Original Article

Role Of Lung Ultrasound In Determining The Position Of The Endotracheal Tube

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Abstract

Appropriate placement of endotracheal tubes is paramount for optimal visualization of the operative field during thoracic surgeries that require lung ventilation. Appropriate placement of endotracheal tubes is therefore confirmed with fiberoptic bronchoscopy (FOB) rather than clinical assessment alone. Recent studies have demonstrated lung ultrasound (US) is superior to clinical assessment alone for confirming placement of endotracheal tubes, So we aimed to discuss the role of ultrasound in determining the position of endotracheal tube.

Introduction:

The polyvinyl chloride (PVC) endotracheal tube is perhaps least glamorous and most ubiquitous bit of equipment. Sir Ivan Magill introduced red rubber tubes of uniform internal diameter (ID) in 1930, and these remained the standard until Mr David Sheridan introduced plastic endotracheal tubes in 1959 **(1)**.

In children younger than 8 years, the narrowest point of the airway is at the level of the circumferential, nondistensible cricoid cartilage. As the child continues to develop, the airway becomes more cylindrical, with the narrowest portion of the airway at the level of the vocal cords**(2)**.

During the last five decades, uncuffed tracheal tubes were recommended for routine use in children aged below 8 years. Cuffed tracheal tubes in patients younger than 8 years of age were only exceptionally used for special indications **(3)**.

The practice of using uncuffed endotracheal tubes has proven to be safe. **Black et al. (4)** studied 2,953 pediatric patients admitted to the intensive care unit during a 4-year period. The children had been nasotracheally intubated with uncuffed endotracheal tubes. None of the patients in the study showed clinical symptoms of acquired subglottic stenosis.

The PVC cuff on the tracheal tube requires the tube to be sized down by one-half size to accommodate the increase in the external diameter created by the bulk of the cuff. Because small changes in diameter result in large increases in resistance, this downsizing results in an increased work of breathing during spontaneous ventilation. This requirement for downsizing is a concern, especially in the smaller sizes of tracheal tubes. Although current ventilation techniques can readily overcome this increased resistance, the successful suctioning of secretions in the smaller tubes is challenging **(5)**.

Numerous formulas and tables guide the practitioner to use endotracheal tubes in infants and children younger than 8 years. The most common is the modified Cole formula [4 + (age/4)] for children aged 2 and older, with standard recommendations for younger children, based on both age and weight. Unhappily, patients sometimes do not conform to these formulas **(6)**.

Khine et al. (7) found that the rate of reintubation required with uncuffed tubes is 30% in children younger than 2 years and 18% in patients 2 years or older. When the leak around the endotracheal tube is too large to allow effective positive pressure ventilation, the tube must be exchanged, necessitating additional laryngoscopy and intubation attempts.

The degree of neuromuscular relaxation and the position of the head affect the leak around an endotracheal tube. Thus, when the endotracheal tube is initially placed, the leak around the tube may be within the appropriate range. As the neuromuscular blockade fully onsets or the anesthetic depth enhances relaxation, or the patient's head is moved for surgical indications, what was initially a correctly sized tube may prove to be inadequate. At best, changing the tube causes delay; at the worst, it is an impossible task because the patient is already prepped and draped and the airway is not easily and safely accessible and, as with all procedures, the first attempt may prove to be the most straight forward **(8)**.

The debate over cuffed versus uncuffed endotracheal tubes continues **(9)**. **Holzki et al. (10)** are by far the most ardent detractors of cuffed endotracheal tubes in pediatrics. They contend that stridor is not an adequate end point for identifying tracheal mucosal injury and that all incidences of airway complications should be evaluated with endoscopy. They correctly maintain that symptoms of injury may not present immediately, though it is unclear if they propose that all children undergo endoscopy with extubation. They prospectively collected pictures of airway injuries incurred by intubation, though it is unclear what airway management parameters were associated with these injuries. They documented a marked increase in the incidence of severe airway injury at their institution, coinciding by **Khine et al. (7)**.

