical and chemical properties the results were not accurate and precise. This is because; the conventional methods like photo elasticity and strain gauge method are not reliable to predict the pressure distribution in the subject. The use of traditional method such as load-to-failure bench-top testing unable to create a mechanism of failure seen clinically. Thompson and his co-workers (2011) have summarized that the use of method finite element analysis (FEA) is becoming more popular because of its ability to accurately evaluating the biomechanical behavior of the complex artificial material structures are irregular and heterogeneous.

In order to testing biological material properties and anatomy, usually mechanical testing with the biomaterials always require a large number of samples but by using of finite element analysis the traditional specimen requirements can be circumvented and by using of mathematical models it also eliminated the need for a large number of dental experiments. In current research, the structure of the mouthguard was divided into many small and medium segments of elements with specific physical characteristics in ANSYS.

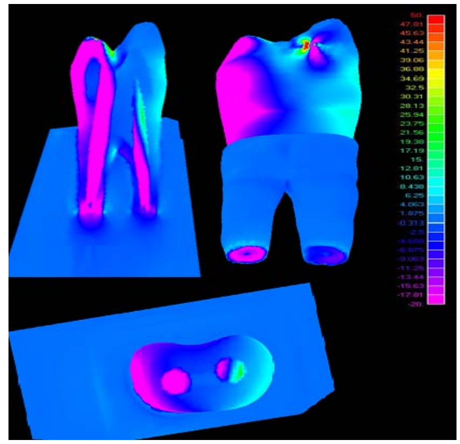


Figure-3. Analysis using of finite element method (Borcic and Braut, 2012).

Wootton *et al*. (2014) have used the CFD tool to analyze the flow patterns which are difficult, expensive or impossible to study by using of experimental techniques. These tool also have been use in others research to model the upper airway fluids dynamics using CFD and investigate the strength of correlation between various CFD endpoints, anatomical endpoints, and obstructive sleep apnea syndrome (OSAS). Figure-4 shows that the air flow that enters the mouth when the athlete using the mouthguard was far better than other methods.

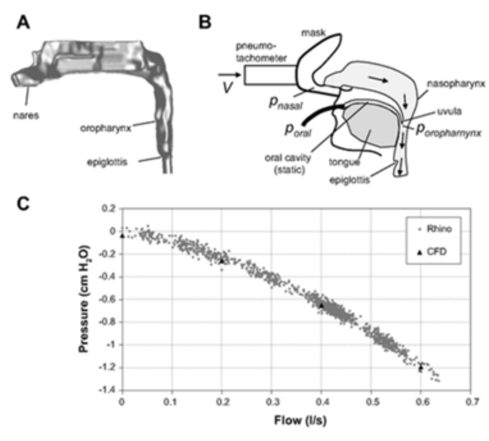


Figure-4. Application of CFD that’s relate to upper airways (Wootton *et al*., 2014).

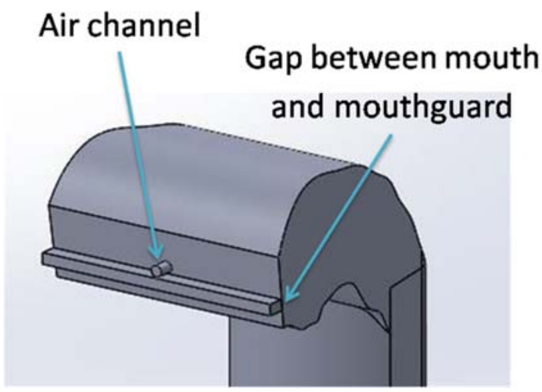
METHODOLOGY

The CT scan machine is used to get the view of a person during wearing a mouthguard. The scanned image is used for further analyzed in the ANSYS software. In addition, the custom-made mouthguards is scanned and converted from STL file format to Geomagic Studio software. This software can transform the 3D scan data and polygon meshes from an ATOS 3D scanner into an accurate and editable 3D digital model. Finally, the edited

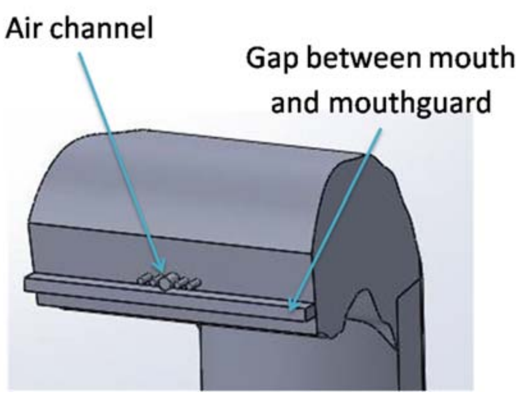
ARPN Journal of Engineering and Applied Sciences

surface of the mouthguard model is translated into an IEGS file to ensure the files can be read in the CAD software.

