

# Use of intraoperative ultrasonography for identification and management of pneumothorax caused by iatrogenic diaphragm defect: a case report and literature review

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## Abstract

Transthoracic ultrasound has been widely accepted for the evaluation of many thoracic diseases, including pleural effusion, atelectasis, pneumothorax, and pneumonia with subpleural effusion. Application of ultrasonography for the diagnosis of pneumothorax is an effective and timely intraoperative technique. We herein present a patient who developed pneumothorax following diaphragmatic injury during laparoscopic cholecystectomy. The pneumothorax was rapidly identified by bedside ultrasound. The compressed lung was successfully re-expanded using positive end-expiratory pressure (PEEP) ventilation under real-time ultrasound monitoring, and closed thoracic drainage was avoided. Therefore, the correct use of ultrasound can identify the adequate PEEP level that is able to promote resolution of pneumothorax induced by diaphragmatic injury.

## Keywords

Ultrasonography, pneumothorax, cholecystectomy, laparoscopic, positive end-expiratory pressure, diaphragmatic injury

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## Background

The reported incidence of pneumothorax caused by diaphragmatic injury following laparoscopic surgery is about 3%.<sup>1,2</sup> Different from pneumothorax caused by other kinds of lung damage, mild or moderate pneumothorax induced by carbon dioxide (CO<sub>2</sub>) pneumoperitoneum is often automatically eliminated within several hours, while tension pneumothorax requires prompt thoracic closed drainage.<sup>3-5</sup> A chest radiograph is usually the initial tool used to detect potential pneumothorax.<sup>3</sup> However, research has demonstrated that point-of-care chest ultrasonography, a nonradiative, timely, and inexpensive measure, is more accurate than chest X-ray, showing 81% sensitivity and 100% specificity.<sup>6</sup> Transthoracic ultrasound has been widely accepted in the evaluation of many thoracic diseases, such as pleural effusion, atelectasis, pneumothorax, and pneumonia with subpleural effusion.<sup>7</sup> Ultrasonography is a timely and effective tool for the diagnosis and management of pneumothorax.<sup>4,7</sup> Positive end-expiratory pressure (PEEP) ventilation has been used to inflate the lung when pneumothorax is induced by diaphragmatic injury during CO<sub>2</sub> pneumoperitoneum.<sup>3</sup>

## Case presentation

A 73-year-old woman (weight, 65 kg; height, 158 cm) was diagnosed with gallstones and cholecystitis, and she was planned to undergo laparoscopic cholecystectomy under general anesthesia combined with a transverse abdominal muscle block. The patient had a medical history of chest distress and pain for which she underwent percutaneous coronary intervention in 2013. She also had a 10-year history of hypertension, and her blood pressure was maintained at 130–140/80–90 mmHg by taking antihypertensive drugs. She also

had diabetes and had maintained a normal blood glucose level by taking metformin and generic sulfonylurea for several years. No obvious abnormalities were found by laboratory examination, electrocardiography, and chest radiography.

In the operating room, standard monitors for noninvasive blood pressure, electrocardiography, and pulse oximetry (SpO<sub>2</sub>) were attached to the patient. Her baseline blood pressure was 170/100 mmHg, heart rate was 90 bpm, and SpO<sub>2</sub> was 96% on air. An arterial line was placed under local anesthesia, and the blood gas analysis showed no abnormalities. Anesthesia was induced with 25 µg of sufentanil and 18 mg of etomidate followed by 10 mg of cisatracurium for muscle relaxation. Tracheal intubation was uneventful. The bilateral lungs inflated symmetrically, the breath sounds were normal, and the airway pressure was 14 cmH<sub>2</sub>O. An ultrasound-guided right transverse abdominal muscle block was performed with 25 mL of 0.25% ropivacaine. Anesthesia was maintained with 2% sevoflurane and remifentanyl (0.15 µg/kg/min) pumped intravenously.

Pneumoperitoneum was established with CO<sub>2</sub>; the intra-abdominal pressure was kept below 14 mmHg, and the peak airway pressure was 20 cmH<sub>2</sub>O. Fifteen minutes later, the patient's position was changed to a 30° head-up position with the head rotated to the left to facilitate the operation. At this time, the maximum airway pressure and end-tidal CO<sub>2</sub> levels increased to 28 cmH<sub>2</sub>O and 55 mmHg, respectively. Meanwhile, the SpO<sub>2</sub> rapidly decreased to 88% and the hemodynamic parameters remained stable; the blood pressure was 125/80 mmHg and the heart rate was 87 bpm. To improve the patient's oxygenation, we quickly increased the concentration of inspired oxygen from 0.6 to 0.9. Respiratory auscultation was normal in the left lung, but the breath sounds were almost inaudible in the right lung. We considered

