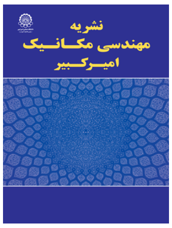

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Numerical simulation of two consecutive human sneezing and examining the dispersion of the resulting droplets in the surroundings

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ABSTRACT: In the present study, by simulating the process of two consecutive sneezes using a real model of the upper airway of a 65-year-old non-smoking man, the dispersion pattern of droplets resulting from the process of two consecutive sneezes has been investigated. Using computational fluid dynamics, the velocity of airflow during two consecutive sneezes was checked and the k-ω SST turbulence model was used to check the flow. Assuming realistic flow rate changes in both sneezes, the maximum flow rate during sneezing according to the subject's age and gender is equal to 553 L/min. In the present study, the simulation has been carried out by considering a wide range of droplets with diameters of 1 to 1000 microns, and about 2 million drops have been injected into the surrounding environment during the process of two consecutive sneezes. In this study, the temperature of the air in the surrounding environment and the air jet coming out of the respiratory system are assumed to be 24 and 35 degrees Celsius, and the relative humidity of the surrounding environment and the air jet is assumed to be 65 and 95%. The maximum rate of penetration and spread of droplets resulting from two consecutive sneezes in 5 seconds is 19.9 and 7.5% higher than the rate of penetration and distribution of droplets resulting from a single normal sneeze at the same time. Most of the injected droplets have evaporated in the surrounding environment during the process of two consecutive sneezes, and less than 40,000 drops are left in the environment in 5 seconds.

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1- Introduction

The publication and transmission of viruses, especially those related to respiratory diseases, have always been one of the challenges faced by humanity. The necessity to investigate this issue has led researchers from both medical and engineering fields to collectively focus on the topic of airborne infectious disease transmission [1]. Virus transmission methods can be categorized into two main approaches. The first method involves direct contact of mucous membranes in the mouth, nose, or eyes with contaminated surfaces, while the second method is the spread of viruses through respiratory processes. In the latter method, viruses infiltrate into droplets of saliva or nasal mucus and, through respiratory processes such as sneezing and coughing, enter the surrounding environment. When these droplets are inhaled by others, the chain of virus transmission continues to spread. Analyzing the sneezing process requires proper preparation in two main aspects. The first aspect relates to modeling and meshing that align with the research objectives and the the second aspect involves selecting appropriate solution methods, equations, and boundary conditions. In this research, a simulation of the sneezing process with two consecutive sneezes was conducted for a 65-year-old non-smoking male, taking into account the upper respiratory system and the impact of the air jet resulting from two consecutive sneezes. Previous studies have not considered the effects of a secondary jet resulting from the second sneeze on the dispersion and penetration of droplets from two consecutive sneezes. However, in this study, an attempt was made to investigate the increase in droplet dispersion and penetration resulting from two consecutive sneezes and compare it with the results of a single sneeze under identical conditions.

2- Methodology

In the present study, the actual geometry of the upper respiratory system was utilized to simulate airflow during a sneeze. To create the upper respiratory system, CT scan images of a healthy, 65-year-old, non-smoking male subject were employed. The dimensions of the computational domain surrounding the subject are 3 meters (height) × 3 meters (width) × 5 meters (length). Further details regarding the computational domain geometry are considered in the study by Zandaf et al [2].

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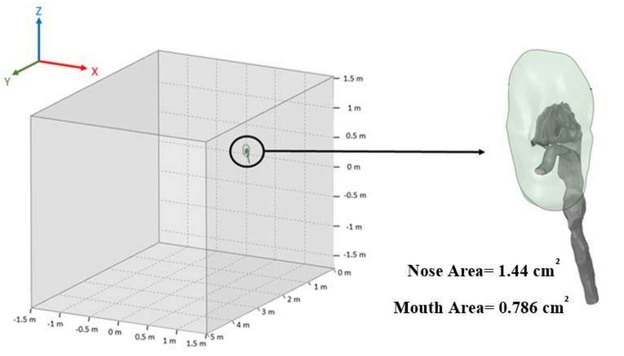

Fig. 1. The computational domain [2]

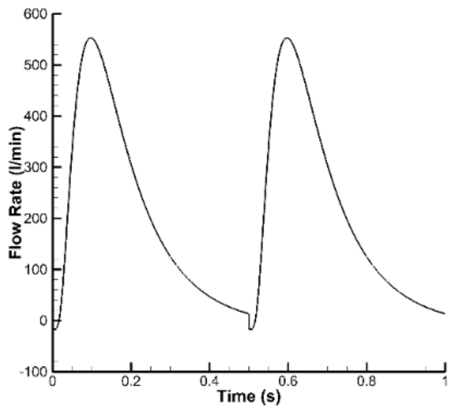

Fig.2. Changes of flow according to time during sneezing

To generate the network, ICEM CFD software was used. To appropriately simulate the interactions between the airflow and the walls of the upper respiratory device, a prism layer with 4 layers was utilized. The height of the first layer is 0.01 millimeters, and a growth rate of 2.1 is employed the mesh with 1.7 million cells has been selected as the appropriate mesh in terms of accuracy and efficiency.

