

Verification of endotracheal intubation in obese patients – temporal comparison of ultrasound vs. auscultation and capnography

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Background: Ultrasound (US) may have an emerging role as an adjunct in verification of endotracheal intubation. Obtaining optimal US images in obese patients is generally regarded more difficult than for other patients. This study compared the time consumption of bilateral lung US with auscultation and capnography for verifying endotracheal intubation in obese patients.

Methods: A prospective, paired and investigator-blinded study performed in the operating theatre. Twenty-four adult patients requiring endotracheal intubation for bariatric surgery were included. During post-intubation bag ventilation, bilateral lung US was performed for detection of lungsliding indicating lung ventilation simultaneous with capnography and auscultation of epigastrium and chest. Primary outcome measure was the time difference to confirmed endotracheal intubation between US and auscultation alone. The secondary outcome measure was time difference between US and auscultation combined with capnography.

Results: Both methods verified endotracheal tube placement in all patients. No significant difference was found between US compared with auscultation alone. Median time for verification by auscultation alone was 47.5 s [interquartile (IQR) 40–51 s], with a mean difference of –0.3 s in favor of US (95% confidence interval –3.5–2.9 s) $P = 0.87$. Comparing US with the combination of auscultation and capnography, there was a significant difference between the two methods. Median time for verification by US was 43 s (IQR 40–51 s) vs. 55 s (IQR 46–65 s), $P < 0.0001$.

Conclusion: In obese patients, verification of endotracheal tube placement with US is as fast as auscultation alone and faster than the standard method of auscultation and capnography.

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ULTRASOUND (US) may have an emerging role as an adjunct in verification of endotracheal (ET) intubation. A number of studies have investigated the utility of US in airway management in different clinical settings with promising results. In these studies, various methods are used for confirming the ET tube position, either transcricothyroid or transtracheal US for direct visualisation of the passage of the ET tube,^{1–3} bilateral lung US for lungsliding as an indication of bilateral lung ventilation^{4–7} or a combination of both methods.⁸

Obesity is traditionally regarded as a complicating factor in the diagnostic use of US. Accordingly, verification of ET intubation by US detection of lungsliding could be difficult due to phase aberration

and increased distance to target organ (pleura) due to subcutaneous fat, resulting in beam attenuation.^{9,10}

In a previous study examining the utility of US in verifying ET intubation by comparing time consumption between bilateral lung US vs. the traditional combination of chest auscultation and capnography in a non-selected patient population, we found the US method to be significantly faster than the combination of auscultation and capnography, whereas there was no significant difference in time between the US method and auscultation alone.⁵ Surprisingly, in a small subgroup of obese patients in this study, we found US to be markedly faster than conventional auscultation and capnography. The present study aims to explore this finding further by comparing the time consumption for ET

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tube verification between bilateral transthoracic US for lungsliding and auscultation alone as well as the combined methods of auscultation and capnography in obese patients.

Extrapolating from the results in our previous study, our hypothesis was that US verification of ET intubation is as fast as auscultation alone and faster than the combined methods of chest auscultation and capnography in obese patients. The primary outcome measure was the difference in time to confirmed ET intubation between US and auscultation alone. The secondary outcome measure was the difference in time to confirmed ET intubation between US and auscultation combined with capnography.

Methods

This study was designed as a prospective, paired and investigator-blinded study and carried out during daytime in October 2010 in the operating suite of an urban teaching hospital in Copenhagen, Denmark. The Committees on Biomedical Research Ethics for the capital region of Denmark approved the study (journal number H3-2009-105), and subsequently, the study was registered in <http://www.clinicaltrials.gov> (identifying number NCT01227486). Written informed consent was obtained from all patients. Patients eligible for study enrolment were 18–60 years old with body mass index (BMI) ≥ 35 kg/m² who were admitted for elective bariatric surgery and planned for conventional ET intubation. Exclusion criteria were history of previous difficult intubation or suspected difficult intubation.

Anaesthesia was induced with remifentanil infusion 0.5 µg/kg/min total body weight (TBW) and thiopental 3–4 mg/kg (TBW). Following a trial of mask ventilation, neuromuscular blockade was performed with rocuronium 0.6 mg/kg (TBW). ET intubation was attempted first by direct laryngoscopy, and in case of failure to visualise the vocal cords, a GlideScope® (Verathon Inc. Bothell, WA, USA) video laryngoscope was used.