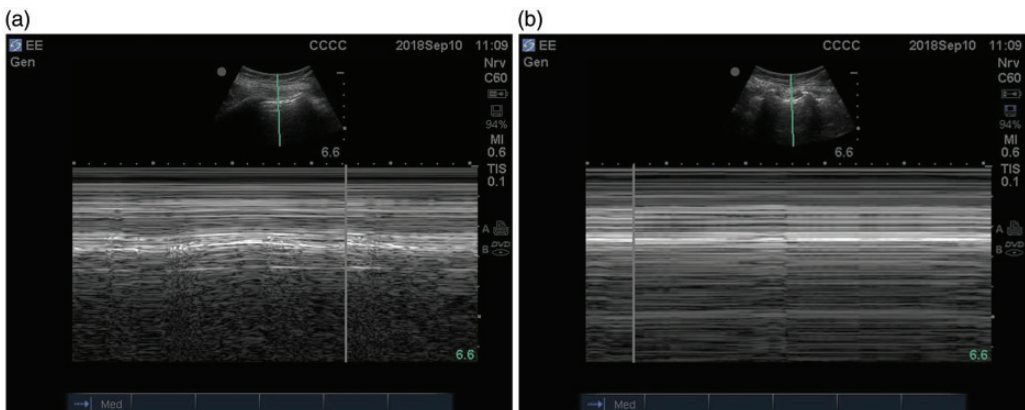
that the endotracheal tube might have entered the right main bronchus when adjusting the patient's position. However, fiberoptic bronchoscopy showed that the endotracheal catheter position was normal and no secretions were blocking the right bronchus (Figure 1). A chest ultrasound examination was immediately performed to exclude pneumothorax (M-Turbo high-frequency linear array probe; SonoSite,



**Figure 1.** Fiber bronchoscopy showed that the location of the endotracheal catheter was normal and that no secretions were blocking the right bronchus. However, the breath sounds were almost inaudible in the right lung.

Bothell, WA, USA). Lung sliding and the seashore sign were detected in the left lung (Figure 2(a)), but the absence of lung sliding and the presence of the barcode sign were shown in the right lung (Figure 2(b)). These findings were strong evidence of pneumothorax. The surgeon then inspected the diaphragm in detail and found a small hole of about 1 cm in the right diaphragm (Figure 3).

Atelectasis of the lung was resolved by slow hand-controlled ventilation, and PEEP ventilation at 5 to 10 cmH<sub>2</sub>O was added. The patient's blood pressure and heart rate remained normal by increasing the infusion speed of the Ringer's solution. The airway pressure decreased to 21 cmH<sub>2</sub>O, and the bilateral breath sounds were symmetrical and clear. After the ultrasound confirmed that the lung had re-expanded, the surgeon sutured the damaged diaphragm in 1 minute while the lung expansion was maintained by hand to prevent the CO<sub>2</sub> from re-entering the pleural cavity. The airway pressure returned to 14 cmH<sub>2</sub>O. Finally, the gallbladder was removed and the operation was finished. The patient's spontaneous breathing and



**Figure 2.** Chest ultrasound was immediately performed to diagnose pneumothorax after confirming that the breath sounds were almost inaudible in the right lung during carbon dioxide pneumoperitoneum in laparoscopic cholecystectomy (M-Turbo high-frequency linear array probe; SonoSite, Bothell, WA, USA). (a) Lung sliding and the seashore sign were detected in the left lung, but (b) the absence of lung sliding and the presence of the barcode sign were detected in the right lung.



**Figure 3.** The surgeons inspected the diaphragm in detail and found a small hole of about 1 cm in the right diaphragm (black arrow) during carbon dioxide pneumoperitoneum in laparoscopic cholecystectomy.

consciousness returned. She reported no pain or discomfort in the post-anesthesia care unit. The patient was later transported to the general ward and discharged 5 days after surgery.

This case report was approved by the Ethics Committee of Tongji Hospital of Tongji Medical College, Huazhong University of Science and Technology. Written informed consent for publication was obtained from the patient.

## Discussion

Pneumothorax is a recognized complication of laparoscopic surgery.<sup>3,8-14</sup> The incidence ranged from 6.0% to 15.2% in the 1990s and decreased to 0.1% to 2.0% with improvements in laparoscopic techniques.<sup>3,5,13</sup> The potential causes of

intraoperative pneumothorax can be divided into two categories: congenital defects and iatrogenic factors. Iatrogenic causes include direct injury to the diaphragm, rupture of emphysematous bullae, and central venous puncture and catheterization.<sup>1</sup> However, diaphragmatic injury following laparoscopic cholecystectomy is an extremely rare complication, and it can become life-threatening as in the case of respiratory distress syndrome induced by a giant diaphragmatic hernia.<sup>15</sup> Diaphragmatic injury may occur during the laparoscopic procedure if the holding or dissecting instrument slips off, particularly in difficult cases where significant traction is necessary.<sup>9</sup> We searched PubMed for all published case reports of patients who developed pneumothorax during laparoscopy from 1993 to the present and found 13 cases (Table 1).

