Pleurodesis is improved by an even distribution of powder applied to the surface of the pleurae (see Fig. 2). Pleurodesis can fail if there is a “patchy distribution of talc” [4], and fails up to 57% of the time when attempted using an indwelling pleural catheter that cannot be actively aimed inside the body [5]. The alternative, if the physician wishes to aim the powder delivery tube, is currently thoracoscopic surgery, which requires larger incisions to admit endoscopes and other tools [6].

In this paper, we propose the CRISP robot as a new and less invasive way to deliver the powder to the pleura. We hypothesize that the CRISP robot approach will enable surgeons to more thoroughly cover the pleural surfaces with powder during pleurodesis and do so solely through needle-sized openings that produce no scarring and do not even require sutures after surgery. This promises to enable better pleural adhesion and a lower recurrence rates of lung collapse for patients.

MATERIALS AND METHODS

Our CRISP robot prototype system is shown in Fig. 3a. To enable the needles to attach to one another within the patient, a snare made of a Nitinol wire basket is inserted through a needle made of superelastic Nitinol tubing (OD: 1.17 mm, ID: 0.85 mm). This needle is used to grasp the powder deployment tube inside the chest cavity, which is made from PEEK (OD: 1.70 mm, ID: 1.00 mm). The base of each needle is controlled by a robot manipulator (AUBO Robotics). The insertion length of each needle is controlled by a linear actuator consisting of a motor driving a lead screw.
Our CRISP robot prototype is teleoperated with a 3D Systems Touch haptic device. The user controls the pose of the distal end of the powder spray tube using resolved rates control. The points along the needle shafts that coincide with the chest wall are programmed to remain at remote center of motion points, as described in [2].

Experiment Design: To evaluate the surface coverage improvement enabled by our robot, we compared it to the current manual approach. The manual approach consists of deploying the powder applicator through or attached to a rigid endoscope and tilting it to aim the powder. We simulated this by tilting the powder delivery tube through all possible angles through the entry port while spraying powder. To perform these experiments, we created a phantom model of the lung cavity by segmenting a CT scan of a patient with a partially collapsed left lung. We segmented the air in the pleural space and 3D printed an anatomically accurate volume. The phantom interior was lined with a transparent film layer covered with slow tacking spray adhesive to enable powder to adhere to the film. To facilitate these experiments, the phantom was made in two halves, so that the top half of the cavity could be sprayed while viewing through the bottom, and vice versa. Both the robotic and manual experiments were conducted in this manner.

The powder was colored red to enable easy visualization of surface coverage. After spraying the powder onto the surface, the film covering the interior of the lung cavity was removed and photographed. Coverage percentages were computed in MATLAB by thresholding HSV images to segment colored regions and converting pixel dimensions to physical dimensions using a ruler that was included in each image.

RESULTS

The results of the manual spraying are shown in Fig. 3b. Since the tube could only be tilted, and not bent to aim at all surfaces, it could achieve good coverage only on the side of the cavity opposite to the one where it entered the chest (i.e., the right-hand side of Fig. 3b). In contrast, the CRISP robot enabled the tube to be aimed in many directions, as shown by the greater coverage visible in Fig. 3c. In particular, notice the improved coverage of the surface of the cavity through which the spray tube was introduced. Quantitatively, image processing revealed that the robotic method covered 860 cm² of the interior area, while the manual method achieved 513 cm².

DISCUSSION

As seen in Fig. 3, more complete coverage of the pleural surface was achieved with the CRISP robot, due to its ability to aim the powder applicator within the chest cavity. This illustrates the feasibility of delivering better coverage less invasively than can be done by current manual techniques, which seems likely to improve the success rate of the procedure. We believe this is just one of many potential interventions that may be enabled in the future by the CRISP approach. The ability to access the lung cavity with a teleoperated system through needle-size openings that do not scar and require only a simple band-aid to close after surgery opens up new possibilities in less invasive lung biopsy and intervention, that may one day improve outcomes for many patients.

REFERENCES