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Confirmation of Correct Tracheal Tube Placement in Newborn Infants

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39

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51 Georg M. Schmölzer: Dr. Schmölzer conceptualized and designed the study, carried
 52 out the initial literature search and analysis of available literature, drafted the initial
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54

55 Megan O'Reilly: Dr. O'Reilly carried out the initial literature search and analysis of
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59 Peter G. Davis: Dr. Davis performed a literature search and analysis of available
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 65 submitted.

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

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74

75 **Abbreviations:**

76 NICU - Neonatal intensive care unit

77 DR - Delivery room

78 CO₂ - Carbon dioxide

79

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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.

97 **Background**

98 Tracheal intubation remains a common procedure in the neonatal intensive care unit
 99 (NICU) and the delivery room (DR)¹⁻⁵. The insertion of a tube into the trachea to
 100 inflate the lungs of newborn infants has been routinely practiced for almost a century.
 101 James Blundell described digital intubation in 1834 as “Inserting a tracheal catheter
 102 guided along the fingers, through which the accoucheur could inflate the infant’s
 103 lungs with his own breath”⁶. However, it took almost a century until Flagg described
 104 his technique of introducing a metal tube into the trachea, using a small
 105 laryngoscope incorporating an electric light⁷. Blaikley and Gibberd later suggested
 106 using a rubber catheter instead of the rigid metal tube in 1935⁸. Until the 1970s,
 107 tracheal intubation was considered a simple procedure once the anatomy and the
 108 manipulation of the laryngoscope were understood^{9,10}. With the introduction of chest
 109 radiography, tube position became clearly visible and malposition of the tracheal tube
 110 was able to be detected¹¹.

111
 112 The current gold standard for confirming tube position is a chest radiograph, however
 113 this is often delayed until after ventilation via the tube has been commenced¹¹. Rapid
 114 confirmation of correct tracheal tube placement at the point of care is important
 115 because tube malposition is associated with serious adverse outcomes, including
 116 hypoxemia, pneumothorax, lung collapse and death^{1-3,12-15}. This has led to the
 117 development of new methods to confirm correct tube placement. Various techniques
 118 have been studied to enable i) correct tube placement and ii) optimal position within
 119 the trachea (Table 1). These techniques include i) clinical signs, ii) measurement of
 120 tube length based on parameters of body size or gestational age, iii) fiber optic
 121 techniques, iv) respiratory function, iv) chest radiograph, vi) capnography, vii)
 122 ultrasonography, and viii) magnetic detection. However, rates of correct tube
 123 placement, particularly for junior medical staff, are less than 50% and accidental
 124 esophageal intubation is common^{1,2,5,16}.

125
 126 The aim of this article was to review the available literature about tracheal tube
 127 placement in neonates. Critical issues that must be addressed when correctly placing
 128 a tracheal tube include i) correct placement of the tube in the trachea and not the
 129 esophagus, ii) proper depth of the tube and iii) time to complete the procedure. The
 130 article describes intubation in the NICU and DR. All the available techniques and
 131 devices described can be used in both the NICU and DR during emergency and non-
 132 emergency intubations.

133

134 **Search strategy**

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

141 **Tracheal vs. esophageal tube placement**

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

146 *Clinical signs*

147 International resuscitation guidelines recommend clinical signs and CO₂ detectors to
148 confirm correct tube placement¹⁷. Clinical signs of correct tube placement include a
149 prompt increase in heart rate, chest wall movement, visualization during direct
150 laryngoscopy of the tube passing through the vocal cords, presence of breath sounds
151 in the axillae and absence of breath sounds in the epigastrium and condensation in
152 the tube during expiration¹⁷. Direct laryngoscopy to observe passage of the tube
153 through the vocal cords was first described by Roberts in 1949⁹. Condensation of
154 water vapor in the tube lumen, although less likely with esophageal intubation, can
155 occur and hence is not a reliable sign¹⁸. In 1964, Doss reported his experience in an
156 essay on “Resuscitation of the Newborn”, stating that “The chest is auscultated while
157 blowing into the tube to verify that the latter is in the trachea”¹⁰. Bednarek et al., in
158 1975, reported 9/14 intubation of the right main bronchus: Four were without
159 complications, four caused atelectasis of varying degrees and one resulted in
160 bilateral pneumothoraces¹⁵. “Chest rise” is another clinical sign used to identify
161 correct tube placement. Doss described his observation of unilateral chest rise to
162 identify unilateral main bronchus intubation; “If only the right lung expands the tube is
163 withdrawn a little”¹⁰. More important, movement of the chest wall simulating
164 ventilation of the lungs can be seen with an esophageal tube¹⁸. Observational studies
165 in the delivery room during mask ventilation have shown that judgment of chest rise
166 is inaccurate^{21,22}. Several studies have reported that recognition of esophageal
167 intubation, using clinical signs alone, may take several minutes^{2,4,5,18,19}. In summary,
168 a number of clinical signs aim to identify correct tube placement but none have been
169 systematically studied. The best indicator that the tube is in the trachea remains the
170 clinical response when the patient shows a prompt increase in heart rate^{17,20}.

