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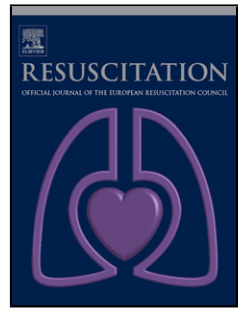


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# Confirmation of Correct Tracheal Tube Placement in Newborn Infants

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**Author's contribution:**

Georg M. Schmölzer: Dr. Schmölzer conceptualized and designed the study, carried out the initial literature search and analysis of available literature, drafted the initial manuscript, and approved the final manuscript as submitted.

Megan O'Reilly: Dr. O'Reilly carried out the initial literature search and analysis of available literature, reviewed and revised the manuscript, and approved the final manuscript as submitted.

Peter G. Davis: Dr. Davis performed a literature search and analysis of available literature, reviewed and revised the manuscript, and approved the final manuscript as submitted.

Po-Yin Cheung: Dr. Cheung performed a literature search and analysis of available literature, reviewed and revised the manuscript, and approved the final manuscript as submitted.

Charles Christoph Roehr: Dr. Roehr conceptualized and designed the study, performed a literature search and analysis of available literature, reviewed and revised the manuscript, and approved the final manuscript as submitted.

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**Abbreviations:**

NICU - Neonatal intensive care unit

DR - Delivery room

$CO_2$ - Carbon dioxide

**Abstract**

Tracheal intubation remains a common procedure during neonatal intensive care. Rapid confirmation of correct tube placement is important because tube malposition is associated with serious adverse outcomes. The current gold standard test to confirm tube position is a chest radiograph, however this is often delayed until after ventilation has commenced. Hence, point of care methods to confirm correct tube placement have been developed. The aim of this article is to review the available literature on tube placement in newborn infants. We reviewed books, resuscitation manuals and articles from 1830 to the present with the search terms “Infant, Newborn”, “Endotracheal intubation”, “Resuscitation”, “Clinical signs”, “Radiography”, “Respiratory Function Tests”, “Laryngoscopy”, “Ultrasonography”, and “Bronchoscopy”. Various techniques have been studied to help clinicians assess tube placement. However, despite 85 years of clinical practice, the search for higher success rates and quicker intubation continues. Currently, chest radiography remains the gold standard test to confirm tube position. However, rigorous evaluation of new techniques is required to ensure the safety of newborn infants.

## Background

Tracheal intubation remains a common procedure in the neonatal intensive care unit (NICU) and the delivery room (DR)[1-5]. The insertion of a tube into the trachea to inflate the lungs of newborn infants has been routinely practiced for almost a century. James Blundell described digital intubation in 1834 as "Inserting a tracheal catheter guided along the fingers, through which the accoucheur could inflate the infant's lungs with his own breath"[6]. However, it took almost a century until Flagg described his technique of introducing a metal tube into the trachea, using a small laryngoscope incorporating an electric light[7]. Blaikley and Gibberd later suggested using a rubber catheter instead of the rigid metal tube in 1935[8]. Until the 1970s, tracheal intubation was considered a simple procedure once the anatomy and the manipulation of the laryngoscope were understood[9,10]. With the introduction of chest radiography, tube position became clearly visible and malposition of the tracheal tube was able to be detected[11].

The current gold standard for confirming tube position is a chest radiograph, however this is often delayed until after ventilation via the tube has been commenced[11]. Rapid confirmation of correct tracheal tube placement at the point of care is important because tube malposition is associated with serious adverse outcomes, including hypoxemia, pneumothorax, lung collapse and death[1-3,12-15]. This has led to the development of new methods to confirm correct tube placement. Various techniques have been studied to enable i) correct tube placement and ii) optimal position within the trachea (Table 1). These techniques include i) clinical signs, ii) measurement of tube length based on parameters of body size or gestational age, iii) fiber optic techniques, iv) respiratory function, iv) chest radiograph, vi) capnography, vii) ultrasonography, and viii) magnetic detection. However, rates of correct tube placement, particularly for junior medical staff, are less than 50% and accidental esophageal intubation is common[1,2,5,16].

The aim of this article was to review the available literature about tracheal tube placement in neonates. Critical issues that must be addressed when correctly placing a tracheal tube include i) correct placement of the tube in the trachea and not the esophagus, ii) proper depth of the tube and iii) time to complete the procedure. The article describes intubation in the NICU and DR. All the available techniques and devices described can be used in both the NICU and DR during emergency and non-emergency intubations.