Point-of-Care Ultrasonography

Ultrasonography has been widely used in medicine for decades but often by specific users such as cardiologists, obstetricians, and radiologists. In the last several years, the use of this imaging modality has moved to the bedside, with clinicians performing and interpreting focused point of care ultrasonography to aid in immediate assessment and management of their patients**(11)**.

Point-of-care ultrasound (POCUS) describes the acquisition and interpretation of images by the treating clinician, the end-user, at the bedside. It allows for real-time, data-informed clinical decisions, without dependence on a specialist to obtain the images or to interpret them. In pediatric critical care, this ultrasound framework lends itself perfectly as it allows for procedures to be done safely and for rapid, convenient serial reassessments aimed at improving diagnosis and monitoring **(12)**.

In the past decade, significant advancements have been made in pediatric critical care POCUS. However, as with most significant advancements, it is not without controversy. The rise of POCUS has been rapid, and many questions remain unanswered, including those related to competency and training. Usage can alter workflow, increase the financial burden, and incorrect interpretations made by inadequately trained users can pose significant risks to patients. However, when POCUS is used as a supplement to existing clinical aids, or as an extension of the physical exam, rather than an independent tool to overrule or replace other diagnostic modality, its benefits are immense, and can provide critical information and guidance in taking care of our patient **(13)**.

Acute respiratory failure, often secondary to pneumonia, bronchiolitis, and asthma exacerbation is the most common reason for admission to the PICU with pneumonia being the leading cause of death in children worldwide **(14)**.

Thoracic ultrasound has several advantages over traditional radiographic imaging of the pleura, including absence of radiation, better portability, real-time imaging, and the ability to perform dynamic imaging. The color and power Doppler capability of US enables visualization of vascular structures and perfusion of normal organs, tumors, or inflammatory lesions without the need for intravenous contrast administration, and M-mode imaging has proved helpful for evaluating pneumothorax and lung and diaphragmatic motion **(15)** Since that precocious exposure of infants and children to radiation may lead to a higher risk of developing malignancies later in life due to both the latency of the effect of radiation exposure on the cells and the fact that growing children are inherently more radiosensitive, because they have a larger proportion of dividing cells. Ultrasound avoids the use of ionizing radiation **(16)**.

While US is best performed by trained sonographers, medical students and doctors at the bedside are now being trained in its use. This raises the potential for diagnostic capabilities in rural and remote settings where other imaging modalities are not available. Hence, in many clinical settings where rapid diagnosis can facilitate improved clinical outcomes and potentially reduce antibiotic use, interest in the use of US for the diagnosis of pneumonia in children is growing **(17)**.

For many years transthoracic ultrasound was limited exclusively to the examination of pleural effusions. However, over the past few years ultrasonography of the pleural space and lung parenchyma is gaining a wide consensus in different conditions in clinical practice, particularly in emergency conditions **(18)**.

Ultrasonography (US) can be used to explore the surfaces of the lungs through the intercostal spaces, but the presence of the ribs and of air in the expanded lung reduces the value of this imaging modality in the examination of deeper thoracic structures. Nevertheless, US is considered a reliable, inexpensive, safe, and reproducible diagnostic method for the work-up of patients with diseases of the diaphragm (neoplasms, paresis), thoracic wall (abscesses, fistulas, neoplasms), lung (atelectasis, pulmonary consolidation), anterosuperior mediastinum (neoplasms, lymphoma, cysts), the region between the thorax and the abdomen, and above all, the pleurae (extrapleural masses, pleural effusions) **(19)**.

Advantages of lung ultrasound (20):

The strong points of US are as follows:

- The technique and its sonographic signs are easy to learn.
- It offers a practical tool to complete the general objective examination, facilitating a rapid and efficient diagnosis even in critical conditions.
- It is useful as bedside tool: for establishing the pharmacological treatment, monitoring its efficacy, and guiding eventual diagnostic and therapeutic interventional procedures.

