A Risk Reduction Technique for Five Invasive Procedures in the Emergency Room Using a Compact and Lightweight X-ray Unit

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Short title: Portable X-ray and invasive procedures

Keywords: Thoracic radiography; Complications; Central venous catheters, Chest tubes;
Tracheotomy

Abstract

Background: Many invasive procedures are performed in the emergency room (ER), which have potential risks and complications. Due to limitations, especially with respect to size, portable X-ray devices are generally not used during such procedures. However, they have been miniaturized, enabling physicians to capture X-ray images by themselves..

Methods: We developed a safe, compact, and lightweight X-ray unit and performed five invasive procedures in the ER. In all the procedures, a chest X-ray image was taken to confirm its utility.

Results: Case 1 (central venous catheter placement): After needle and guidewire insertion and the placement of the catheter, the location of catheter could be confirmed.

Case 2 (chest tube insertion): During the insertion of the chest tube into the pleural space, it was observed that the tip of the thoracic tube was at the appropriate location.

Case 3 (percutaneous tracheostomy or cricothyroidotomy): After needle and guidewire insertion, it was visualized that the guidewire was in the right main bronchus and that the tube was inserted into the trachea. Case 4 (resuscitative endovascular aortic balloon of the aorta): The captured image revealed that the catheter was located in zone I before

50 balloon inflation. Case 5 (Sengstaken–Blakemore tube): The image revealed that the

51 balloon was located in the stomach.

52 *Conclusions:* The devised portable X-ray unit could contribute medical safety during

53 invasive procedures frequently performed in the ER.

54

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Introduction

Critically ill patients, regardless of the cause, are first transferred to the emergency room (ER) for diagnosis and resuscitation. Many invasive procedures performed for such patients in the ER are associated with potential risks as they could be the cause for post procedural complications.^{1, 2} Intraoperative imaging such as ultrasonography and fluoroscopy have been used to reduce some of the complications. However, the patients must be transported to the fluoroscopy room. In addition, as ultrasound wave get disrupted by air/gas and do not penetrate deep, certain areas cannot be visualized. Although intraoperative radiology does not require the patient to be moved and can capture images from area that cannot be visualized with ultrasound, its use has been limited because of the conventional instrument size and reliance on technicians.³

Over the years, portable X-ray devices have become miniaturized, permitting physicians to take X-ray images anywhere with ease⁴⁻⁶. Thus, intraoperative X-ray devices offer safety benefits in medical procedures. However, little is known about the use of portable X-ray devices during invasive procedures. Having developed and assessed the safety of one such compact and lightweight X-ray unit, we, herein report its utility for frequently performed invasive procedures in the ER.

Materials and Methods

Setting

This study was conducted in a single institution and approved by the Ethics committee of Nippon Medical School Hospital, Japan (30-09-993). It may be noted that in Japan, only doctors and radiology technicians are authorized to administer X-rays.

Medical equipment

A compact and lightweight X-ray unit developed has been commercialized and comprises of the following three parts: an X-ray tube, weighing only 3.5 kg (CALNEO Xair, Fujifilm Corporation, Tokyo, Japan); a laptop through which the operator controls the functioning of machine; and a flat panel (CALNEO Smart, Fujifilm Corporation, Tokyo, Japan) (Fig. 1). Depending on the body part being examined, the following three parameters were preset: the chest (90 kV, 0.5 mAs), abdomen (90 kV, 2.5 mAs), and extremities (70 kV, 2 mAs). Although conventional mobile X-ray units require knowledge like kV and mAs settings before examination, this device is superior in terms of usability. This device has received approval from the Pharmaceuticals and Medical Devices Agency, Japan, for marketing.

92 *Procedures*

93 In this study, chest radiographs were taken to confirm the location of the catheter or
94 tube tips during five invasive procedures frequently preformed in the ER. These were
95 central venous catheter (CVC) (or peripherally inserted central catheters) placement,
96 chest tube insertion, percutaneous tracheotomy (or cricothyroidotomy), resuscitative
97 endovascular balloon occlusion of the aorta (REBOA), and Sengstaken–Blakemore
98 (SB) tube insertion.

