Grid sensitivity studies for validation of human upper airways

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Abstract. The studies of simulation in biomechanical engineering using computational fluid dynamics is the crucial approach nowadays for advance human surgery. The accuracy of result of simulation will help the surgery more efficient and less damage to the patient. The propose this research to investigate the most efficient number of elements could be used in validation the result of simulation of human upper airway. This research finds the 129k number of elements would give the accurate result in analysing human upper airway.

1. Introduction

Obstruction Sleep Apnea (OSA) occurs during sleep due to transient obstructions within the airway. The obstructions usually block the flow of air in respiration. Numerous obstructions might become due to breakdown, excessive bulkiness or laxity of airway tissues (i.e., soft palate and uvula) which disrupted the airway, leading to hypopnea or apnea. Relaxation of the throat muscle and the impact of gravity normally allows soft tissues and tongue to move into the mouth area. The dense fatty tissue in the neck can potentially lead the upper airway blockage that contributes to partial blocking and snoring and respiratory pauses during sleep. The degree of OSA is measured every hour of sleep by the number of incidents. The Apnea-Hypopneas Index (AHI) is used to ascertain the degree of the OSA condition, calculating an estimated rate of obstructive apneas and hypopneas per bedtime.

Previously, the study observed soft tissue vibration and snoring could affect the soft tissue, tube, and nerves which might change the patient's sleep disorders [1, 2]. While the noise and snoring metrics have been analyzed, they have never been associated with airflow symptoms, which may play a role in collapsing of airways. In the fluid mechanic phenomena, the turbulent air flow could cause the vibration even in rapid time may cause structure damage. In the other engineering phenomena such as in nuclear plant [3-5], aircraft design [6] and structure design [7-9] been studied to analyze the damage of structure cause by vibration that induced from the turbulent flow. From this finding shown the turbulent flow will cause vibration that could damage soft tissue, vessel and nerves with the same argument in other engineering phenomena.

CFD has been widely used to evaluate upper airway structure and ventilation, and to investigate Sleep-Disordered Breathing (SDB) virtual reality surgery [10-12]. Faizal et al. [13] review the important of computational simulation for understanding human upper airways in determination of sleep apnea. Powell et al. [14] produced complete CFD model that include detail of pharyngeal has been constructed to investigate human upper airway that been used for surgery.
Moyin et al. [15] was report using CFD to discover a patient's pharyngeal airway model before and after surgery that generalizes airflow and discomfort profile to decide whether the treatment outcome is linked. This research carries out 7 OSA patient that investigate their upper airways and the result shown 2 OSA patient still having OSA even after treatment. Flow pattern in the human upper airway [16] have been studied using experimental or CFD but the common result on focus on velocity, pressure and wall shear stress. Same goes to the Mylavarapu et al. [17] finding that used computational model that employ CFD techniques have emerged from simultaneous modelling of the airflow velocity, pressure and wall shear stress in human upper airways. In the knowledge of turbulent flow in human upper airways is important to avoided patient get caught for OSA in the future. We wish to focus on the studies of turbulent airflow in pharyngeal airway for patient diagnose OSA. The finding to be explain in details by visualize in Turbulent Kinetic Energy (TKE) to show severity of the OSA patient in the pharyngeal airway. This world greatly increases the viability of prediction based on the computational method. The result shows a more accurate but fairly simpler upper airway model that explains the prediction of TKE and suggested the possibility of a CFD approach to investigate OSA source.

2. Method to study human upper airway

For CFD, the model focus on the segmentation of pharyngeal in human upper airway as seen in Figure 1. TKE in the upper airway were obtain by considering all the important parameter and boundary condition used in previous researcher.

![Figure 1. OSA patient (Responder 1): Sigittal view of the upper airway together with the side view of the meshing airway model. The anatomical location marked on the MRI image in 1,2,3,4 and 5 that refer to: (1) nasal choane level – inlet of the CFD model; (2) minimum cross section area; (3) tip of uvula; (5) base of epiglottis – outlet of the CFD model.](image)

2.1. Subject and model construction

The OSA subject were selected to conducting upper airway MRI and their characteristic shown in Table 1. A total 431 number of frames with 0.3mm slide thickness covering the upper airway MRI of subject were perform using a i-CAT Cone Beam 3D Dental Imagine System (version 3.1.62 supplied by Imaging Science International, Hatfield, USA) as shown in Fig 2. The airway boundary is identified in each of the axial scan by using threshold based on the gray scale intensity and patient awake and in the supine position as previously in explain by Chan et al. [18]. Each of the MRI scan is 534 pixel by 534 pixel with the pixel spacing 0.3 by 0.3mm. MRI data is stored in the database.
DICOM (Digital Imaging and Medicine Communications). We then inserted the DICOM photos into Mimics program (version 15.0; Materialise, Leuven, Belgium). The upper airway image segmentation was conducted on the basis of the Hounsfield units allocated to each pixel in the DICOM image sequence. The surface of the airway model was created using Pulmonary function of the segment airways.

\[ \text{Fig 2. The airways of OSA patient. (a) coronal view (b) axial (c) sagittal (d) 3D volume pharyngeal airway.} \]

2.2. Human upper airway mesh generation
The model where been transfer to 3Matic to create volume mesh. In this volume mesh, an unstructured tetrahedral volume mesh was developed. A mesh sensitivity grid study was performed on model with the different grid scale. The 5 grid size were performed to shown the acceptable accuracy as shown in their previously approach research.

2.3. Upper airway numerical modelling
The fluid governing equation were solved in ANSYS Fluent 15.0 (ANSYS, United State). During inhalation, the typical shear stress transportation (SST) k-\( \omega \) model was used to model the upper airway, the flow was incompressible and Newtonian. By analysing the existing findings with the previous findings of the researcher and our initial sensitivity test of applying specific Grid size, the
approximation of the SST k-equivalent model in solving the complicated upper airway flow was demonstrated.

3. Results
The 5-grids already been carried out in this research with the different element Grid 1 (63,143 element), Grid 2 (94,639 element), Grid 3 (129,152 element), Grid 4 (156,311 element) and Grid 5 (185,474).

![Figure 3. Grid Sensitivity studies in human upper airway for Static Pressure in wall.](image)

Human upper airway been analyse with the 5 different grid. The Fig.3 shown that with increasing the number of element, the result will be remain constant. This also can be seen in Fig. 4 for consistency of the grid after increasing the number of element.

![Figure 4. Min Static Pressure with different number of elements.](image)

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