Improving neonatal resuscitation at birth: technique and devices
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Citation

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Introduction
The transition to extra-uterine life at birth represents one of the greatest physiologic challenges that humans encounter and begins with lung aeration and the onset of air-breathing. Preterm infants often fail to create functional residual capacity because they have an impaired ability to clear airway liquid. Therefore, preterm infants, more often than term infants, need respiratory support after birth. Neonatal ‘resuscitation’ comprises, in most cases, the establishment of adequate ventilation. Although caregivers are familiar with the concept of ventilator induced lung injury and preterm lungs are most vulnerable at birth, so far little effort has been made to determine the adequacy and efficacy of ventilation in the delivery room. Successful neonatal resuscitation depends not only on a good strategy, but also on using optimal technique and devices.

The general aim of this thesis was to evaluate the efficacy and adequacy of neonatal resuscitation. This thesis comprises manikin studies and observational studies in the delivery room to evaluate and optimise current resuscitation technique and the use of devices.

In chapter 2 we evaluated mask technique and tested the efficacy of training in optimal mask handling during simulated neonatal resuscitation. Seventy participants (consultants, registrars and nurses) from neonatal units were asked to administer positive pressure ventilation at a gas flow rate of 8 L/minute and a frequency of 40–60/minute to a modified leak-free manikin, resembling a term newborn, using a Neopuff T-piece device. Recordings were made (1) before training, (2) after training in mask handling technique and (3) three weeks later. Leak was measured using a respiratory function monitor. Obstruction (tidal volume < 60% of optimal tidal volume) and severe obstruction (< 30% of optimal tidal volume) were calculated when leak was minimal. We observed that mask ventilation during simulated neonatal resuscitation was often hampered by large leaks at the face mask. Training in mask ventilation was effective in reducing mask leak and the effect of training persisted after three weeks. However, airway obstruction occurred more often and therefore, training of mask technique should also focus on the prevention of airway obstruction.

When an infant needs resuscitation after birth, the efficacy of ventilation is clinically assessed by evaluating the adequacy of chest excursions. According to neonatal resuscitation 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. However, there is no available definition for ‘adequate’ chest excursion. In chapter 3 we tested the accuracy of the assessment of ‘adequate’ chest excursions by measuring intra- and inter-observer variability of participants during simulated neonatal resuscitation on a manikin with a low compliant lung and a manikin with a high compliant lung. For this study, thirty-seven staff members (8 neonatologists, 8 registrars and 21 nurses) of the NICU at the Leiden University Medical Center ventilated two different intubated, leak-free manikins twice. Blinded to the manometer, participants could change peak inflating pressure (PIP) until they found chest excursions to be ‘adequate’, at which time the given inflating pressures were recorded. There was a large variation of PIPs chosen to reach ‘adequate’ chest excursion for each participant as well as between participants. We concluded that ‘adequate’ chest excursion is a very subjective parameter and a poor predictor of appropriate ventilation during neonatal resuscitation.

In chapter 4 the compressive force applied to the head of a manikin during simulated mask ventilation was measured. We also determined whether this force increased in response to an attempt to correct mask leak. Twenty-four participants (consultants, fellows and nurses) from the neonatal unit were asked to mask-ventilate a modified, leak-free, newborn manikin using a self-inflating bag (SIB) and a T-piece resuscitator (TPR). Recordings were made before and after the participants were informed about their mask leak and requested to correct this. Airway pressure and gas flow were measured using a respiratory function monitor. The force applied to the head was measured using a concealed custom-made weighing scale. We observed that large forces were exerted on the head of the manikin with either an SIB or TPR, with no significant difference between these two devices. However, the amount of force did not correlate with the amount of mask leak the operator was trying to correct or whether or not airway obstruction occurred. It is not known what the effect of this large force is on a newborn infant’s head, but it may be injurious or have adverse effects on the cerebral circulation.

In chapter 5 an observational study is presented, which evaluates initial sustained inflations (SIs) and consecutive inflations (CIs) during T-piece mask ventilation in preterm infants < 32 weeks’ gestation at birth. We measured airway pressures, gas flow, expired tidal volume (V_t), mask leak, airway obstruction, heart rate and oxygen saturation. The resuscitation was video recorded. SIs and CIs during the first five minutes of respiratory support were analysed for large leak (> 60%), low V_t (< 2.5 mL/kg), high V_t (> 15 mL/kg in SIs, > 10 mL/kg in CIs) and airway obstruction. This study showed that mask ventilation in preterm infants is often hampered by large and variable mask leaks which reduce tidal
volumes, especially during sustained inflations. However, in most infants heart rate and oxygen saturation increased quickly and they could be transported to the NICU on CPAP. Potentially injurious high tidal volumes were seen in 12% of inflations, especially when mask leak was small. Airway obstruction did occur and may have been underreported because of mask leak. We concluded that mask ventilation of preterm infants at birth was often ineffective, but this did not seem to have influenced outcome of the resuscitation. It is possible that the tidal volumes delivered were sufficient or that manual ventilation initiated, or was supported by spontaneous breathing during resuscitation.