**Search strategy**

We reviewed books, resuscitation manuals and articles from 1830 to the present with the search terms “Infant, Newborn”, “Tracheal intubation”, “Resuscitation”, “Clinical signs”, “Radiography”, “Respiratory Function Tests”, “Laryngoscopy”, “Bronchoscopy”, and “Ultrasonography”. All languages were included. The full search strategies for PubMed, EMBASE and PubMed Central are detailed in Appendix 1.

**Tracheal vs. esophageal tube placement**

Various techniques have been studied to determine correct tube placement including i) clinical signs, ii) capnography, iii) respiratory function, iii) fiber optic techniques, and iv) video laryngoscopy, which are described in detail below.

*Clinical signs*

International resuscitation guidelines recommend clinical signs and $CO_2$ detectors to confirm correct tube placement[17]. Clinical signs of correct tube placement include a prompt increase in heart rate, chest wall movement, visualization during direct laryngoscopy of the tube passing through the vocal cords, presence of breath sounds in the axillae and absence of breath sounds in the epigastrium and condensation in the tube during expiration[17]. Direct laryngoscopy to observe passage of the tube through the vocal cords was first described by Roberts in 1949[9]. Condensation of water vapor in the tube lumen, although less likely with esophageal intubation, can occur and hence is not a reliable sign[18]. In 1964, Doss reported his experience in an essay on “Resuscitation of the Newborn”, stating that “The chest is auscultated while blowing into the tube to verify that the latter is in the trachea”[10]. Bednarek et al., in 1975, reported 9/14 intubation of the right main bronchus: Four were without complications, four caused atelectasis of varying degrees and one resulted in bilateral pneumothoraces[15]. “Chest rise” is another clinical sign used to identify correct tube placement. Doss described his observation of unilateral chest rise to identify unilateral main bronchus intubation; “If only the right lung expands the tube is withdrawn a little”[10]. More important, movement of the chest wall simulating ventilation of the lungs can be seen with an esophageal tube[18]. Observational studies in the delivery room during mask ventilation have shown that judgment of chest rise is inaccurate[21,22]. Several studies have reported that recognition of esophageal intubation, using clinical signs alone, may take several minutes[2,4,5,18,19]. In summary, a number of clinical signs aim to identify correct tube placement but none have been systematically studied. The best indicator that the tube is in the trachea remains the clinical response when the patient shows a prompt increase in heart rate[17,20].

*Exhaled Carbon Dioxide ($CO_2$)*

$CO_2$ is exhaled from the lungs at concentrations much higher than present in air. It can be detected using colorimetric devices or measured quantitatively using main-stream, side-stream or micro-stream devices[3-5,19,23-28]. Measuring exhaled $CO_2$ by infrared gas analysis to monitor patients during anesthesia was first described in the 1960s[23,24] (Table 1). However, using end-tidal $CO_2$ to detect correct tube placement was first described in an animal model by Murray in 1983 and in human patients by Linko in 1983[25,26]. International resuscitation guidelines recommend clinical assessment and exhaled $CO_2$ to confirm correct tube placement immediately after intubation[17]. Although $CO_2$ devices are frequently used to assess tube placement[29-32], false negative results may occur, particularly when cardiac output is low[33] or when the infant is in severe respiratory failure and the inflation pressure is not high enough to ventilate the lungs[5,34].

Disposable semi-quantitative colorimetric $CO_2$-detectors are recommended in international guidelines. With each inflation and expiration a pH-sensitive chemical indicator undergoes color change (e.g. from purple to yellow), reflecting the change in $CO_2$ concentration in the gas passing through it. Garey et al. reported the tidal volume threshold achieve color change at the Pedi-Cap with >0.72 mL[27]. An absence of color change suggests that the tube is not in the trachea. However, false negative findings may occur as listed above. Evidence comes from one observational and one prospective cohort study (Table 2). Aziz et al. compared the Pedi-Cap® (Nellcor Puritan Bennett, Pleasanton, CA) with clinical evaluation and radiography findings for tracheal intubation in 45 newborn infants (24 (53%) in the DR and 21 (47%) in the NICU) who required tracheal intubation. In that study, the Pedi-Cap® correctly identified 30 tracheal tube placements and 12 esophageal tube placements (Table 2). However, in three cases a false negative result (no color change) was displayed[4]. Schmölzer et al. compared flow signals with the Pedi-Cap® in 35 intubations (Table 2). The flow signal correctly identified all tube placements correctly, whereas the Pedi-Cap® failed to change color on 12 occasions when the tube was correctly placed[5]. Colorimetric $CO_2$-detectors may mislead clinicians intubating very preterm infants in the delivery room and may fail to change color despite correct tube placement in up to one third of cases[5].

