Improving neonatal resuscitation at birth : technique and devices

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General discussion

Neonatal resuscitation at birth: technique and devices

Based on two reviews:

Hans Fuchs, Kim Schilleman, Helmut D. Hummler, Arjan B. te Pas. Techniques, devices and new modes of non-invasive ventilation employed in the delivery room. *NeoReviews; issue on non-invasive ventilation in the delivery room, invited review*

Kim Schilleman, Frans J. Walther, Stuart B. Hooper, Peter G. Davis, C. Omar F. Kamlin, Arjan B. te Pas, Technique and devices for resuscitation of preterm infants at birth: a review. *Submitted*

Introduction

Approximately 3–5% of infants require resuscitation interventions or respiratory support at birth.[1] Adequate ventilation is the key to successful resuscitation and chest compressions or medication are rarely needed.[2,3] Especially preterm infants (< 32 weeks' gestational age) have more difficulties aerating their lungs[4,5] and approximately 60% of preterm infants need respiratory support at birth.[6] After birth, positive pressure ventilation (PPV), should be applied to infants without adequate respiratory effort in an appropriate, gentle way to create and maintain a functional residual capacity, facilitate gas exchange and minimise lung injury. Especially the immature lung is highly vulnerable to injury and ventilation immediately after birth may affect long-term morbidity and survival.[1,7-13]

Caregivers are guided by national and international guidelines and step-by-step flow charts on how to perform optimal resuscitation.[2,14,15] These resuscitation guidelines are based on very little data and our knowledge of neonatal transition is largely based on observations, assumptions and extrapolation instead of scientific evidence. However, knowledge on transition and resuscitative practice is currently being challenged. Research is rapidly evolving in this area, new evidence in resuscitation strategies is emerging, and there has been a shift to a more gentle and less invasive approach towards respiratory support of the preterm infant.[1,16,17]

Although resuscitation strategies and approach of a preterm infant at birth have been subject to large randomised trials,[18-20] very little attention has been paid to the technique used to provide PPV and the efficacy of the available devices. A good strategy should be combined with an adequate technique and effective device. Although observational and manikin studies are available, little evidence is based on randomised controlled trials investigating resuscitation technique, method of training and type of device.

Better methods of neonatal resuscitation monitoring have become available. Traditionally, the adequacy of ventilation in the delivery room is determined by evaluating chest excursions, heart rate and infant colour.[2] The relative insensitivity of estimating heart rate by palpation or auscultation, the subjectivity in judging colour and the dangers of hyperoxia have led to recommendations to use a pulse oximeter in the delivery room. However, the observation of respiration and chest excursions is still fraught with subjectivity. Respiratory function monitoring is used in the Neonatal Intensive Care Unit (NICU) as feedback for mechanical ventilation, but the same technique is currently not recommended to determine the efficacy of PPV in the delivery room. In 2009, the use of a respiratory function monitor during neonatal resuscitation was introduced in the neonatal division of the Leiden University Medical Center and is now considered standard of care in our delivery room.

The aim of this review is to discuss the results of this thesis, compare it with other studies in this field and to give an update on the currently available literature regarding techniques and devices used in neonatal resuscitation practice.

Mask technique

Primary intervention during neonatal resuscitation often relies on PPV with a facemask as interface. An airtight seal between the mask and the face is important for adequate ventilation.[21] Therefore, one of the most important skills caregivers in this field should have is an optimal mask holding technique. To achieve this skill, both correct placement of the mask and an adequate chin lift are necessary.[21] The rim of the mask should be placed on the tip of the chin and the mask should cover both mouth and nose, but not the eyes.[21] Wood et al. found that a more accurate positioning and better seal was achieved when the mask was rolled onto the face beginning at the tip of the chin as compared to when the mask was placed straight onto the face.[22] They also found that the optimal method of mask holding was dependent on which mask was used.[22] When using a Laerdal mask (Laerdal Medical, Stavanger, Norway), a two-point-top-hold provided the best seal, while for the Fisher & Paykel mask (Fisher & Paykel Healthcare, Auckland, New Zealand) the OK-rim-hold was found optimal.[22] To prevent too much pressure on the head of the infant, a chin lift should be performed using the same pressure upwards as applied by the thumb and index finger downwards onto the face. In this way the force of pushing the mask down on the face of the infant is countered by the chin lift and too much pressure on the head and airway obstruction is prevented.[23]

Tracy et al. tested an alternative, two-hand mask hold during simulated neonatal resuscitation where a second person operated the ventilation device. With this technique, leak decreased significantly.[24] However, in this study mask leak was small with both techniques in this study and although the large number of analysed inflations probably made the difference statistically significant, it is questionable whether this difference would also be clinically significant.

