

Review

Ventilated Post-mortem computed tomography

Guy N Rutt¹, Bruno Morgan², Tanja Germerott³, Michael Thali⁴, Owen Athurs⁵

1. G.N. Rutt (✉), University of Leicester, East Midlands Forensic Pathology Unit, Robert Kilpatrick Building, Leicester, LE2 7LX, United Kingdom. Tel; 0044 116 252 3221, email gnr3@le.ac.uk

2. B. Morgan, University of Leicester Imaging Department, Radiology Department, Leicester Royal Infirmary, Leicester, LE1 5WW, United Kingdom

3. T. Germerott, Medizinische Hochschule Hannover, Carl-Neuberg-Str. 1, 30625 Hannover, Germany

4. M. Thali, University of Zurich, Institute of Forensic Medicine, Winterthurerstrasse 190/52, 8057 Zurich, Switzerland

4. O.J. Arthurs, Department of Radiology, Great Ormond Street Hospital for Children NHS Foundation Trust, London WC1N 3JH, United Kingdom, also UCL Institute of Child Health, London, WC1N 1EH, United Kingdom

Keywords

Forensic, post-mortem computed tomography, ventilation, adults, children, airways

Conflict of Interest

None

Abstract

In an attempt to improve the diagnostic quality of post-mortem computed tomography (PMCT) lung image interpretation, a series of authors have developed an approach that mimics clinical thoracic CT imaging in the dead. Known as *ventilated post-mortem computed tomography* or *VPMCT* this technique has now been developed and applied to adult and paediatric PMCT imaging. This review, authored by the principal pioneers of this system, outlines the developmental stages of VPMCT, bringing the reader up to date with current knowledge and practice.

Introduction

After death, time dependent post-mortem hypostasis (livor mortis) is observed to the external surface and internal organs of the body. For the lungs this change leads to increased attenuation, particularly in the dependent areas of the lungs. This can result in obscuration of lung pathology and can be mistaken for aspiration, pulmonary oedema or pneumonia. Although this is recognised as one of several time dependent changes observed with post-mortem cross sectional imaging, only a limited number of authors have given consideration to this problem to date [1,2,3].

Clinical computed tomography (CT) scans of the thorax are undertaken with breath-hold after inspiration. This lowers average lung density and reduces 'dependent' changes caused by atelectasis and fluid settling. This process makes interstitial or nodular changes more apparent. If functional information is required, for example in the assessment of emphysema or air trapping, then inspiration and expiration scans may be performed [4,5].

In an attempt to improve the diagnostic quality of PMCT lung imaging a series of researchers have developed approaches to mimic clinical thoracic CT imaging in the dead. Known as *ventilated post-mortem computed tomography* or *VPMCT* this technique can now be applied to both adult and paediatric PMCT imaging [6-10,13]. This review, authored by the principal pioneers of this technique, outlines the developmental stages of VPMCT and summarises current knowledge and practice.

Pioneering VPMCT technique in adults

In 2010 Germerott *et al.*, published the first paper concerning VPMCT [6]. To achieve VPMCT they used a portable home care ventilator (Draeger, Hemel Hempsted, UK) set to "pressure support" ventilation mode using a constant pressure with maximum of 40 mmHg. Ventilation pressure was delivered to the lungs using a variety of airways. Where an endotracheal tube was already in place (e.g. due to failed cardiopulmonary resuscitation) they used this, otherwise ventilation was delivered by means of a laryngeal mask (if possible) or a Continuous Positive Airway Pressure (CPAP) mask. Prior to ventilation a baseline scan was undertaken of the thorax with the arms elevated using a 6-slice Scanner (Emotion 6, Siemens Germany). The lungs were then ventilated with simultaneous thoracic imaging. The pre- and post-ventilation lungs were compared and lung volumes measured using a segmentation technique (AMIRA, Visage Imaging GmbH Germany). Initially 5 cadavers were examined: 2 suicides (one intoxication, one exsanguination), and 3 natural deaths due to heart failure. None had chest trauma. The post-mortem interval was 4.5 - 58 hours (mean 32.3 hours). They demonstrated lung inflation after death (Figure 1) in all five cases showing a decrease in lung attenuation in areas affected by hypostasis. They considered they could evaluate the lung parenchyma better for true ante mortem pathology, such as consolidation or lung nodules (Figure 2). No observable ventilator induced lung damage was demonstrated and all three airway types proved adequate for use.