In the present case, the pneumothorax was obviously caused by direct injury to the diaphragm. During CO<sub>2</sub> pneumoperitoneum, the gas enters the chest through the injury site. CO<sub>2</sub> pneumothorax is more likely to occur in the right lateral pleural cavity during laparoscopic cholecystectomy because of the anatomical position of the gallbladder. Park et al.<sup>4</sup> suspected some degree of association between the surgical position and the development of CO<sub>2</sub> pneumothorax. The head-up position plus CO<sub>2</sub> pneumoperitoneum may increase the incidence and severity of CO<sub>2</sub> pneumothorax by pushing the liver and omentum downward, thereby leading to exposure of the diaphragmatic defect within the pressurized abdominal cavity. For this reason, this type of pneumothorax has mainly been reported in laparoscopic upper abdominal surgical procedures. In contrast, the head-down position may have a protective effect against the development of CO<sub>2</sub> pneumothorax.

Pneumothorax is always initially diagnosed by auscultation of decreased or absent breath sounds. In the present case, the intensity of breath sounds was

**Table 1.** Reported cases of pneumothorax during laparoscopy.

Authors	Journal	Year	Operation	Diagnostic method	Therapy
1 Chui et al. <sup>8</sup>	<i>Anaesthesia</i>	1993	Laparoscopic vagotomy	Chest radiograph	Intercostal cannula
2 Seiler et al. <sup>9</sup>	<i>Surg Endosc</i>	1995	Laparoscopic cholecystectomy	Unknown	Chest drain
3 Joris et al. <sup>3</sup>	<i>Anesth Analg</i>	1995	Laparoscopic fundoplication	Symptomatic	PEEP (5–8 cmH <sub>2</sub> O)
4 Dawson and Ferguson <sup>5</sup>	<i>Surg Laparosc Endosc</i>	1997	Laparoscopic cholecystectomy	Chest radiograph	Recovered when pneumoperitoneum rapidly evacuated
5 Shanberg et al. <sup>22</sup>	<i>J Urol</i>	2002	Laparoscopic partial nephrectomy	Chest radiograph	Thoracostomy tube
6 Venkatesh et al. <sup>10</sup>	<i>J Urol</i>	2002	Laparoscopic nephrectomy	Chest radiograph	Chest tube
7 Moore and O'Brien <sup>11</sup>	<i>Anaesthesia</i>	2004	Laparoscopic Nissen's fundoplication	Chest radiograph	PEEP via an Ayre's T-piece
8 Jang et al. <sup>2</sup>	<i>Korean J Anesthesiol</i>	2013	Laparoscopic right adrenalectomy	Ultrasonography	PEEP (5 cmH <sub>2</sub> O)
9 Park et al. <sup>4</sup>	<i>Korean J Anesthesiol</i>	2016	Living-donor right nephrectomy	Chest radiograph	PEEP (5 cmH <sub>2</sub> O)
10 Paul et al. <sup>13</sup>	<i>J Minim Invasive Gynecol</i>	2017	Laparoscopy-assisted gastrectomy	Chest radiograph	Conservative treatment
11 Matsushita et al. <sup>12</sup>	<i>Asian J Endosc Surg</i>	2017	Laparoscopic hysterectomy	Chest radiograph	Thoracostomy tube
12 Bouchagier et al. <sup>15</sup>	<i>Case Rep Surg</i>	2018	Retroperitoneal laparoscopic donor nephrectomy	Chest radiograph	Vacuum drainage
13 Wu and Zhang <sup>14</sup>	<i>BMC Anesthesiol</i>	2018	Laparoscopic cholecystectomy	Chest radiograph	Facial mask oxygen therapy
			Retroperitoneal laparoscopic partial nephrectomy		

PEEP, positive end-expiratory pressure.



diminished not only as compared with the contralateral side, but also as compared with the breath sounds heard over the ipsilateral lung 10 minutes after the beginning of pneumoperitoneum. Chest radiography can facilitate a definitive diagnosis in the outpatient department or inpatient ward. Intraoperative fluoroscopy has also been used to radiologically confirm the diagnosis.<sup>3</sup> However, radiologic examination requires special equipment and machines and cannot be quickly performed in a general operating room. In the present case, when the peak airway pressure increased and the breath sounds in the right lung were lost, we initially suspected a positional change in the endobronchial tube because such clinical presentations sometimes develop after pneumoperitoneum has started. However, fiber bronchoscope examination showed that the right main bronchus was unobstructed and that no secretions were present.

