Assessing Upper Airway Resistance with Esophageal Catheter and Oscillometry

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Abstract— **Esophageal catheters equipped with multiple sensors are typically inserted nasally to reach the esophagus, to measure a range of pressure. These measurements can detect variations in pressure caused by obstructions at different points in the respiratory tract. Pressure sensors along the catheter are positioned differently based on the different anatomical structures of the respiratory tract among individuals. Our research is thus focused on investigating the association between pharyngeal airway resistance obtained from different pressure sensors with the gold standard measurement. We calculated the pressure difference of two sensors relative to atmosphere pressure and estimated pharyngeal airway resistance at the corresponding locations using multiple linear regression models on pressure, airflow, and volume. The gold standard measurement to assess pharyngeal airway resistance was Oscillometry. Participants were grouped by sex, height, and age, and the association of resistance between the two approaches was examined using the Bland-Altman plot and Pearson correlation. In our study, 19 adult participants were included. Our data suggested that those who are either male, taller, or older adults have a longer pharyngeal length compared to female, short, or middle-aged adults. Therefore, to assess pharyngeal airway resistance using a catheter for these groups, we should opt for more proximal pressure sensors, as the distal sensor is placed deeper into the esophagus. This can have significant implications for research studies analyzing data from esophageal catheters.**

Keywords— **Esophageal catheter, Sensors positions, Pharyngeal airway resistance**

I. Introduction

The act of respiration is fundamentally a mechanical procedure [1]. Respiratory diseases impact lung mechanical properties and lung function [2]. Mechanical characteristics of the lungs include factors such as compliance, airway resistance, and tissue elasticity, which collectively determine the relationship between pleural pressure, airflow, and lung volume [3]. Pleural pressure refers to the pressure within the pleural cavity, which is the thin fluid-filled space between the two layers of the pleura surrounding each lung [4]. Pleural pressure changes provide critical information in indicating the presence and severity of respiratory conditions, adjusting treatment plans, and assessing the effectiveness of interventions [5].

To measure pleural pressure, the esophageal catheter is commonly used as esophageal pressure is a surrogate for pleural pressure [3]. Esophageal pressure measurement is a minimally invasive monitoring method that is common in clinical practices for critically ill patients, especially those on mechanical ventilation [6]. On the other hand, to study the pathophysiology of various respiratory conditions, esophageal pressure measurement is used as a research tool [5, 7, 8]. Unlike other methods, it provides direct measurement of pleural pressure and detailed insights into lung mechanics [8]. Esophageal catheters with multiple sensors have been more used for research purposes compared to routine clinical practice. Esophageal catheters are typically inserted through the nose to reach the esophagus. Consequently, it is possible to obtain a gradient of pressure readings by having multiple sensors. These readings can reflect changes in pressure that occur due to obstructions or narrowing at various levels of the airway. For example, pharyngeal airway or nasal resistance which can be a cause/risk factor for obstructive sleep apnea can be evaluated [9].

The length and diameter of the respiratory tract can vary significantly, influenced by sex, body size, and age [10]. In research settings, the accuracy and precision in localizing sensors on esophageal catheters is crucial. In our previous study, we analyzed a 6-sensor esophageal catheter with the first sensor at the distal tip of the catheter, the second at 15 cm above the first, and the third sensor located 2.5 cm proximal to the second one (Figure 1). We showed that in taller and shorter individuals, the third sensor is located below and above the epiglottis, respectively [11]. Therefore, pressure sensors along the catheter are located differently based on the variability in the anatomy of the respiratory system among individuals. Our study aimed to investigate the association between pharyngeal airway resistance obtained from different pressure sensors with the gold standard measurement. This investigation particularly focused on understanding how factors such as sex, height, and age contribute to variations in these measurements.