Following on from this initial work Germerott *et al.*, published a second study in 2012 [7]. This study included 10 cases: 6 natural deaths from heart failure, one exsanguination, one intoxication, one carbon monoxide intoxication and one death from fat embolism and sepsis. They used the same protocol but different ventilator pressures of 10, 20, 30 and 40 mbar. The postmortem intervals this time ranged from 4.5-56 hours (mean 23.7 hours). In this study they observed an increase of lung volume at 20mbar with a maximum effect at 40 mbar (Figure 3). The mean lung volume increase was reported as 1.3 ± 1.1 litres and the heart diameter decreased (as would be seen in clinical inspiratory and expiratory chest X-Rays). Again there was no difference observed between the airways used to

deliver ventilation. Post-mortem lividity was decreased to reveal lung pathology but in the case of ante mortem aspiration ventilation did not affect the pathological changes present (Figure 4). They also observed that when a CPAP mask was used there was an increase in gas distention of the stomach, due to leak of air down the oesophagus, which is often seen when a 'definitive' airway is not used.

In 2013 Germerott *et al.*, published the last in their series of ventilation studies, considering chest trauma [8]. In six cases (five gunshot and one stab wound to the chest) the post-mortem interval for the cases was 11.5-60 hours. All cases were ventilated with a CPAP-mask. Attempts were made to evacuate a pneumo- or haemothorax by suction pump (Figure 5). Pneumothoraces were reduced in 3 cases, were unchanged in 1 case and increased in 1 case. Haemothorax was reduced in 3/6 cases (blood clot proved difficult). In one shotgun injury the pneumothorax increased in size during subsequent ventilation. This approach improved ventilation in 4/6 cases and in one case the projectile tract was identified by using this process.

These three papers set the scene for subsequent technical development and improvement, and the translation of VPMCT from adults into children.

Evolving VPMCT technique in adults

In 2014, the PMCT research group of Leicester, UK published the first of two studies, which expanded on the previous work of Germerott *et al.* They used a Dräger Savina 300 ventilator (Dräger, UK) in so-called "positive end-expiratory pressure" (PEEP) mode with a constant 40cm H₂O (equivalent to 40mbar) of pressure. The group used the i-gel® supraglottic airway to facilitate the delivery of ventilation (Figures 6 and 7). By using the PEEP mode on the ventilator they were able to replicate clinical inspiratory and expiratory lung imaging [9]. Seventeen of the 18 attempted i-gel® insertions were successful, the one failure due to a failure to break down rigor in the jaw enough to insert the supraglottic device. The resulting 17 cases consisted of 10 males and 7 females with an age range of 25-89 years and a post-mortem interval of between 12 to 99 hours. Using this system ventilation increased lung volume between 0 and 146 % (mean increase 40 %). Five of the 17 cases showed the airway insertion to be too high on PMCT, which reduced lung expansion. No injuries were caused during the insertion of the airways and no surgical emphysema or pneumothoraces occurred whilst ventilating, although existing pneumothoraces could increase slightly in size. The method had no adverse effect on subsequent contrast angiography. In some cases air was introduced into the stomach as observed by Germerott *et al.*, but this did not have an adverse effect on lung reporting (Figure 8).

In order to address stomach inflation and reduced lung expansion due to air leak from an incomplete tracheal seal Ruddy *et al.*, [10] described the insertion and use of cuffed airways (also known as definitive airways) to facilitate VPMCT. This paper described the attempted insertion of an endotracheal tube through the traditional oral route using a laryngoscope in the absence of rigor. It also described the use of a number of other airway types and adjuncts where the tube could be inserted down the lumen of the airway or adjunct without direct visualization of the cords. It also described the insertion of a modified endotracheal tube through a crico-thyroidectomy (Figure 9). Of 59 attempts, 56 were successful and stomach distention from leaking air was eliminated. The paper suggests a decision making algorithm to assist with the insertion of a cuffed airway into the trachea.