Ultrasound in determining the position of the endotracheal tube in mechanically ventilated children:

The confirmation of endotracheal tube placement and depth is essential. Following intubation, While dynamic etCO2 monitoring has revolutionized the confirmation of endotracheal placement, there are still several circumstances in which this modality may be misleading (e.g. prolonged arrest, severe status asthmaticus/PE/pulmonary edema, etCO2 detector contamination with drugs/gastric contents). Additionally, etCO2 detectors cannot confirm appropriate endotracheal tube depth, leading to delayed recognition of mainstem placement **(21)**.

Limitations of current confirmation tools:

Choosing the correct tracheal tube size is important in paediatric patients because an inappropriately large tracheal tube may cause damage to the airway. If the tracheal tube is too small, this may lead to difficulties in ventilation or the need to re-intubate with a different size of tracheal tube **(21)**.

Ultrasonography has been suggested to be a useful tool for airway management in children, and may be used to measure the transverse tracheal diameter of the neck in adults and children. Furthermore, a strong correlation exists between ultrasound and magnetic resonance imaging measurements of transverse tracheal diameter at the level of the cricoid cartilage **(22)**

Shibasaki et al. (23) showed that the rate of agreement between the predicted tracheal tube size based on ultrasonic measurement and the final tracheal tube size selected clinically was 98% for cuffed tracheal tubes and 96% for uncuffed tracheal tubes.

As the transverse diameter of the trachea is smaller than the anteroposterior diameter at the cricoid cartilage level, it may be hypothesised that the transverse diameter measured by ultrasound may be used to choose the correct size of tracheal tube. However, there are reasons that ultrasonography may not useful for selecting the correct tracheal tube size: ultrasound may measure only transverse diameter, and thus it is not able to provide information on anteroposterior size discrepancies. The level of sono-probe application may not be at the smallest tracheal lumen diameter, in which case air will not leak within the targeted pressure range **(2)**. Chest x-ray, chest ultrasound, and physical exam can be used to confirm appropriate endotracheal tube depth, however, each has limitations. Ultrasound of the chest/pleura can assess for mainstem intubation by evaluating for bilateral pleural sliding. However, it is only about 50% sensitive (i.e. – bilateral lung sliding will occur in 50% of mainstem intubations) **(21)**. Chest x-rays are accurate for this purpose, but take significant time from ordering until interpretation. The physical exam for mainstem intubation is notoriously unreliable. None of these techniques allow for dynamic assessment of tube placement during repositioning **(24)**.

Recognizing these issues, **Tessaro et al. (25)** developed and validated a new ultrasonography technique that they call TRUST (Tracheal Rapid Ultrasound Saline Test) that can provide rapid, accurate assessment of tube placement and facilitate dynamic repositioning.

Tracheal Rapid Ultrasound Saline Test (TRUST):

Tessaro et al. (25) evaluated the accuracy of tracheal ultrasonography of a saline-inflated endotracheal tube (ETT) cuff for confirming correct ETT insertion depth. TRUST technique uses point-of-care ultrasonography of the anterior neck to confirm tube placement and position in an average of 4 seconds. The endotracheal tube cuff is inflated with saline rather than air to allow visualization. Cuff visualization at the level of the sternal notch corresponds to an ETT tip that is just inferior to the clavicular heads. They concluded that ultrasonography of a saline-inflated ETT cuff at the level of the suprasternal notch appears to be an accurate and rapid method to verify correct depth of ETT insertion in healthy pediatric patients.

Assessing the endotracheal tube position:

Place a high-frequency linear probe in transverse position over the anterior neck at the level of the sternal notch **(25)**.

Figure (1): Deflate the ETT cuff using a 10 mL syringe, noting the volume of air removed. Reinflate the cuff using the same volume of normal saline. As the saline is being injected attempt to visualize the bright posterior walls of the cuff filling within the trachea. Swirling air bubbles will often be seen **(25)**.

