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Simulation of lung lesions for validating the sonography of the flooded lung

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Abstract. The quality of sonography of a unilaterally flooded lung needs to be validated on lesions of different echogenicity, size and subpleural position. Lesions were simulated in 12 young pigs with three different methods. After transbronchial (method 1) or transpleural puncture (method 2), diverse substances were injected into the lung. After 4 weeks, the thorax was opened and the lung flooded for the sonographic location of the lesions.

In method 3, pulmonary lesions were simulated in an acute experiment after thoracotomy by transpleural injection or by filling of a Fogarty catheter balloon and were located sonographically. Transbronchial injection of alcohol invariably led to subsegment atelectasis. Only 25% of thoracoscopically controlled transpleural injections produced focal lesions in experiments in which the animals surived. Representative lesions were found only after alcohol injections. Transpleural injection of blood or a blood/Echovist suspension (method 3) simulated isoechogenic or echo-rich lesions with indistinct boundaries. By filling a Fogarty catheter balloon with saline solution or Echovist suspension, we succeeded in simulating echo-free or echo-rich lesions with smooth contours, located in different subpleural depths. After unilateral lung flooding, sonography successfully detected the locations of all these lesions and revealed their correlation with functional structures. Sonography of the flooded lung might be helpful in the intraoperative location of lesions, especially in the context of video-assisted thoracoscopic surgery.

Key words: Simulation of pulmonary lesions – Bronchoalveolar flooding – Lung sonography

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Introduction

Flooding with a suitable liquid makes the lung accessible for complete ultrasonic examination [4]. For intraoperative application, this method is useful only if it allows small pulmonary lesions to be identified also in the deeper regions of the lung parenchyma. To assess the usefulness of sonography of the flooded lung, the method was tested with lesions differing in echogenicity, size and subpleural location. As the incidence of circular lesions in animal lungs is very low, such lesions had to be simulated experimentally.

Material and methods

The animal experiments were carried out on 12 young female pigs of the race "Deutsches Landschwein" (weight range: 30–47 kg, average: 37.2 kg). The same experimental animals were used for haemodynamic measurements.

Anaesthesia and artificial respiration

Anaesthesia was initiated by an intramuscular injection of 10 mg/kg ketamine (Ketanest) with 150 IE hyaluronidase (Hylase). After cannulation of an ear vein, 6.25 mg dehydrobenzperidol (Droperidol) and 10 mg diazepam (Faustan) were applied in addition. While spontaneous respiration lasted, orotracheal intubation was performed (Magill tube, ID 8.5 mm). After relaxation with 8 mg pancuronium bromide and deepening of the anaesthesia by a dose of 0.2 mg fentanyl, artificial respiration was started with 1 MAC of isofluran in an oxygen/nitrous oxide mix (fraction of inspiratory oxygen $FIO_2 = 0.3$). Anaesthesia and relaxation were maintained by a follow-up injection of 4 mg pancuronium bromide and 0.1–0.2 mg fentanyl, respectively. Respiration under volume control was provided by an intensive respirator (Siemens 900; tidal volume 10 ml/kg, respiratory rate 16–20 cycles/min, positive end-expiratory pressure 6 cm H_2O). Throughout the experiment, 4–6 ml/kg per hour whole electrolyte solution (E 153) was infused. The body core temperature was kept at a constant 37 °C by pre-heating the infusion solutions and covering the animals with heat-insulating foil.

After tracheotomy, a left-bend Robertshaw tube (specially made by Mallinckrodt, with extra-long bronchial leg, 39 Ch) was installed. The correct position of the tube was verified by flexible bronchoscopy (Olympus BF 3C30 Bronchofiberscope). Twenty minutes before the beginning of thoracotomy, the FIO_2 was increased to 1.0. Upon opening of the pleura, respiration was changed to unilateral lung ventilation, while the respirator settings remained unchanged.

The collapsed left lung was flooded with isotonic whole electrolyte solution as described earlier [4].

Simulation of lesions

Method 1 (transbronchial injection)

Combination bronchoscopy (Storz size 8.5 Rigid Bronchoscope, and Olympus P 30 Fiberscope) was performed in three animals while spontaneous respiration lasted after short anaesthesia (initiated by intramuscular injection of 10 mg/kg ketamine and continued by intravenous injection of 1 mg/kg Propofol).