99 While performing the procedure, the physician wearing an X-ray radiation-protective
100 apron, placed the flat panel detector of the unit under the patient and the X-ray tube
101 above. When the guidewire, catheter, or tube was inserted, the physician selected the
102 radiation intensity, pressed the relevant button, and immediately viewed the image on
103 the laptop screen. If the catheter and tube tips were malpositioned, another X-ray image
104 was taken after repositioning.

105

106 **Results**

107 *Case 1: CVC placement*

108 A 48-year-old woman was intubated and received mechanical ventilation after surgical
109 clipping for a cerebral aneurysm. The patient required CVC replacement in the right

internal jugular vein. A physician set the X-ray devices, an ultrasound device, and a flat panel detector under the patient as a part of preoperative preparation (Fig. 2). When the needle and guidewire were inserted, a chest radiograph showed a guidewire in the superior vena cava (Fig. 3a). When the catheter was placed, a chest radiograph showed that the catheter tip was in the appropriate location (Fig. 3b).

Case 2: Chest tube insertion

A 70-year-old woman presented with difficulty breathing. She was diagnosed with congestive heart failure and bilateral pleural effusion. The effusion was drained because oxygen was required to maintain a percutaneous saturation of over 90%. During the insertion of the chest tube into the pleural space, a chest radiograph was taken, which showed that the tip of the thoracic tube had reached the appropriate location (Fig. 4).

Case 3: Percutaneous tracheostomy

A 60-year-old man diagnosed with intracerebral hematoma was intubated and received mechanical ventilation. A tracheostomy was required for prolonged endotracheal intubation. A Pean clamp forceps was placed at the insertion site, and a chest radiograph was taken, with the forceps determining the position of the tip of the intubation tube in

relation to the insertion site (Fig. 5a). The intubation tube was withdrawn 3.5 cm because there was a 3-cm gap between the tip of the intubation tube and the insertion site (Fig. 5b). When the needle and guidewire were inserted, the chest radiograph showed the guidewire in the right main bronchus (Fig. 5c). After adequate dilatation, the dilator was removed, and a tracheostomy tube was inserted into the trachea above the guiding catheter.

Case 4: REBOA

A 70-year-old man was transported to the ER after a road accident. Computed tomography (CT) revealed splenic and renal hemorrhage, as well as a pelvic fracture. The patient's blood pressure decreased after the CT scan. A REBOA catheter was inserted and advanced into the aorta; following which a 7-French introducer sheath was inserted through the right femoral artery. A chest radiography revealed the REBOA catheter in zone I, extending from the origin of the left subclavian artery to the celiac artery before balloon inflation (Fig. 6). After balloon inflation, the patient's blood pressure increased, and splenectomy could be performed.

Case 5: SB tube insertion

A 48-year-old man diagnosed with alcoholic cirrhosis and esophageal varices presented with hematemesis and was transferred to our hospital. He presented with hypotension and anemia with a hemoglobin level of 3.1 g/dL. As it was difficult to stop the bleeding with an endoscope, an SB tube was inserted. Following balloon inflation, a chest radiograph revealed that the balloon was located in the stomach (Fig. 7). The SB tube was then pulled, and the esophageal balloon was inflated. Subsequently, the blood pressure increased and the hemoglobin level normalized. The next day, the endoscopic variceal ligation was performed successfully.

Discussion

We developed an intraprocedural visualization technique which uses a compact and lightweight X-ray unit in five frequently performed invasive procedures. Based on the observations from these case studies, it can be implied that this technique can reduce the risk of complications during invasive procedures.

We reviewed the complications of each procedure and described how a compact and lightweight X-ray unit are useful for preventing complications.

