Improving neonatal resuscitation at birth : technique and devices

Schilleman, K.

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Leak and obstruction with mask ventilation during simulated neonatal resuscitation

Kim Schilleman
Ruben S.G.M. Witlox
Enrico Lopriore
Colin J. Morley
Frans J. Walther
Arjan B. te Pas

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Abstract

Objective

To evaluate mask technique during simulated neonatal resuscitation and test the effectiveness of training in optimal mask handling.

Methods

Seventy participants (consultants, registrars and nurses) from neonatal units were asked to administer positive pressure ventilation at a flow of 8 L/min and a frequency of 40–60/min to a modified leak-free, term newborn manikin (lung compliance 0.5 mL/cm H_2O) using a Neopuff T-piece device. Recordings were made (1) before training, (2) after training in mask handling and (3) three weeks later. Leak was calculated. Obstruction (tidal volume < 60% of optimal tidal volume) and severe obstruction (< 30% of optimal tidal volume) were calculated when leak was minimal.

Results

For the 70 participants, median (IQR) leak was 71 (32–95) % before training, 10 (5–37) % directly after training and 15 (4–33) % three weeks later ($p < 0.001$). When leak was minimal, gas flow obstruction was observed before, directly after training and three weeks later in 46%, 42% and 37% of inflations, respectively. Severe obstruction did not occur.

Conclusion

Mask ventilation during simulated neonatal resuscitation was often hampered by the occurrence of large leaks at the face mask. Moderate airway obstruction occurred frequently when effort was taken to minimise leak. Training in mask ventilation reduced mask leak but should also focus on preventing airway obstruction.

Introduction

Approximately 10% of infants require resuscitative intervention at birth.[1] Establishing effective ventilation is key for successful resuscitation. Chest compressions and medication are rarely needed during resuscitation and are often secondary to improper ventilation.[2]
Caregivers are guided by resuscitation procedures; a face mask is commonly recommended and widely used for initial ventilation after birth.[3-5] An airtight seal between the mask and the face is important for successful ventilation.[1] However, leak at the mask is a common cause of inadequate ventilation or even failure of resuscitation.[6,7] Achieving an airtight seal can be difficult and most clinicians do not recognise leak between the mask and the face.[8] With variable leaks, variable tidal volumes will be delivered, possibly leading to inadequate or even harmful large volumes. On the other hand, too much pressure is often applied to the mask to prevent leak, which may lead to obstruction of the mouth and nose.[9]
Although neonatal resuscitation teaching programmes emphasise the importance of mask ventilation, evaluation of caregivers' skill in applying the mask and ventilating a manikin is subjective. How well skills and technique are maintained probably depends on the frequency and quality of training and on how frequently personnel are involved in resuscitation.
The objective of this study was to evaluate mask technique during simulated neonatal resuscitation by neonatal staff in an academic and a regional hospital. In addition, we tested the effectiveness of instruction in optimal mask handling.

Methods

The study was performed in the neonatal intensive care centre of an academic hospital (Leiden University Medical Center, Leiden, The Netherlands) and in the paediatric department of a regional district hospital (Reinier de Graaf Gasthuis, Delft, the Netherlands), which has a neonatal high care unit. Neonatal and paediatric staff members were asked to administer positive pressure ventilation to a modified (to be internally leak-free) manikin (Laerdal Resusci Baby; Laerdal, Stavanger, Norway), representing a term newborn. In this manikin the original 'lung' was replaced with a 50 mL test lung (Dräger, Lübeck, Germany) positioned so inflation caused visible chest rise. Non-distensible tubing connected the lung to the mouth to ensure that the manikin was airtight (figure 1).[6,10,11]

