Monitoring during Neonatal Transport

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Abstract

Approximately 1% of newborn infants require transport for continuation of neonatal care. Main indications are congenital malformations, respiratory distress syndrome and hypoxic ischemic encephalopathy. Specialized neonatal transport teams are skilled in patient care, communication, equipment management, and extensively trained in resuscitation, stabilization, and transport of critically ill infants. There is increasing evidence that clinical assessment is imprecise and can be misleading. This article aims to describe potential monitoring to aid the neonatal transport team during stabilisation and transport of critical ill newborns.

Keywords: Newborn; Infants; Neonatal transport; Respiratory function tests; Pulse oximetry; Carbon dioxide

Abbreviations: NICU: Neonatal intensive Care Unit; DR: Delivery Room; SpO₂: Oxygen Saturation; HR: Heart Rate; RFM: Respiratory Function Monitor; ETT: Endo Tracheal Tube; PIP: Peak Inflation Pressure; PEEP: Positive End Expiratory Pressure; Vₜ: Tidal Volume; CO₂: Carbon dioxide; ETCO₂: End Tidal Carbon dioxide; TCO₂: Transcutaneous Carbon dioxide; PPV: Positive Pressure Ventilation

Introduction

Approximately 1% of newborn infants require transport for continuation of neonatal care [1-7]. One third occur within the first 24 hours and the remaining during the first week [2,4,7]. Main indications for neonatal transports are congenital malformations, respiratory distress syndrome and hypoxic ischemic encephalopathy [1-5,7-10]. Specialized neonatal transport teams are skilled in patient care, communication, equipment management, and extensively trained in resuscitation, stabilization, and transport of critically ill infants [3,4,6,11-15]. Both the critically ill neonate and the neonatal transport team are exposed to mechanical stressors e.g: shock, vibration, and noise during emergency transports [12,15-18]. Exposure to these stressors affects the critical ill neonate as well as the transport team and their ability to assess an infant during transport [4,12,15,16-18]. An ambulance has more dynamic effects in terms of braking, shock, and impulsive noise than a helicopter [16]. However, a helicopter produces higher mean noise levels compared to an ambulance. Sittig et al. compared the noise level in four different helicopters [18]. Although an incubator provided a 6 decibel decrease in noise exposure compared to the crew cabin, the average noise level in the incubator in all aircraft was almost 80 decibels. This level of noise is much higher than the proposed limits of 45 decibels for neonatal intensive care unit noise exposure and 60 decibels during transport [18]. These noise levels make it difficult to assess a critical ill neonate [3,4,12,15,16,18,19].

Search Strategies

The aim of this article is to review the available literature about monitoring during neonatal transport. We reviewed books, resuscitation manuals and articles from 1950 to the present with the search terms "Infant, Newborn", "Neonatal transport", "Respiratory Function Tests", "Heart Rate", "Pulse Oximetry", "Carbon Dioxide", and "Temperature". Only human studies were included.

Clinical Assessment

Clinical assessment during neonatal transport includes respiratory (e.g. respiratory rate and respiratory distress), cardiovascular (e.g. heart rate and color) and neurological signs (e.g. tone and responsiveness).

However, exposure to mechanical stressors such as shock, vibration or noise makes clinical assessment difficult during neonatal transport [20].

International resuscitation guidelines recommend assessment of chest wall movements to guide mask ventilation in the delivery room [20]. However, recent studies have shown that chest rise to assess tidal volume delivery during mask ventilation is imprecise [21,22]. During neonatal transport, assessment of chest rise to assess ventilation is limited [2]. However, a respiratory function monitor (RFM) can provide the clinical team with continuously measured respiratory parameters (Figures 1-7) [2,23,24].

Absent or unilateral air entry during auscultation could be an indicator of pneumothorax. However, noise levels and vibrations in helicopters or ambulances make clinical diagnosis of a pneumothorax challenging [16,19]. Although an esophageal stethoscope can identify breathing sounds during transport, no study has assessed it’s potential to diagnose a pneumothorax [25].

Oxygen Saturation (SpO₂)

Fetal oxygen saturation is normally around 60% with a potential decrease during labor and birth to around 30% [26]. Immediately after birth, term infants have SpO₂ values around 60%, which continue to rise to >90% over the next 10 minutes [27]. Studies have demonstrated that SpO₂ values can be obtained within 90 seconds after birth [27-30]. This is important, since judging an infants color is imprecise [31-32]. Neonatal transports carried out over-night makes the assessment of an infant’s color challenging. In addition, incubators are covered to decrease the impact from the environment, which blocks light inside the incubator making colour assessment challenging, even during the day in an aircraft or ambulance.

During air transport the barometric pressure decreases with altitude; at sea level barometric pressure is 760 mmHg compared to 565 mmHg in a pressurized aircraft [15]. This will lead to an equivalent percentage.
arterial oxygen saturation [39]. Pulse oximetry is based on infrared light absorption of oxygenated and deoxygenated haemoglobin [20,39]. A sensor is placed around an infant’s wrist and light-emitting diodes send infrared light to a photodetector on the other side [20,39]. SpO₂ is estimated from transmission of light through pulsatile tissue bed. In addition, each heart beat results in a surge of arterial blood flow [21,22,40], which is used to measure HR [2,39].