171
 172 *Exhaled Carbon Dioxide (CO₂)*
 173 CO₂ is exhaled from the lungs at concentrations much higher than present in air. It
 174 can be detected using colorimetric devices or measured quantitatively using main-
 175 stream, side-stream or micro-stream devices^{3-5,19,23-28}. Measuring exhaled CO₂ by
 176 infrared gas analysis to monitor patients during anesthesia was first described in the
 177 1960s^{23,24} (Table 1). However, using end-tidal CO₂ to detect correct tube placement
 178 was first described in an animal model by Murray in 1983 and in human patients by
 179 Linko in 1983^{25,26}. International resuscitation guidelines recommend clinical
 180 assessment and exhaled CO₂ to confirm correct tube placement immediately after
 181 intubation¹⁷. Although CO₂ devices are frequently used to assess tube placement²⁹⁻³²,
 182 false negative results may occur, particularly when cardiac output is low³³ or when
 183 the infant is in severe respiratory failure and the inflation pressure is not high enough
 184 to ventilate the lungs^{5,34}.

185
 186 Disposable semi-quantitative colorimetric CO₂-detectors are recommended in
 187 international guidelines. With each inflation and expiration a pH-sensitive chemical
 188 indicator undergoes color change (e.g. from purple to yellow), reflecting the change
 189 in CO₂ concentration in the gas passing through it. Garey et al. reported the tidal
 190 volume threshold achieve color change at the Pedi-Cap with >0.72 mL²⁷. An absence
 191 of color change suggests that the tube is not in the trachea. However, false negative
 192 findings may occur as listed above. Evidence comes from one observational and one
 193 prospective cohort study (Table 2). Aziz et al. compared the Pedi-Cap® (Nelcor
 194 Puritan Bennett, Pleasanton, CA) with clinical evaluation and radiography findings for
 195 tracheal intubation in 45 newborn infants (24 (53%) in the DR and 21 (47%) in the
 196 NICU) who required tracheal intubation. In that study, the Pedi-Cap® correctly
 197 identified 30 tracheal tube placements and 12 esophageal tube placements (Table
 198 2). However, in three cases a false negative result (no color change) was displayed⁴.
 199 Schmölzer et al. compared flow signals with the Pedi-Cap® in 35 intubations (Table
 200 2). The flow signal correctly identified all tube placements correctly, whereas the
 201 Pedi-Cap® failed to change color on 12 occasions when the tube was correctly
 202 placed⁵. Colorimetric CO₂-detectors may mislead clinicians intubating very preterm
 203 infants in the delivery room and may fail to change color despite correct tube
 204 placement in up to one third of cases⁵.

205
 206 Systems with either main-stream, side-stream or micro-stream measurement of end-
 207 tidal CO₂ have been described^{3,19,28} (Table 2). Repetto et al. compared end-tidal CO₂

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. 30sec¹⁹. Roberts et al. compared side-stream capnography with clinical assessment in 100 intubations in 55 infants³. 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 cases³. In comparison, Hosono et al. demonstrated that compared to clinical assessment, micro-stream CO₂-detectors correctly identified all tube placements, whereas clinical assessment failed to identify three of eleven esophageal tube placements²⁸. We need to emphasize that although micro-stream CO₂-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 CO₂ 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 CO₂-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 placement³⁵ (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 volume³⁶. A flow sensor placed between the tube and the ventilation device can be used to determine tube placement³⁷. 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 CO₂-detector in an ovine model of neonatal resuscitation³⁷. Both colorimetric CO₂-detector and flow signal identified all tube placements correctly. However, the colorimetric CO₂-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 placement². 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 CO₂-detector during 35 intubation attempts of 20 infants during neonatal resuscitation⁵. 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 CO₂-detector failed to change color despite the flow wave indicating correct placement. This study suggests that colorimetric CO₂-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 tree³⁸. 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.