In chapter 2 of this thesis, we tested the mask holding techniques of consultants, registrars and nurses in our unit using a Laerdal round mask on a manikin.[23] We found that caregivers use many different holding techniques and that there was a high median percentage of mask leak in all groups. After teaching our caregivers the optimal mask holding technique described by Wood et al.,[22] we found that mask leak decreased significantly and that this effect persisted three weeks later when we retested the same caregivers.[23]

Studies have used different methods and definitions to assess airway obstruction and this may have influenced the variance in incidence of airway obstruction.[23,25,26] We reported that airway obstruction occurred often during this study and did not decrease after training.[23] In fact, considering that airway obstruction can only be measured when there is a minimal leak and the number of inflations with minimal leak increased after training, the absolute amount of obstructed inflations increased considerably after training.[23] We observed that participants pressed harder on the mask in order to minimise mask leak and this probably caused more airway obstruction after the training. However, this could not be confirmed when we studied the compressive force on the head of a manikin during simulated mask ventilation (chapter 4).[27] We observed a large variation in the amount of compressive force applied by the participants, but even the lowest force applied (606 grams) equated to a very significant pressure (49 mmHg) that could potentially be put on the newborn infant's skull. The applied force did, however, not correlate with the attempt to minimise mask leak or the occurrence of airway obstruction.[27] We experienced that the set ventilatory pressures on the manometer of the TPR only decrease in the presence of a very large leak. Thus, when set peak inflating pressure (PIP) and positive end expiratory pressure (PEEP) are not accurately reached, there is already a large leak. This confirms the findings of O'Donnell et al. that the manometer on the Neopuff T-piece device is not a good indicator of mask leak.[28] It is possible that a higher gas flow rate can compensate for mask leak.[29] A good mask seal, and thus minimal leak, when using a TPR, can be identified by a hissing sound due to air escaping from the PEEP valve and a blowing sound of the TPR during inspiration.[22,23]

These manikin studies taught us that inadequate mask holding occurs often and that mask leak, but not airway obstruction, was significantly reduced by training of correct mask technique. It is very important to regularly train caregivers in optimal mask technique, to enable them to learn and maintain this very important skill. During training, attention should be paid not only to reducing mask leak, but also on preventing airway obstruction. Pressing too hard on the mask should be avoided.

Although most caregivers are trained on manikins for mask technique, it is difficult to extrapolate the findings from manikin studies to resuscitation of human infants. Neonatal resuscitation is more stressful than a simulated setting and the response of an infant can be unpredictable. Mask ventilation of human infants may be even more difficult than on a manikin.

In our observational study (chapter 5), recording mask ventilation in preterm infants at birth, we confirmed that mask ventilation is frequently hampered by large leaks, leading to low and variable tidal volumes, especially during the initial sustained inflations. Large mask leaks during sustained inflations made it unlikely that the intended effect of these inflations, i.e. clearance of lung liquid and creation of functional residual capacity, was achieved.

Airway obstruction was observed less often in preterm infants than during our manikin studies. During our observational study in preterm infants, we detected airway obstruction in 20/27 included infants (74%) and in 108/837 inflations (13%) that were eligible for analysis. This may be due to caregivers paying more attention to the force applied onto the mask and/or that less flexion/hyperextension occurred. However, because mask leak is a confounder to airway obstruction it is possible that the occurrence of airway obstruction was underestimated.[23] Preterm infants are prone to airway obstruction due to their relatively large tongues and small mandibles.[25] Airway obstruction often occurs at the upper pharyngeal or laryngeal level near the vocal cords.[30,31] As head position influences airway obstruction, one could speculate that obstruction can be caused by flexing or overextending the neck,[23,25] but this has never been investigated. In a study by Schmölzer et al. obstruction was less likely to re-occur after repositioning of the facemask.[26] Perhaps, wrong mask position or too much pressure on the head of the infant obstructed the nose and/or the mouth.[23] However, in chapter 4 we found no correlation between the force applied to the head of a manikin and the amount of obstruction. It is possible that the rigid material of a manikin makes it more difficult to cause obstruction than in a human infant More studies are necessary to explain the aetiology of airway obstruction during neonatal resuscitation after birth.