Zandaf et al. [2] calculated the boundary conditions for a normal single sneeze. According to the results of Busco et al. [3], the duration of a single sneeze is about 0.51 seconds, and about 0.23 seconds, the air jet enters the surrounding environment as droplets. Then only the air jet is injected into the surrounding environment. In this study, contrary to the results of Gupta et al [4], which discussed the decrease in volume flow rate in the second cough for the process of two consecutive coughs, it is assumed that the first sneeze was taken for 0.51 seconds and the second sneeze after that. The first sneeze (in 0.51 seconds) will start to calculate the maximum effect of the second sneeze jet for spreading and penetrating the droplets from the first sneeze, and before the start of the second sneeze, the inhaling process has occurred again for 0.016 seconds. Finally, the second sneeze ended in 1.02 seconds and the maximum flow rate occurred in 0.10 and 0.61 seconds. the flow rate changes from the beginning of the trachea according to Figure 2. The formulation of flow rate changes in terms of time is expressed in equation (1).

$$FlowRate(t)=\begin{cases} a+\dfrac{b}{t}exp\left(-0.5\left(\dfrac{Ln\left(\dfrac{t}{c}\right)}{d}\right)^2\right) & for \quad t\le 0.51s \\ a+\dfrac{b}{(t\text{-}0.51)}exp\left(-0.5\left(\dfrac{Ln\left(\dfrac{t-0.51}{c}\right)}{d}\right)^2\right) & for \quad t>0.51s \end{cases} \tag{1}$$

The values of constants *a*, *b*, *c,* and *d* presented in equation 1 are equal to -17.1430, 69.5510, 0.1535, and 0.6780.

The equations governing the fluid domain can be expressed as equations (2), (3), and (4). The equation of forces affecting a droplet is expressed as equation (5).

$$\frac{\partial\rho}{\partial t}+\frac{\partial\rho\hat{u}_i}{\partial x_i}=0 \tag{2}$$

$$\frac{\partial\rho u_i}{\partial t}+\frac{\partial\rho u_i u_j}{\partial x_i}=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\rho\,\overline{u'_i u'_j}\right] \tag{3}$$

$$\frac{\partial\rho c_p T}{\partial t}+\frac{\partial\left(\rho c_p u_i T\right)}{\partial x_j}=k\frac{\partial^2 T}{\partial x_j^2} \tag{4}$$

$$m_p\frac{dv}{dt}=F_{Drag}+F_{Gravity}=\frac{\rho_c\pi C_d d_p^2\left|U-V\right|\left(U-V\right)}{8C_c}+m_p g \tag{5}$$

3- Results and Discussion

In the present study, with the help of computational fluid dynamics, the simulation of the diffusion pattern of droplets resulting from two consecutive sneezes has been investigated. Figure 3 shows the location of the droplets resulting from two consecutive sneezes at 1 and 3 seconds corresponding to the viewing angle along the Z axis.

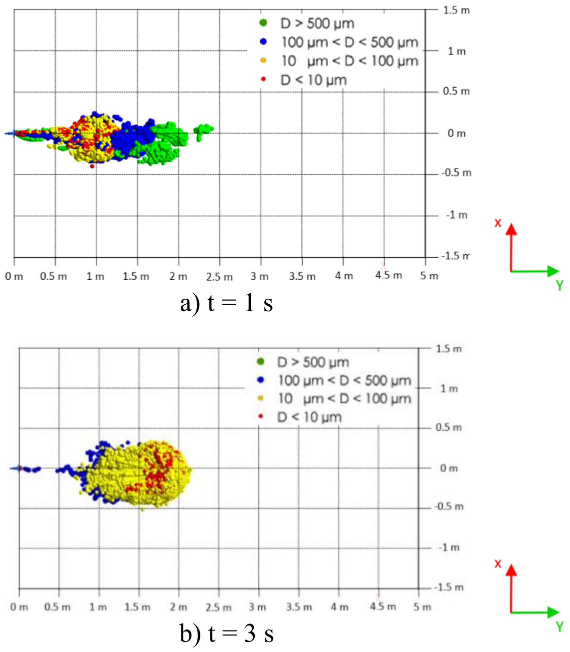

Fig. 3. Diameter contour, spread, and penetration of droplets caused by two consecutive sneezes in (a) t= 1s and (b) t= 3s

4- Conclusion

The simulation of the distribution of droplets resulting from two consecutive sneezes determined that the large droplets quickly moved away from the front of the mouth; so that the second jet resulting from sneezing did not have much effect on them; But the small droplets resulting from the first sneeze due to the small distance they have taken in front of the mouth and nose compared to the larger droplets; The second jet resulting from the second sneeze affected them and increased the spread and penetration of these droplets at the same time compared to a normal sneeze. The rate of penetration and distribution of droplets resulting from two consecutive sneezes in 5 seconds is 19.9 and 7.5% higher than the penetration and distribution of droplets resulting from one sneeze at the same time.

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