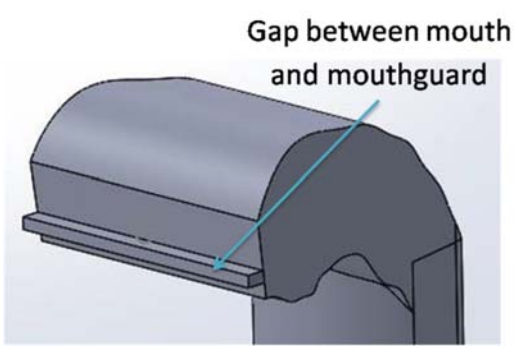
The completed model data is then transferred into the ANSYS CFD software to examine the airflow pattern when an athlete wearing of mouthguard. The CFD model of the mouthguard designs are shown in Figure-5. From the simulation, it can identify the pattern of airflow such as laminar, turbulent, transitional flows, internal flow and external flow.



(a)



(b)



(c)

Figure-5. Mouthguard (a) design 1, (b) design 2 and (c) design 3.

RESULT AND DISCUSSIONS

Two type of simulations were conducted; firstly is to determine the flow of air which enter the mouthguard which related to the performance of an athlete. Secondly, the study on pressure is conducted to the model with the objective to determine the pressure at the outside and inside of the model. The constant velocity of air, 10 m/s is used to the model and that's the standard speed of an athlete run 100 m distance. Figure-5 and Table-1 showed the maximum and minimum value of velocity and pressure imposed to the model of mouth cavity. The simulation shows the velocity of the air goes into the mouth of athlete when wearing three different type of the mouthguards. The observation is mainly focuses on the mouthguard that having and without having an air channel. Every air routes plays an important role to ensure the amount of air supported the breathing of the athlete as shown in the Figure-5. It can be observed that the maximum velocity is located at every mouthguard channel and gap between the mouth as well as mouthguard itself. The maximum velocity occurs due to the initial high velocity of air entered the mouth. In addition, the temperature at the entrance was slightly increased. The fastest flow of velocity was obtained from the first design, with the recorded value of 10.9 m/sec compared to design 2 and 3 with the value of 5.93 and 5.4 m/sec, respectively. Meaning that, design 1 helps the athlete to breathe more smoothly than design 2 and 3.

Table-1. Overall minimum and maximum velocity and pressure for the model simulation analysis.

S. No	Analysis	Design Model of Mouthguard	Value of the Analysis	
			Minimum	Maximum
1	Velocity Analysis (m / sec)	1	2.062×10^{0}	1.091×10
2		2	1.912×10^{-3}	5.927×10^{0}
3		3	3.781×10^{-3}	5.395×10^{0}
4	Pressure Analysis (Pa)	1	-4.823×10^{1}	3.109×10
5		2	-1.168×10^{1}	7.044×10^{0}
6		3	-8.883×10^{0}	7.588×10^{0}

To analyze the pressure behavior of the three different mouthguard design, the atmospheric pressure 1 atm (101325 Pa) was used which is standard value at the sea level. From the result (Figure-6), it can be observed that the difference value of pressure occurs in the entire parts of the all mouthguard designs. The maximum pressure was located inside of the model while the minimum pressure was placed at the entrance. Besides, the value of pressure gradually increases starting from the entrance to the exit of the mouthguard model. The first mouthguard design recorded the maximum value of the pressure value at 31.1 Pa as shown in Figure-6. Meanwhile, design 2 recorded the lowest value of pressure.