If the cuff is not seen, sweep the probe superiorly along the trachea to the level of the vocal cords to search for the saline-inflated cuff. Once air bubbles have dissolved, the saline inflated cuff is recognized by its posterior wall, appearing as horizontal hyperechoic lines interrupted by shadowing from air within the endotracheal tube **(25)**.

In addition, children undergoing general anaesthesia experienced significantly more adverse events after tracheal tube removal, when there was no air leak at 25 cmH2O. A leak pressure of 30 cm H2O may be allowable in cases requiring a short intubation period **(8)**.

Although the appropriateness of tracheal tube size was evaluated using the air leak test, this test has its shortcomings in terms of the determination of optimal tube size; for example, the air leak test is not able to predict an increased risk of adverse events after extubation or the risk of re-intubation in children **(26)**.

Furthermore, the incidence of inter-observer variations for the assessment of leak pressures is high, and leak pressure depends on head position and the degree of neuromuscular blockade. However, there are no other feasible practical methods for confirming the correct tracheal tube size after intubation **(27)**.

Unlike adults, laryngeal calcification is not encountered in children. Therefore, laryngeal calcification, one of the limitations of performing ultrasonographic measurements of the larynx, does not influence ultrasonographic findings in paediatric patients. Thus, ultrasonography may be more useful for the selection of tracheal tube size in children **(28)**.

Ahn et al. (29) compared auscultation and the ultrasound-guided lung sliding sign to confirm optimal positioning of the tracheal tube in paediatric patients younger than 24 months. They found that use of the ultrasound-guided lung sliding sign was more accurate than auscultation for optimal positioning of the tracheal tube.

Shebl and Said (30) assessed the role of tracheal ultrasonography in confirming ETT placement in ICU patients and concluded that tracheal ultrasound can be a rapid and safe tool to confirm correct endotracheal tube placement.

Abdel Rahman et al. (31) predicted the value of diaphragmatic and lung US indices as new parameters in prediction of the weaning outcome in pediatric age group. They concluded that diaphragmatic and lung US is a quick and non-harmful technique for prediction of weaning success with highly accurate results compared to the other traditional medical parameters alone as we may face many cases ready for weaning by traditional parameters but which failed with weaning process progress.

In neonates and infants:

Slovis and Poland (32) published a case series using a portable US machine to perform 21 sonographic evaluations on 16 infants with concurrent XR. The suprasternal window was utilized with the probe placed in the midsagittal position. This prospective study reported an US visualization rate of 86%and a close correlation between the distance of the ETT tip to the aortic arch on US and the distance of the tip to the carina on XR (r = 0.80). Optimal tube position was determined to be 1 cm above the aortic arch on US, which correlates with 0.5 cm above the carina on XR. To improve visualization, the ETT tip was oscillated up and down in the airway a few millimeters in each direction. They advocated using US to replace XRs that are taken solely for evaluation of ETT position.

Concerned about the potential risks of oscillating the ETT, **Lingle (33)** tried using an US "standoff pad" over the infant's chest and neck to improve visualization. The use of the "standoff pad" facilitated visualization and minimized handling.

Rather than using the aortic arch, **Dennington et al. (34)** chose the superior portion of the right pulmonary artery as the US anatomic equivalent of the carina and their landmark for measuring ETT depth. They visualized all ETT tips by US and reported 100% concordance between US and XR. The US examinations, done by a neonatologist and a trained respiratory therapist, took less than 5 min and were well tolerated.

Sethi et al. (35) reported an average of 19 min for imaging and interpretation with US compared to 47 min with XR. US was able to visualize 90% of ETT tips; in the neonates with failed visualizations, the ETT tip was lying at or above the first thoracic vertebrae.

