Form 3

Abstract of Thesis

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Title	Experimental and computational study of the aerodynamic sound generation in the lung airway represented by simplified and realistic model (単純形状および実形状モデルを用いた肺気道内空力音の実験と数値解析)

Abstract of Thesis

One of the efforts to improve the accuracy and objectivity of the respiratory diseases detection by lung sound analysis is by improving our knowledge regarding the sound generation mechanisms. Here, aerodynamic sound generation studies were performed to reveal the factors affecting the sound generation in tracheobronchial models. In the beginning, a simplified T-branch model was utilized as a simplification of the airway bifurcating branching geometry. A constriction was located on the mother branch to recreate a bronchoconstriction of the airways. The acoustic sound pressure and the flow fluctuation at a point downstream the constriction were measured while varying the constriction severity and the airflow rates. As results, a clear relationship between the Reynolds number and the overall sound pressure level was observed. A minimum Reynolds number of 4000 was required to generate 2 dB sound. The increase of the turbulence strength was also found as the Reynolds number increase. However, the relationship between the Reynolds number and the turbulence strength was not as clear as the overall sound pressure level. This may indicates that a single point measurement of the flow fluctuation may be not enough to describe the relationship between the flow fluctuation and the generated sound. To regenerate the flow condition in a more realistic geometry, a silicone airway model based on CT-image based image of an 11 years old boy was constructed. The model is a silicone in a rectangular prism shape with tracheobronchial cavity. Acoustic pressure of 680 points were measured and mapped when air flowing through the airway cavity at inspiratory and expiratory direction. This enables us to locate the original aerodynamic sound sources as fluid moving through the tracheobronchial without considering the complexity of the tissues and bones in the chest anatomy. It was found that the characteristics of the sound is different between inspiration and expiration. In expiration, a wide band sound frequency ranging from 1000 Hz to 4000 Hz can be detected, while in the inspiration, the sound spectra was found in the range of 1000-2000 Hz. However, similar location distribution of the sound sources were observed. At frequency less than 1500 Hz, the trachea region show higher sound level compared to the small airways, however, at frequency more than 2000 Hz small airways are generating higher sound level compared to trachea and main bronchus region. This may indicate that the generated sound depends on the geometry and the dimension of the airways. To observe the flow condition relying on the sound generation in the silicone airway model, computational fluid simulations were performed for the same geometry with the same rate used in the measurement. Calculating the sound source terms based on the Lighthill acoustic analogy, the locations of the sound sources and the frequency dependency of the sound sources were observed. Similar results of the sound source distributions between simulations and experimental measurements were obtained. The sound in the trachea region has lower frequency characteristics compared to the sound observed in the small airways. The computational simulations show a different flow condition related to the sound generation in expiration and inspiration. In the expiration case, flow collision, flow impingement, and flow separation are related to the location of the sound sources. While flow impingement and flow separation are the main mechanisms contributing in the sound generation in the inspiration maneuver.

様式7

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

本論文は，流体力学的観点から気管支呼吸音の特性や発生条件，メカニズムの解明を目指して行った実験的および数値シミュレーションによる理論的研究の成果をまとめたものである．まず，気管支をT型分岐管とする簡単化モデルを用いて,呼吸音が発生する条件および気道の狭窄と分岐が呼吸音の発生に及ぼす影響について実験的に調べた．その結果，気流速度や気道のサイズ，母気道の狭窄の程度に関わらず，狭窄部でのレイノルズ数が4000以上になれば，2dB以上の呼吸音が発生することを見出した．また，呼吸音発生に対して気道の分岐より狭窄の影響の方が強く現れ，狭窄が強いほどより高周波数の音が発生することがわかった．これらの実験結果は，気道内の気流が乱流に遷移することにより気管支呼吸音が発生することを示唆しており，臨床における正常呼吸音から異常呼吸音への変化を理解する上で重要な知見と言える．次に，小児肺のCT画像から抽出した5-7世代の中枢気道の３次元形状に基づき，シリコンブロック内に実形状の気道を再現したモデルを作成し，マイクロフォンアレイを用いて吸気時および呼気時における呼吸音の発生部位と周波数特性を調べた．その結果，気管分岐部近傍では，呼気時に1000-4000Hzの比較的広い周波数帯域の音が発生し，吸気時にはそれより低い周波数帯域の音が発生することがわかった．また，細い気管支ほど高い周波数の呼吸音が発生することを明らかにした．さらに，実験と同じ気道の実形状モデルを用いて数値流体解析を行い，Lighthillの音響アナロジーに基づいて音源と発生音の周波数特性について考察した結果，気流と気道壁や，気流同士の衝突によって生じる分岐部における気流の乱れが呼吸音の音源となっていることを明らかにした．また，吸気時と呼気時のフローパターンの相違が呼吸音の周波数特性に反映されることを示した．こうした流体力学的観点からの呼吸音の理解は，呼吸器系の異常を非侵襲かつ簡便に発見する手段として使われてきた聴診の精度を高め，新たな手法の開発につながるものである．以上，本研究で得られた成果は機械科学および生体医工学において学術的意義が高く，博士（工学）の学位論文として価値のあるものと認める．