It is difficult to measure the effect of inadequate mask technique during neonatal resuscitation. Despite the large leaks and low tidal volumes we measured during initial sustained inflations and consecutive inflations, most infants' heart rate increased and they could be transported to the NICU on CPAP. The outcome of resuscitation was probably influenced by the occurrence of spontaneous breathing (discussed below). However, variability in mask leak can lead to the delivery of variable or inappropriate tidal volumes. We observed that more consistent tidal volumes were delivered when mask leak was minimal. With results presented in this thesis it remains difficult to assess the clinical significance and effect of mask leak during neonatal resuscitation and more studies are needed.

Recommendations

Caregivers should use a holding technique that is optimal for the type of mask used, as this will minimise leak. Consequently, more adequate and less variable tidal volumes will be delivered. Training of mask technique should not only focus on reducing leak, but also on the prevention of airway obstruction and/or too much pressure on the head of the infant. The amount of force required to ensure a good seal between the mask and face should be countered by the chin lift. More studies are needed to assess the effect of the compressive force applied to the head of an infant, for example on peripheral or capillary blood circulation.

Devices

Interfaces for neonatal resuscitation - masks and nasal tube

The international guidelines for neonatal resuscitation do not discuss the use of interfaces.[14,15] However, Perlman et al. state in their recommendation for upper airway interface devices, that both masks or nasal prongs can be used for respiratory support.[2] It is not known how many units use nasal tubes as an alternative to facemasks.[32-34] O'Donnell et al. reported in 2004 that a round face mask is used most often (85% round mask, 15% anatomical mask, 11% both).[33] More recent surveys do not inform us about the type of interfaces units use.[32,34]

Masks

The different models of face masks are roughly categorised into round and anatomically shaped masks. Caregivers generally preferred a round mask over an anatomically shaped mask.[35] Despite claims that face masks with cushioned rims provide a better fit to the face of the infant and require less pressure to form a seal, this has never been tested.[21]

While a good mask seal probably depends on the right holding technique,[22] different masks were tested for the occurrence of leak, with conflicting results.[35-37] Palme et al. found that less leak occurred using a round Laerdal mask than an anatomically shaped mask.[36] However, in this study, mask leak was indirectly measured as a decrease in peak pressure and the masks were tested on spontaneously breathing infants.[36] Also, untrained and inexperienced students and nurses participated in this study.[36] The difference in leak between a round and anatomically shaped mask could not be confirmed in a more recent study.[35] Wood et al. compared two different round masks but did not find differences in leak related to the type of mask.[37]

Nasal tube

Problems with mask seal may be avoided by using a nasal tube as interface. The nasal tube is inserted into one nostril for 3–4 cm and mouth and other nostril are closed. The international neonatal resuscitation guidelines state no preference for either face masks or nasal tubes as interface during resuscitation after birth.[2] Segedin et al. showed that manual mask ventilation was more successful when performed via the nasal route.[38] Capasso et al. performed a randomised trial comparing nasal cannula with face masks during resuscitation of newborns with moderate asphyxia. Infants resuscitated with nasal cannula needed significantly less intubation (0.6% vs. 6.3%; $p < 0.001$) and chest compressions (1.65% vs. 8.28%; $p < 0.001$).[39] Studies have shown that use of nasal tubes instead of facemasks during stabilisation of preterm infants at birth has led to less intubations in the delivery room.[40,41] However, in these studies the ventilatory strategies contained more differences than only mask versus nasal tube. Currently, there is an on-going randomised controlled trial in Melbourne (Australia) and Leiden (the Netherlands) comparing mask with nasal tube as interface during resuscitation of preterm infants at birth.

Recommendations

At this moment no preference for an interface can be stated, but a nasal tube might be a good alternative for a mask to avoid mask leak. We recommend to use one type of mask/interface and train caregivers in the unit in adequate use of this interface.