Systems with either main-stream, side-stream or micro-stream measurement of end-tidal $CO_2$ have been described[3,19,28] (Table 2). Repetto et al. compared end-tidal $CO_2$

with clinical assessment in the NICU and DR. The median times required for capnographic and clinical determination of tracheal intubation were 9sec vs. 35sec, and for esophageal intubation 9sec vs. 30sec[19]. Roberts et al. compared side-stream capnography with clinical assessment in 100 intubations in 55 infants[3]. Capnography rapidly and correctly identified esophageal tube placements in 39 of 40 infants (mean 1.6 sec). Capnography failed to identify successful tracheal intubation on only one occasion. Clinical indicators of esophageal position were much slower (mean 97.1sec) and failed to identify successful tracheal intubation in 5 of 60 cases[3]. In comparison, Hosono et al. demonstrated that compared to clinical assessment, micro-stream $CO_2$-detectors correctly identified all tube placements, whereas clinical assessment failed to identify three of eleven esophageal tube placements[28]. We need to emphasize that although micro-stream $CO_2$-detectors can be used to identify correct tube placement, inexperience and lack of knowledge about the displayed waveforms may lead to misinterpretation of the signals. Therefore, anyone using this device must be trained to interpret capnography waveform signals (Figure 1). In addition, all $CO_2$ devices may display false negative results particularly when cardiac output is low or when the infant is in severe respiratory failure and the inflation pressure is not sufficient to ventilate the lungs. Although observational studies have evaluated side-stream or micro-stream $CO_2$-detectors, neither have been evaluated in randomized trials in neonates.

*Respiratory Function Monitor*

In a Scottish medical negligence case from 1973, John Robinson first described the use of airway pressure and gas flow waves to identify correct tube placement[35] (Table 1). Robinson reported that tidal volume measurements are feasible and suggested that airway pressure and gas flow should be used to differentiate tracheal from esophageal tube placement (Figure 1)[35]. Almost any respiratory function monitor can be used to measure and display airway pressure, gas flow and tidal volume[36]. A flow sensor placed between the tube and the ventilation device can be used to determine tube placement[37]. The operator should look for inspiratory and expiratory gas flow waves. If gas flow can be observed in both directions, the tube is in the trachea. If only inspiratory gas flow is observed, the tube is most likely in the esophagus. Recently, Schmölzer et al. compared the gas flow signals to a colorimetric $CO_2$-detector in an ovine model of neonatal resuscitation[37]. Both colorimetric $CO_2$-detector and flow signal identified all tube placements correctly. However, the colorimetric $CO_2$-detector required at least three and up to 10 inflations to identify tube location compared to one to two inflations with the flow sensor. The available evidence during neonatal resuscitation derives from two observational studies in the DR[2,5] (Table 2). O'Donnell et al. compared clinical assessment (n=33 infants) and flow signal (n=7 infants) for identification of correct tube placement[2]. Clinical assessment of tube position took 39sec compared to 19sec using a flow signal. Schmölzer et al. compared the gas flow sensor to a colorimetric $CO_2$-detector during 35 intubation attempts of 20 infants during neonatal resuscitation[5]. In 21 (60%) intubations, both methods correctly identified successful tube placement, and in 3 (9%) intubations both methods indicated the tube was not in the trachea. However, in the remaining 11 (31%) intubations the colorimetric $CO_2$-detector failed to change color despite the flow wave indicating correct placement. This study suggests that colorimetric $CO_2$-detectors may fail to change color despite correct tube placement in up to one third of cases and therefore may mislead clinicians intubating very preterm infants in the DR. However, neither gas flow nor airway pressure monitoring can distinguish tube placement in the trachea from one of the main bronchi, which is a major limitation. Recently, in an animal model, electrical impedance tomography was shown to correctly identify tube misplacement in the bronchial tree[38]. This device is currently best regarded as a research tool and is not available to clinicians. Substantial training in the use of this technology is required to ensure correct interpretation of the signals produced.