These studies have provided the practitioner with a method of mimicking clinical inspiratory lung imaging, using a cuffed tube in the presence of rigor without stomach distension. Further work is ongoing comparing PMCT pulmonary findings with autopsy and histological examination of the lung.

The group at Leicester have made one other interesting observation through their UK Resuscitation Council funded research. Following the publication by an Australian group that defrosted frozen cadavers used for resuscitation training [11], produced end tidal CO₂ traces similar to living individuals the group at Leicester repeated this work in non-frozen recently deceased refrigerated cadavers. In a short communication to the Emergency Medical Journal [12] they illustrate how, using the Dräger Savina 300 ventilator with an endotracheal tube, they also observed end tidal CO₂ traces similar to those seen in living patient. The source of this CO₂ and its potential application to autopsy practice, for example in relation to the estimation of the post-mortem interval, is being further considered.

Applying VPMCT in children

An important technical development in VPMCT was delivered in 2015, with the publication of a study by *Arthurs et al.*, who translated the use of supraglottic airways in adult cadavers to PMCT imaging in children [13]. Post-mortem changes in the lungs of children make diagnostic interpretation extremely difficult [14]. In some circumstances, the lungs are almost completely opaque with very little aeration, making image interpretation almost impossible. Thus, almost any aeration of the lungs at PM imaging would be expected to be beneficial, but there are a number of size-related issues to overcome.

The first problem is that endotracheal tubes in the very young are often non-cuffed and allow significant air leakage if used for subsequent PM imaging. This reduces effective ventilation and causes significant gastric distension. The second problem is to decide whether a ventilator or other system is required to inflate the lungs.

To investigate these issues within the paediatric age group *Arthurs et al.*, undertook VPMCT in twelve cases, 6 males and 6 females, median age 3–304 days. To deliver the air to the lungs they started by using a paediatric self-inflating resuscitation bag (Lifesaver® Disposable Manual Resuscitator; Teleflex, Buckinghamshire, UK). Several breaths were delivered with this device, judging lung inflation by seeing the chest rise. Some of the cases were then further ventilated using an Integral Silicone Laryngeal Mask airway (Fannin UK Ltd, Wellingborough, Northamptonshire, UK) with a ventilator in PEEP mode. They demonstrated that the use of the supraglottic airway in this age group gave better lung inflation than un-cuffed endotracheal tubes or face masks, improved lung image interpretation (Figure 10), and did not cause the same gastric dilation as seen in adults. Due to the size of the patients and desire to maintain a minimally invasive approach, surgical airways, such as tracheostomy, were not attempted.

The self-inflating resuscitation bag was found to inflate the lungs in most cases, although better results were achieved with the ventilator in PEEP mode. Two cases investigated did develop a small post-mortem pneumothorax, highlighting the importance of pre-ventilation images. They also found that inflation of areas of normal lungs helped to identify areas of abnormal lung which did not inflate, and further work in this area is ongoing.

This work shows that VPMCT is feasible, relatively simple to perform, and gives good results in children. VPMCT was found to highlight areas of abnormality in paediatric lungs and in future could be useful to exclude paediatric lung disease and guide lung sampling if required.

Summary

Over the last few years there has been a widening realisation that PMCT is here to stay and that the traditional invasive autopsy alone no longer is the gold standard for death investigation [15]. Diagnostic hurdles created by post-mortem changes are being overcome, for example through the use of PMCT angiography for the diagnosis of vascular disease. Now, starting with the work of our three teams, we hope to overcome the problems that post-mortem changes cause to lung diagnosis in adults and children. By translating clinical processes and equipment into the post-mortem setting, we hope we have taken PMCT a step further to not only being an adjunct to but, in the right circumstances, a replacement for the traditional invasive autopsy.

Together, this evidence suggests that VPMCT can be used across a range of potential patient groups and situations, with minimal adaptations in technique.