II. Methods

A. Study Design and Participants

In this study, adult participants were instructed to use a nose clip to restrict nasal airflow for Oscillometry, as well as airflow, and pressure measurements. While we did not capture nasal resistance due to the restricted airflow through the nose, our focus of this study remained appropriate as the measurements with both approaches were consistent. The pharyngeal airway comprises three distinct regions: the nasopharynx, the velopharynx, and the oropharynx. Consequently, we assessed pharyngeal airway resistance that predominantly reflected velopharyngeal and oropharyngeal resistance. This study was approved by the Research Ethics Board of University Health Network, and before participation, all participants provided written consent.

B. Measurements

Airflow and pressure were measured using Vmax Encore 229 and Gaeltec esophageal catheter (Gaeltec Ltd; Hackensack, NJ) at a sampling frequency of 1000 Hz. This catheter consists of a series of closely spaced 6-pressure sensors. The catheter was inserted through the nasal cavity until the pressure sensor at the tip of the catheter was inside the esophagus. Therefore, the first sensor measured esophageal or pleural pressure. Subjects also performed Oscillometry over a range of frequencies from 5-37 Hz to measure respiratory impedance including respiratory resistance and reactance (elastic recoil characteristic) [12].

C. Data Analysis

The data analysis details were mentioned in our previous work [11]. The volume signal was estimated as integral of the airflow signal. Noise removal, validation algorithms, and curve fitting techniques were employed to reduce pressure signal irregularities. We calculated the pressure difference of P_3, and P_4 from atmosphere pressure (P_0). Subsequently, a multiple linear regression model was used to estimate resistance using pressure, airflow, and volume data as shown in Equation 1. Therefore, two sets of pharyngeal resistance were obtained from P_3, and P_4 (R-P_3, and R-P_4, respectively).

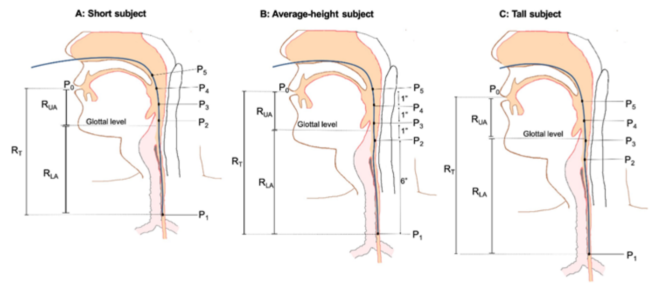

Fig. 1: The schematic position of the pressure sensors for A) short, B) average-height, and C) tall subjects [11].

$$Pressure = resistance \times flow + elastance \times volume \quad (1)$$

We focused on resistance in this study as unlike smaller airways, elastic characteristics of the pharyngeal airway are not as commonly defined [13]. For Oscillometry measurements, higher frequencies reflect the resistance in the large airways [12]. Consequently, we considered resistance at a high frequency of 19 Hz (R_{19}). They primarily reflect how easily air moves through the major bronchi and trachea. Since the nose was closed, R_{19} in this study was mostly influenced by upper or pharyngeal airway resistance. First, we examined the association between the two evaluations for resistance obtained from P_3 and P_4 with R_{19} using the Bland-Altman plot and Pearson correlation. Subsequently, we grouped subjects into three categories, and we repeated this analysis for each category. Groups were as follows: 1) senior (age $\geq$ 60 years) or middle-aged adults (age $<$ 60 years), 2) short (height $<$ 162 cm), or tall height (height $\geq$ 162 cm) group, 3) female or male group.

III. Results

We studied on 19 adult participants. We calculated the association and correlation between R-P_3, and R-P_4 with Oscillometry measurements. Our results indicated that two methods to measure pharyngeal airway resistance were significantly correlated calculated from P_3 and P_4 with R_{19} (r = 0.60, p = 0.007 and r = 0.75, p = 0.0002, respectively). We also assessed the association of R-P_3, and R-P_4 with R_{19} for different categorizations based on sex, height, and age. For sex categorization, data from 6 females (age: 53.7±15.6 years, height: 161.4±7.2 cm, BMI: 25.2±4.9 kg/m^2), and 13 males (age: 48.6±14.1 years, height: 173.0±6.9 cm, BMI: 26.9±3.7 kg/m^2) were included. Our findings indicated a strong significant correlation between R-P_3 with R_{19} among female adults (r = 0.98, p = 0.0008), but this correlation was not significant in males (r = -0.08, p = 0.80). On the other hand, we found a significant correlation between R-P_4 and

R_{19} for both males and females (r = 0.65, p = 0.02 and r = 0.83, p = 0.04, respectively). More details about the significant correlation for males were shown in Figure 2.