*Fiber Optic Devices*

A fiber optic laryngoscope/ bronchoscope for endotracheal intubation was first described by Stiles in 1972[39] (Table 1). These devices emit light, and development of the ultrathin bronchoscope has made flexible endoscopic intubation for the neonate and small infant possible. Advantages include: i) easy identification of the carina or the esophagus and ii) intubation can be performed either via nasal or oral route, high correlation with chest radiograph[39-42]. However, limitations and disadvantages include i) desaturation during the procedure, ii) time required to visualize the vocal cords, and iii) special training which is necessary to operate the flexible fiberscope efficiently in emergency settings[39-42].

Fiber optic devices have been used to i) intubate newborn infants in the NICU[43] and ii) assess correct tracheal tube placement[40,41]. Finer et al. described non-emergency endoscopic intubation of newborn infants in the NICU using a bronchoscope[43]. The majority of those infants were intubated prior to surgery or to investigate upper airway abnormalities. There was evidence of transient hypoxemia during the introduction of the bronchoscope into the trachea, but no infant had an oxygen saturation lower than 85%[43]. The longest part of the procedure was time required to visualize the vocal cords adequately, and the most difficult aspect was the introduction of the tip of the bronchoscope into the trachea[43]. Although fiber optic tracheal intubation is a reliable method of neonatal intubation and used in the NICU, devices are not readily available in emergency situations. For this reason the technique has not been adopted for delivery room intubations. This has led to the development of fiber optic stylets, including viewing windows at the top of the shaft stylet, miniature screens, and video laryngoscopes[44].

*Video Laryngoscopy*

Video laryngoscopy provides a view from the tip of the laryngoscope blade during conventional direct laryngoscopy. These devices may use fiber optic image transmission to a miniature screen or have an embedded small camera head. Advantages of video laryngoscopes include: i) the image and light bundle does not interfere with the operator's view of the airway, so the standard technique of laryngoscopy remains possible, and ii) the light provided by the fiber optic bundle is safe and does not cause burns[45-49]. Disadvantages include: i) increased weight of the laryngoscope handle, and ii) failure of the light source, although this can occur with any laryngoscope[45-49]. In the pediatric age group, video-assisted intubation was first reported by Weiss in 2000 (Table 1)[45]. In 100 children aged from 3 months to 14.3 years the trachea was successfully intubated on the first attempt without arterial oxygen desaturation. Vanderhal et al. reported their preliminary experience using a video laryngoscope[46]. Although three intubations required more than three attempts with the video laryngoscope, the overall number of intubation attempts was reduced[46]. Trevisanuto et al. reported video guided intubation using the GlideScope® in five newborn infants[47]. Intubation with the GlideScope® was successful in three of the five cases, however in two cases direct laryngoscopy was performed after two failed attempts with the GlideScope®[47]. A randomized trial compared success rate of correct tube placement for the GlideScope® video laryngoscope with direct laryngoscopy[48] and reported no difference between the two devices[48]. Although, video laryngoscopes appear to be efficient and safe, randomized trials are required to compare each video laryngoscope with a conventional direct laryngoscope, with the other video laryngoscopes, and with the other types of intubation devices.

**Correct tube position within the Trachea**

Various techniques have been studied to determine optimal position within the trachea including i) chest radiograph, ii) measurement of tube length based on parameters of body size or gestational age, iii) external digital tracheal palpation, iv) fiber optic techniques, and v) ultrasonography.

*Chest Radiograph*

A chest radiograph can be used to confirm correct tube position within the trachea, which should be just below the level of the vocal cords and well above the carina. Various techniques have been described to achieve tube positioning above the carina prior to X-ray confirmation, but tube displacement, particularly into the right main bronchus, remains common[11,50]. While the current gold standard to assess correct tube placement is chest radiography, no study has formally investigated the use of chest radiographs to confirm tracheal tube placement in either the NICU or DR[11]. Guidelines for the interpretation of chest X-ray to assess correct tube placement vary. Usually, the lower limit for the position of the tube is measured in relation to the carina. The tip should be between 0.2 to 2 cm above the carina[11,13,15,51]. The medial border of the clavicles has been used in studies as reference point, however the position of the clavicles can range from the 4$^{th}$ cervical vertebrae to the 2$^{nd}$ thoracic vertebrae on chest radiographs[51]. In addition, studies have shown that head extension or flexion from the neutral position can move a tracheal tube by an average of 0.7 cm in either direction in newborns[51]. Hence using the 1$^{st}$ thoracic vertebrae has been suggested to be an alternative reference point.