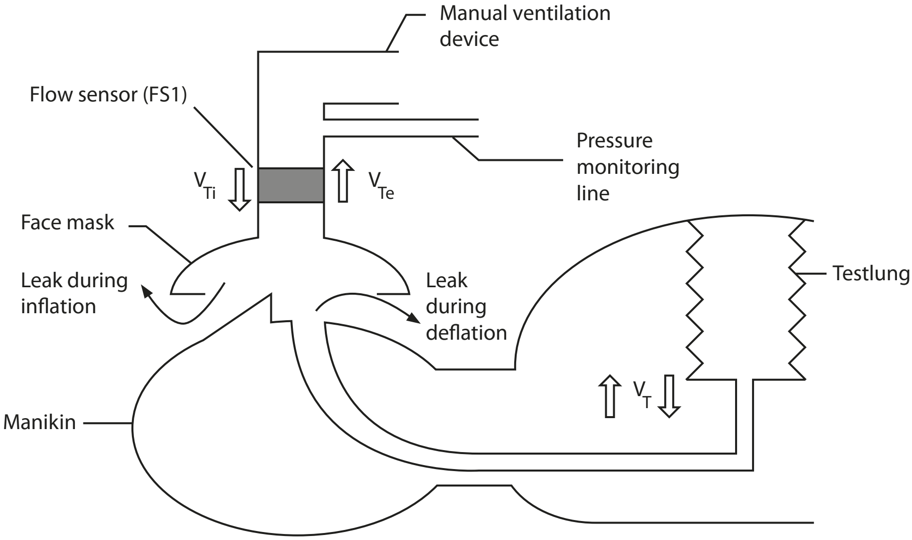

Figure 1. Diagram of the system used for recording airway pressures and gas flow, and calculating inspired and expired tidal volumes and facemask leak. (Diagram courtesy of Colm O'Donnell)

Positive pressure ventilation was applied using a T-piece infant resuscitator (Neopuff; Fisher & Paykel Healthcare, Auckland, New Zealand) in combination with a size 0/1 Laerdal round mask. The Neopuff was set to a peak inflating pressure (PIP) of 30 cm H_2O and a positive end expiratory pressure (PEEP) of 5 cm H_2O. Gas flow was set to 8 L/min. All recordings were made using a Florian respiratory monitor (Acutronic Medical Systems, Hirzel, Switzerland). This respiratory monitor uses a hot wire anemometer as a flow sensor and has a dead space of < 1 mL to detect gas flow. The flow sensor was placed between the T-piece and the face mask. The flow signal is integrated to measure inspired and expired tidal volumes. Gas volume was calibrated using 10 mL and 50 mL syringes before the study and regularly during the study. The Florian monitor was always turned on and kept warm in order to prevent drifting. The hot wire anemometer was zeroed by the researchers each time recordings were made. The pressure sensor was placed in the distal section of the Neopuff T-piece tubing. Signals for flow, pressure and volume were digitised and recorded at 200 Hz using Spectra Physiological software (Grove Medical, London, UK) (figure 2 A–C). Using Spectra the signals for flow, pressure and volume were calibrated regularly before and during the study. The difference between inspired and expired tidal volume was used to calculate the leak (figure 2 A,B).