Pressure delivering devices - self-inflating bag, flow-inflating bag and T-piece resuscitator

According to the 2010 international neonatal resuscitation guidelines, ventilation can be performed with a self-inflating bag (SIB), a flow-inflating bag (FIB) or a pressure limited T-piece resuscitator (TPR). No preference for one device over another is expressed in these guidelines.[2,14,15] In 2004 a worldwide survey of neonatal resuscitation practice showed that the SIB was most commonly used (83% SIB, 25% FIB, 30% TPR), but there was an overlap in devices used.[33] In a recent survey in 2010, performed in the German speaking countries in Europe, the SIB was most often used as well, but FIB was used less often than in a previous worldwide survey (85% SIB, 6% FIB, 40% TPR).[34] Interestingly, the most recent survey also claimed that in 42% of the units a mechanical ventilator was used as a resuscitation device, avoiding manual ventilation.[34] As there was more than one type of device available in some units in both surveys, we are not sure how often each of the devices is used and what the prevailing preferences were in the units.[33,34] In contrast to the results of these two surveys, Leone et al. reported in 2006 that the FIB was used in half of the interviewed centres in the United States (40% SIB, 51% FIB, 14% TPR).[32] During the studies for this thesis (since 2008) a TPR was used for neonatal resuscitation in the delivery room of our unit.

T-piece Resuscitator

A TPR is a pressure-limited resuscitation device in which a continuous gas flow is used to deliver a pre-set PIP and PEEP. A commonly used TPR is the Neopuff Infant Resuscitator (Fisher & Paykel, Auckland, New Zealand).[33] The maximum pressure, PIP and PEEP are set with turning knobs and pressures are shown on an inbuilt manometer. Inflations are generated by closing the outlet hole on the T-piece with a finger. PEEP is generated by a cone-shaped, spring-loaded restrictive valve at the T-piece. The system is considered easy to use, even for inexperienced operators, and was preferred by most operators in a study comparing manual ventilation devices.[35,42-44]

Pressures

In most studies a TPR was found to deliver set pressures and, because the pressure is not generated by the hand of the caregiver, tidal volumes were more consistent than with an SIB or FIB.[43,45-47] With a TPR, it is possible to deliver adequate sustained inflations[45,46] and PEEP, which are now considered to be vital factors when trying to achieve lung aeration at birth.[20,48-52] It is also possible to deliver CPAP immediately after PPV in order to maintain the functional residual capacity created.[1,45,46]

Leak

One study reported more mask leak with a TPR when compared to an SIB without a PEEP valve.[42] This is confirmed in another study comparing one-person and two-person mask ventilation, although mask leak was minimal in all groups.[24]

Gas flow rate

In chapter 8 of this thesis we tested the effect of increasing gas flow rates (5–15 L/min) with and without re-adjusting the PIP and PEEP to their original settings.[53] When pressures were not re-adjusted to their original setting, higher gas flow rates slightly increased PIP, but led to a significant increase in PEEP. The decreasing difference between PIP and PEEP resulted in a decrease in tidal volume. Secondly, with increasing gas flow rate, mask leak increased.[53] This was confirmed by our study (chapter 7) testing whether a lower gas flow rate could be used during resuscitation.[29]

Various issues have been reported on gas flow rate when using a TPR. Hawkes et al. showed that very high flows (> 80 L/min) overrule the safety valve and can deliver excessive PIP and PEEP values.[54] In addition, they found that the PEEP valve is more sensitive when lower gas flow rates are used.[55] Although it is good that awareness has been raised about these issues, the general physical characteristics of the valves of the TPR have been measured. Hawkes et al. actually demonstrated a problem in standard gas flow meters, not a fault in the TPR.[56] Some Flow meters lack a built-in safety function that limit the maximum flow delivered and are capable of delivering much higher than intended flows. Even when the maximum flow on the scale shows 15 L/min, it is possible to increase the flow to 85 L/min. When using a T-piece device for resuscitation clinicians should be aware of the effect of changing gas flow on airway pressures. It has also been shown that the PEEP valve is more sensitive at lower flow rates.[55] This is also a physical characteristic of the spring loaded valve; when it is closer to full occlusion, a larger increase or decrease in PEEP can be expected with a minor adjustment at the valve. The manufacturer recommends gas flow rates of 5–15 L/min.

Operator experience

One study found that inexperienced caregivers were not capable to set up the Neopuff T-piece device.[57] However, the inexperienced caregivers in this study were midwives who rarely had to resuscitate infants and, though other devices were available in the unit, had a preference for an SIB.[57] Röhr et al. showed that a TPR was a better device (more consistent pressures) in inexperienced hands than an SIB.[44] Regular training is needed to update and maintain skills and techniques in the use of delivery room equipment.