*Estimation of correct endotracheal tube insertion*

Several formulae have been proposed to achieve correct tube placement within the trachea[12,52-57]. In 1987 Yates et al. developed a formula based on tube lengths recorded in their study (internal diameter x 3 + 2 cm)[52]. However, this formula has not been tested in further studies. In 1979, Tochen described a simple formula to determine the depth of tube insertion[53]. The "tip-to-lip" distance or “7-8-9 rule”, estimates the depth (cm) of tube insertion to be [1.17 * infant’s weight (in kg) + 5.58][53]. Using this formula an infant weighing 1kg would be intubated to a depth of 7cm, a 2kg infant to a depth of 8cm, and a 3kg infant to a depth of 9cm[53]. However, several studies have shown that the Tochen’s 7-8-9 rule led to incorrect tube placement in almost half of the infants studied. Peterson et al. studied the accuracy of the 7-8-9 rule for tube placement in 75 consecutively intubated infants of less than 32 weeks gestation[54]. Although correct tube placement was confirmed in infants > 750g body weight, tube depth was overestimated in infants < 750g[54]. Amarilyo et al. also assessed the reliability of the 7-8-9 rule during oro-tracheal intubation in 31 infants < 1000g[12]. In almost half of the infants (47%), the rule resulted in incorrect tube placement when checked by chest radiograph[12]. Furthermore, Kempley et al. recently re-examined Tochen's rule and reported that it assumes a linear relationship between tube and body length and body weight[56,57]. The relationship, although linear for gestational age, is non-linear for body weight[57]. Furthermore, the rule does not apply for naso-tracheal intubation.

*External digital tracheal palpation*

The practice of tube palpation dates back to the time of its first use in 1834 by British obstetrician, James Blundell, who used an tracheal tube to resuscitate an infant[6]. Blundell noted that following digital intubation "the tracheal pipe can be felt on the front of the neck whether the instrument is lying in the trachea or esophagus"[6]. Bednarek et al. in 1975 reported that tracheal tube position could be confirmed using digital suprasternal palpation in neonates and small infants[15]. Once the tube is placed and the tip can be gently palpated in the suprasternal notch the position is considered correct. Two studies compared external digital tracheal palpation to direct laryngoscopy[15,58]. Bednarek et al. reported that infants in the palpation group had significantly more accurate tube placements, significantly lower rates of complications, and no adverse effects compared to direct laryngoscopy[15]. In a randomized controlled trial, Jain et al. showed that digital palpation correctly predicted tube position on chest radiograph in 70% of included infants[58]. Digital palpation resulted in a small, non-significant improvement in rates of correct placement compared with standard weight based criteria[58]. The authors concluded that suprasternal palpation appears to be a simple and teachable method of confirming tracheal tube position in neonates when chest radiograph is unavailable, and may be especially helpful during neonatal resuscitation prior to surfactant administration.

*Fiber Optic Devices*

Fiber optic devices have been used to i) intubate newborn infants in the NICU[43] and ii) assess correct tracheal tube placement.[40,41] Vigneswaran et al. studied the use of a 1.8mm fiberoptic bronchoscope for confirmation of tracheal tube position in 20 intubated infants[40]. They concluded that the bronchoscopic technique of determining tracheal tube position is as safe and accurate as the radiologic technique (correlation 0.91)[40]. Shinwell et al. reported their experience in 65 infants[41] and reported that the accuracy of bronchoscopic measurement of tracheal tube tip position improved markedly with user experience and correlated very well (0.96) with chest radiograph[41]. Although fiber optic tracheal intubation is a reliable approach for neonatal intubation and used in the NICU, devices are not readily available in emergency situations.