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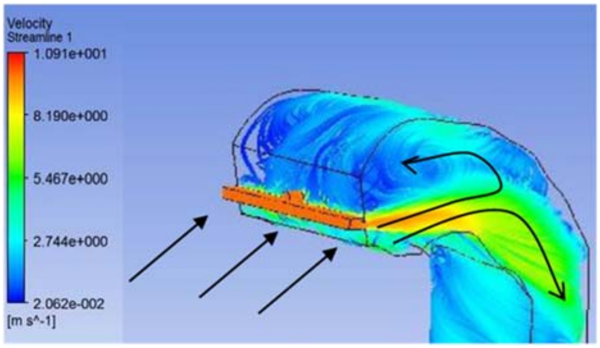
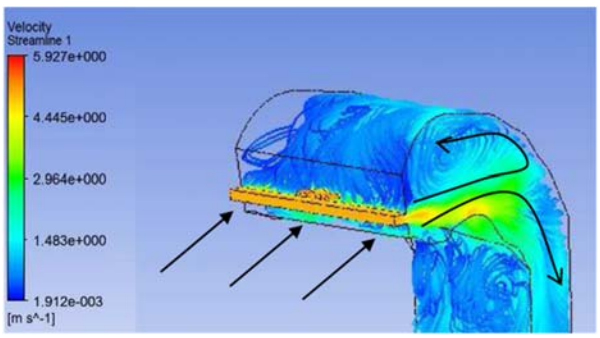
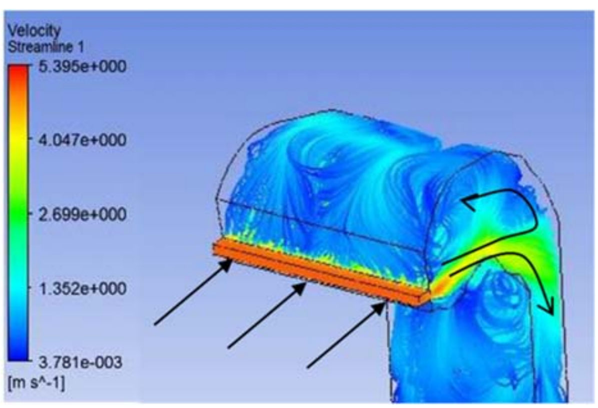


(a) Design 1

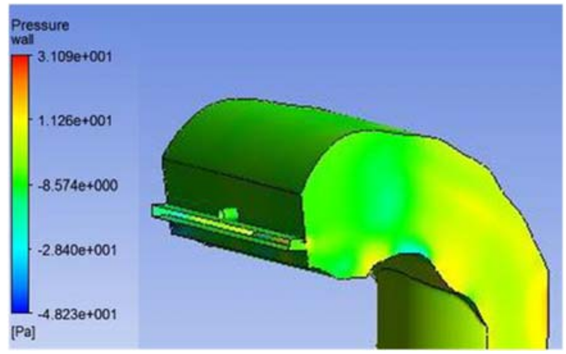


(b) Design 2

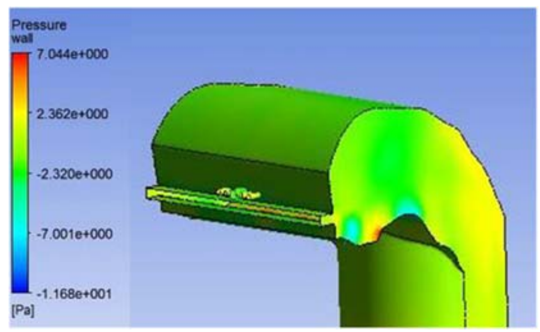


(c) Design 3

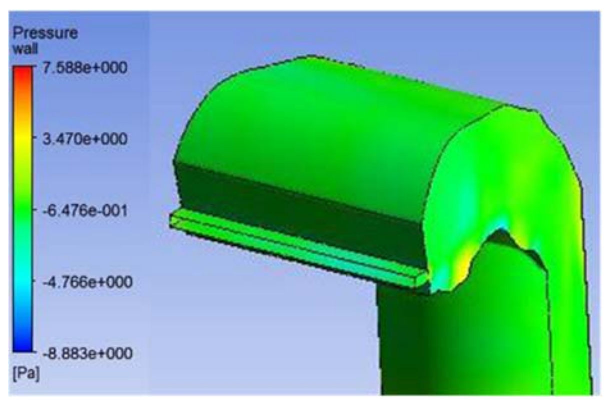
Figure-6. Result of velocity for various design of mouthguard.



(a) Design 1



(b) Design 2



(c) Design 3

Figure-7. Result of pressure for various design of mouthguard.

CONCLUSIONS

Based on the analysis results, it can be determined that:

1. The velocity of air which enters the models were higher at the entrance and gradually reduce its speed after go to the bottom part of the model.
2. The flow of air form afterward outside air enter the entrance of the models was in laminar form.
3. For pressure, it appears conversely and opposite with the result of velocity, where the air pressure at the entrance is lower and significantly increases at the bottom of the model.
4. The design, shape and number of channel design of the mouthguard slightly influence the outcome result. For example, by increasing the channel size, it allows more volume of air to enter into the model.

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