Vibration can cause intermittent failure or signal artifacts [2,17,23,24,41]. Short et al. tested seven different pulse oximeters during helicopter flight [16,17,19]. With the exception of two pulse oximeters, all demonstrated minimal signal artifact [17,25].

Transcranial oximetry is a new method to measure continuous changes in brain blood oxygen saturation by using near-infrared spectroscopy. However, this has only been reported in adult volunteers.

Heart Rate

Dawson et al. recently described changes in HR in the first minutes after birth [26,42]. Furthermore, an increase in HR is an important reduction in partial oxygen pressure, which causes a decrease in displayed SpO₂ values [33,34]. During fixed-wing air transports, cabin pressure can be adjusted. However, during helicopter transport cabin pressure cannot be adjusted, which can cause a decrease in an infant’s oxygen saturation [15,33-35]. A study comparing pulse oximetry and near infrared spectroscopy reported a slight decrease in SpO₂ and cerebral oxygen saturation levels with increasing altitude (0 to 5,000 feet). However, the study was carried out in adult volunteers and the lowest SpO₂ level remained within the adult physiological range [36]. Graham and Houston brought eight patients with chronic obstructive pulmonary disease (COPD) from sea level to 1920m and found that the PaO₂ fell from 66 to 52mmHg after 3h [37]. During commercial flights, patients with COPD or restrictive lung diseases demonstrate that patients develop significant arterial hypoxemia when exposed to altitudes of 1830 to 3050m and that oxygenation worsens with minimal levels of exertion [38]. However, no study has evaluated the changes in oxygenation in term or preterm infants.

A pulse oximeter continuously measures SpO₂ and heart rate (HR) non-invasively (Figure 8). Further advantages are close correlation with
clinical indicator of adequate breathing and respiratory support [27,43]. International resuscitation guidelines recommend assessment of an infant’s HR immediately after birth using a stethoscope [20,27-30]. Alternatively the umbilical cord can also be palpated [20,31,32].

An observational study in the delivery room showed that auscultation and umbilical cord palpation is inaccurate and underestimates HR compared to an electrocardiogram [15,44]. Kamlin et al. determined the accuracy of HR obtained by pulse oximetry relative to HR obtained by 3-lead electrocardiography in newborn infants in the delivery room [30,33,34]. Pulse oximetry provided an accurate display of newborn infants’ HR in the delivery room, including those infants receiving advanced resuscitation [15,30,33-35]. Hence pulse oximetry can be used to determine an infant’s HR during neonatal transport (Figure 8). In addition, a pulse oximeter displays HR continuously during neonatal transports, thus allowing the team to continue resuscitation efforts without stopping to listen to the HR (Figure 8) [36,39]. Alternatively, an esophageal stethoscope has been reported to continuously monitored heart sounds [25].

Respiratory Function Monitor (RFM)

Guidance of mechanically ventilated infants by displayed respiratory function is standard of care in the NICU [23,45,46]. In addition, tidal volume monitoring has recently been advocated for neonatal resuscitation and neonatal simulation [24,47-51]. However, this technique has not been implemented during neonatal transport [2].

To monitor respiratory function allow sensor is placed between the ventilation device and endotracheal tube (ETT). An airway pressure line measures peak inflation pressure (PIP) and positive end expiratory pressure (PEEP) directly from the circuit. The monitor automatically calculates tidal volume (Vₜ) passing through the sensor by integrating the flow signal. Furthermore, the RFM continuously displays graphical waveforms and numerics of PIP, PEEP, Vₜ, leak around the ETT, minute ventilation, respiratory rate, inspiration and expiration times [24,49,52-55].

Intubation remains a common procedure during neonatal resuscitation, stabilization and transport [2,3,12]. In the delivery room, esophageal intubation is common particularly for junior staff [56-59]. Furthermore, around 40% of all intubated neonates in the NICU had incorrectly placed ETT [60-62]. The current gold standard to identify correct tube placement is a two-view chest radiograph.

Neonatal resuscitation guidelines recommend clinical signs and exhaled CO₂ (Figure 4) to assess correct ETT placement [20]. However, clinical signs can be misleading and studies using exhaled CO₂ detectors reported false negative results [56-58,63-66]. In comparison a RFM has been described to correctly identify ETT placement (Figure 5).
infants during the first 24 hours [74]. Alternatively, an esophageal stethoscope has been reported to detect breath sounds [25].