Acknowledgements

OJA is funded by an NIHR Clinician Scientist Fellowship award. This article presents independent opinion funded by the National Institute for Health Research (NIHR) and supported by the Great Ormond Street Hospital Biomedical Research Centre. The views expressed are those of the author and not necessarily those of the NHS, the NIHR or the Department of Health. We wish also to thank Ms Alison Brough of the East Midlands Forensic Pathology Unit for the production of some of the CT images.

Figures

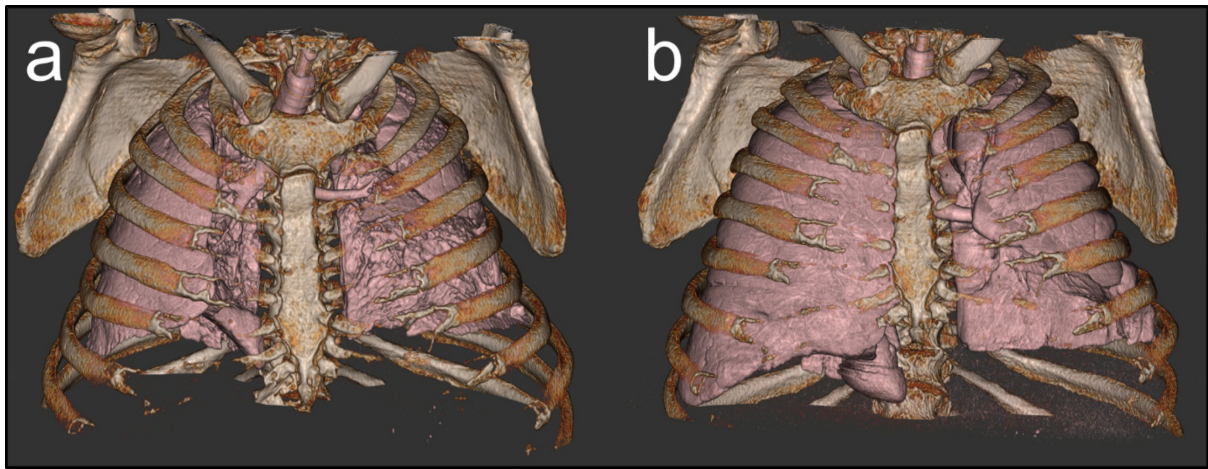


Fig 1. Pre (a) and post (b) ventilation of a cadaver using a Draeger portable home ventilator. Source: Germerott *et al.*, *Leg Medicine* 2010; 12:276-279

