Effectiveness of the Mandibular Advancement Device for treating Sleep Apnea and Snoring

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***Abstract*— Mandibular Advancement Device (DAM ®) is used in the treatment of chronic snoring, where it is effective in about 100% of the cases and/or in the treatment of Sleep Apnoea-Hypopnoea Syndrome (SAHS). Its main function is to procure a forwarding or advancement of the lower maxillary beyond the upper maxillary, with the purpose of keeping a sufficiently permeable and free airway, so as to avoid to a great extent its accidental or unconscious closure. It consists of two dental mini orthodontics appliances that are attached with a small clip. The study aims to measure the effectiveness of the DAM ® for treating Sleep Apnea and Snoring.**

We have studied the speed and pressure changes in the upper airway of patients for two different situations. The first case presents five patients with Sleep Apnea. This event will be confronted with changes that take place in the geometry of the upper airway of the five patients when it is applied the DAM ® in the treatment. The techniques used are:

- ***Medical imaging, 3D computed tomography.***
- ***Segmentation and geometry construction.***
- ***Calculation and analysis of fluid dynamics (CFD).***

The results show an increase of the volume of the upper airway between 25-30% in the patients that used DAM ®. The effectiveness of the DAM ® is based in the increase of the volume of the upper airway.

I. Introduction

Obstructive Sleep Apnea Syndrome (OSAS) mainly consists in the development of recurrent episodes of airflow limitation during sleep, as a result of anatomical and functional alterations of the Upper Airway (UA) that leads to collapse, causing decreases in oxyhemoglobin saturation (SaO2) and arousals that lead to a restless sleep, daytime sleepiness, and neuropsychiatric and cardio-respiratory disorders. OSAS has been identified with different meanings, has been called Hipersommia Syndrome and Periodic Breathing (HSRP), Ondine's curse, and Pickwick syndrome associated with obesity. Now called OSAS (Obstructive Sleep Apnea Syndrome) or Anglo-Saxon literature OSA syndrome (OSA), or simply SAS (Sleep Apnea Syndrome), which includes all other diseases. Several researchers have attempted to define this phenomenon [1] [2] [3] [4], but they do not agree. Decreases in flow signal range from 30% to 90% or reductions the observer deems "significant" or "discernible." On the other hand falls in SaO_2 between 2% -4% by different laboratories. Even the definition of arousal is not the same in many sleep units and what is worse; there is significant variability in both inter-observer and intraobserver at identification time.

The first treatment, as in most systemic diseases, should be reducing the most common risk factors such as obesity, alcohol, sedatives, sleep deprivation and snuff, and avoid sleeping backs. The two pillars on which the treatment of patients with OSAS rests are mechanical processes such as Continuous Positive Pressure Ventilation (CPAP) and dietary measures of sleep hygiene. Not to mention the surgical procedures that seek to provide a wider anatomical basis for the passage of air. Other mechanical systems used are: continuous flow nasal, nasopharyngeal intubation and intraoral devices. The American Association of Sleep Disorders (ASDA) defines the IntraOral Appliances (AIO) designed to treat OSAS as "devices that are inserted into the mouth to reposition the jaw, tongue and other supporting road upper airway for the treatment of snoring and / or obstructive sleep apnea." The AIO in the treatment of OSAS offer great advantages in some patients. They are comfortable and easy to handle, non-invasive, reversible action, cheap, easy to manufacture and generally well accepted by patients. Given its ease of use, performance and level of preference by patients is becoming an effective alternative and useful in the range of treatment of obstructive sleep apnea. Mandibular Advancement Devices (DAM ®) increases the space in the upper airway, advancing the mandible on the maxilla, so as to prevent its fortuitous or unconscious closure. DAM ® is an alternative in the treatment of OSAS, usually for cases in which snoring is the primary symptom, when a fault occurs in surgical, as uvulopalatopharyngoplasty (rescue treatment) in patients who travel frequently and for patients who do not tolerate CPAP. The best results are obtained with intraoral devices that allow for gradual progression forward. [5] [6] [7] [8].
Mandibular Advancement Device (DAM ®) consists of two dental mini orthodontics appliances that are attached with a small clip.

The study aims to measure the effectiveness of the DAM ® for treating Sleep Apnea and Snoring.

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II. METHODS AND MATERIALS

A. Summary of the study

Changes of air speed and pressure in the upper airway of several patients using mandibular advancement devices have been studied. The three alternatives studied for the patients have been: patient resting (alternative 1), patient with DAM ® in position 1 (alternative 2, mouth opened), and patient with DAM ® in position 2 (alternative 3, mouth closed). This event will be confronted with changes that take place in the geometry of the upper airway of the patients in order to determinate a correct position of the DAM® in the treatment. In this article will show the results obtained for one of the patients.