CVC insertion: Procedures for CVC insertion have progressed in terms of safety and ease of performance. However, the complication rate of CVC insertion continues to remain high. A retrospective cohort study described an overall complication rate of 15%. The complications included failure to place the catheter (22%), arterial puncture (5%), catheter malposition (4%), pneumothorax (1%), subcutaneous hematoma (1%), hemothorax (< 1%), and cardiac arrest (< 1%). Ultrasound-guided techniques have reduced the risk of inadvertent arterial puncture (risk ratio [RR] 0.21, 95% confidence interval [CI] 0.06 to 0.82; $P = 0.02$) and hematoma (RR 0.26, 95% CI 0.09 to 0.76; $P = 0.01$) for the subclavian vein. However, ultrasound-guided techniques cannot detect misplacement of the CVC or ensure placement at the appropriate location. Fluoroscopy is often used for insertion of peripherally inserted central catheter and a randomized controlled trial revealed that mispositioning of catheter tip was significantly lower in fluoroscopy guided technique compared with blind bedside technique⁷. An X-ray guided technique, on the contrary, might avoid arrhythmia that can be induced by inserting a guidewire and catheter too deeply.⁸ Moreover, using this technique, physicians can spot any abnormal findings even in case of an iatrogenic pneumothorax.

Chest tube insertion: Chest tube drains are indicated in case of a hemothorax, massive pleural effusion, large or progressive pneumothorax, and postoperatively in thoracic surgery. All intrathoracic organs, including the lung, diaphragm, heart, large vessels, and esophagus, are potentially at a risk of injury during the chest tube insertion. A chest tube placed in the right ventricle, though rare, is life-threatening Early (<24 h after placement) complications occurred in 3%, and 8% of cases have been reported.⁹ Although point-of-care ultrasound during tube insertion has been used to reduce complications,¹⁰ it cannot confirm the placement of the tip of the chest tube, which could be placed at an inappropriate location such as within the interlobar space. Appropriate placement of the tip of the chest tube can be confirmed using a compact and lightweight X-ray unit.

Percutaneous tracheostomy (or cricothyroidotomy): The technique of percutaneous tracheostomy was developed in 1985, based on modification of the Seldinger principles. The advantages of this technique as compared with surgical tracheostomy are simplicity, a smaller skin incision, lower incidence of wound infections and peristomal bleeding, and decreased mortality rates associated with patient transfer.¹¹⁻¹⁵ However, perioperative complications of percutaneous tracheostomy include paratracheal

insertion, tracheal laceration, pneumothorax, loss of airway, and hemorrhage.¹⁶ An X-ray guided technique could assist confirming the location of the tube and guidewire during the procedure and paratracheal insertion, thereby reducing the possibility of developing a tracheoesophageal fistula. Additionally, though bronchoscopy might be helpful for percutaneous tracheostomy¹⁷, it occupies more space and requires an operator too. Hence the compact and lightweight X-ray unit could replace a bronchoscope. Moreover, our technique can be applied not only in percutaneous tracheostomy but also in cricothyroidotomy.

REBOA: REBOA is an alternative to aortic clamping by thoracotomy for non-compressible torso hemorrhage and is a tool for temporary hemostasis. Confirming the position of the REBOA catheter when inflated by fluoroscopy or X-ray imaging is recommended. The actual and theoretical risks include unintended placement in the aortic arch, renal artery, zone II, or contralateral iliac artery.¹⁸ A number of complications, such as aortic injury, ischemic injury, arterial dissection, thrombosis, and embolic events, have been reported.^{19, 20} The appropriate placement of the tip of the REBOA catheter can thus be confirmed using the compact and lightweight X-ray unit.

SB tube: Many major complications caused by inflation of the gastric balloon outside the stomach have been reported, including airway obstruction, tracheal injury, esophageal rupture, and jejunal rupture.²¹⁻²⁶ Although the position can be confirmed by auscultation, the manufacturer recommends the use of fluoroscopy. However, rupture of the esophageal varices often results in shock due to massive bleeding, and the patient may have difficulty in moving. Hence, the compact and lightweight X-ray unit may be useful in this procedure too.