264

265 *Fiber Optic Devices*

266 A fiber optic laryngoscope/ bronchoscope for endotracheal intubation was first
267 described by Stiles in 1972³⁹ (Table 1). These devices emit light, and development of
268 the ultrathin bronchoscope has made flexible endoscopic intubation for the neonate
269 and small infant possible. Advantages include: i) easy identification of the carina or
270 the esophagus and ii) intubation can be performed either via nasal or oral route, high
271 correlation with chest radiograph³⁹⁻⁴². However, limitations and disadvantages include
272 i) desaturation during the procedure, ii) time required to visualize the vocal cords,
273 and iii) special training which is necessary to operate the flexible fiberscope
274 efficiently in emergency settings³⁹⁻⁴².

275 Fiber optic devices have been used to i) intubate newborn infants in the NICU⁴³ and
276 ii) assess correct tracheal tube placement^{40,41}. Finer et al. described non-emergency
277 endoscopic intubation of newborn infants in the NICU using a bronchoscope⁴³. The
278 majority of those infants were intubated prior to surgery or to investigate upper
279 airway abnormalities. There was evidence of transient hypoxemia during the
280 introduction of the bronchoscope into the trachea, but no infant had an oxygen
281 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 trachea⁴³. 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 laryngoscopes⁴⁴.

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 burns⁴⁵⁻⁴⁹. Disadvantages include: i) increased weight of the laryngoscope handle, and ii) failure of the light source, although this can occur with any laryngoscope⁴⁵⁻⁴⁹. 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 laryngoscope⁴⁶. Although three intubations required more than three attempts with the video laryngoscope, the overall number of intubation attempts was reduced⁴⁶. Trevisanuto et al. reported video guided intubation using the GlideScope[®] in five newborn infants⁴⁷. 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 laryngoscopy⁴⁸ and reported no difference between the two devices⁴⁸. 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.

320

321 *Chest Radiograph*

322 A chest radiograph can be used to confirm correct tube position within the trachea,
323 which should be just below the level of the vocal cords and well above the carina.
324 Various techniques have been described to achieve tube positioning above the
325 carina prior to X-ray confirmation, but tube displacement, particularly into the right
326 main bronchus, remains common^{11,50}. While the current gold standard to assess
327 correct tube placement is chest radiography, no study has formally investigated the
328 use of chest radiographs to confirm tracheal tube placement in either the NICU or
329 DR¹¹. Guidelines for the interpretation of chest X-ray to assess correct tube
330 placement vary. Usually, the lower limit for the position of the tube is measured in
331 relation to the carina. The tip should be between 0.2 to 2 cm above the
332 carina^{11,13,15,51}. The medial border of the clavicles has been used in studies as
333 reference point, however the position of the clavicles can range from the 4th cervical
334 vertebrae to the 2nd thoracic vertebrae on chest radiographs⁵¹. In addition, studies
335 have shown that head extension or flexion from the neutral position can move a
336 tracheal tube by an average of 0.7 cm in either direction in newborns⁵¹. Hence using
337 the 1st thoracic vertebrae has been suggested to be an alternative reference point.

338

339 *Estimation of correct endotracheal tube insertion*

340 Several formulae have been proposed to achieve correct tube placement within the
341 trachea^{12,52-57}. In 1987 Yates et al. developed a formula based on tube lengths
342 recorded in their study (internal diameter x 3 + 2 cm)⁵². However, this formula has not
343 been tested in further studies. In 1979, Tochen described a simple formula to
344 determine the depth of tube insertion⁵³. The "tip-to-lip" distance or "7-8-9 rule",
345 estimates the depth (cm) of tube insertion to be $[1.17 * \text{infant's weight (in kg)} +$
346 $5.58]$ ⁵³. Using this formula an infant weighing 1kg would be intubated to a depth of
347 7cm, a 2kg infant to a depth of 8cm, and a 3kg infant to a depth of 9cm⁵³. However,
348 several studies have shown that the Tochen's 7-8-9 rule led to incorrect tube
349 placement in almost half of the infants studied. Peterson et al. studied the accuracy
350 of the 7-8-9 rule for tube placement in 75 consecutively intubated infants of less than
351 32 weeks gestation⁵⁴. Although correct tube placement was confirmed in infants >
352 750g body weight, tube depth was overestimated in infants < 750g⁵⁴. Amarilyo et al.
353 also assessed the reliability of the 7-8-9 rule during oro-tracheal intubation in 31
354 infants < 1000g¹². In almost half of the infants (47%), the rule resulted in incorrect

355 tube placement when checked by chest radiograph¹². Furthermore, Kempley et al.
 356 recently re-examined Tochen's rule and reported that it assumes a linear relationship
 357 between tube and body length and body weight^{56,57}. The relationship, although linear
 358 for gestational age, is non-linear for body weight⁵⁷. Furthermore, the rule does not
 359 apply for naso-tracheal intubation.