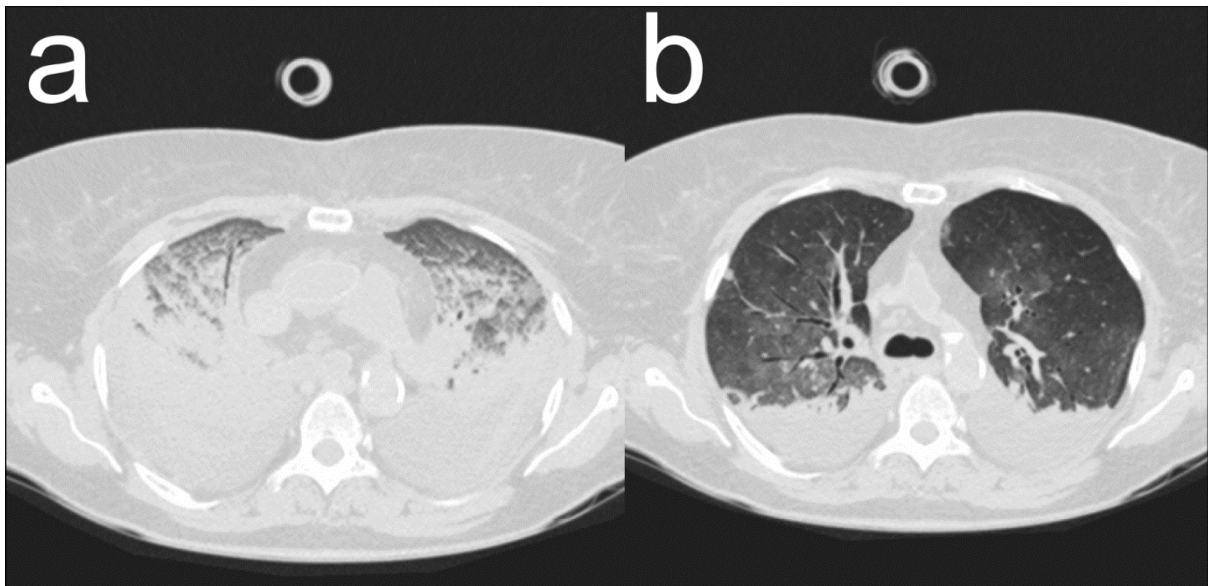


Fig 2. Pre (a) and post (b) ventilation of a cadaver illustrating the clearing of the lungs. When the left lung is better aerated, a pleural nodule is identified, which was previously obscured by post mortem hypostasis. Source: Germerott *et al.*, Leg Medicine 2010; 12:276-279

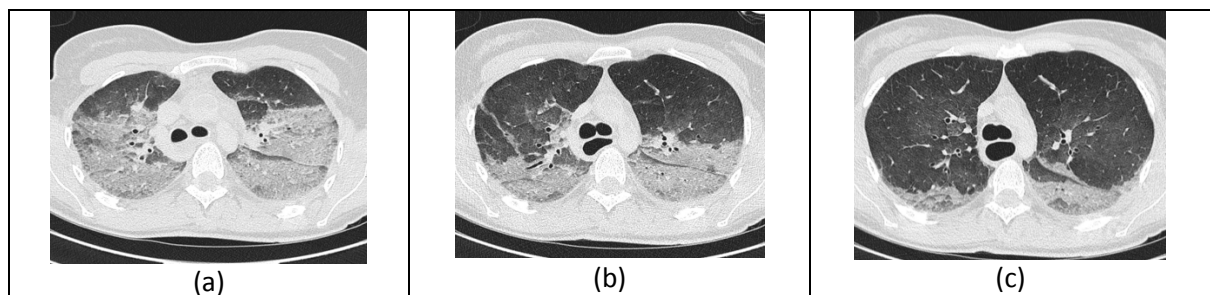


Fig 3. Pre-vent (a) followed by VPMCT at (b) 20mbar and (c) 40mbar illustrating the clearing of the lungs of post-mortem attenuation caused by hypostasis. Source. Germerott *et al.* Leg Medicine 2012; 223-228

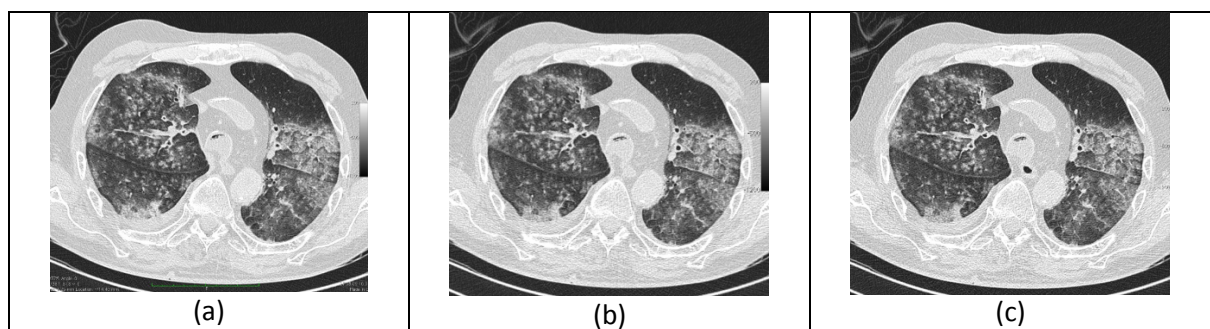


Fig 4. Pre-vent (a) followed by VPMCT at (b) 20mbar and (c) 40mbar illustrating that VPMCTA does not affect the presence of ante mortem aspiration. Source. Germerott *et al.*, Leg Medicine 2012; 223-228

