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COMPUTATIONAL FLUID DYNAMICS ANALYSIS OF AIRFLOW ALTERATION IN THE TRACHEA BEFORE AND AFTER VASCULAR RING SURGERY

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Abstract

Resection of the vessels that encircle and compress the trachea and the esophagus is the major components of the vascular ring surgery (VRS). In general, the forced expiratory volume in the first second (FEV1) measurement is applied to assess the obstructive airway diseases caused by CVR. In some cases, however, the FEV1 measurement cannot provide useful specific information to the effectiveness of the VRS. Furthermore, there has been little research about the quantitative approach for analyzing the airway resistance before and after the VRS. The purpose of this study is to apply the computational fluid dynamic (CFD) technique to evaluate the tracheal airway pressure change before and after the VRS based on patient CT-scan images. We selected the twelve patients whose age from 6 to 14 years old with tracheal stenosis and compared the pressure drops across the selected length of the tracheal airway segment before and after VRS. Computer simulations were performed to obtain the velocity field and viscous pressure drops in a realistic, three-dimensional, patient-specific (Computed tomography-scan-based) model for twelve patients with CVR. The tracheal airway 3-D surface geometry was reconstructed by the Amira software. The unstructured tetrahedral meshes of 3-D flow field in the trachea were employed by the ANSYS ICEM CFD software. In this study, the tracheal aerodynamic resistance was represented as a pressure drop in the tracheal airway. The airflow field in the tracheal airway was solved by the Navier-Stokes equations in the ESI CFD-ACE+ software. Furthermore, the three velocities (0.01 m/s, 0.1 m/s, and 1 m/s) were used to calculate the pressure drop in the tracheal airway for both inspiratory and expiratory flow patterns. With the same inspiratory inlet velocity 0.1 m/s (i.e. the air flow rate of 7.0896 cm3/s), the pressure drops across the selected length (Ls=5.03 cm) of the tracheal stenosis before and after VRS were 0.1789 and 0.0967 Pa, respectively. In this case, the improvement percentage by VRS was 45.95%. In the expiratory phase, by contrast, the improvement percentage was 40.65% for the same air flow rate of 7.0896 cm3/s. When the inspiratory velocity reached 1 m/s, the pressure drop became 4.988 Pa and the improvement percentage was 43.32 %. Computer simulation results also show that after a surgical treatment the pressure drop in the tracheal airway was significantly decreased, especially for low inspiratory and expiratory velocities. In other words, the flow resistance in the tracheal airway becomes decreased after VRS when the airway is expanded. The airway flow resistance of tracheal stenosis caused by CVR can be augmented by increased air flow velocity. CFD approach can be a useful method for quantifying the change of airway resistance and evaluating the effectiveness of relief of tracheal stenosis by VRS.

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