proceedings

Eurosensors PARIS 2017 September 3-6 • 2017 • XXXI conference

MDPI

Proceedings

Development of Catheter Flow Sensor for Breathing Measurements at Different Levels of Tracheobronchial Airway †

Tomohiro Fujinori [1], Yoshihiro Hasegawa [1], Miyoko Matsushima [2], Tsutomo Kawabe [2] and Mitsuhiro Shikida [1,*]

[1] Hiroshima City University, 3-4-1, Ozuka-Higashi, Asa-Minami-Ku, Hiroshima 731-3194, Japan
[2] Nagoya University, 1-1-20, Daiko-Minami, Higashi-ku, Nagoya 464-8673, Japan
* Correspondence: mc69003@e.hiroshima-cu.ac.jp; Tel.: +81-(0)82-830-1500 or +81-(0)82-830-1656
† Presented at the Eurosensors 2017 Conference, Paris, France, 3–6 September 2017.

Published: 21 August 2017

Abstract: We attempted to develop different sized catheter flow sensors for evaluating breathing characteristics at different levels of the tracheobronchial airway in a lung system. Two catheter flow sensors with 1.8 and 3.5 mm outer diameters were designed for measuring breathing characteristics in bronchus- and bronchiole- regions in the lung system, respectively. They were fabricated by using photolithography and heat shrinkable tube packaging processes. We experimentally investigated the fundamental sensor characteristic and found that the sensor output depended on the mean flow velocity. The developed catheter flow sensors also successfully detected the oscillating airflow produced by an artificial ventilator.

Keywords: COPD; catheter flow sensor; breathing measurement

1. Introduction

The number of people suffering from chronic obstructive pulmonary disease (COPD) is increasing rapidly and is currently estimated to be 210 million. COPD occurs when the lung alveoli collapse due to aging or absorbing too much cigarette smoke over a long period of time. According to World Health Organization statistics, COPD is the fourth leading cause of death in the world and is expected to become the third by 2030 [1]. Generally, a spirometer is used to evaluate the respiratory system when COPD develops. However, breathing characteristics are difficult to evaluate directly at lesions region. Thus, microelectromechanical systems (MEMS) technologies were previously applied to produce a novel miniaturized flow sensor to precisely evaluate COPD (Figure 1) [2]. This flow sensor can measure breathing characteristics in lesions with high accuracy because it is inserted in lesioned parts directly. However, the respiratory system consists of many levels of a tracheobronchial airway that has different inner diameters that diverge like a tree, and the lung alveoli are located at the end of the diverging bronchi (Figure 2). Thus, flow sensors of various sizes that accord with the inner diameters of the tracheobronchial airway are needed to measure breathing everywhere in the lung. Thus, two catheter flow sensors with 1.8 and 3.5 mm outer diameters were developed for evaluating breathing characteristics in bronchus- and bronchiole-regions in the lung system in this study.

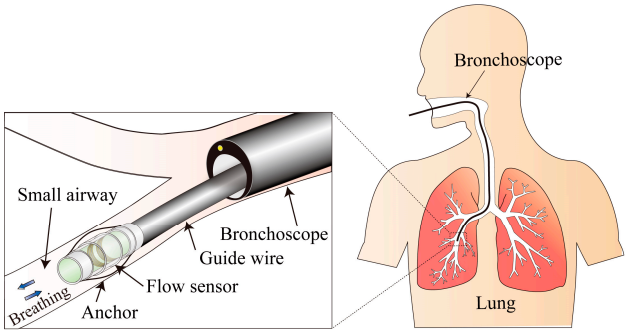


Figure 1. Breathing measurements by catheter flow sensor at tracheobronchial airway.