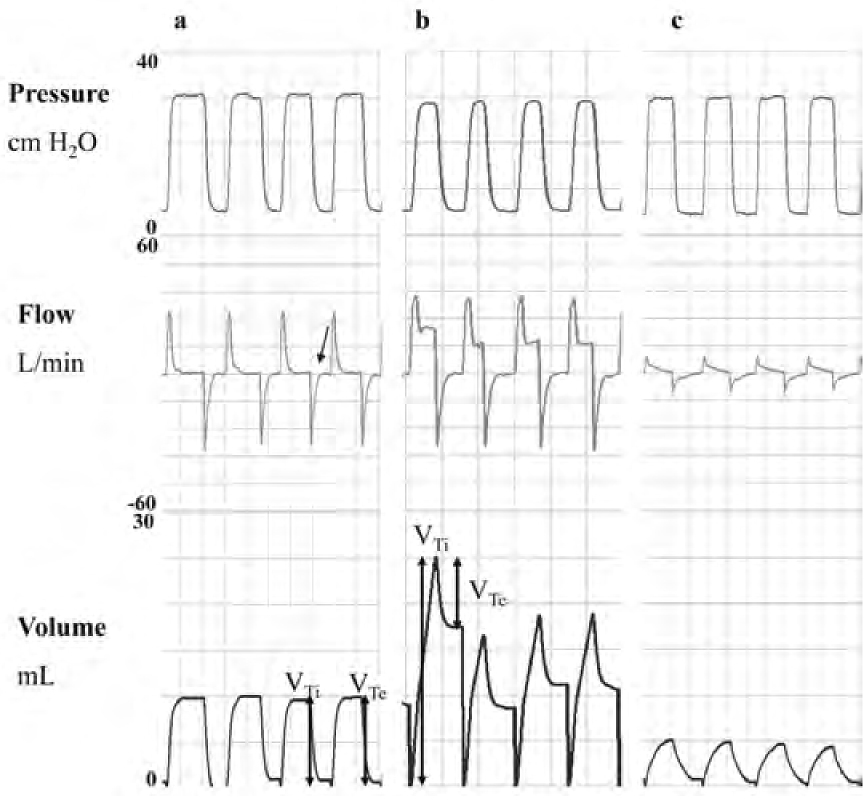

Figure 2. Examples of recordings. (A) A recording with minimal leak and no obstruction: flow returns to zero at the end of the inspiratory flow wave (arrow) and inspired tidal volume (V_{Ti}) is approximately the same as expired tidal volume (V_{Te}). (B) A recording with a large air leak between the mask and the manikin: flow does not return to zero at the end of inspiratory flow wave (arrow) and V_{Te} is much smaller than V_{Ti} (average leak is 60% in this recording). (C) A recording with minimal leak but moderate obstruction of the airway: small inspiratory and expiratory flow waves, average leak is 5%.

All participants were asked to ventilate the manikin at a ventilation rate of about 40–60/min according to the technique they had been taught during their medical or nursing training. They were allowed time to get used to the device and manikin before the ventilation was recorded for 60 seconds. The participants then received a demonstration and brief instruction in the optimal technique of handling a Laerdal mask[10] (see description in Methods section) and were given a few minutes to practise. Subsequently a second 60 second recording was made. Neither the Florian nor the Spectra monitor were visible to the participants.

In order to evaluate whether the effect of training had been retained, a third recording was made approximately three weeks later. This time, no additional instructions were

given. Afterwards the participants were asked to fill in a short questionnaire.
All participants received the same demonstration and training and were allowed to practice for an equal length of time. The following technique was demonstrated and practised (figure 3): place the manikin's head in a neutral position and gently roll the mask upwards onto the face from the tip of the chin. Hold the mask with the two-point-top hold where the thumb and index finger apply balanced pressure to the top flat portion of the mask where the silicone is thickest. The stem is not held and the fingers should not encroach onto the skirt of the mask. The thumb and index finger apply an even pressure on top of the mask. The third, fourth and fifth finger perform a chin lift using the same pressure upwards as applied by the thumb and index finger downwards.[10] In this technique the mask is squeezed onto the face between the downward thrust of the fingers and upward pull of the chin lift. Merely pushing the mask down onto the face may cause obstruction. When a good mask seal and minimal leak were achieved a high pitched whistling sound could be heard due to the air escaping from the Neopuff PEEP valve. With minimal leak, the PEEP was maintained and the set PIP was reached during ventilation.

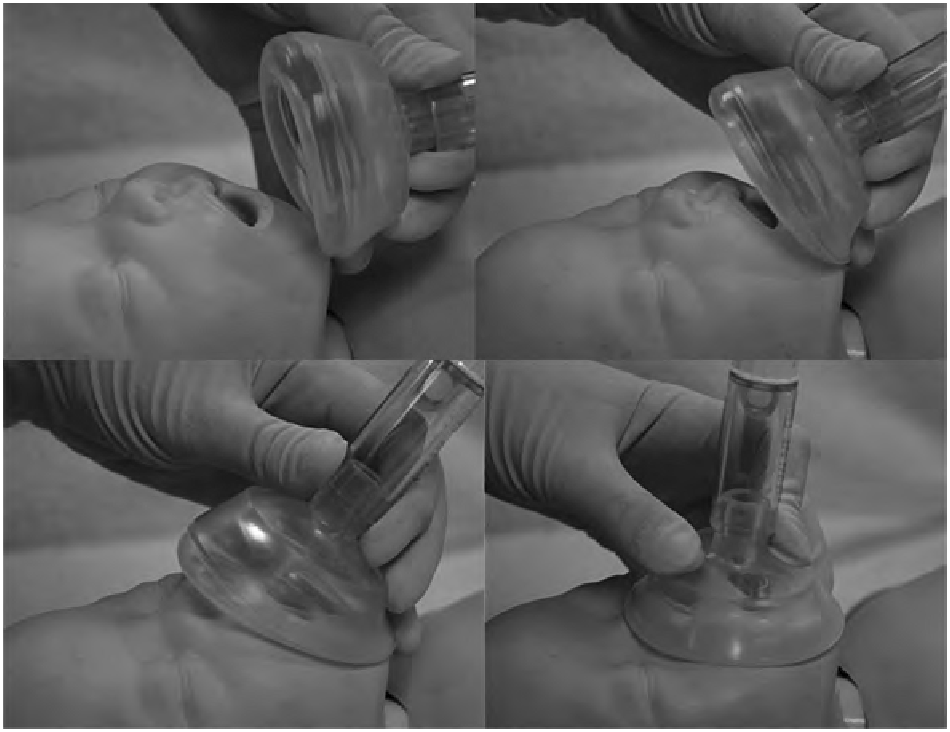

Figure 3. The demonstrated mask technique. Place the manikin's head in a neutral position and gently roll the mask upwards onto the face from the tip of the chin. Hold the mask with the two-point-top hold where the thumb and index finger apply balanced pressure to the top flat portion of