*Ultrasound*

In 1986 Slovis et al. demonstrated that real-time ultrasound could be used to verify correct tube position in newborn infants[59] (Table 1). Slovis et al. used the aortic arch as a reference point and showed that tube position could be accurately determined in 18/21 (85%) intubations[59]. Lingle et al. showed similar results using the same technique[60]. Galicinao et al. used two views with a linear transducer in infants and children to verify correct tube placement[61]. Compared to physical examination + colorimetric devices + chest radiography, bedside ultrasound was much faster[61]. Dennington et al. (Table 2) reported good correlation between ultrasound and radiograph measurements with most values being within 0.5 cm[62]. Advantages of ultrasonography over radiography include: i) reduced radiation, ii) less handling, particularly in critically ill infants, iii) potential to determine the tube position in the delivery room particularly for early surfactant delivery and iv) earlier detection of complications from malposition[59-62]. Disadvantages of ultrasonography are i) the specialized skills required, ii) difficulties to correctly identify anatomical landmarks and iv) lack of widespread availability[59-62]. These observational studies demonstrate that ultrasound can be used to visualize tracheal tube position in infants. However, 1-2 specially trained investigators performed all ultrasound evaluations in the reported studies, which is a major limitation of these studies. And therefore it is not applicable for daily clinical use. Randomized control trials are required before implementation of this technique.

**Duration of the procedure**

Guidelines of the Neonatal Resuscitation Program developed by the American Academy of Pediatrics recommend that the intubation procedure is completed within 30 seconds[17]. Two observational studies reported the times to intubate preterm infants in the DR using a laryngoscope[2,63]. Overall, 50-60% of intubation attempts were successful, with the majority occurring within 30 seconds[2,63]. Interestingly, two studies reported that digital intubation was significantly faster compared to intubation using a laryngoscope[64,65]. However, digital intubation is not routinely used during neonatal intubation.

Several studies have reported that experience significantly increased success rate of tracheal intubation[1,2,16,63]. O'Donnell et al. reported a significant difference between grades of doctors, with more senior doctors intubating more rapidly[2]. However, the study by Lane et al. reported that fellows were on average 10 seconds faster than 1st year residents or consultants[63]. The main concern is the decrease exposure of endotracheal intubation during residency and fellowship training[1,16]. Leone et al. reported that the mean number of intubation attempts per resident throughout training decreased from 38 (±19) in 1994 to 12 (±6) in 2002[1]. In addition, non-invasive methods of respiratory support has been advocated which further reduces the number of intubation attempts[66,67]. Manikin studies reported significant improvement in the time to visualize the vocal cords with the video laryngoscope compared to direct laryngoscopy[68]. However, success rate were similar within the groups[68]. In comparison, a randomized trial comparing intubation time for the GlideScope® video laryngoscope with direct laryngoscopy reported no difference in intubation time or success rate of intubation between the devices[48].

## Conclusions

Currently chest radiography remains the accepted standard test to confirm tube position. An increase in heart rate is the best indication of effective ventilation. Exhaled $CO_2$ may give misleading, false negative results and readings should be interpreted in conjunction with clinical signs. Respiratory function monitors, video laryngoscopes, fiber optic devices and ultrasound to confirm tube position are promising methods but require evidence from clinical trials before recommendations can be made for their use in clinical practice.

**Figure legend:**

**Figure 1:** Figure 1A: Esophageal and tracheal flow waves to identify correct tube placement comparison described by Robinson 1973[35]. In comparison airway pressure, gas flow, tidal volume and end-tidal $CO_2$ waves from a preterm infant born at 29 weeks gestation requiring intubation in the delivery room. Figure 1B - Esophageal intubation: Gas flow towards the infant is present. However, no expiratory gas flow, tidal volume or end-tidal carbon $CO_2$ is displayed. Figure 1C – Tracheal intubation: Gas flow towards and away from the infant is present. In addition, tidal volume or end-tidal $CO_2$ are displayed.

Figure 1A: Reproduced from [Respiratory recording from the oesophagus, Robinson[35]), Br Med J. 1974; 4 (5938), 225, 2012] with permission from BMJ Publishing Group Ltd.

Figure 1B &1C: Reproduced from [Monitoring during neonatal transport, O'Reilly[71], Emergency Medicine 2012,epub] with permission from O'Reilly et al.