Three investigators were involved in the practical conduct of the study: one certified nurse anaesthetist performing the intubation and subsequent bag ventilation of the patient, one anaesthetist performing the US investigation and one anaesthetist administering drugs and performing the auscultation. The anaesthetist responsible for all US investigations, a 2nd-year specialist-in-training, had some experience with US for regional anaesthesia and vascular access and received a 1-h didactic lesson on lung US before conducting the study.

The investigators performing auscultation and US were blinded from each other by a drape hung across the patient's chest. Furthermore, the ultrasonographer was blinded from the verbal communication between the other investigators by wearing headphones playing white noise.

US investigation was performed with a Sonosite S-ICU equipped with a HFL 38X linear 13–6 MHz transducer (Sonosite, Bothell, WA, USA). To determine optimal transducer position for visualisation of the pleura, a 2-dimensional real-time US scan was performed during pre-oxygenation with the transducer placed in the sagittal plane in the 2nd or 3rd intercostal space in the midclavicular line bilaterally. During post-intubation bag ventilation, the transducer was placed first at the right side of the chest and subsequently the left side for detection of lungsliding as indication of bilateral lung ventilation.

Standard protocol was followed for auscultation with the investigator first auscultating over the epigastrium, then right and left lung in that order. Six uniform curves on the capnograph during bag-valve ventilation were regarded as final proof of ET intubation.^{11–13}

Age, height, BMI, American Society of Anesthesiologists (ASA) physical status score and Cormack–Lehane grading of direct laryngoscopy were recorded. All intubations were recorded on camera and stored as AVI files for later analysis. Furthermore, 60-s US recordings of the intubation procedures were recorded. Time measurement started when the laryngoscope blade was introduced into the oral cavity. US detection of lungsliding on both sides of the chest was indicated by inaudible signals to the camera, as were auscultation over the epigastrium and both sides of the chest. Finally, the investigator performing the ventilations indicated six bag ventilations with unchanged capnography. Afterwards, duration of the different end points were measured by reviewing the recorded AVI files.

For statistical analysis, the SAS system ver. 8.2 (SAS Institute Inc., Cary, NC, USA) was used.

Age was reported as median with range. BMI, ASA physical status score and absolute time were reported as median with 25% to 75% range [interquartile range (IQR)], as was 'number of ventilations' and 'time to six ventilations'. Difference in time was calculated as 'new method (US) minus old method' and reported as mean with 95% confidence interval (CI).

Methods were compared using a paired *t*-test, and *P*-values below 0.05 were considered statistically significant.

For sample size calculations, data from a previous study were used.⁵ In this study, the standard deviation (SD) of the difference between US and auscultation was 8 s. We aimed at recognising a difference of 1 SD, as a difference of 8 s in practice would mean that the two methods were equal. Using a significance level of 0.05, a power of 90% could be reached by enrolling 21 patients in the study, but it was decided to enroll 24 to allow for dropouts.

Results

In total, 24 patients were enrolled in the study. Two patients were excluded, one due to an unexpected difficult airway situation, and one because the camera was not turned on, making it impossible to record time consumption. Thus, 22 patients, 12 men and 10 women, were available for comparison of methods. Median age was 42 years (range 32–64 years). Median BMI was 41.5 kg/m² (IQR 39–45), and median ASA physical status score was 2 (IQR 2–2). In all 22 patients, direct laryngoscopy was attempted, and 19 were intubated this way. The remaining three patients were intubated using Glidescope® after one failed intubation attempt. Fifteen patients were classified as Cormack grade 1, four were classified as Cormack grade 2, one as grade 3 and two as grade 4. None of the ET tubes needed repositioning during anaesthesia.

Comparing US with auscultation alone, we found no significant difference in time to final verification between the two methods. Median time for verification by auscultation alone was 47.5 s (IQR 40–51 s), with a mean difference of –0.3 s in favour of US (95%CI –3.5–2.9 s) $P = 0.87$.

Comparing US with the combination of auscultation and capnography, there was a significant difference between the two methods. Median time for verification by US was 43 s (IQR 40–51 s) vs. 55 s (IQR 46–65 s), to verification by auscultation and six uniform curves on the capnograph, $P < 0.0001$. Mean difference was –8.0 s in favour of US (95% CI –11.2– –4.8 s).

When comparing the number of ventilations performed to verify ET tube placement, we also found no significant difference. With US, a median of four (IQR 3–4) ventilations was administered, and with auscultation, a median of four (IQR 3–5) ventilations were given, $P = 0.64$.