For height categorization, data from 6 short adults (2 males, age: 57.2±16.1 years, height: 159.7±5.1 cm, BMI: 26.1±3.9 kg/m^2), and 13 tall adults (11 males, age: 47.0±12.8 years, height: 173.8±6.1 cm, BMI: 26.5±4.3 kg/m^2) were included. Our analysis revealed a significant correlation between R-P_3 and R_{19} in short adults (r = 0.90, p = 0.01, Figure 3a), which was not observed in the tall group (r = 0.30, p = 0.31). In contrast, a significant correlation was found between R-P_4 and R_{19} among tall adults (r = 0.76, p = 0.003, Figure 3b), but this association was not significant in the short group (r = 0.71, p = 0.12).

For age categorization, data from 12 middle-aged adults (8 males, age: 41.4±9.7 years, height: 171.8±8.3 cm, BMI: 26.4±4.4 kg/m^2), and 7 seniors (5 males, age: 65.3±4.8 years, height: 165.1±8.5 cm, BMI: 26.4±3.8 kg/m^2) were included. For the association between R-P_3 and R_{19}, we showed that there is a significant high correlation for middle-aged adults (r = 0.73, p = 0.007, Figure 4a) but not in senior adults (r = 0.64, p = 0.12). Conversely, for the correlation between R-P_4 and R_{19}, we showed that the significant high correlation for senior adults (r = 0.83, p = 0.02, Figure 4b) as well as in middle-aged adults (r = 0.72, p = 0.008).

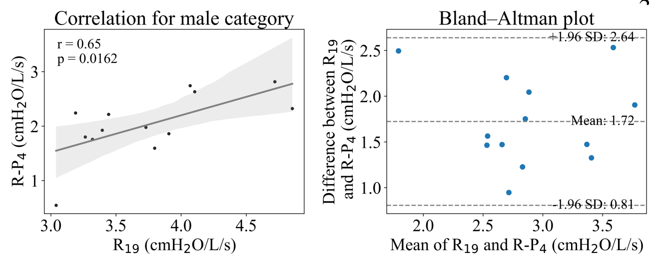

Fig. 2: The association and significant correlations between R_{19} with R-P_4 for males using the Pearson correlation and Bland-Altman plot.

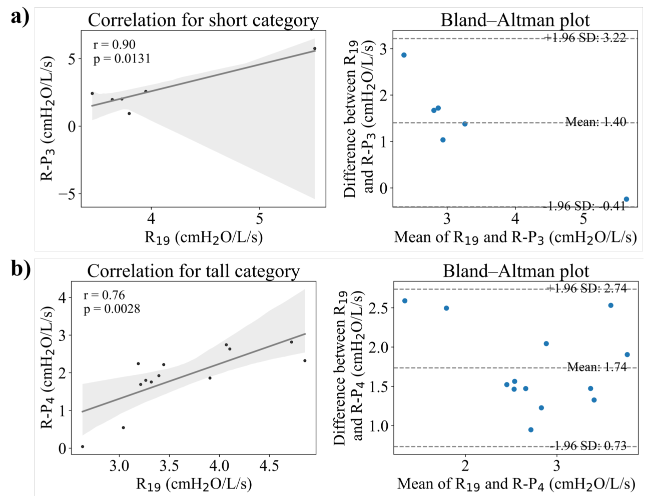

Fig. 3: The association and significant correlations between R_{19} with R-P_3 and R-P_4 for a) short and b) tall adults, respectively.