A flexible needle (Olympus NA-1 C) was used to perform a transbronchial puncture of a bronchial subsegment in the left lower lobe and to inject 3, 4 and 6 ml of 95% alcohol,

respectively. After a survival time of 24 h, anaesthesia, intubation of a double lumen tube and ventilation of the right lung were performed as described. After thoracotomy and flooding of the left lung, the lung was examined by transpleural sonography.

Method 2 (thoracoscopic transpleural injection)

After short intravenous anaesthesia as in method 1 and orotracheal intubation (Magill tube, ID 8.5 mm), thoracoscopy (Storz Operation Thoracoscope) of the left pleural cavity was performed in four animals after short-time relaxation and analgesia (1 mg/kg Rocuronium bromide; 0.1 mg fentanyl). Transpleural injection with a rigid needle (puncture capillary specially made by Storz; or CHIBA Type 22G needle with mandrel) was performed via the working channel of the thoracoscope or after a separate puncture of the chest wall. Each animal was given four injections of different substances (autologous blood, blood/Echovist suspension, 95% alcohol, Lipiodol Ultra-Fluid) and at different locations. Injection depths (2 and 3 cm) and injected volumes (0.5, 1.0 and 1.5 ml) were varied interindividually. Injections were made in the partially collapsed lung under thoracoscopic observation. The lung was then decollapsed by manual inflation, and the thoracal incision was sealed hermetically. At the end of anaesthesia, intermittent positive pressure ventilation was replaced by synchronized intermittent mandatory ventilation. When spontaneous respiration reached a sufficient level, extubation was performed under a continuous positive airway pressure of 5 cm H_2O; the animals then survived for 4 weeks. Lung sonography was made by the method described.

Method 3 (transpleural application after thoracotomy)

Thoracotomy of the left-hand side was performed on five animals after anaesthesia and intubation of a double lumen tube. Ventilation of the right lung and atelectasis of the left lung were followed by transpleural injections of autologous blood and blood/Echovist suspension, and a transpleural application of a Fogarty catheter at varying depths of the lung parenchyma. The balloon of the catheter was filled with physiological saline solution or blood/Echovist suspension. After flooding of the left lung, the simulated lesions were examined by transpleural sonography. (Fig. 1).

Sonography

Transpleural sonography was performed with 5 MHz and 7.5 MHz linear- or curved-array scanners (Diagnostic Ultrasound System 3535 of B&K Medical). Endobronchial sonography was performed with an ultrasonic catheter (12.5 MHz, 6 F; Boston Scientific) which was connected to an intravascular (IVUS) ultrasound machine (Boston Scientific).

Results

Method 1

After thoracotomy, macroscopic examination invariably revealed an atelectatic region of the parenchyma, topped by a local fibrinous pleurisy. Sonography identified a wedge-shaped, homogeneous lesion, which extended up to the visceral pleura and produced only low echoes. The lesion was relatively well demarcated from the surrounding flooded lung parenchyma, which had a higher echo reflex density (Fig. 2).