Time to six ventilations after ET intubation was 18.5 s (IQR 13–22), corresponding to a ventilatory rate of approximately 20 breaths per min.

Discussion

The principal finding of this study is that for a novice lung ultrasonographer, verification of ET intubation by bilateral lung US in obese patients is as fast as auscultation. Furthermore, we found that verification of ET intubation by bilateral lung US was significantly faster than the combination of auscultation and end-tidal carbon dioxide (ETCO₂) measurement for six breaths. These findings are in line with our previous study in a non-selected patient group.⁵ To our knowledge, this is the first study examining the utility of US in airway management in an obese population, and the data indicate that obesity should not be seen as a problem for using US in verification of ET intubation by detecting bilateral lungsliding.

Obesity has been associated with difficult airway management.¹⁴ In a study of 22,660 attempted mask ventilations, authors found BMI ≥ 30 kg/m² to be an independent predictor of difficult mask ventilation.¹⁵ Difficult mask ventilation may increase the risk of gastric insufflation and aspiration following induction of anaesthesia. Whether obesity is associated with difficult intubation is the subject of debate. Some studies indicate BMI ≥ 35 kg/m² as a weak predictor of difficult intubation.^{16–19} One study suggests that difficult intubation in obese patients could be caused by suboptimal positioning²⁰ and, further to this, another study argues that BMI > 35 kg/m² does not per se predict difficult laryngoscopy following optimal positioning.²¹

With obesity follows several changes in pulmonary physiology. Among these are decreases in chest wall compliance, vital capacity, expiratory reserve volume and functional residual capacity, as well as increases in respiratory resistance and airway resistance.²² In the apnoeic patient, these alterations combined with increased intra-abdominal pressure and a hyperdynamic circulation²² may lead to a rapid onset of hypoxaemia despite sufficient preoxygenation if mask ventilation is difficult, and ET intubation is not obtained in a timely manner.^{23,24}

With the present epidemic of obesity, a growing number of obese patients present for all kinds of surgery or with acute medical illness requiring airway management, and in the case of difficult mask ventilation, the anaesthetist is often faced with the difficult task of securing the airway by ET intubation in the short interval following preoxygenation before hypoxaemia sets in.

Besides direct visualisation of ET tube passage through the vocal cords, the anaesthetist relies on

different secondary measures for verification of ET tube placement. These include mist condensation in the ET tube, chest auscultation and ETCO_2 detection by capnography or colourimetric devices.¹³ However, each of these methods for verification has limitations. Observation of mist condensation in the ET tube is unreliable in distinguishing between oesophageal and ET intubation. ETCO_2 detection is limited by low specificity and sensitivity in situations of low cardiac output, cardiac arrest and hypothermia. In the case of prolonged mask ventilation with gastric insufflation prior to intubation, ETCO_2 detection may give false-positive results for up to five breaths.¹³ Finally, post-intubation auscultation of the stomach for gastric insufflation and the chest for breath sounds may be difficult to interpret, especially in the obese patient or in a noisy acute or pre-hospital setting. Thus, none of these methods are fail safe, and therefore, a combination of methods are often used, auscultation and capnography being a usual clinical standard.

US may have an emerging role as an adjunct in verifying ET intubation. A number of studies have reported good reliability for ET tube positioning by US detection of lungsliding,⁴⁻⁸ and, in the absence of pneumothorax, unilateral lungsliding indicates unilateral lung ventilation⁶ and may thus point to main stem intubation.

In obese patients, US is generally associated with poor imaging quality because of difficult positioning of the patient, increased travelling distance of the US beams, phase aberration and fat attenuation.^{9,10,25} In a small controlled prospective study, the authors found that the quality of US imaging of the abdominal muscle layers to be of lower quality in obese volunteers compared with non-obese volunteers.²⁶ We found no studies examining the use of US in visualising pleura or in the detection of lungsliding in obese patients. As mentioned above, pre-procedural positioning of the obese patient is an important factor for optimising laryngoscopy and subsequent intubation. We speculate that placing the obese patient in the ramped position might also improve US visualisation of the pleura in the upper intercostal spaces by gravity displacing subcutaneous fat tissue downwards. Image quality may be further enhanced by compressing the subcutaneous tissues with the probe and by adjusting focus depth to the pleural line.