B. Numerical and physiological data

The images of the patients for the 3 different states (without DAM ®, with DAM ® in two different positions) were obtained using the Toshiba Aquilion 64-slice spiral CT (Toshiba, Japan) during apnea and when they held a supine position in the Department of Radiology at Oviedo University. The present upper airway model consists of pharynx and larynx (anatomical area below 1st and 4th vertebrae) for the three different states as its shown in Figure 1. Later on, the airway model was segmented using a Digital Image Processing Platform (DiPPo) [9]. DiPPo includes a variety of ITK filters, which are use interactively by the clinicians to determinate the volume of interest of the problem. After segmenting the larynx-pharynx model geometry were smoothly in order to generate a computational mesh. For the computational mesh we have use GiD [10]. The tetrahedral mesh generated, from the voxels obtained in the segmentation, was obtained to combine Marching Cubes method to generate first the boundary mesh first and then an advancing front method to fill the interior with tetrahedral. The computational meshes used for the 3 different cases were generated using the same procedure and its have around 1 million of tetrahedral elements.

Assuming incompressible and Newtonian airflow, the governing equations for the airflow through the upper airway are described as follows.

$$\rho = -pI + 2\mu\varepsilon(u)$$
$$\varepsilon(u) = \frac{1}{2}(\nabla u + \nabla u^T)$$

where p is the fluid pressure, I is the unit tensor, μ denotes the apparent fluid viscosity and ε(u) is the rate-of-strain tensor. Therefore, according to this, airflow is simulated with average air properties: fluid dynamic viscosity $\mu = 1.846 \times 10^{-5}$ $kgm^{-1}s^{-1}$ and density $\rho = 1.1614$ kg/m^3. Due to the highly convective flow in the pharynx-larynx model and in the general in the respiratory system, the numerical scheme requires a stabilization technique in order to avoid oscillations in the numerical solution. In this study an innovative stabilization method based on the Finite Increment Calculus(FIC) concept is applied that preserves the consistency of the scheme. Convergence was achieved when all mass, velocity component and energy changes, from iteration to iteration, were less than 10^8. The stabilized Navier-Stokes equations are solved numerically by means of a finite-element method, and its implementation as done in TDYN (COMPASSIS.SA) a fluid dynamics and multi-physics simulation environment.

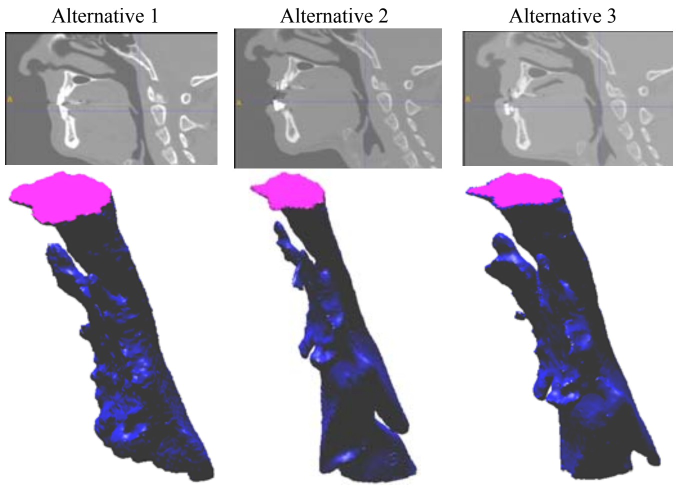

Fig. 1. Upper-airway for the different states: patient resting (alternative 1), patient with DAM ® in position 1 (alternative 2), and patient with DAM ® in position 2 (alternative 3).For all the cases it is possible to observe how the mandibula change its configuration.

For simulating complete breathing cycle, a typical flow input waveform alters in a sine wave shape mode $U=\sin(2\pi ft)$ which corresponds to transient respiration mode in a breathing period was impose in the velopharynx. The adopted respiratory cycle is T=4 s which agrees with that of common humans. The airway conduit is assumed to be smooth and rigid. So a no-slip condition can be imposed at the surface of upper airway walls. A zero-pressure assumption condition is established at the outlet (Glottis)

III. RESULTS AND DISCUSSION

Numerical simulation of air flow in the upper airway model for a 3 cycles of breath is completed. The value of velocity and pressure can be obtained at any point in the model. In order to identify the flow characteristics of the whole upper airway, Fig.2 and 3 displays the results for the 3 different alternatives. To study the area changes for the alternatives four section have been chosen (section 1: velopharynx, section 2: Up-Epiglottis, section 3: Bottom-Epiglottis and section 4: Glottis. Next table shows the area of the upper-airway for the different alternatives.