Quintela et al. (36) compared US to capnography and XR for ETT positioning in their neonatal (NICU) and pediatric intensive care units (PICU). The study involved two phases: intubation with immediate confirmation of tracheal vs esophageal location by tracheal US and capnography and determination of ETT depth by thoracic US and XR. They found no significant differences between US and capnography in their ability to detect endotracheal vs esophageal intubation in infants; however, US was significantly slower than capnography, 34 vs 7 s, respectively.

In contrast, ETT depth was determined using the "sliding lung sign" of visceral-parietal pleural movement with the US transducer placed along the mid-axillary line of the chest bilaterally. This technique, utilized in older children and adults with whom the midsagittal suprasternal window is poorly visualized, infers approximate ETT depth by viewing the lung movements bilaterally instead of direct US visualization of the ETT tip position. Detection of ETT position by US was not significantly different from XR, but US was faster in determining appropriate depth, 0.25 vs 20 min, respectively **(21)**.

Chowdhry et al. (37) conducted the largest infant trial to date with 56 US and XR image pairs obtained from 29 neonates. The midsagittal suprasternal view was used. Defining a "deep" ETT as <1 cm above the apex of the aortic arch by US and beyond the body of the third thoracic vertebrae on XR, US had a sensitivity of 86%and specificity of 96%for identifying deeply positioned ETTs. The study sonographers included a pediatric radiologist and 12 US technicians who underwent a one-time 1-h training session.

de Kock et al. (38) tried using the thyroid, anatomically corresponding to the proximal tracheal and C6/C7 vertebrae, as the cephalic US landmark in addition to the aortic arch. Ideal ETT tip placement was defined as between the thyroid and aortic arch on US, equating to about 1.5–2.25 cm from the level of the aortic arch. Though all 30 ETT tips were visualized, US missed six tips that were malpositioned by XR interpretation. They postulated that patient repositioning and neck positioning between the exams accounted for the discrepancy.

Older children (1-18 years old):

Hsieh et al. (39) evaluated diaphragm US vs capnography and XR for secondary confirmation of ETT position in 59 patients in their PICU. The group predominantly used the transverse substernal view to capture the bilateral diaphragm motion in a single scanning plane. Supplemental views included sagittally scanning the diaphragms at the left and right mid-axillary lines at the lower chest. Proper ETT position is inferred as the diaphragm would move toward the abdomen bilaterally if the ETT were well positioned, whereas one side would show exaggerated movement if the ETT were in the ipsilateral main bronchus. An ETT in the esophagus would show reverse diaphragm motion as positive pressure is delivered into the abdomen. Using this technique, they identified two esophageal intubations and eight right mainstem bronchus intubations by US; all of which were repositioned immediately with US guidance.

Kerrey et al. (40) studied diaphragm US vs XR for ETT confirmation in 127 intubated patients in their pediatric emergency department (PED). Study sonographers included 10 PEM physicians and nine respiratory therapists who underwent a diaphragm US training program and then performed reviewed US examinations on pediatric volunteers. They utilized a technique similar to that used by **Hsieh et al. (39)**. Sonographers executing the US and radiologists reading the confirmatory XR were blinded to the interpretations of the other modality. With XR as the gold standard, US had a sensitivity of 91%, specificity of 50%, a positive predictive value (PPV) of 89%, and a negative predictive value (NPV) of 57% for detecting mainstem intubations. In patients who received two independent US exams, agreement of ETT position between the sonographers was 97%. XR results took a median of 8 min longer than US to be communicated to the providing physician.

Galicinao et al. (41) investigated the usefulness of US for ETT placement on 99 patients from the PED and PICU. They underwent an American College of Emergency Physician-sponsored US course, had ≥1 year US experience, and credentialing through their institutional program. The US transducer was placed in the transverse and sagittal positions at the level of the cricothyroid membrane. In 50 patients, US was compared to capnography and XR. The mean time to determine ETT position by US was 17 s, compared to 14 min by XR. US had a sensitivity, specificity, PPV, and NPVof 100% in confirming ETT placement. US even detected ETT position where capnography failed to detect proper ETT placement (two cases) or did not clearly detect improper placement (one case). They reported difficulty imaging patients with subjectively shorter necks and those with small cervical collars.