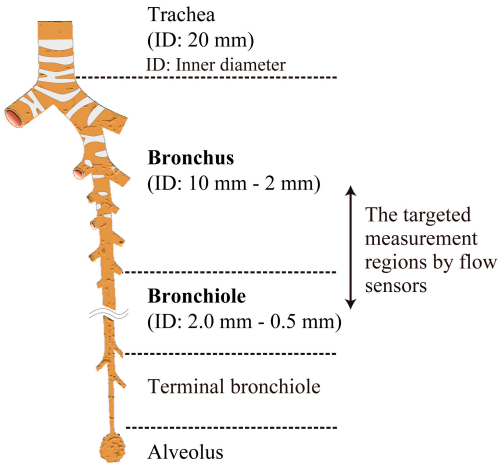
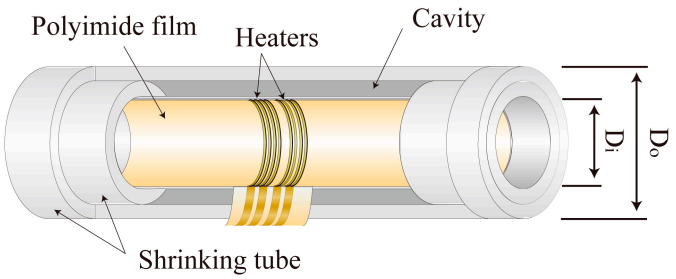


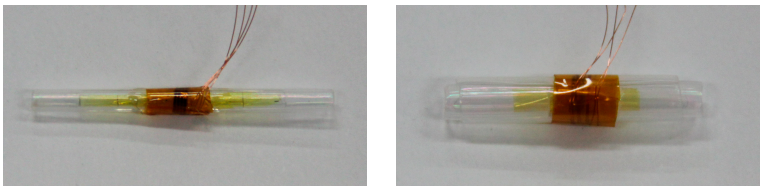
Figure 2. Targeted breathing measurement region by flow sensor at different levels of tracheobronchial airway.

2. Catheter Flow Sensor

A schematic view of a catheter flow sensor is shown in Figure 3a. To fit the inside surface of the tracheobronchial airway into bronchus- and bronchiole-regions, the two different sized catheter flow sensors were designed and then fabricated by using photolithography and heat shrinkable tube packaging. Two metal heaters working as the flow velocity and flow direction sensors were formed on the polyimide film by a lift-off process. Then, the fabricated sensor film was assembled on the inside surface of the tube by the heat shrinkable tube. The heat transfer between the heaters and airflow was used to measure the airflow passing through the inside of the tube on the operation principle. A cavity working as the thermal isolation was formed at the heaters outside by adding one more tube. The airflow temperature inside a body is constant, so only a heater element was formed as the simplest structure for increasing the mechanical reliability. The fabricated catheter flow sensors are shown in Figure 3b,c.



(**a**)

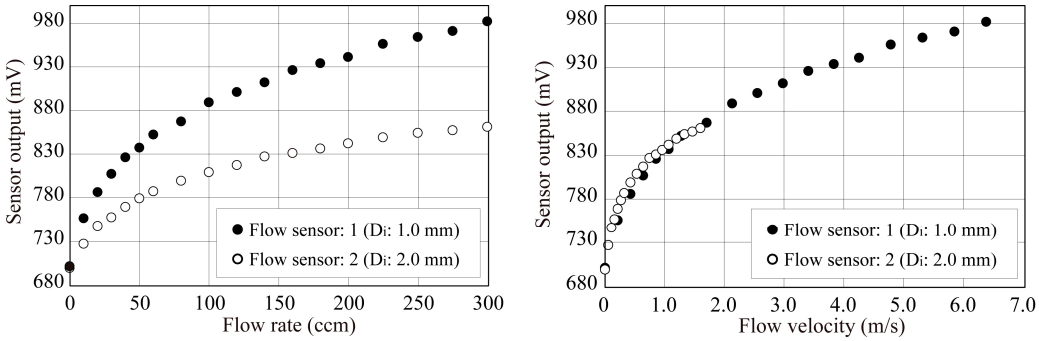


(**b**) (**c**)

Figure 3. The fabricated catheter flow sensors: (**a**) Schematic view of catheter flow sensor; (**b**) Catheter flow sensor for bronchiole use (Di = 1.0 mm, Do = 1.8 mm); (**c**) Catheter flow sensor for bronchus use (Di = 2.0 mm, Do = 3.5 mm).