TABLE I
AREA OF THE UPPER-AIRWAY (MM^2).

Section	Alternative 1	Alternative 2	Alternative 3
1	555,22	498,88	449,931
2	157,48	100,47	152,31
3	105,26	77,69	135,82
4	376,63	392,57	556,89

The results show an increase of the area of the upper airway between 25-30% in the patient using DAM ® in position 2 (alternative 3).

Figure 2 shows pressure distribution in the upper airway during the second breath cycle for the three different alternatives. The graph represents pressure versus time of one point in the centre of the upper airway situated in the Up-Epiglottis area (it could be the third zone). These results support that patient with DAM ® in position 2 (alternative 3) has the biggest pressure gradient. The pressure distribution in the airway can be used to evaluate the role of airway shape in flow resistance.

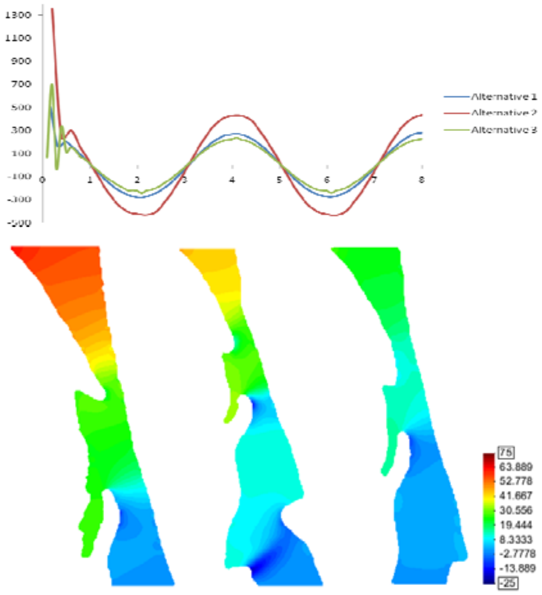

Fig: 2: Pressure distribution (Pa) and graph (x-axis graph represents time in seconds, and the y-axis represents pressure in Pa) for the three different alternatives. The oscillation in first cycle is due numerical stabilization procedures.

Figure 3 shows the air speed in the upper airway at the same time in the second breath cycle. It is demonstrated that the pharyngeal jet extends from the velopharynx into the hypopharynx and flows along the posterior pharyngeal airway. This pharyngeal jetting region carries the air into the oropharynx and hypopharynx, and results in an uneven velocity profile at the pharyngeal airway. While the velocity magnitude is significantly reduce near the nasopharynx. It is clear that the constriction of the velopharynx causes an acceleration of flow as air passes through the velopharynx and into the hypopharynx. The maximum velocity is reached in Up-Epiglottis. And we can observe in alternative 3 how the velocity decreased in this area.

IV. Conclusion

The purposes of the numerical simulations in this work are to describe the airflow profile in the larynx-pharynx model in three different states during 3 cycles of breathing condition and correlate the flow characteristics obtained using CFD with the complex geometry of the airway passages, in order to improve the position of the DAM. For this study, the alternative 3 makes changes in the area of the upper airway provoking that the air flow will be more continuous along the upper airway improving the breathing cycle. CFD can help us to understand how the breath human physiology is in order to study the apnea phenomena and improve the optimum position of the DAM ® device. More patients are being studied to determinate will be the correct position of this mandibular devices.

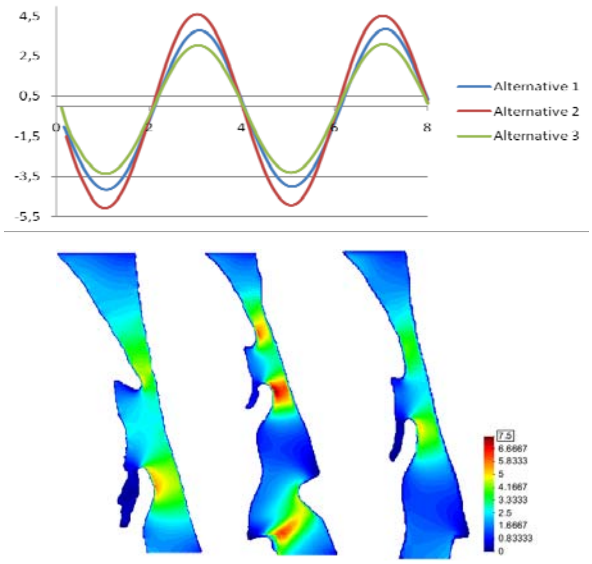

Fig. 3. Velocity airflow (m/s) distribution for the three alternatives. The air speed (m/s) distribution shown was taken at the same time.

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