Sustained inflations

With a TPR sustained inflations of various length can easily be delivered by occluding the PEEP valve on the T-piece.[58] In an audit of our resuscitation practices (chapter 9) we observed a large variation in inspiration times when initial sustained inflations were given. Apparently, it is difficult for caregivers to follow recommendations on inspiration times while resuscitating. McHale et al. showed that inexperienced caregivers gave longer inspiration times than advised, but inspiration times were shorter when caregivers were distracted.[59] However, these results were not compared with bagging devices. A respiratory function monitor (discussed below) could be used as a feedback device to monitor inspiration times. Inconsistent inspiration times could also be avoided by using a mechanical ventilator instead of a TPR for PPV.

Self-inflating bags

Self-inflating bags re-expand after compression, due to their elastic recoil. The advantage is that, for delivering PPV, no gas source or flow is needed. However, if needed and available, gas flow for oxygen delivery can be attached to the bag. Even when no reservoir bag is attached to an SIB, oxygen concentrations > 70% can be reached.[60] There are many models available, but the most popular model is the Laerdal Infant Resuscitator (Laerdal Medical, Stavanger, Norway).[33]

Pressures

A pressure relief valve limits the maximum PIP that can be delivered (40 cm H_2O). However, studies have found that with the SIB significantly higher and more variable PIP was delivered when compared to a TPR.[45,61] They also observed that the pressure relief valve often fails to prevent the delivery of excessive hand-driven PIP.[45,61] It is therefore recommended to use a manometer to monitor PIP.[35,43] With a PEEP valve attached, the SIB is able to generate some PEEP, but significantly less than the FIB or TPR.[35,45,62] PEEP decreases rapidly and to deliver a PEEP of 5 cm H_2O one must set the PEEP valve to 7 cm H_2O and ventilate with a rate of 60/min.[63] In addition, Röhr et al. showed that most PEEP valves of the SIB in their unit did not reach the set PEEP of 5 cm H_2O and a wide variation in delivered PEEP was seen (mean (SD) PEEP 2.95 (1.82) cm H_2O). The reason for this difference in performance is unknown, but apparently valves should be checked regularly for adequate PEEP provision.[62]

Leak

Studies have found that leak during ventilation with the SIB was comparable to, or lower than leak during ventilation with the Neopuff T-piece device.[35,42] However, in these studies no PEEP valve was attached to the SIB and as there is no pressurisation at the end of expiration, less leak will be measured.[35,42] In addition, with an SIB, leak will sooner result in loss of pressure than with an FIB or TPR, as there is no constant gas flow to compensate for the leak.

Sustained inflations

The absence of constant gas flow makes it very difficult to deliver sustained inflations with an SIB. Caregivers were, even after practice, unable to maintain a sustained inflation for three seconds.[45,58,64] A larger model than the commonly used 240 mL bag (e.g. a 500 mL bag) may sustain inflation pressure longer,[63,65] but using a larger bag will increase the risk of delivering inappropriate tidal volumes.

Flow-inflating bags

Flow-inflating (or anaesthesia) bags are inflated by a compressed gas source that delivers continuous flow.

Pressures delivered

FIB are capable of delivering a wide range of PIP. Several studies have shown that the delivered pressures were significantly less consistent than with a TPR or SIB,[42,43,45,46,66] and inappropriate PIP was often observed (13–15 cm H_2O above target pressure).[42,46] It is advised to use a manometer to deliver more consistent pressures, but this has not been tested.[33,43] PEEP can be generated by adjusting the rate of gas escape from the outlet by manual squeeze or a valve can be attached to the outlet. PEEP can be delivered with an FIB, but studies show a higher variability in PEEP when compared to a TPR and the average PEEP level is lower than intended.[42]

Leak

Higher leaks were observed with an FIB when compared to an SIB and TPR.[42] If there is large leak, an FIB will fail to deliver any tidal volume.[67]

Sustained inflations

Although an FIB can be used to deliver sustained inflations, most operators are unable to deliver a prolonged inflation lasting five seconds while maintaining a constant PIP.[46]

Operator experience

Studies showed that especially inexperienced operators found an FIB to be more difficult in use than an SIB.[45,46,68] Operators need to be experienced to be able to use an FIB appropriately.