the mask where the silicone is thickest. The stem is not held and the fingers should not encroach onto the skirt of the mask. The thumb and index finger apply an even pressure on top of the mask. The third, fourth and fifth finger perform a chin lift with the same pressure upwards as applied by the thumb and index finger downwards. In this technique the mask is squeezed onto the face, between the downward thrust of the fingers and upward pull of the chin lift.

Each inflation was analysed separately using Spectra physiological software. The tidal volumes and percentage of leak were calculated for each inflation. Because each participant had a different ventilation rate and hence number of inflations given in 60 seconds, the mean tidal volumes and leak percentages were calculated for each participant for each recording. Further calculations were based on these means to eliminate the influence of a difference in ventilation rate. More than one recording was made for some of the participants to determine the level of intra-personal variability in the percentage of mask leak.

Additionally, airway obstruction was calculated from the recordings (figure 2C). To try and minimise leak the resuscitator may apply too much pressure on the mask and so obstruct the mouth and nose. Measuring obstruction is complicated by the confounding effect of leak as large leaks make it impossible to determine if obstruction is also occurring. To determine how often participants caused obstruction during almost leak-free inflations, we calculated the incidence of obstruction from inflations with less than 10% leak. As pressures and flow were constant, we reasoned that each inflation with a tidal volume of < 60% of the optimal tidal volume was caused by obstruction. We chose < 60% because the stiff material used for the manikin makes it more difficult to cause complete obstruction. We defined severe obstruction as a tidal volume of < 30% of the optimal tidal volume. Optimal tidal volume was defined as the maximum expired tidal volume reached in the inflations with < 10% leak.

Results are given as mean (SD) or median (IQR) were appropriate. To assess the effect of training on mask technique, a Wilcoxon non-parametric test for related samples was used to calculate the difference in face mask leak between the first (before training) and the second recording (directly after training), as well as between the first (before training) and the third recording (three weeks after training). $p < 0.05$ were considered to indicate statistical significance. Reported p values are two-sided. Data were analysed using SPSS for Windows 16.0.

Due to the observational character of this study, without the involvement of patients, approval of the Institutional Research Board of our hospital was not required.

Results

Participants

Recordings were made of 70 participants: 34 from the academic hospital and 36 from the regional hospital. All participants were classified into one of three groups: consultants (neonatologists, paediatricians and neonatal fellows), paediatric registrars and nurses. The number of participants in each group for each recording is shown in table 1. A third recording could not be made for logistical reasons for one participant from the academic hospital and 13 participants from the regional hospital. Results are given for all recordings obtained.

Table 1. Number of participants

	Recording 1 (before training)	Recording 2 (after training)	Recording 3 (three weeks after training)
Both hospitals	70	70	56
Academic	34	34	33
Consultants	10	10	10
Registrars	12	12	11
Nurses	12	12	12
Regional	36	36	23
Consultants	7	7	5
Registrars	8	8	7
Nurses	21	21	11

Leak at the face mask

For the first, second and third recordings a total of 1089, 1138 and 1075 inflations were analysed from the academic hospital and 1226, 1324 and 811 inflations from the regional hospital. Median (IQR) leak as high as 71 (32–95) % occurred during the first recording in all participants. After training the median leak decreased to 10 (5–37) % ($p < 0.001$) and remained low three weeks after training (15 (4–33) %) as compared to the first recording ($p < 0.001$). No significant differences in leak were found between the hospitals in all three recordings.

The consultants in both hospitals showed the lowest median (IQR) leak of 34 (8–70) % and a small reduction in leak after training (14 (7–27) %; $p < 0.05$) and three weeks after training (25 (10–44) %; NS) (figure 4). Before training, a large leak was measured in both registrars (65 (27–87) %) and nurses (89 (47–98) %) (figure 4). After training, a large reduction was measured in both groups (registrars 11 (5–34) %; $p < 0.001$ and nurses 8 (5–38) %; p <

0.001) (figure 4). This effect remained when measured three weeks after training (registrars 6 (3–21) %; p < 0.01 and nurses 16 (6–31) %; p < 0.01) (figure 4).