360

361 *External digital tracheal palpation*

362 The practice of tube palpation dates back to the time of its first use in 1834 by British
 363 obstetrician, James Blundell, who used an tracheal tube to resuscitate an infant⁶.
 364 Blundell noted that following digital intubation "the tracheal pipe can be felt on the
 365 front of the neck whether the instrument is lying in the trachea or esophagus"⁶.
 366 Bednarek et al. in 1975 reported that tracheal tube position could be confirmed using
 367 digital suprasternal palpation in neonates and small infants¹⁵. Once the tube is
 368 placed and the tip can be gently palpated in the suprasternal notch the position is
 369 considered correct. Two studies compared external digital tracheal palpation to direct
 370 laryngoscopy^{15,58}. Bednarek et al. reported that infants in the palpation group had
 371 significantly more accurate tube placements, significantly lower rates of
 372 complications, and no adverse effects compared to direct laryngoscopy¹⁵. In a
 373 randomized controlled trial, Jain et al. showed that digital palpation correctly
 374 predicted tube position on chest radiograph in 70% of included infants⁵⁸. Digital
 375 palpation resulted in a small, non-significant improvement in rates of correct
 376 placement compared with standard weight based criteria⁵⁸. The authors concluded
 377 that suprasternal palpation appears to be a simple and teachable method of
 378 confirming tracheal tube position in neonates when chest radiograph is unavailable,
 379 and may be especially helpful during neonatal resuscitation prior to surfactant
 380 administration.

381

382 *Fiber Optic Devices*

383 Fiber optic devices have been used to i) intubate newborn infants in the NICU⁴³ and
 384 ii) assess correct tracheal tube placement.^{40,41} Vigneswaran et al. studied the use of
 385 a 1.8mm fiberoptic bronchoscope for confirmation of tracheal tube position in 20
 386 intubated infants⁴⁰. They concluded that the bronchoscopic technique of determining
 387 tracheal tube position is as safe and accurate as the radiologic technique (correlation
 388 0.91)⁴⁰. Shinwell et al. reported their experience in 65 infants⁴¹ and reported that the
 389 accuracy of bronchoscopic measurement of tracheal tube tip position improved
 390 markedly with user experience and correlated very well (0.96) with chest
 391 radiograph⁴¹. 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.

394

395 *Ultrasound*

396 In 1986 Slovis et al. demonstrated that real-time ultrasound could be used to verify
397 correct tube position in newborn infants⁵⁹ (Table 1). Slovis et al. used the aortic arch
398 as a reference point and showed that tube position could be accurately determined in
399 18/21 (85%) intubations⁵⁹. Lingle et al. showed similar results using the same
400 technique⁶⁰. Galicinao et al. used two views with a linear transducer in infants and
401 children to verify correct tube placement⁶¹. Compared to physical examination +
402 colorimetric devices + chest radiography, bedside ultrasound was much faster⁶¹.
403 Dennington et al. (Table 2) reported good correlation between ultrasound and
404 radiograph measurements with most values being within 0.5 cm⁶². Advantages of
405 ultrasonography over radiography include: i) reduced radiation, ii) less handling,
406 particularly in critically ill infants, iii) potential to determine the tube position in the
407 delivery room particularly for early surfactant delivery and iv) earlier detection of
408 complications from malposition⁵⁹⁻⁶². Disadvantages of ultrasonography are i) the
409 specialized skills required, ii) difficulties to correctly identify anatomical landmarks
410 and iv) lack of widespread availability⁵⁹⁻⁶². These observational studies demonstrate
411 that ultrasound can be used to visualize tracheal tube position in infants. However, 1-
412 2 specially trained investigators performed all ultrasound evaluations in the reported
413 studies, which is a major limitation of these studies. And therefore it is not applicable
414 for daily clinical use. Randomized control trials are required before implementation of
415 this technique.

416

417 **Duration of the procedure**

418 Guidelines of the Neonatal Resuscitation Program developed by the American
419 Academy of Pediatrics recommend that the intubation procedure is completed within
420 30 seconds¹⁷. Two observational studies reported the times to intubate preterm
421 infants in the DR using a laryngoscope^{2,63}. Overall, 50-60% of intubation attempts
422 were successful, with the majority occurring within 30 seconds^{2,63}. Interestingly, two
423 studies reported that digital intubation was significantly faster compared to intubation
424 using a laryngoscope^{64,65}. However, digital intubation is not routinely used during
425 neonatal intubation.