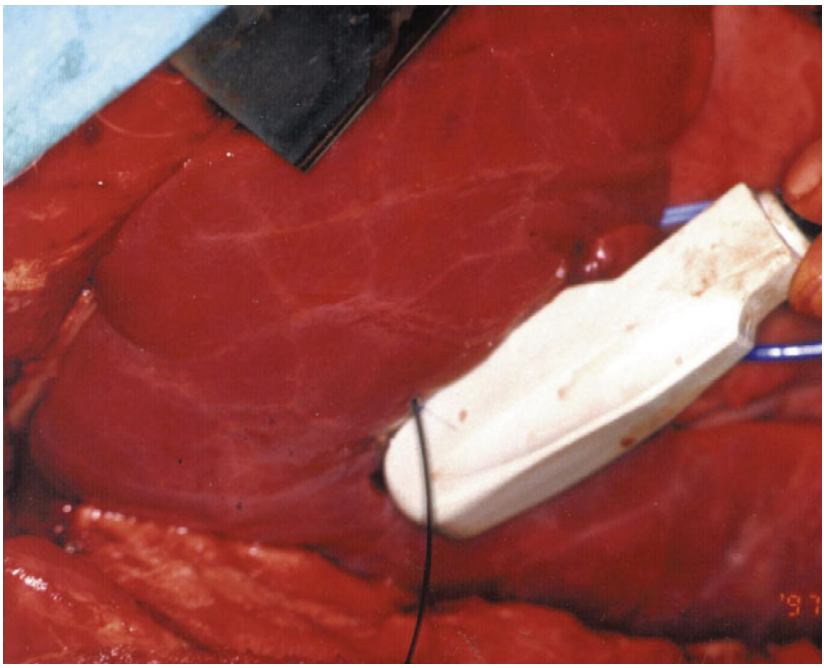

Fig. 1. Ultrasonic probe on a flooded lung; locating an intrapulmonary Fogarty catheter

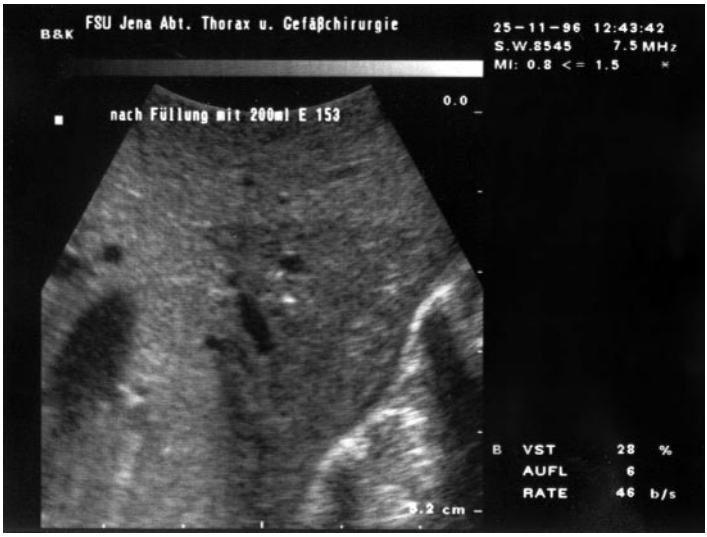

Fig. 2. Wedge-shaped parenchyma lesion with distinct boundary, extending up to the visceral pleura, 24 h after transbronchial alcohol injection

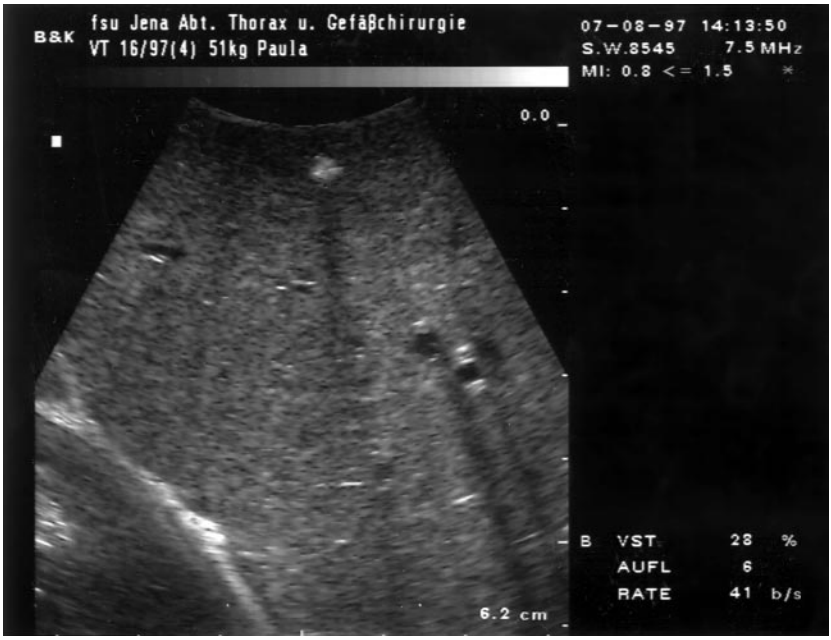

Fig. 3. Intrapulmonary, echo-rich lesion with indistinct boundary, after transpleural injection of a blood/Echovist suspension

Method 2

Of 16 injections, only four (25%) were identified as lung lesions by sonography. Rounded lesions were only seen at the locations of alcohol injection; they were almost of the same density as the lung parenchyma and could only be recognized by their low-reflection margins.