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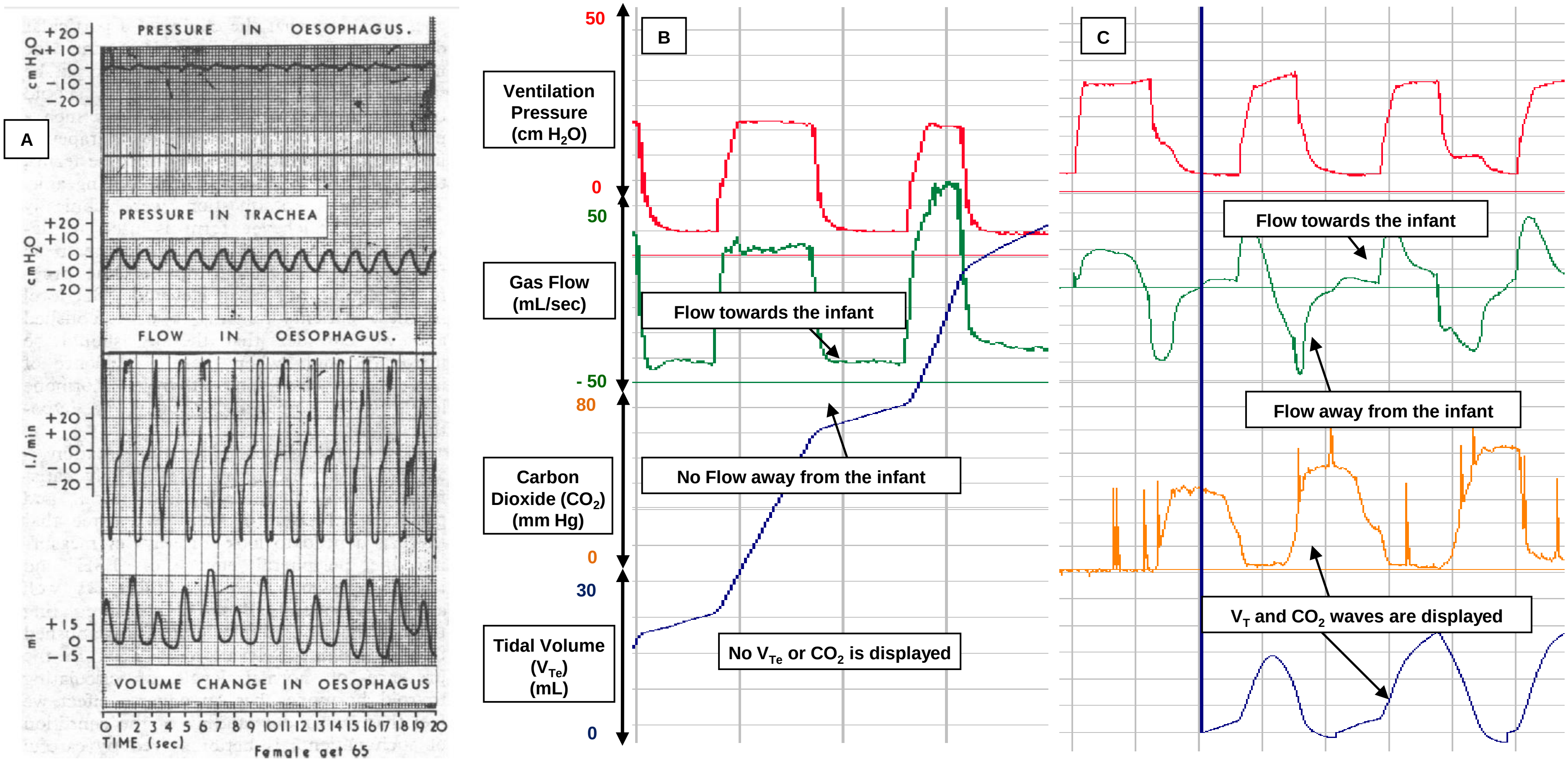
**Timeline: Evolution of endotracheal tube placement in newborn infants**