Marciniak et al. (22) investigated the use of US in the peri-operative setting, where XR is not routinely used for ETT confirmation. They utilized a transverse suprasternal view to visualize the vocal cords and its movements during real-time intubation. They reported rarely visualizing the ETT tube directly going through the vocal cords; however, they indirectly observed the widening of the cords at the base of the glottis with every successful intubation.

The study by **Quintela et al. (36)** on US vs capnography and XR for ETT position included 15 patients from their PICU. In this population, they also found no statistically significant differences between tracheal US and capnography or between thoracic US and XR in identifying correct endotracheal vs esophageal intubation and assessment of ETT insertion depth, respectively. However, US was not slower than capnography in their PICU patients, a contrast to their NICU patient subset.

Tessaro et al. (25) explored the use of US to visualize salineinflated ETT cuffs to determine appropriate ETT depth. They called their technique the tracheal rapid US saline test, or T.R.U.S.T. An ETT was guided into the mainstem bronchus assisted by a fiberoptic bronchoscope and then the cuff was inflated with saline. The ETT was gradually withdrawn until the sonographer noted the appearance of the saline-inflated cuff at the level of the sternal notch, which has been shown to correlate to the correct depth of ETT tip insertion. US visualization of the saline-inflated cuff had a sensitivity and specificity of 99 and 96%, respectively, a PPV of 97%, and a NPVof 99% in determining correct ETT position and ruling out mainstem bronchial intubation.

Repositioning a misplaced tube:

The sternal notch is the optimal point for the cuff of the tube. If the cuff is visualized cephalad to the sternal notch, consider inserting the tube further to prevent extubation. The movement of the cuff can be followed dynamically during repositioning with ultrasound.

If the cuff is not visualized from the sternal notch to the larynx, then the cuff is either deep to the sternum, signifying a tube tip that is likely maintem, or in the esophagus. If there is no evidence of an esophageal intubation, hold the probe at the sternal notch and slowly withdraw the tube until the saline-filled cuff is visualized. As long as your cuff is not overinflated, moving the tube while the cuff is inflated with saline should not cause mucosal damage moving from the smaller mainstem bronchus towards the larger trachea. If doubt exists whether a saline-filled cuff is being visualized on screen, the saline can be withdrawn from the cuff while observing the structure in question. If the structure shrinks and disappears, it was the cuff **(25)**.

Hazards for lung ultrasound:

Because LUS is an operator-dependent method, there is a need for training bedside physicians so that they can perform the examination correctly and be responsible for the consequent interventions. Because LUS is a newly developed tool, there is a lack of professionals trained in using the method. In addition, there is a lack of specific criteria for the training and certification of professionals in the various fields of medicine. It has been proposed that LUS examination be standardized in order to facilitate learning and clinical follow-up **(42)**.

Another limitation of the method is that, because LUS examination is essentially dynamic, it is difficult to document and store LUS findings appropriately for subsequent comparisons. In addition, the presence of obesity, dressings, or subcutaneous emphysema can preclude the use of LUS. Furthermore, because the presence of air is the greatest enemy of US, abnormalities surrounded by air cannot be evaluated by the method **(43)**.

References:

1. **Berry FA (1990):** Anesthetic Management of Difficult and Routine Pediatric Patients. 2nd ed. New York, NY: Churchill Livingston Inc.
2. **Litman RS, Weissend EE, Shibata D et al. (2003):** Developmental changes of laryngeal dimensions in unparalyzed, sedated children. Anesthesiology; 98(1): 41-45.
3. **Weiss M, Dullenkopf A (2007):** Cuffed tracheal tubes in children: past, present and future. Expert Rev Med Devices; 4: 73-82.
4. **Black AE, Hatch DJ, Nauth-Misir N (1990):** Complications of nasotracheal intubation in neonates, infants and children: a review of 4 years' experience in a children's hospital. Br J Anaesth; 65(4): 461-467.
5. **Fine GF, Borland LM (2004):** The future of the cuffed endotracheal tube. Paediatr Anaesth; 14(1): 38-42.
6. **Cote CJ, Todres ID, Goudsouzian NG et al. (2001):** A Practice of Anesthesia for Infants and Children. 3rd ed. Philadelphia, PA: WB Saunders Company.
7. **Khine HH, Corddry DH, Kettrick RG et al. (1997):** Comparison of cuffed and uncuffed endotracheal tubes in young children during general anesthesia. Anesthesiology 1997; 86:627-31.
8. **Suominen P, Taivainen T, Tuominen N et al. (2006):** Optimally fitted tracheal tubes decrease the probability of postextubation adverse events in children undergoing general anesthesia. Pediatr Anesth; 16: 641-7.
9. **Lonnqvist PA (2009):** Cuffed or uncuffed tracheal tubes during anaesthesia in infants and small children: time to put the eternal discussion to rest? Br J Anaesth; 103(6): 783-785.
10. **Holzki J, Laschat M, Puder C (2009):** Stridor is not a scientifically valid outcome measure for assessing airway injury. Paediatr Anaesth; 19(suppl 1): 180-197.
11. **Burton L, Bhagava V and Kong M (2022):** Point-of-care ultrasound in the pediatric intensive care unit; 9: Article 830160.
12. **Díaz-Gómez JL, Mayo PH, Koenig SJ (2021):** Point-of-care ultrasonography. N Engl J Med; 385: 1593–602.
13. **Singh Y, Tissot C, Fraga MV et al. (2020):** International evidence-based guidelines on Point of Care Ultrasound (POCUS) for critically ill neonates and children issued by the POCUS working group of the european society of paediatric and neonatal intensive care (ESPNIC). Crit Care; 24: 65.