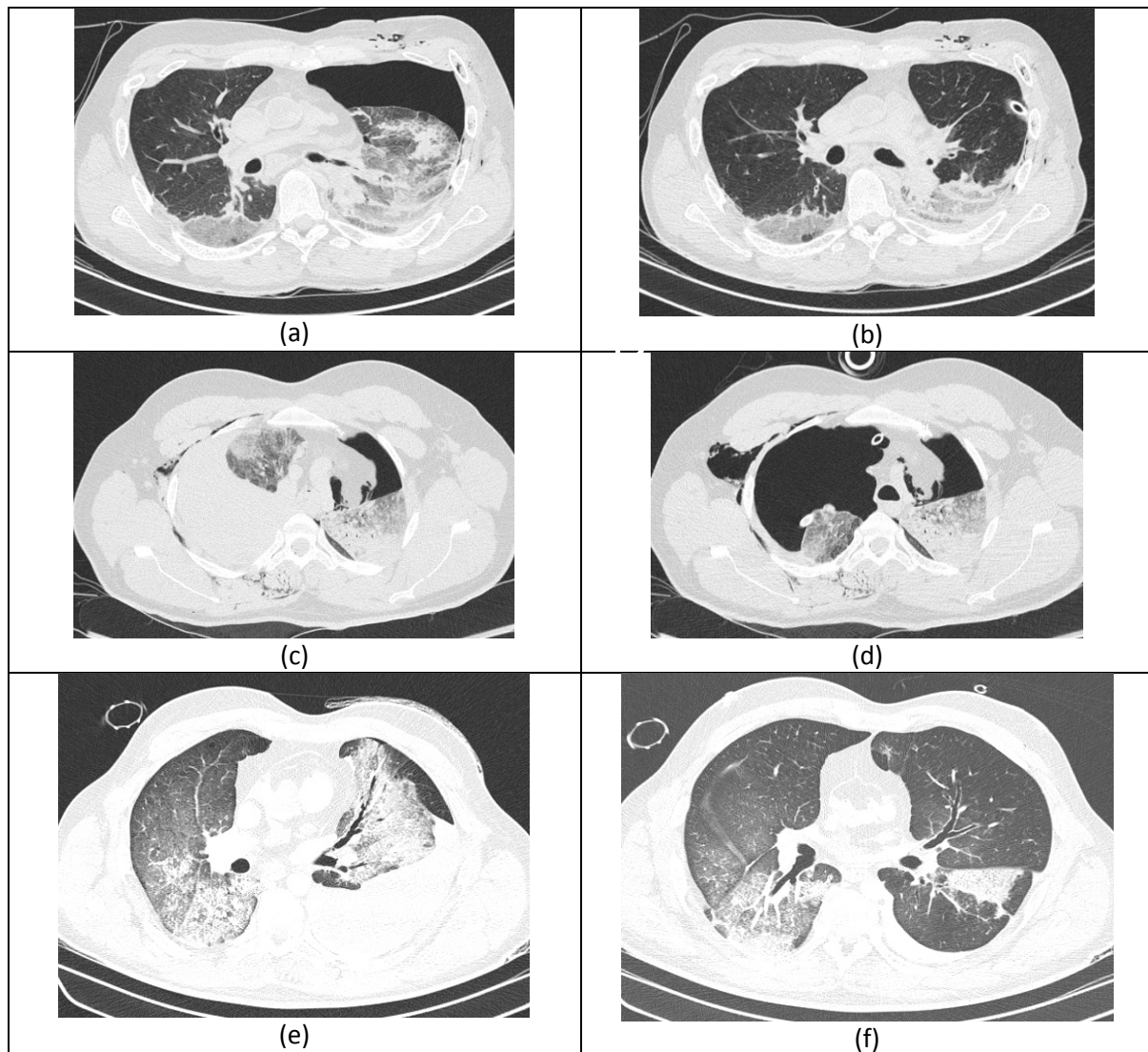


Fig 5. Pre-ventilation images without evacuation of a (a) pneumothorax and (c) haemothorax showing evacuation of the pathology post ventilation at 40mbar ((b) pneumothorax and (d) haemothorax). The lung in (b) is seen to reflate. Re-expansion? of the lung following evacuation is illustrated in (e (pre-ventilation)) and (d (40mbar)). Source: Germerott *et al.*, Leg Med (Tokyo). 2013;15:298-302