<u>Recommendations</u>

According to the most recent evidence, the TPR is the best device available for neonatal resuscitation. It delivers the most consistent pressures and with adequate technique a sustained inflation and PEEP can be delivered. It is also possible to deliver CPAP. It is, however, advisable not to change the gas flow rate during resuscitation.[53] We advise to choose a gas flow (about 8 L/min), then set the PIP and PEEP and to not change the gas flow during the resuscitation as set pressures will then change as well. If pressures are not reached, mask hold needs to be evaluated, as this is most likely due to mask leak.[23] The pressures settings should be checked at all times.

The SIB as pressure delivering device should only be used when there is no TPR or gas source available. A manometer and PEEP valve should be attached and these valves should be checked regularly.

In inexperienced hands the FIB is an inappropriate device for neonatal resuscitation and must be considered obsolete for ventilating preterm infants at birth.

Devices for monitoring

Pulse oximetry

International guidelines recommend to start with evaluating heart rate, breathing and colour of infants.[2] Heart rate indicates the need for resuscitation and remains the most important clinical indicator of its efficacy.[2] Clinical assessment of heart rate by auscultation or palpation was found to be very inaccurate, with auscultation being more sensitive than palpation.[69,70] One study found that the assessment of heart rate by auscultation would have led to incorrect resuscitative action in 28% of occasions.[71] Kamlin et al. found that pulse oximetry provided accurate measurement of an infant's heart rate.[72] To acquire accurate pulse oximetry data fast, it is recommended to apply the sensor to the right hand or wrist of the infant before connecting it to the pulse oximeter.[73,74]

Guidelines recommend to start PPV within one minute when the infant's heart rate is < 100 beats per minute. Dawson et al. showed that the median heart rate of healthy infants, who did not require interventions at birth, was often < 100 beats per minute in the first two minutes after birth. Heart rate of preterm infants started lower and rose slower than in term infants.[75] This suggests that a heart rate < 100 beats per minute in the first minutes after birth may not be pathological and that heart rate alone is not enough to decide whether ventilatory support is needed. It is important to include other vital parameters, such as the presence of breathing, oxygen saturation and muscle tone, in the decision whether to start PPV in the delivery room.

After birth, oxygen saturation can be estimated by looking at the infant's colour. However, other factors, besides oxygenation, influence infant's colour.[76] Assessment of infant's colour was found to be an subjective method, with a wide variation between observers and therefore an unreliable method to estimate an infant's oxygenation.[77] Instead, a pulse oximeter should be used to measure oxygen saturation at birth.

Oxygen saturation of the foetus in utero is estimated to be < 60%,[78] and can decrease to around 30% during labour.[79] Median oxygen saturation of healthy infants at one and two minutes after birth was found to be 66% and 73%, respectively.[80] It takes around 5–8 minutes to reach an oxygen saturation > 90%.[80-82] Oxygen saturation was significantly lower after birth and took longer to rise to a stable level in preterm infants and in infants born through caesarean section.[80,82,83]

Recommendations
For the evaluation of heart rate and oxygen saturation, the use of a pulse oximeter is recommended. As low heart rate and/or oxygen saturation can occur in healthy infants in the first minutes after birth, other parameters should be included in the decision whether to start respiratory support.

Respiratory function monitoring

When an infant needs resuscitation after birth, the adequacy of ventilation is clinically assessed by the adequacy of chest excursions. According to the guidelines, the choice of ventilatory pressures should be guided by the achievement of an improvement in heart rate and visible chest excursions. Excessive chest wall movement should be avoided.[2] There is no available definition for 'adequate' chest excursions and the movement of the chest can vary widely between infants due to differences in compliance of the lungs and thorax. In addition, it is difficult to observe chest movements in an infant wrapped in blankets or a polythene wrap. When the chest is not moving during ventilation, either the pressures are too low or there is leak and/or airway obstruction and mask hold should be improved.
In chapter 3 of this thesis we reported that estimating 'adequate' chest excursion is subjective and observer dependent.[84] We found a large variation in pressures that were used to reach 'adequate' chest excursions in two different manikins.[84] The adequacy of ventilation and delivered tidal volumes during neonatal resuscitation should not be evaluated by chest excursions, as they were found to be a poor predictor for delivered tidal volume.[85]