Time reduction

This device has several potential advantages. Physicians can take X-ray images by themselves as soon as the patient is presented to the hospital and save at least the travel time compared with technician. If physician A technician would take on average 12.4 min from being informed to get the portable X-ray unit and 22.7 min to upload images and archive them in the communication systems²⁷. In addition, though fluoroscopy-guided procedures can prevent complications, they require transferring the patient to the fluoroscopy room.⁷ According to a study of peripherally inserted central catheters, the average transfer time was approximately 26 min, which was similar to the procedure

time.⁸ Our technique could be particularly useful for critically ill patients who cannot be transferred safely to the fluoroscopy room.

Radiation dose

A single chest X-ray causes an exposure to 0.02 mGy of radiation⁵ whereas fluoroscopy causes 20 mGy/min of radiation²⁸. A total of 0.63 min is required to insert a CVC by radiologists using fluoroscopy,²⁹ and patients are exposed to an average of 12 mGy of radiation with fluoroscopy during CVC insertion. Therefore, a compact X-ray technique would reduce the lower radiation exposure to patients during CVC insertion as compared with fluoroscopy.²⁹

Limitations

This study has several limitations. First, no control group was included in this study. Although we think that visible is safer than invisible, it could not be evaluated how the device would contribute to safety. As far as we know, no trouble has been caused by this method, but there is a possibility that some trouble may occur. There is insufficient consideration of risk assessment and trouble shooting. Second, the study did not evaluate image quality. No X-ray images were retaken because of poor quality.

251 Emergency physicians are not familiar with adjusting the position of the flat panel
252 detector. Hence, at times, the image could not be captured. It would probably more
253 appropriate to use a larger panel to resolve this issue.

254

255 **Conclusions**

256 We have introduced a visualization technique for invasive procedures using a compact
257 and lightweight X-ray unit in the ER. It can be implied that this technique can reduce
258 the risk of complications during invasive procedures.

259 **Abbreviations**

260 CI, confidence interval

261 CT, computed tomography

262 CVC, central venous catheter

263 ER, emergency room

264 REBOA, resuscitative endovascular balloon occlusion of the aorta

265 RR, risk ratio

266 SB, Sengstaken–Blakemore

267

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377

Figure Legends

Figure 1

Illustration of the compact and lightweight X-ray unit and comparison with other widely used portable X-ray devices (Sirius 130 HP, Hitachi, Tokyo, Japan). The compact and lightweight X-ray unit comprises three parts: an X-ray tube (CALNEO Xair, Fujifilm Corporation, Tokyo, Japan), a laptop computer and a flat panel detector (CALNEO Smart, Fujifilm Corporation, Tokyo, Japan).

Figure 2

Setting for the compact and lightweight X-ray unit and ultrasonography device. A physician sets the X-ray unit, an ultrasound device, and a flat panel detector under the patient as a part of preoperative preparation.

Figure 3

Central venous catheter placement. (A) Chest X-ray image showing the tip of the guidewire (arrowhead) in the superior vena cava. (B) Chest X-ray image showing the tip of catheter (arrowhead) in the superior vena cava.

396 Figure 4

397 Chest tube insertion. Chest X-ray image showing bilateral pleural effusion. The tip of
398 the chest tube (arrowhead) is located at the left apical pulmonary lesion.

399

400 Figure 5

401 Percutaneous tracheostomy. (A) Image showing a distance of 3 cm between the tip of
402 endotracheal tube and the Pean clamp forceps. (B) Image showing the location of the tip
403 of the endotracheal tube compared with the Pean clamp forceps following the
404 withdrawal of the endotracheal tube by 3.5 cm. (C) Chest X-ray image showing the
405 guidewire in the right main bronchus.

406

407 Figure 6

408 Resuscitative endovascular balloon occlusion of the aorta. Chest X-ray image showing
409 the tip of the resuscitative endovascular balloon occlusion of the aorta catheter
410 (arrowhead) in zone I.

411

412

413

414 Figure 7

415 Sengstaken–Blakemore (SB) tube insertion. Chest X-ray image showing the balloon of
416 the SB tube (arrowhead) in the stomach.

417

418 **Acknowledgments**

419 This study was conducted in collaboration with Fujifilm Corporation (Tokyo, Japan),
420 which provided the medical equipment and technical support.

421

Fig. 1

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Fig. 7