The findings in chapter 5 prompted us to evaluate breathing in preterm infants receiving mask ventilation. In chapter 6 recordings from the study presented in chapter 5 were analysed for the presence of breathing during mask ventilation and how this related to inflations. Breaths were identified and waveforms were divided into breaths, breaths coinciding with an inflation, and inflations. We compared the expired tidal volumes ($V_{Te}$) of these three types. We found that very preterm infants often breathe during and between initial sustained inflations and subsequent consecutive inflations immediately after birth. The $V_{Te}$ of breaths was similar to that of inflations. Most infants left the delivery room on CPAP and low oxygen supplementation. We concluded that breathing occurs more often than observed by clinicians and that breathing probably contributes to ventilation of preterm infants immediately after birth.

In the Leiden University Medical Center a T-piece resuscitator is used for positive pressure ventilation at birth. However, resuscitation guidelines do not give recommendations on gas flow rate. In chapter 7 we investigated the effect of a high and a low gas flow rate on peak inflating pressure (PIP) and positive end expiratory pressure (PEEP), expired tidal volume ($V_{Te}$) and mask leak during simulated neonatal resuscitation. Gas flow rates of 5 and 10 L/minute were tested during Neopuff T-piece positive pressure ventilation. In the first part of the study, pressure ranges were measured with both gas flow rates, while ventilating an intubated manikin. In the second part of the study, paediatric staff mask-ventilated a manikin with both gas flow rates, a PIP of 30 cm H$_2$O and a PEEP of 5 cm H$_2$O. Part 1 demonstrated that a PEEP of 5 cm H$_2$O could only be reached with a minimal gas flow rate of 6 L/min. Part 2 showed that mask leak decreased when a lower gas flow rate was used. $V_{Te}$ and PEEP only decreased when large leaks occurred. PIP did not decrease when a higher gas flow rate was used. Therefore, a low gas flow rate during neonatal mask ventilation may be a good alternative approach to reduce mask leak, provided that inflation time and gas flow rate warrant that set pressures can be reached.
When using a T-piece device, caregivers may try to improve airway pressures by increasing gas flow rate instead of correcting mask position. In Chapter 8, we tested the effects of four different gas flow settings on peak inflating pressure (PIP), positive end expiratory pressure (PEEP), expired tidal volume ($V_{Te}$) and mask leak during simulated neonatal positive pressure ventilation.

Twenty neonatal staff members delivered positive pressure ventilation to a modified, leak-free manikin with a Neopuff T-piece resuscitation device. The study was divided into two parts (study A and study B). Study A: positive pressure ventilation for four minutes at PIP 30 cm H$_2$O and PEEP 5 cm H$_2$O. Each minute gas flow was increased from 5 to 8, 10, and 15 L/min. Pressure settings were unchanged. Study B: same pressure settings; positive pressure ventilation for one minute with each gas flow rate setting (5, 8, 10 and 15 L/min) in a random order, at a rate of ~60/min. The pressures were adjusted to maintain the same PIP and PEEP after each gas flow rate change. We found that increasing gas flow dramatically increased PEEP and mask leak, which reduced tidal volume. When using a T-piece device for resuscitation, clinicians should be aware of the effect of changes in gas flow rate on the delivered airway pressures. We advise to choose a gas flow rate (about 8 L/min), set the ventilatory pressures and not to change the gas flow rate during the resuscitation again. If the required ventilatory pressures are not reached, poor mask technique should be considered and corrected instead of making changes in the gas flow rate.

In Chapter 9 delivery room management of preterm infants at birth was evaluated and compared with local resuscitation guidelines. Physiological parameters (airway pressures, gas flow, tidal volume, heart rate and oxygen saturation) were measured, the use of supplemental oxygen was recorded and a video recording of the resuscitation was made. We observed that neonatal caregivers often deviate from resuscitation guidelines. In agreement with other recent studies, we found that approximately two thirds of infants would receive unnecessary ventilation if the guidelines were followed. Results of this study suggest that more time is needed for the initial steps in the resuscitation algorithm and the evaluation of the condition of the infant. The recommended time period for interventions in the guidelines maybe too short and possibly, for some interventions, also too soon. Another difficulty is the judgment of the presence and adequacy of spontaneous breathing. A respiratory function monitor may add objectivity to this judgment and thereby improve the quality of resuscitation. However, we found that caregivers hardly used the monitor for evaluating mask technique. Although caregivers are accustomed to looking at several monitors in the neonatal intensive care unit, they are not accustomed to integrating the information from a respiratory function monitor during resuscitation in the delivery room. Neonatal resuscitation training should incorporate use of a respiratory
function monitor to assess the efficacy of ventilation in the delivery room. Caregivers should be trained to interpret the data on the monitor or an extra person in the delivery room should observe the monitor and give feedback to the resuscitating caregiver.

In chapter 10 the results from the studies in this thesis and the available literature about techniques and devices currently used in neonatal resuscitation practice are discussed. In conclusion, mask ventilation is difficult and mostly inefficient. Spontaneous breathing, which is often missed, contributes to the improvement of infants at birth. Mask holding technique should be trained with a focus on leak and airway obstruction. A respiratory function monitor is a useful device for feedback of mask technique, both during training and neonatal resuscitation in the delivery room, and will also help in determining the adequacy of tidal volumes and spontaneous breathing. A T-piece resuscitator seems to be the best pressure delivering device available, but use of a fixed gas flow rate is recommended. Caregivers often deviate from the provided algorithms in the resuscitation guidelines and do not spend enough time for clinical evaluation of the infant. More time should be devoted to the initial steps in the algorithm. Future research and clinical practice should focus on training of optimal mask technique, establishing the efficacy of a respiratory function monitor during training and in the delivery room, and the development of more efficient ventilation techniques that focus on the presence of spontaneous breathing.