The lesions were between 5 mm and 8 mm in diameter. They were found at subpleural depths of 2 cm and 3 cm, corresponding to the injection depths.

Method 3

Lesions simulated by the injection of blood and blood/Echovist suspension did not show up in sonography of the atelectatic lung immediately after injection, whereas sonographic location was possible after lung flooding. Lesions produced by blood injection had the same reflex density as the lung parenchyma and could only be located by small zero-reflex margins. Blood/Echovist injection lesions showed up considerably better due to their high reflex density, although their contours were blurred (Fig. 3).

The lesions simulated by filling of the Fogarty catheter balloon showed highly distinct borders. Saline filling simulated echo-free cystic lesions

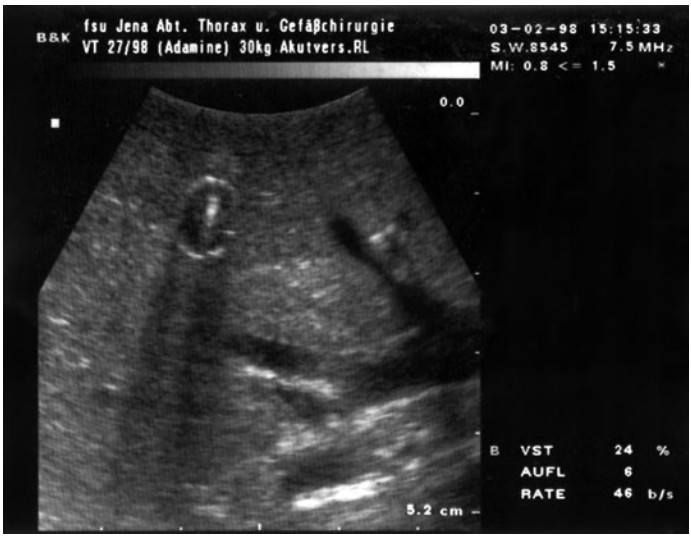

Fig. 4. Intrapulmonary, echo-free cystic lesion, after saline filling of a Fogarty catheter balloon

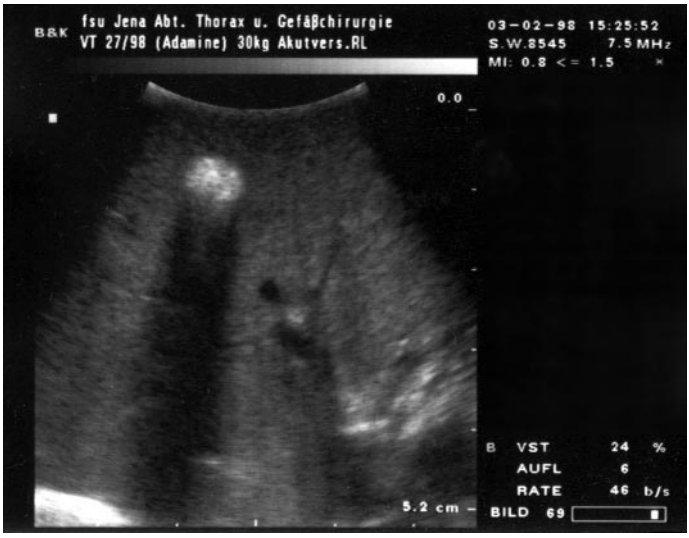

Fig. 5. Intrapulmonary, echo-rich lesion with distinct boundary, after filling the Fogarty catheter balloon with sonographic contrast medium

(Fig. 4), whereas lesions simulated by Echovist had a high reflex density (Fig. 5) and allowed their size and location in the parenchyma to be easily varied. Simultaneously, endobronchial sonography with an ultrasonic catheter also allows the location of lesions. The relation between the lesion and the functional structures is well visible (Fig. 6).