IV. Discussion

In this research, we studied the upper/pharyngeal airway resistance obtained from pressure sensors of an esophageal catheter with 6 closely spaced pressure sensors. Our gold standard measurement was Oscillolometry and to assess the pharyngeal airway resistance, we studied the resistance obtained from the frequency of 19 Hz. Our results showed these two techniques to measure upper/pharyngeal airway resistance are highly correlated. While the correlations vary across different demographic groups.

Based on our results, when categorized by sex, R_{19} was significantly correlated with both R-P_3 and R-P_4 among female adults. However, based on the values of the correlation coefficients, we observed that the correlation between R_{19} and R-P_3 was stronger. We also demonstrated that in male adults the only significant correlation is between R_{19} and R-P_4. Similar findings were observed in a few studies that examined the effect of sex on anatomical factors such as the size of the pharynx, and airway. Previous studies demonstrated that the pharyngeal length is longer in men than in women independent of other factors [14, 15].

Additionally, significant correlations were found between R_{19} and R-P_3 in short adults, as well as between R_{19} and R-P_4 in tall adults. A potential explanation for these correlations is that taller height corresponds to a longer airway length. Studies on upper airway length normalize or adjust their data for height, this indeed suggests that height has a key influence in airway length analysis [15, 16].

Besides, we observed a significant correlation between R_{19} with both R-P_3 and R-P_4 for middle-aged adults. However, we observed that the correlation between R_{19} and R-P_3 was stronger. In addition, for senior adults, we only found a significant correlation between R_{19} and R-P_4. This suggests that those who are older tend to have longer upper airways. Our findings in this study are consistent with previous observations. A longitudinal study on young adults with an average age of 20 showed that soft palate length and vertical pharyngeal length increase after 32 years [17]. Another study showed that while the pharyngeal airway length increased with age, this trend was significant only for women, not for men [18]. However, Shigeta et al. found a statistically significant correlation between pharyngeal airway length and age in both men and women after adjusting for height. Additionally,

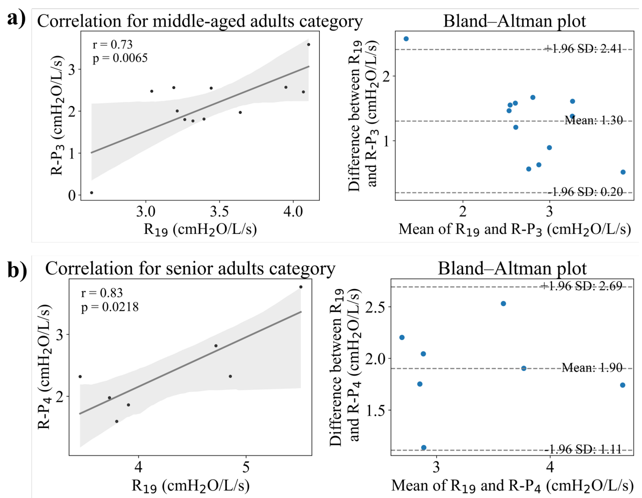

Fig. 4: The association and significant correlations between R_{19} with R-P_3 and R-P_4 for a) middle-aged and b) senior adults, respectively.

they showed that total oropharynx length increased significantly by 0.428 mm and 0.153 mm per year of age in males and females respectively before and after adjusting for height and BMI [15].

This study has a few limitations. First, participants were selected without considering any respiratory conditions they might have. We chose this sample to generalize the localization only based on demographics. However, in future studies, it is important to consider the influence of respiratory/sleep disorders such as sleep apnea on pharyngeal anatomy and physiology. We wanted to assess the sensor localization, rather than having our findings con-founded by disease. Second, our sample size was small, and further analysis should be conducted in the future with more diverse samples.

V. Conclusion

We concluded that based on the associations with Oscillometry, for male, taller, or senior adults, we should opt for more proximal pressure sensors to obtain the resistance. Therefore, the positions of the catheter sensors along the respiratory tract in calculating resistance for different groups of individuals based on sex, height, and age should be considered in research studies.

VI. Conflict of Interest

The authors declare have no competing conflict of interest.

VII. Acknowledgements

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