With the use of US becoming more widespread in a multitude of clinical settings, and the technology becoming both cheaper and increasingly portable, lung US may have a future role as an adjunct in

airway management.²⁷ Visualisation of bilateral lungsliding in an intubated patient indicates ET intubation, and this may have relevance especially in selected settings such as the pre-hospital environment including inter-hospital transfer and aero medical transport of critically ill patients. As shown in the present and our previous study, the necessary skill level is easily obtained.⁵

The use of US in verification of ET intubation has been described as time consuming,⁸ but time consumption could be minimised by using machines with short start-up times and by including the US technology in a protocolised fashion in the pre-intubation preparations. The pre-intubation lung US examination used in the present study not only locates the optimal probe position for visualising the pleura in the spontaneously breathing patient but also reliably detects a possible pneumothorax.²⁸⁻³⁰ Extending the pre-scan by performing additional views of the pleura in the mid-axillary line at the level of the diaphragm will supplement the clinical information with information of possible pleural effusions (e.g. hemothorax)³¹ or lung consolidation/atelectasis.³² This extended pre-scan could even be part of other focused US examinations in the unstable acutely ill patient, e.g. the Extended Focused Assessment with Sonography in Trauma. The present study was carried out using a high-frequency linear probe providing optimal surface resolution and visualisation of the pleura on the anterior chest, but an extended examination visualising deeper structures requires a low-frequency micro-convex or curved-array probe. The pre-scan may be carried out during pre-oxygenation or might be omitted if conditions so dictate, with ET tube position subsequently confirmed by a post-intubation scan. In this study, three investigators were involved in intubating the patient, but in a regular clinical setting, only two persons are required – one person performing the pre-oxygenation, intubation and subsequent bag ventilation and one person performing the pre-scan, administering drugs and assisting the clinician performing the intubation during laryngoscopy and finally, performing the post-intubation scan during bag ventilation.

Some limitations to evaluating the ultrasonographic lungsliding sign need mentioning. Pathology in the subcutaneous tissue (e.g. emphysema),³⁰ pleura (e.g. inflammation or pleural adherences) or lung tissue (e.g. bullae) may influence the ultrasonographic findings of normal lungsliding, and thus, challenge diagnostics. Lungsliding theoretically enables us to distinguish between tracheal and

endo-bronchial intubation, but results are conflicting.^{6,7,33} Mechanically transmitted movement of an inflated lung may produce lungsliding on the opposite side. Likewise, an ET tube with an inflated cuff just at the entry of the main stem bronchus could, in theory, also allow for leakage and subsequently, minimal pleural movements interpreted as lungsliding on the opposite side. Finally, ultrasonography is very dependent on the individual sonographer interpreting the image on the screen to reach a diagnosis. Absence of lungsliding immediately post-intubation should always be viewed in the clinical context and – if a pre-intubation scan was obtained – correlated with the findings of the pre-intubation scan.

There are a number of limitations to the present study. First, this was a single-centre study with a small sample size performed in a controlled setting. With this small sample size in mind, all interventions were performed by the same investigator throughout the study in order to minimise inter-investigator variation. With the ultrasonographer gaining experience as the study went on, this may overestimate the accuracy of the results.

Investigator bias was sought minimised by visual as well as auditory blinding between the ultrasonographer and the auscultating investigator. None of these investigators were blinded from the nurse anaesthetist performing the intubations as this, in our opinion, would be highly unlikely under normal circumstances. The intubating nurse anaesthetist was responsible for the bag ventilation, and investigator bias is possible in this context by willfully delaying ventilations. However, with a median time for administration of the six ventilations corresponding to a supranormal respiratory rate of 20 breaths per min, this aspect of investigator bias should be negligible.

As in our previous study, we did not measure time consumption for the pre-intubation US scan and as such cannot report duration of the procedure in this patient population.

Finally, although we detected no main stem intubations by either US or the practical standard of combined auscultation and ETCO₂ measurement during the conduct of the study, we did not exclude these by chest X-ray or fibre-optic inspection. These were omitted as auscultation and capnography were considered the practical standard to verify ET position of the tube. As such, we cannot report any difference in time consumption between the methods for detecting oesophageal or main stem intubation.

Future studies should investigate the time consumption between US and the combined methods in detecting oesophageal intubation as well as describe the utility in the emergency room, in the pre-hospital setting and during transportation/retrieval of intubated patients.

We conclude that in a group of obese patients undergoing elective bariatric surgery, verification of ET tube placement by bilateral lung US is as fast as auscultation alone and faster than the combined methods of auscultation and capnography.

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