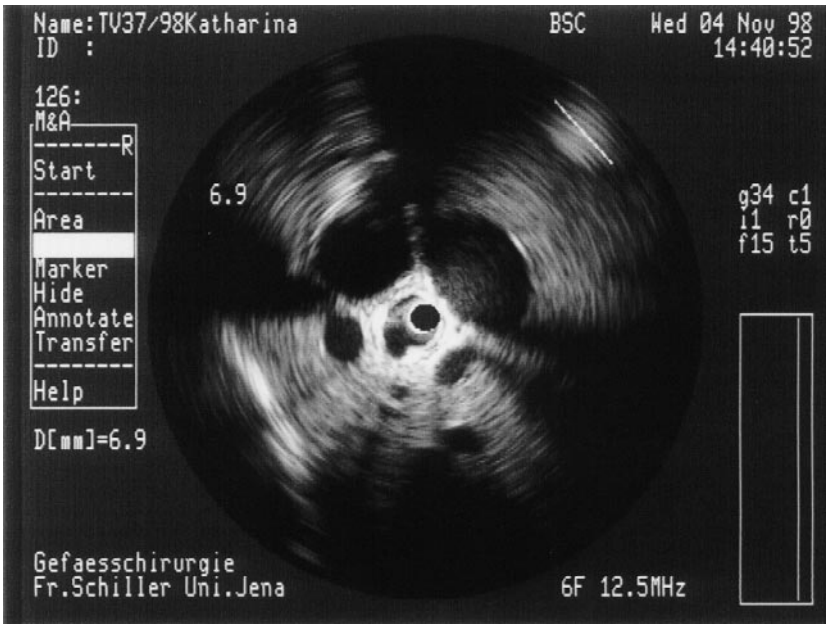

Fig. 6. Visualization of an echo-rich lesion and relation with functional structures by endobronchial sonography

Discussion

The first clinical experience of sonographic detection of lung lesions in the context of video-assisted thoracoscopic surgery (VATS) showed the difficulties caused by the residual air content in the collapsed lung. The only lesions that show up sonographically are those lying immediately below the pleura in direct contact with the visceral pleura [1, 3, 5]. The correlation between the location of a lung lesion and functional structures cannot be assessed. Lesions lying in the parenchyma at greater depths do not show up. In our own clinical study, the ultrasonic probe detected only 9.7% of the intra-parenchymal lesions in the context of VATS [3].

Gossot et al. [2] used an isolated lung in vitro as a training model, into which he sutured a lymphatic node after incision of the visceral pleura. Sonographic location of the lesion was rather difficult, however, due to residual air.

It seems possible to solve these problems by unilateral lung flooding.

To validate the use of sonography of the flooded lung, we had to develop other in-vivo methods of lesion simulation. We wanted to simulate lesions of different sizes, reflex densities and depths inside the parenchyma and to show their correlations with functional structures.

The results show that transbronchial injection of alcohol did not produce lesions that were completely surrounded by ventilated lung tissue as desired. Presumably, peribronchial alcohol injection caused a local bronchitis, which obliterated the bronchial subsegment and led to consecutive subsegment atelectasis.

The simulation of lesions by thoracoscopic transpleural injection was also unsatisfactory. Probably the volumes injected were too low, and their complete resorption prevented the formation of permanent lesions. It does not seem probable that such lesions merely escaped sonographic detection, since lesion-like changes were sonographically manifest after alcohol injections.

In the acute experiment after thoracotomy and transpleural injection of various substances, all lesions showed up in sonograms, although lesions simulated by blood injection were isodense and very difficult to locate. The injection techniques described failed to simulate reflex-free cystic lesions to a satisfactory degree.

Both reflex-free and highly reflective lesions of different sizes were simulated by the application of a Fogarty catheter into the parenchyma and filling the balloon with saline solution or a sonographic contrast medium. This method also permitted very small lesions (3 mm diameter) to be demarcated from the lung parenchyma.

In summary, we can state that lung lesions of differing size and echogenicity can be simulated by transpleural injection of a blood/sonographic contrast medium suspension, or by application of a Fogarty catheter. These lesions, even those deep inside the parenchyma, can be detected by sonography after lung flooding. The sonographs clearly indicate the spatial relationship between lesions and functional structures. These methods of in-vivo simulation of lung lesions seem to make it possible to achieve a very close approximation to the pathomorphology of benign lesions in humans.

Infiltrative malignant growths, e.g. into the vascular or bronchial wall, cannot be simulated in animal experiments.

Sonography of the flooded lung could therefore be very helpful in the location of lesions, e.g. in video-assisted thoracoscopic surgery.

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