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New noncontact sensor for detecting pulmonary tumors during video-assisted thoracic surgery

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ABSTRACT

Background: Small pulmonary tumors are difficult to localize during video-assisted thoracic surgery (VATS) because of lack of direct tissue contact. However, in partial lung resection, tumor localization is quite important. The aim of this study was to evaluate the safety and feasibility of a new noncontact sensor for detecting pulmonary nodules during VATS using human and porcine models.

Methods: The sensor, based on the principle of phase differences, comprises an air nozzle for producing air pulse jets and an optical fiber sensor to measure phase differences and visualize object stiffness. For *in vivo* assessment, we developed a porcine model by inserting plastic balls mimicking tumors into the pig lungs after thoracotomy and then scanned the lungs. The sensor sensitivity was evaluated by measuring the ratio of the depth of the ball from the lung surface to the ball diameter (D/S). For the *ex vivo* human model, partially resected lung tissue with tumors was obtained from six patients and then scanned.

Results: In the porcine model, 32 of 37 (86.5%), 70 of 94 (74.5%), and 60 of 100 (60.0%) tumors were detected in the categories $D/S \leq 1$, $1 < D/S \leq 2$, and $D/S > 2$, respectively. Sensor safety was confirmed with an air jet at pressures between 0.05 and 0.15 MPa directed onto the lung surface; all the examined lungs including the pleura remained intact microscopically. In six patients, all nodules were successfully detected.

Conclusions: Our noncontact sensor is a safe and feasible tool for detecting small pulmonary tumors during VATS.

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Introduction

With the improving performance of computed tomography (CT), the incidence of detection of small peripheral pulmonary nodules has increased.[1,2] Recently, video-assisted thoracic surgery (VATS) has been proposed as a less-invasive approach for the resection of pulmonary tumors in selected patients.[3,4] Although VATS has the advantage of being less invasive, a major problem associated with this method is the difficulty to intraoperatively localize pulmonary nodules by hand.[5] Especially, detection is difficult after lung deflation by one-lung ventilation to ensure working space during the surgical procedure, because the nodule position changes from that determined by the CT scan; therefore, the CT data cannot be used during VATS. In anatomic segmentectomy or lobectomy, tumor localization is not mandatory. However, in the case of partial lung resection, which is the approach often chosen for an indeterminate nodule, localization of the nodule during surgery is quite important. Therefore, we developed a noncontact sensor for detecting pulmonary tumors during VATS. In this study, we also examined the safety and feasibility of the sensor by using human and porcine models.

Materials and methods

Principle of the sensor

Figure 1 shows the working principle of the noncontact sensor. Object displacement by air jet flow is measured on the basis of the relationship between the reflected light quantity and distance from the tissue surface (Fig. 1A). The distance sensor provides sinusoidal output with individual phases for the air pulse jets (Fig. 1B). When the sensor scans a tumor, the output from the optical fiber sensor changes because of the presence of the tumor (Fig. 1C). The phase difference between the input force and output of the distance sensor is displayed directly on a monitor in real time.

By plotting the input force and output distance onto the horizontal and vertical axes of an oscillograph to draw a Lissajous diagram, one can clearly detect a change in phase α, which in turn reflects an increase in stiffness, such as that caused by a tumor in lung tissue (Fig. 2A and B). As shown in Figure 2C, the plastic ball could be detected by the sensor based on the change in the Lissajous patterns after 4.7 s of scanning.

Figure 3 shows the noncontact sensor, comprising an air nozzle, an optical fiber-based distance sensor (FU-4F; Keyence, Tokyo, Japan), and a pressure sensor (AP-43; Keyence) to measure the input force. The total diameter of the sensor tip is 10 mm, which is sufficiently small for use during the surgical procedure.

Sensor measurement system

Figure 4 shows the measurement system of the noncontact sensor. The system is composed of three parts: (1) air supply system with an air compressor and solenoid valves for providing the air pulse jets; (2) sensor head; and (3) personal computer (PC) for controlling the air pressure and obtaining data from both the pressure sensor and optical fiber sensor. The PC sends a periodic on–off signal to the solenoid valve, and outputs from the sensors are fed into the PC through an analog-to-digital converter.

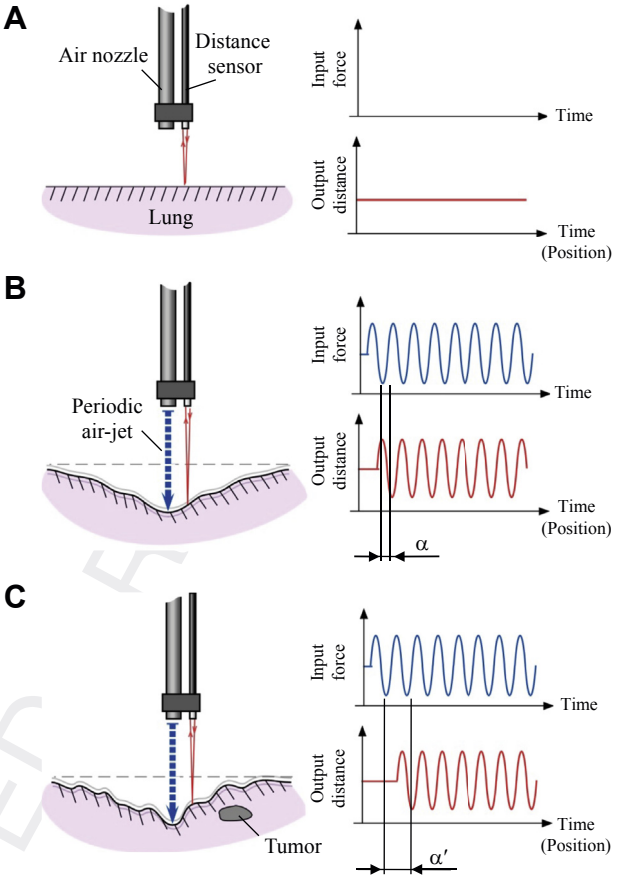

Fig. 1 – Working principle of the noncontact sensor based on the phase difference. The sensor consists of an air nozzle producing air pulse jets to induce deformity and an optical fiber sensor to measure phase differences and visualize object stiffness. (A) Distance between the sensor and object is measured by the optical fiber sensor. (B) The distance sensor provides a sinusoidal output for the air pulse jets. (C) When the sensor scans a tumor, the output from the optical fiber sensor changes because of the presence of the tumor. Color version of figure is available online.

Porcine model experiment

To examine the safety and feasibility of the sensor *in vivo*, we developed a porcine model using six male castrated pigs (12-wk old, 40 kg). Medetomidine and midazolam (40 μg/kg each) were mixed and injected intramuscularly into the pigs. Then, 10 μg/kg of pentobarbital was injected intravenously. Univent tubes were intubated to produce one-lung ventilation. Under general anesthesia (2%–3% isoflurane inhalation), the pigs were mechanically ventilated and thoracotomy was performed. All animals have received humane care in compliance with the Guide for the Care and Use of Laboratory Animals

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