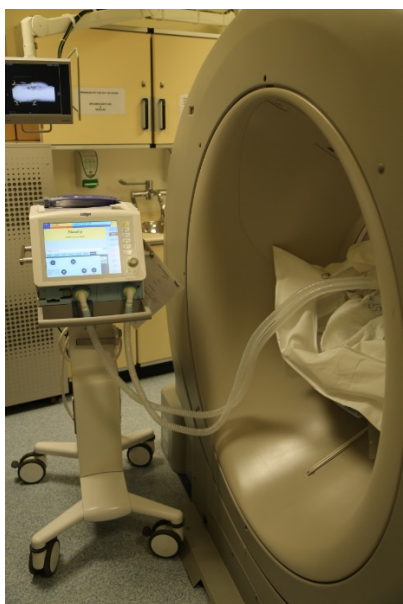
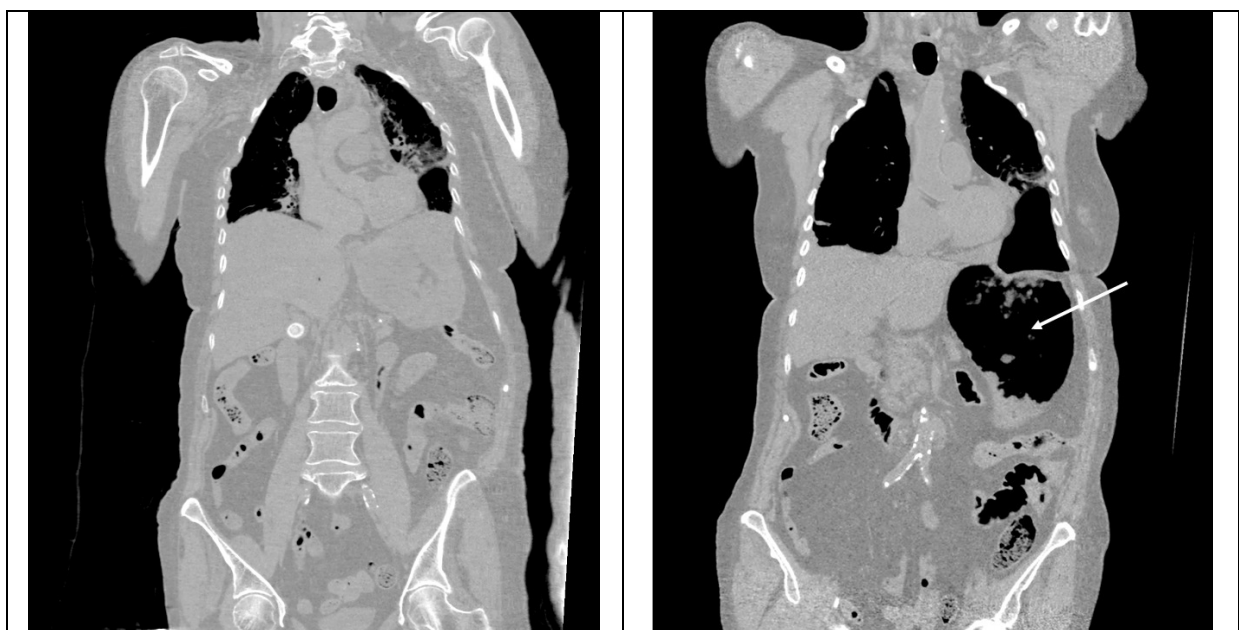


Fig 6. The Dräger Savina 300 ventilator in operation whilst undertaking VPMCT



Fig 7. An i-gel® supraglottic airway correctly placed into a cadaver.



(a)	(b)
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Fig 8. Pre (a) and post (b) VPMCT showing the expansion of the stomach by air (arrow) when a non-definitive airway is used to deliver ventilation.