14. **Poongundran P, Shann F, Shekerdemian L et al. (2010):** Three decades of pediatric intensive care: who was admitted, what happened in intensive care, and what happened afterward. Pediatr Crit Care Med; 11: 549–55.
15. **Lobo L (2006):** The neonatal chest. European Journal of Radiology; 60(2): 152-158.
16. **Smargiassi A, Inchingolo R, Soldati G et al. (2013):** The role of chest ultrasonography in the management of respiratory diseases. Multidisciplinary Respiratory Medicine; 8: 55.
17. **Solomon S.D. and Saldana F (2014):** Point-of-care ultrasound in medical education: Stop listening and look. N Engl J Med; 370(12): 1083–85.
18. **Biagi C, Pierantoni L, Baldazzi M et al. (2018):** Lung ultrasound for the diagnosis of pneumonia in children with acute bronchiolitis. BMC Pulm. Med.; 18: 191.
19. **Beckh S, Bolcskei PL and Lessnau KD (2002):** Real-time chest ultrasonography: a comprehensive review for the pulmonologist. Chest; 122: 1759–1773.
20. **Lichtenstein DA (2014):** Lung ultrasound in the critically ill. Ann Intensive Care; 4(1): 1–1.
21. **Sim SS, Lien WC, Chou HC et al. (2012):** Ultrasonographic lung sliding sign in confirming proper endotracheal intubation during emergency intubation. Resuscitation; 83: 307–312.
22. **Marciniak B, Fayoux P, Hébrard A et al. (2009):** Airway management in children: ultrasonography assessment of tracheal intubation in real time? Anesth Analg; 108: 461–465.
23. **Shibasaki M, Nakajima Y, Ishii S et al. (2010):** Prediction of pediatric endotracheal tube size by ultrasonography. Anesthesiology; 113: 819–24.
24. **Sitzwohl C et al. (2010):** Endobronchial intubation detected by insertion depth of endotracheal tube, bilateral auscultation, or observation of chest movements: randomised trial. BMJ; 341: c5943.
25. **Tessaro MO, Salant EP, Arroyo AC et al. (2015):** Tracheal rapid ultrasound saline test (T.R.U.S.T.) for confirming correct endotracheal tube depth in children. Resuscitation; 89: 8–12.
26. **Suominen PK, Tuominen NA, Salminen JT et al. (2007):** The air-leak test is not a good predictor of postextubation adverse events in children undergoing cardiac surgery. Journal of Cardiothoracic and Vascular Anesthesia; 21: 197–202.
27. **Schwartz RE, Stayer SA, Pasquariello CA (1993):** Tracheal tube leak test – is there inter-observer agreement? Canadian Journal of Anesthesia; 40: 1049–52.
28. **Bertolani M, Calandra Buonaura P, Spina V et al. (1993):** Spinecho anatomy of the larynx in MRI at 1.5 T. Journal de Radiologie; 74: 1–12.
29. **Ahn JH, Kwon E, Lee SY et al. (2019):** Ultrasound-guided lung sliding sign to confirm optimal depth of tracheal tube insertion in young children. British Journal of Anaesthesia; 123(3): 309-315.
30. **Shebl E and Said AM (2019):** The role of tracheal ultrasonography in confirming endotracheal tube placement in respiratory intensive-care unit patients. The Egyptian Journal of Chest Diseases and Tuberculosis; 68: 351-355.
31. **Abdel Rahman DA, Saber S and El-Maghraby A (2020):** Diaphragm and lung ultrasound indices in prediction of outcome of weaning from mechanical ventilation in pediatric intensive care unit. The Indian Journal of Pediatrics; 87(6): 413-420.
32. **Slovis TL, Poland RL (1986):** Endotracheal tubes in neonates: sonographic positioning. Radiology; 160: 262–263.
33. **Lingle PA (1988):** Sonographic verification of endotracheal tube position in neonates: a modified technique. J Clin Ultrasound; 16: 605–609.
34. **Dennington D, Vali P, Finer NN, Kim JH (2012):** Ultrasound confirmation of endotracheal tube position in neonates. Neonatology; 102: 185–189.
35. **Sethi A, Nimbalkar A, Patel D, Kungwani A (2014):** Point of care ultrasonography for position of tip of endotracheal tube in neonates. Indian Pediatr; 51: 119–121.
36. **Quintela PA, Erroz IO, Matilla MM et al. (2014):** Usefulness of bedside ultrasound compared to capnography and X-ray for tracheal intubation. Anales de Pediatría (Barc); 81: 283–288.
37. **Chowdhry R, Dangman B, Pinheiro JM (2015):** The concordance of ultrasound technique versus X-ray to confirm endotracheal tube position in neonates. J. Perinatol. 35, 481–484.
38. **de Kock SH, Otto SF, Joubert G (2015):** The feasibility of determining the position of an endotracheal tube in neonates by using bedside ultrasonography compared with chest radiographs. S Afr J CH; 9: 3–5.

39. **Hsieh KS, Lee CL, Lin CC, Huang TC (2004):** Secondary confirmation of endotracheal tube position by ultrasound image. Crit Care; 32: S374–S377.
40. **Kerrey BT, Geis GL, Quinn AM et al. (2009):** A prospective comparison of diaphragmatic ultrasound and chest radiography to determine endotracheal tube position in a pediatric emergency department. Pediatrics; 123: e1039–e1044.
41. **Galicinao J, Bush AJ, Godambe SA (2007):** Use of bedside ultrasonography for endotracheal tube placement in pediatric patients: a feasibility study. Pediatrics; 120: 1297–1303.
42. **Tutino L, Cianchi G and Peris A (2010):** Time needed to achieve completeness and accuracy in bedside lung ultrasound reporting in intensive care unit. Scand J Trauma ResuscEmerg Med; 18: 44.
43. **Koenig SJ, Narasimhan M and Mayo PH (2011):** Thoracic ultrasonography for the pulmonary specialist. Chest; 140(5): 1332-41.