3. Experiments

A commercially available mass flow controller was used as the standard, and the flow sensor was operated by a constant temperature circuit consisting of bridge and feedback circuits to shorten the response time. The voltage values applied to heaters were set to 0.7 V corresponding to the heater temperature of 60 °C in calm conditions, and the applied flow rate was controlled at 0–300 ccm by the mass flow controller. The fundamental sensor characteristic, flow rate vs. sensor output curve, is shown in Figure 4a. The sensor outputs against the flow rate depended on the inner diameter of the catheter flow sensor because the mean flow velocity decreases as the inner tube diameter increases. Thus, the obtained data was re-plotted to show the relationship between the mean flow velocity and sensor output (Figure 4b), and we found the sensor outputs were coincident at the same flow velocity condition even if the inner tube diameters were different. This means that we can design different sized catheter flow sensors on the basis of the mean flow velocity in the tube.



(**a**) (**b**)

Figure 4. Sensor output vs. flow-rate and –velocity: (**a**) Flow rate vs. sensor output; (**b**) Mean flow velocity vs. sensor output.

We also found that we can improve the sensitivity of the flow sensor especially in a low flow rate region below 50 ccm by using differential values of two heaters, as shown in Figure 5.

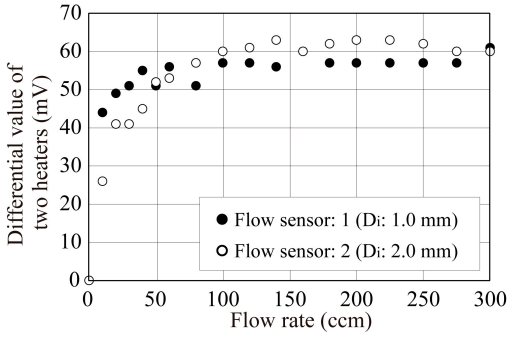
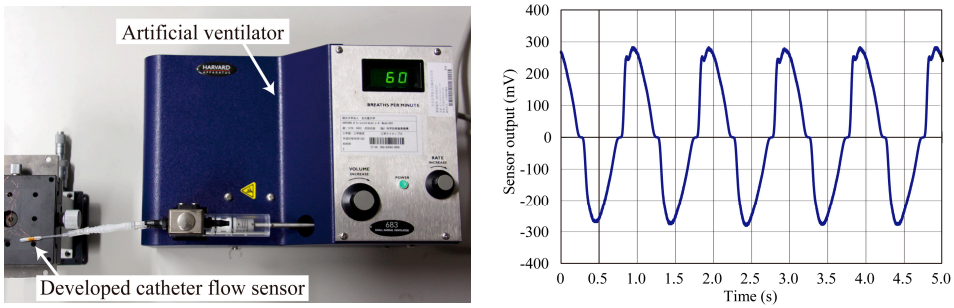


Figure 5. Differential values of two heaters vs. flow-rate.

Finally, the developed catheter flow sensor was connected to the artificial ventilator instead of an animal to evaluate the oscillating airflow detection. The frequency of the artificial ventilator was set to 1.0 Hz in the experiment. As shown in Figure 6, the developed catheter flow sensors successfully detected the oscillating airflow produced by the ventilator.



(**a**) (**b**)

Figure 6. Oscillating airflow measurements by artificial ventilator: (**a**) Experimental setup; (**b**) Measured waveform by catheter flow sensor.

4. Conclusions

We developed different sized catheter flow sensors for evaluating breathing characteristics at different levels of the tracheobronchial airway in a lung system. The main findings are summarized below.

(1) The sensor outputs were coincident at the same flow velocity condition even if the inner tube diameters were different.
(2) The developed catheter flow sensors successfully detected the oscillating airflow produced by the ventilator.

Acknowledgments: This research was supported by JSPS KAKENHI Grant Number 26286034, Japan.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Independent Administrative Institution, Environmental Restoration and Conservation Agency. Available online: http://www.erca.go.jp/ (accessed on 11 June 2014).
2. Shikida, M.; Naito, J.; Yokota, T.; Kawabe, T.; Hayashi, Y.; Sato, K. A catheter-type flow sensor for measurement of aspirated- and inspired-air characteristics in bronchial region. *J. Micromech. Microeng.* **2009**, *19*, 105027.