Chest ultrasonography is readily available and considered to be almost as accurate as computed tomography.<sup>13,16</sup> In cases such as that described herein, bedside ultrasonography is the best substitute for radiography during the operation. The M-mode can display a sign resembling a seashore because of the sliding pleura. Lung sliding appears when the lung and parietal pleura are in direct apposition and a side-to-side oscillating movement of the pleural line is shown on the screen. Healthy parenchyma and a properly ventilated lung usually exhibit a grainy, discontinuous, seashore-like pattern in M-mode.<sup>17</sup> When the two pleural layers are separated by gas, as in the presence of pneumothorax, this movement is suppressed.<sup>18</sup> In such cases, lung sliding is absent and the lung point becomes appreciable.<sup>16,19</sup> When the lung is compressed and still, the pleura exhibits a barcode sign.<sup>7</sup> This sign can facilitate rapid establishment of a definitive diagnosis of pneumothorax. In the present case, pneumothorax was diagnosed in a timely

manner using the emergency bedside pulmonary ultrasound protocol.<sup>17</sup>

When pneumothorax occurs intraoperatively, the collapsed lung should be expanded as quickly as possible to decrease the injury associated with anoxia and altered hemodynamics. Placing a closed drainage tube in the thoracic cavity is a common approach to reduce the intrathoracic pressure.<sup>1,20-22</sup> However, this is not always necessary for treatment of CO<sub>2</sub> pneumothorax induced by diaphragmatic injury during laparoscopic surgery.<sup>3,15</sup> In the present case, we were first able to decrease the gradient between the abdominal and pleural cavities by changing the ventilator strategy and re-expanding the lung. High PEEP is often used to correct hypoxia in patients with acute respiratory distress syndrome, but high PEEP can induce cardiovascular impairment. Kirby et al.<sup>23</sup> found that the apparent deterioration of hemodynamics induced by a PEEP of 12 cmH<sub>2</sub>O could be reversed by augmentation of the blood volume. A recent study showed that high PEEP (25 cmH<sub>2</sub>O) could cause impairments in the systemic circulation and that fluid loading restored the circulation status in a canine model.<sup>24</sup> However, very few reports have used high PEEP to manage pneumothorax during an operation. In the present case, we initially used positive-pressure ventilation to dilate the collapsed lungs when pneumothorax was diagnosed. Under the premise of maintaining stable circulation, we gradually increased PEEP from 5 to 10 cmH<sub>2</sub>O and found that normal ventilation could be achieved completely to prevent CO<sub>2</sub> gas from re-entering the chest. Thus, circulation and breathing remained stable, and the surgeon found and repaired the injured site of the diaphragm. The high PEEP lasted about 10 minutes. In our opinion, when PEEP is approximately equal to the pneumoperitoneum pressure, pulmonary collapse can be avoided; however, high PEEP must be used to ensure circulation stability.

This case had several limitations. First, we did not use ultrasound to assess the function of the injured diaphragm. Many studies have demonstrated that ultrasound can be used to assess functional impairment of the diaphragm.<sup>25–27</sup> Diaphragmatic dysfunction occurring not only during laparoscopic cholecystectomy but also thoracic surgery might determine the effect on diaphragmatic function required to promote the development of pulmonary postoperative complications. Diaphragmatic ultrasound evaluation has recently been used to identify the risk of postoperative pulmonary complications in patients undergoing thoracoscopic and thoracotomy procedures.<sup>28</sup> In the present case, because laparoscopic surgery was performed, the diaphragmatic damage was quickly found and repaired, and the function of the diaphragm was not evaluated by ultrasound. Second, no clear pictures of the diaphragmatic injury were collected. Because of the limited time, we only obtained pictures using a mobile phone; no clear pictures or videos could be collected by the laparoscopic camera system. Third, our experience using high PEEP in the treatment of intraoperative pneumothorax is insufficient. Further studies are required to determine whether high PEEP is useful for avoiding pneumothorax in laparoscopic surgery.

In summary, pneumothorax often occurs during laparoscopic surgery, and we should remain vigilant for this complication. Ultrasound can be used to achieve a rapid intraoperative diagnosis of pneumothorax, and additional intraoperative or postoperative PEEP ventilation can be an effective therapy for CO<sub>2</sub> pneumothorax, potentially avoiding the need for closed drainage of the thoracic cavity.


#### Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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