During neonatal transport mechanical ventilation is indirectly guided by HR, SpO2, end-tidal CO2 (ETCO2) or transcutaneous CO2(TCO2) and O2 tension [26,68,69]. Tracy et al. demonstrated that 25% of preterm infants receiving ventilation in the delivery room were over-ventilated and have hypocapnia on arrival in the NICU [70]. This has also been observed during neonatal transports [4,68]. Lilley et al. demonstrated that infants achieved target transcutaneous CO2 tension within 15 minutes when ventilation was guided by an RFM [2]. However, the study design and low numbers of included infants did not allow the results to be directly attributed to the use of the RFM. Furthermore, an RFM can be used to identify leak around the endotracheal tube (Figure 2) [2,53,71], airway obstruction (Figure 3) [53,54,72], correct and esophageal tube placement (Figure 4) [58,63,67], accidental extubation (Figure 5) [24], and adequate tidal volume delivery (Figure 6) [2,21,22,49]. An esophageal stethoscope has been reported to detect ETT obstruction and displacement. However, it is unclear whether similar benefits will be observed and of the outcomes following mechanical ventilation with an RFM during neonatal transport in conjunction with the standard techniques of clinical assessment [52,73].

Carbon Dioxide Monitoring

Arterial blood gas analysis remains the gold standard for assessing the adequacy of mechanical ventilation [74]. However, continuous non-invasive CO2 monitoring has become an important bedside tool during neonatal transport [68,74-78]. CO2 can be effectively monitored during neonatal transport with either ETCO2 [68,75,76,79,80], TCO2 [68,69] or arterial CO2 measurement [69]. ETCO2 is measured using main-, side- or microstream technology [68,75,81,82]. Potential clinical applications are identification of correct ETT placement (Figure 4) [83] and airway obstruction (Figure 5) [84]. In addition, colorimetric CO2 detectors have been advocated [20] to identify correct ETT placement [57,58,63,65-67,85]. Recently colorimetric CO2 detectors have also been used to observe return of spontaneous circulation during resuscitation [75,76]. Tracy et al. showed that 25% of preterm infants ventilated in the delivery room had hypocapnia on arrival in the NICU [70]. Therefore continuous CO2 monitoring should be used during mechanical ventilation. Tingay et al. showed that ETCO2 was imprecise compared to arterial CO2, which suggests that TCO2 should currently be considered for non-invasive CO2 monitoring during neonatal transport [68,69]. However, there are some concerns with using TCO2. TCO2 probe warms the skin to 43°C, which results in vasodilatation of the capillary bed beneath. This facilitates CO2 diffusion from capillary lumen to the membrane of the TCO2 monitor [69]. This can cause alteration of the CO2 solubility in blood, burn injuries, and increases tissue metabolic rate by 4–5% for every °C [69,74,78,82]. In addition, improper calibration, trapped air bubbles, and damaged membranes are possible and may be difficult to detect [78]. The presence of hyperoxemia (PaO2 > 100 torr), hypoperfused state (shock, acidosis), or improper electrode placement might increase the discrepancy between arterial and transcutaneous values [78]. In comparison, birth weight, site of transcutaneous probe application, mean blood pressure and mean airway pressure does not affect TCO2 measurement [74]. Although non-invasive monitoring are promising and new technologies are emerging, the current available methods cannot be substituted for arterial CO2 analyses in preterm infants during the first 24 hours [74].

**Temperature**

Maintaining an appropriate thermal environment for newborn infants and avoidance of cold stress is important for short- and long term outcomes [33,87,88]. Studies reviewing neonatal transports over the last 4 decades reported a decreased rate of hypothermia (<36.0%) [4,15,87]. Alarming, hypothermia was present in around one third of infants ≤1000g at arrival of the transport team [4]. Despite active warming measures some infants remained hypothermic at arrival in the NICU [87]. In comparison, the rate of hyperthermia has increased significantly from 12% in 1977-79 to 24% in 1995-96 at arrival of the transport team for all infants except infants ≤1000g [87].

More recently, cooling for hypoxic ischemic encephalopathy has been advocated during neonatal transport. Therapeutic hypothermia can be achieved with passive or active cooling [1,8,89,90]. Passive cooling is achieved by allowing the infant to cool naturally with no external intervention. Although, passive cooling is a simple and effective technique, it has the potential for both over- and under cooling particularly without appropriate monitoring [1,89,90]. Active cooling requires adjuncts (e.g cold gel packs) [8,89]. However, active cooling without rectal temperature monitoring can result in overcooling [89,90]. Using skin temperature to monitor core temperature in neonates undergoing therapeutic hypothermia is not reliable [90]. Although, rectal temperature monitoring is used during cooling [8], esophageal temperature monitoring has been reported to be superior compared to tympanic, rectal, axillary, and bladder temperatures over a wide range of temperatures [91].

**Conclusion**

The information presented is from applicable clinical studies in neonatal intensive care and delivery room resuscitation. Unfortunately, there is a lack of trials during neonatal transport, which are urgently needed. However, it is extremely difficult to undertake good detailed randomised studies during emergency neonatal transports.

Specialized neonatal transport teams require skills in patient care, equipment management, and training in resuscitation, stabilization, and transport of critically ill infants. Clinical assessment is difficult during neonatal transport, hence extended monitoring to guide clinical status during transport is mandatory.

**Conflict of Interest**

None.

**References**

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