A respiratory function monitor measures airway pressure, gas flow and tidal volume. The difference between inspired and expired tidal volume equals mask leak. Different respiratory function monitors are available and they mainly differ in the information displayed on the screen.[86] Use of a respiratory function monitor requires training in the interpretation of the displayed waveforms. A respiratory function monitor is a non-invasive method to objectively measure respiratory parameters and to help the caregiver make decisions in accordance to the resuscitation algorithm. The displayed parameters are routinely used in the NICU, where caregivers are accustomed to looking at several monitors for feedback.[87-89] The monitor can display tidal volume, minute volume, ventilatory rate and pressures. In addition, the presence and adequacy of spontaneous breathing can be estimated by observing the waveforms on the monitor. The flow and volume waves show whether mask leak or airway obstruction is present. Wood et al. showed that mask leak could be reduced significantly when participants were able to look at a resuscitation monitor.[90] Caregivers can use the data on the monitor to adjust their face mask position, mask hold or change to a larger tube if no effective ventilation occurs.[91]

O'Donnell et al. found that most preterm infants are not apnoeic after birth.[92] In chapter 6 of this thesis we evaluated breathing during mask ventilation of preterm infants at birth and how it related to the inflations given by the caregivers. We observed that many very preterm infants breathe during and between initial sustained inflations and subsequent consecutive inflations immediately after birth. Despite large mask leak and low tidal volume during inflations, in most preterm infants heart rate and saturation quickly improved and most infants left the delivery room on CPAP with low oxygen supplementation. The expired tidal volumes of breaths were similar to those of inflations. It is likely that the presence of spontaneous breathing contributed to the effect of ventilation of preterm infants immediately after birth. It is possible that spontaneous breathing was already present or had started in response to the PPV given. Breathing could be initiated in response to an inflation inducing Head's paradoxical reflex.[93,94]

When a set pressure is used during ventilation, compliance of the lung and the inspiratory effort of the infant are the major contributors to the delivered tidal volume.[95] Use of ventilation that is not synchronised with an inspiration could be counterproductive.[96] It is also possible that placement of a mask on the infant's face stimulates the trigeminal area and thereby increases tidal volume.[97,98] More research is needed to determine the role of breathing during manual ventilation and whether triggered ventilation should be applied at birth.

A respiratory function monitor can also be used for auditing resuscitation practices, as presented in chapter 9. The recording of flow waves and respiratory parameters in combination with pulse oximetry and video recording will provide caregivers with valuable information for evaluating resuscitation. We evaluated delivery room management of preterm infants in our unit by recording video and physiological parameters and compared it with the local resuscitation guidelines.[99] We found that caregivers often deviate from resuscitation guidelines and that respiratory function monitoring parameters were often not used during resuscitation. In 7/34 infants (21%) interventions were performed according to guidelines. Time from birth to initial evaluation was longer than the recommended 30 seconds from birth (65 (15) seconds). Caregivers took very little time to evaluate heart rate (6 (3) seconds) and the decision whether respiratory support needed to be started was sometimes inappropriate. Respiratory support was started at 70 (23) seconds, but some infants were not evaluated beforehand. Results from this audit emphasise that caregivers need more time for the initial steps in the resuscitation algorithm than currently recommended. In addition, these time limits seemed to lead to inadequate evaluation and inappropriate decisions and should therefore maybe even be removed.

Another important finding of this study was that spontaneous breathing was often missed by the clinician, leading to unnecessary respiratory support. This confirms our earlier finding that breathing is difficult to observe clinically in preterm infants. As we were using a respiratory function monitor in the delivery room, this finding was against expectations. However, caregivers stated they hardly used the monitor for evaluating mask technique. In most occasions the information from the monitor was not used to make clinical decisions at all, and only in a small number of occasions the monitor was used for evaluating spontaneous breathing. All caregivers indicated that they evaluated chest excursions, rather than the monitor, to adjust peak pressures. Most caregivers find the respiratory function monitor useful, but they found it difficult to incorporate the information during resuscitation. They all indicated that extra training or an extra person reading the monitor would be necessary.

Although caregivers are accustomed to using and interpreting several monitors in the NICU, they are apparently not accustomed to integrate the information from a respiratory monitor during resuscitation in the delivery room. Caregivers are traditionally trained to perform resuscitation by primarily focusing on clinical signs and not so much on incorporating the feedback from a respiratory monitor. Caregivers should therefore be trained in how to incorporate the feedback from the respiratory function monitor to assess the effectiveness of ventilation. This will be difficult to implement immediately and will probably require time to be integrated as well as to redesign current training courses. Another option is to have an extra person available during resuscitation who interprets the monitor parameters and guides the resuscitating caregiver.

