Abstract—In this work, Computational analysis of air flow in human respiratory tract model is done by the use of CFD technique. Fluid Structure Interaction (FSI) method is used on the third-to-sixth generation simplified respiratory tract model for computational study. The modulus of Elasticity is varied in a range of 1 to 5 MPa and its effect on flow-physics is captured inside human airway model. The variation of velocity and its effect on deformation has been captured for both rigid and flexible model and its analysis is carried out. The result from simulation shows that as the Modulus of elasticity increases, wall deformation decreases.

Keywords—Compliant human airway model, Computational Fluid Dynamics (CFD), Fluid Structure Interaction (FSI), Modulus of elasticity (E).

I. INTRODUCTION

The human respiratory model is similar to the Y-shaped bifurcated duct. Its main function is to exchange oxygen and carbon dioxide between the lungs and atmosphere. The human respiratory tracts are flexible in nature. However most of the previous CFD studies considered it as rigid wall [1-3].

Koombua et al. [4] discussed CFD study of flexible human respiratory wall considering it homogeneous/isotropic having density 1365.6 kg/m³ and Young's modulus of elasticity of 5.8 MPa. Third to fifth generation simplified model was considered for the study. It was found that wall elasticity affected the fluid pressure and wall strain distribution while no significant change is observed on flow velocity and wall shear stress (WSS). Later, Koombua and pidaparti [5] varied value of elasticity in their study and noted corresponding effects. Fluid-Structure Interaction (FSI) study of rigid and compliant CT scan model was discussed by Xia et al.[6]. It is noted that the respiratory wall deformation increases with the increase in Reynolds number. In case of compliant wall, the peak wall shear stress is found five times greater than that of the rigid wall.

The present study is concentrated to see the effects of Young's modulus of elasticity on the deformation of respiratory wall. FSI method in Ansys-Fluent-Academic [7] has been used to capture and study the wall deformation. The velocity contours of the different cross section have been obtained to see the effects of wall elasticity.

II. MODEL OF HUMAN RESPIRATORY TRACT

Third to fifth generation simplified model of human respiratory model is taken in the present study. The dimensions of the respiratory model is adopted from Koombua et al.[4]. For the study of compliant airway, both of the domain namely solid and fluid are constructed in Ansys-Workbench and is shown in the Fig.1. Thickness of the solid domain (in green colour) is taken as 5 mm, however the fluid domain (in yellow colour) is created using 'fill-up option available in Ansys-Workbench.
III. GRID GENERATION

Grid generation of both the fluid and solid domain is done using the tetrahedral elements because it provides minimum skewness at the curved surfaces. The size of the tetrahedral elements is taken from 0.25 to 0.35 mm.

IV. BOUNDARY CONDITIONS

Parabolic inlet velocity profile (Re=1935) and outlet pressure is applied at the inlet of third generation bronchus and outlet of fifth generation bronchus respectively. The inlet velocity is applied corresponding to the inlet mass flow rate 60 L/min at the inlet of trachea. The properties of air at normal conditions are considered in the present study i.e., density is 1.19 kg/m$^3$ and dynamic viscosity is $1.82 \times 10^{-5}$ kg/ms.

V. NUMERICAL SIMULATION

The commercial CFD packages 'Ansys-Fluent 19.0'(Academic) and 'Ansys-Structural 19.0'(Academic) have been used for fluid-structure interaction (FSI) study. The different terms of the transport equation were discretized using second-order upwind scheme. A convergence criterion is taken as $10^{-4}$. Two-way coupling method has been used to study the effects of fluid on wall and vice versa.

V. GRID INDEPENDENCY

Grid independency test is performed to verify the computational accuracy of the airway model. Initially 16710 elements was generated which was further refined six times. Grid is found independent for 1152284 numbers of elements. Table 1 shows how the grid independency is achieved.

| Case | Number of elements | Successive increase in elements | Avg. Velocity* |
|------|--------------------|--------------------------------|---------------|
| 1    | 16710              |                                | 3.880         |
| 2    | 78906              | 372.2%                         | 3.900         |
| 3    | 132867             | 68.4%                          | 3.810         |
VI. CFD Model Validation

The present computational results were validated with the results reported by Koombua et al. [4]. The velocity contours for the two results is shown in the Fig. 2. The maximum local velocity is computed 10.19 m/s against the velocity 10.17 m/s reported in Koombua et al. [4].

![Fig. 2: CFD Validation of the Present Model](image)

VII. RESULTS AND DISCUSSION

A. Velocity Distribution:

The velocity contours corresponding to the Young's modulus of elasticity equals to 0.4 MPa are shown in Fig. 3. Three different horizontal planes are located at the inlet and bifurcation junction is plotted in the following figure. Since parabolic profile is given at the inlet of the third generation bronchus, maximum velocity is therefore, obtained in the center of the bronchus.

However, as airflow moves towards the bifurcation (divider), velocity distribution is skewed towards the inner wall at the fourth generation bronchus due to centrifugal force.
B. Total Deformation

Total deformation (deflection) is computed for different range of Young’s modulus of elasticity (E). The total deformation contour for elasticity 1.0 MPa and 0.4 MPa is shown in Fig. 4. Maximum deformation is observed at the bifurcation junction. Higher deformation is obtained for $E = 0.4$ MPa as compared to that for $E = 1.0$ MPa.

It is found that as the Young’s modulus of elasticity increases, total deformation decreases. Total deformation is computed as $7.46 \times 10^{-6}$ and $18.73 \times 10^{-6}$ m corresponding to Young’s modulus of elasticity 1.0 MPa and 0.4 MPa respectively (Fig. 5).
E= 1.0 MPa

Fig.4: Distribution of Total Deformation

E= 0.4 MPa

Fig.5: Elasticity versus total deformation

VIII. CONCLUSIONS

The airflow study in the compliant human respiratory model has been carried out for different range of Young’s modulus of elasticity. The conclusions are given below:

1) It is found that as the value of Elasticity increases, total wall deformation decreases.
2) Fluid-structure interaction (FSI) method helps to find out the realistic flow physics in human airways.
3) The present study helps to correlate the medical aspects with the engineering solution.

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