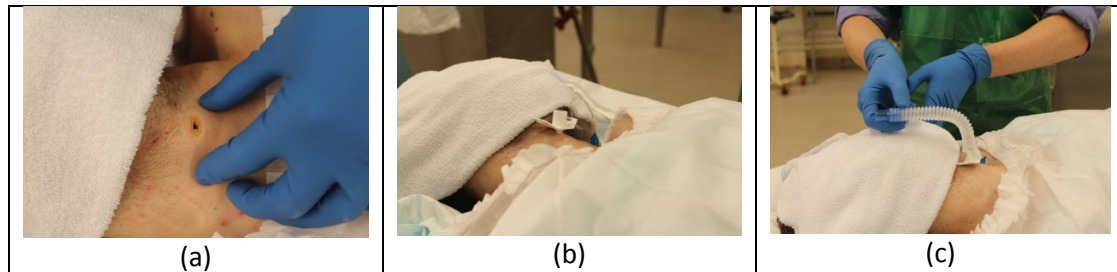


Fig 9 (a) A small incision is made in the crico-thyroid membrane. (b) An airway, in this case a tracheostomy tube, is inserted through the incision into the trachea. (c) The airway is connected to the ventilator by a suitable conduit.

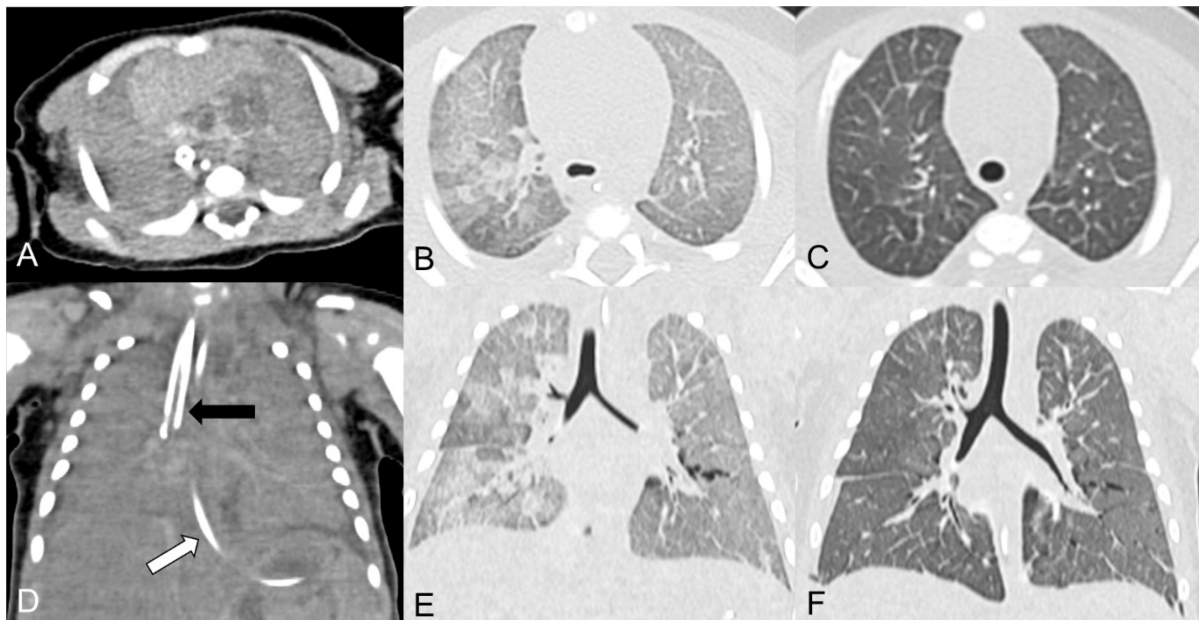


Fig 10. Example of two-stage VPMCT in a 28-day-old infant. Axial (a–c) and coronal (d–f) PMCT are shown: before ventilation (a, d), after bag/mask ventilation (b, e) and after PEEP ventilation (c, f). The ET tube tip was in the right main bronchus prior to ventilation (black arrow) and Replaced by a laryngeal airway for VPMCT (b – f). A nasogastric tube is also demonstrated (white arrow). Reproduced with permission from: Arthurs OJ et al., Int J Legal Med. 2015

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