| | |
|---|---|
| 1834 | J. Blundell describes digital intubation and external digital tracheal palpation for correct tube placement for the treatment of Asphyxia Neonatorum[6] |
| 1895 | A. Kirstein invented the modern laryngoscope[69] |
| 1921 | Sir I. Magill recommends the sniffing position for endotracheal intubation[70] |
| 1928 | P.J. Flagg describes his technique of introducing a metal tube into the trachea using a small electrically lighted laryngoscope[7] |
| 1935 | J.B. Blaikley and G.F. Gibberd suggest to use a rubber catheter instead of the rigid tube[8] |
| 1949 | H. Roberts recommends “When intubation is required in an asphyxiated newborn infant, the endotracheal tube should be passed though the vocal cord by direct laryngoscopy”[9] |
| 1964 | A.D. Doss describes: “The chest is auscultated while blowing into the tube to verify that the latter is in the trachea”[10] |
| 1964 | Chest wall assessment to assess main bronchus intubation is described by A.D. Doss: “If only the right lung expands the tube is withdrawn a little”[10] |
| 1966 | Carbon dioxide monitoring during anesthesia is described by GW Burton[23] |
| 1971 | L.R. Kuhns firstly describes tracheal tube position in infants using chest radiograph[11] |
| 1972 | C. Stiles describes flexible fiber optic laryngoscope[39] |
| 1974 | J. Robinson describes the assessment of tube placement using respiratory function[35] |
| 1979 - onwards | Calculations to correctly position an oropharyngeal and nasopharyngeal tube[12,52-55,57] |
| 1983 | First report of capnography for detection of accidental esophageal intubation in adults by K. Linko[26] |
| 1986 | First study describing Ultrasound to confirm correct tube position[59] |
| 1990 | Magnetically detectable tracheal tubes[14] |
| 1992 - onwards | Studies investigating colorimetric, main, side and micro-stream $CO_2$-detectors[2-5,19,28] |
| 2000 | M. Weiss describes the video laryngoscopy technique for the intubation of newborns[45] |
| 2006 - onwards | Studies examining respiratory functions to detect correct tube placement[2,5] |
| 2007 - onwards | Studies examining ultrasound to detect correct tube placement[61,62] |

**Table 2: Comparison of available studies**

| Study | Design | Comparison | Number of intubations | Results | PP |
|---|---|---|---|---|---|
| | | | **External digital tracheal palpation** | | |
| Jain[58] | Randomized trial | Chest radiograph vs. suprasternal digital tracheal palpation | 54 | Digital palpation correctly predicted tube position by chest radiograph in 70% | 75 |
| | | | **Exhaled Carbon dioxide** | | |
| Aziz[4] | Observational | Clinical Assessment vs. PediCap® | 45 | $CO_2$ correctly identified 30/33 tracheal, 12/12 esophageal tubes, 3/33 tubes wrongly identified by the PediCap® as in the esophagus, clinical assessment correctly identified all tubes (33 tracheal, 12 esophageal) | 10 |
| Repetto[19] | Observational | Clinical Assessment vs. Main-stream end-tidal $CO_2$ | 27 | $CO_2$ and clinical assessment correctly identified 16/16 tracheal, 11/11 esophageal tubes | 10 |
| Roberts[3] | Observational | Clinical Assessment vs. Side-stream end-tidal $CO_2$ | 100 | $CO_2$ correctly identified 59/60 tracheal, 40/40 esophageal intubations, and failed to identified 1 tracheal intubation; clinical assessment failed to identify 36/40 esophageal intubation | 62 |
| Hosono[28] | Observational | Clinical Assessment vs. Micro-stream end-tidal $CO_2$ | 54 | $CO_2$ correctly identified 40/40 tracheal, 14/14 esophageal tubes; clinical assessment failed to identify 3/14 esophageal intubation | 93 |
| | | | **Respiratory Function Monitor** | | |
| Schmölzer[5] | Observational | Flow sensor vs. PediCap® | 35 | Flow sensor correctly identified 32/32 tracheal, 3/3 esophageal tubes; PediCap® correctly identified 21/32 tracheal, 3/3 esophageal intubations; 11/32 tubes wrongly identified by the PediCap® as in the esophagus | 10 |
| | | | **Ultrasound** | | |
| Lingle[60] | Observational | Ultrasound vs. Chest radiograph | 9 | Placement of 4 tubes correctly identified, 2 misplacement | To |
| Dennington[62] | Observational | Ultrasound vs. Chest radiograph | 29 | Placement of 29 tubes correct identified | No ana |

Figure 1


A
PRESSURE IN OESOPHAGUS.
cm H2O
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VOLUME CHANGE IN OESOPHAGUS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
TIME (sec)
Female get 65
B
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0
Ventilation Pressure (cm H2O)
Gas Flow (mL/sec)
Carbon Dioxide (CO2) (mm Hg)
Tidal Volume (VTe) (mL)
Flow towards the infant
No Flow away from the infant
No VTe or CO2 is displayed
C
Flow towards the infant
Flow away from the infant
VT and CO2 waves are displayed