426 Several studies have reported that experience significantly increased success rate of
427 tracheal intubation^{1,2,16,63}. O'Donnell et al. reported a significant difference between
428 grades of doctors, with more senior doctors intubating more rapidly². However, the

429 study by Lane et al. reported that fellows were on average 10 seconds faster than 1st
430 year residents or consultants⁶³. The main concern is the decrease exposure of
431 endotracheal intubation during residency and fellowship training^{1,16}. Leone et al.
432 reported that the mean number of intubation attempts per resident throughout
433 training decreased from 38 (± 19) in 1994 to 12 (± 6) in 2002¹. In addition, non-
434 invasive methods of respiratory support has been advocated which further reduces
435 the number of intubation attempts^{66,67}. Manikin studies reported significant
436 improvement in the time to visualize the vocal cords with the video laryngoscope
437 compared to direct laryngoscopy⁶⁸. However, success rate were similar within the
438 groups⁶⁸. In comparison, a randomized trial comparing intubation time for the
439 GlideScope[®] video laryngoscope with direct laryngoscopy reported no difference in
440 intubation time or success rate of intubation between the devices⁴⁸.

441

442 **Conclusions**

443 Currently chest radiography remains the accepted standard test to confirm tube
444 position. An increase in heart rate is the best indication of effective ventilation.
445 Exhaled CO₂ may give misleading, false negative results and readings should be
446 interpreted in conjunction with clinical signs. Respiratory function monitors, video
447 laryngoscopes, fiber optic devices and ultrasound to confirm tube position are
448 promising methods but require evidence from clinical trials before recommendations
449 can be made for their use in clinical practice.

450

451 **Figure legend:**

452 **Figure 1:** Figure 1A: Esophageal and tracheal flow waves to identify correct tube
453 placement comparison described by Robinson 1973³⁵. In comparison airway
454 pressure, gas flow, tidal volume and end-tidal CO₂ waves from a preterm infant born
455 at 29 weeks gestation requiring intubation in the delivery room. Figure 1B -
456 Esophageal intubation: Gas flow towards the infant is present. However, no
457 expiratory gas flow, tidal volume or end-tidal carbon CO₂ is displayed. Figure 1C –
458 Tracheal intubation: Gas flow towards and away from the infant is present. In
459 addition, tidal volume or end-tidal CO₂ are displayed.

460 Figure 1A: Reproduced from [Respiratory recording from the oesophagus,
461 Robinson³⁵], Br Med J. 1974; 4 (5938), 225, 2012] with permission from BMJ
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463 Figure 1B & 1C: Reproduced from [Monitoring during neonatal transport, O'Reilly⁷¹,
464 Emergency Medicine 2012, epub] with permission from O'Reilly et al.

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761 **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 Neonatorum⁶
- 1895 A. Kirstein invented the modern laryngoscope⁶⁹
- 1921 Sir I. Magill recommends the sniffing position for endotracheal intubation⁷⁰
- 1928 P.J. Flagg describes his technique of introducing a metal tube into the trachea using a small electrically lighted laryngoscope⁷
- 1935 J.B. Blaikley and G.F. Gibberd suggest to use a rubber catheter instead of the rigid tube⁸
- 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 Burton²³
- 1971 L.R. Kuhns firstly describes tracheal tube position in infants using chest radiograph¹¹
- 1972 C. Stiles describes flexible fiber optic laryngoscope³⁹
- 1974 J. Robinson describes the assessment of tube placement using respiratory function³⁵
- 1979 - Calculations to correctly position an oropharyngeal and
onwards nasopharyngeal tube^{12,52-55,57}
- 1983 First report of capnography for detection of accidental esophageal intubation in adults by K. Linko²⁶
- 1986 First study describing Ultrasound to confirm correct tube position⁵⁹
- 1990 Magnetically detectable tracheal tubes¹⁴
- 1992 - Studies investigating colorimetric, main, side and micro-stream CO₂-
onwards detectors^{2-5,19,28}
- 2000 M. Weiss describes the video laryngoscopy technique for the intubation of newborns⁴⁵
- 2006 - Studies examining respiratory functions to detect correct tube
onwards placement^{2,5}
- 2007 - Studies examining ultrasound to detect correct tube placement^{61,62}
onwards

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764 **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)	100%
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	100%
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 identify 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	100%
Ultrasound					
Lingle ⁶⁰	Observational	Ultrasound vs. Chest radiograph	9	Placement of 4 tubes correctly identified, 2 misplacement	Too small
Dennington ⁶²	Observational	Ultrasound vs. Chest radiograph	29	Placement of 29 tubes correct identified	No analysis

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Figure 1

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