Recommendations

A respiratory function monitor can be useful as a feedback device during neonatal resuscitation. It adds objectivity to the assessment of respiratory parameters and the presence of breathing. It will provide the caregiver with feedback on their mask technique. Caregivers need to be trained to use the information from a respiratory function monitor in the delivery room. A large randomised trial is needed to determine the efficacy of a respiratory function monitor in the delivery room during neonatal resuscitation.

Conclusions

Although progress has been made with the results of this thesis, more studies are needed to optimise resuscitation technique and the use of devices.

Mask ventilation of preterm infants is often inadequate with large leak and low tidal volumes. Especially during the initial sustained inflations tidal volumes are often too low to expect the intended effect. Airway obstruction occurred less often than expected, but may have been underestimated. Most preterm infants breathe during and in between inflations and this is often missed by caregivers. Spontaneous breathing probably contributed to the effectiveness of ventilation.

Mask ventilation is more difficult than most caregivers expect and training of adequate technique is essential. Using a holding technique that is optimal for the mask used will minimise mask leak and consequently deliver more adequate and less variable tidal volumes. Training of mask technique should not only focus on minimising leak, but also on the prevention of airway obstruction. The use of a respiratory function monitor is useful for feedback during training of mask holding technique.

The T-piece resuscitator has many advantages over either bagging device and is currently the best device available for neonatal resuscitation, especially for preterm infants. It is, however, advisable not to change the gas flow rate during resuscitation. If pressures are not reached, mask hold needs to be evaluated, as this is most likely due to mask leak.

Clinical evaluation of heart rate, colour, and chest rise is subjective and inaccurate. A pulse oximeter is more reliable for the assessment of heart rate and oxygen saturation. The adequacy of ventilation and delivered tidal volumes during neonatal resuscitation should not be evaluated by chest excursions only. When chest excursion is not observed during ventilation, either the pressures are too low or there is mask leak or airway obstruction and mask hold should be improved.

A respiratory function monitor measures tidal volumes and adds objectivity to the assessment of breathing. Although most caregivers are familiar with the feedback of the mechanical ventilator monitors in the NICU, caregivers are not accustomed to the use of a respiratory function monitor in the delivery room. Caregivers need to be trained to incorporate the feedback given by a respiratory function monitor during neonatal resuscitation.

Caregivers often deviate from the provided algorithms in resuscitation guidelines. They take only a short time period for initial evaluation of infants and spontaneous breathing is often missed. More time seems to be needed for the initial steps in the algorithm and the time limit should be removed or expanded.

Future perspectives

Our studies identified some difficulties in neonatal resuscitation and a number of research questions have risen that need to be addressed in the future. Suggestions and/or advise for future research are:

1. Because training of mask technique has shown to improve neonatal resuscitation skills, leak-free training manikins and monitoring devices providing feedback on mask technique should be developed and their efficacy established.
2. It is not known what the effect of leak is on neonatal resuscitation outcome. Future studies should focus on establishing these effects and determine whether improved techniques positively affect neonatal morbidity and mortality.
3. Studies should focus on easier, alternative methods to deliver PPV. The technique of ventilation through a nasal tube might be beneficial. Currently, a randomised controlled trial comparing face mask versus nasal tube for the ventilation of preterm infants in the delivery room is being performed in the Leiden University Medical Center in Leiden, the Netherlands and the Royal Women's Hospital in Melbourne, Australia. The use of short bi-nasal prongs should be compared with the mask as well. The use of bi-nasal prongs can be continued during transport and in the NICU, so the interface does not have to be changed with the risk of losing PEEP intermittently.
4. A large randomised controlled trial is needed to investigate the effect of a respiratory function monitor in the delivery room on the clinical outcome of preterm infants. We urge companies to develop an easy-to-use respiratory function monitor that provides caregivers with feedback on respiratory parameters and resuscitation technique.
5. As most caregivers fail in delivering recommended inspiration times and pressures, use of a mechanical ventilator in the delivery room should be compared with a TPR.
6. Spontaneous breathing of preterm infants at birth should be used more efficiently. The possible benefits of triggered ventilation (i.e. synchronised) ventilation at birth should be investigated to determine whether this can lead to more efficient ventilatory support.

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