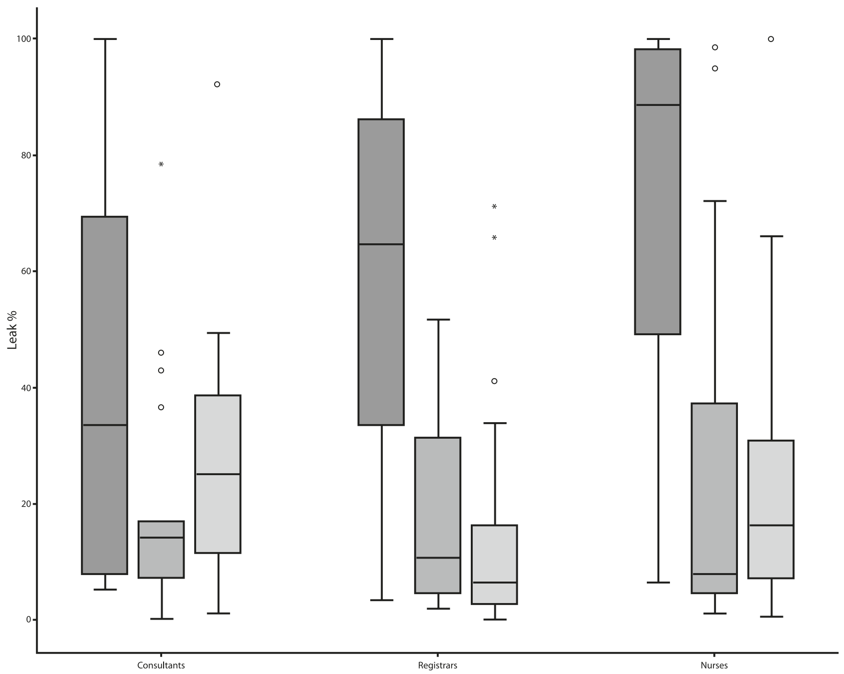

Figure 4. Percentages of leak in both hospitals before, directly after and three weeks after training (left, middle and right boxes, respectively, in each cluster). The box plots show median values (solid black bar), IQR (margins of box), range of data, outliers (circles) and extreme values (asterisks).

Intra-individual variability of leak measurement

Fifteen participants were asked to repeat their recording up to five times to assess the level of intra-personal variance which was estimated using a linear mixed model with random person effect. The interclass correlation coefficient was 0.23. This suggests fair agreement of intra-personal variance. Participants with small leaks had less variability within recordings than participants with higher leaks.

Obstruction

To eliminate the confounding effect of leak, the amount of obstruction was determined in inflations with minimal air leak (air leak < 10%). Minimal leak occurred in the recordings before training, after training and three weeks later in 12% (274/2315), 51% (1258/2462) and 48% (897/1886) of inflations, respectively. Obstruction (tidal volume < 60% of optimal tidal volume) occurred before, directly after and three weeks after training in 46%

(126/274), 42% (534/1258) and 37% (710/1886) of inflations with minimal leak, respectively (NS). Severe obstruction (< 30% of optimal tidal volume) occurred in 0%, 0% and 2% of inflations before, directly after and three weeks after training.

Questionnaire

The questionnaire showed that consultants had an average of 13 years of experience, registrars 4 years and nurses 13 years. Of all respondents, 83% had been trained in mask handling techniques during their medical training, 40% had learned about mask technique during a Neonatal Life Support or Advanced Paediatric Life Support course and 30% had learned during simulation trainings organised by the unit.

All the participants considered the instruction and demonstration of the mask handling technique during this study to be sufficient and thought it would improve the quality of resuscitation. The training brought new insights for 81% and all participants indicated they would prefer if leak and obstruction during resuscitation could be monitored.

Discussion

In this study we simulated neonatal resuscitation to evaluate mask positioning and holding technique. We found a high percentage of air leak during mask ventilation. We also demonstrated that participants frequently cause obstruction when trying to minimise leak, possibly by applying too much pressure to the head, but severe obstruction was rare. Such inadequate mask ventilation with leak and obstruction delivers in inconsistent and inadequate tidal volumes and could result in inefficient and possible harmful resuscitation. Previous studies have shown comparable percentages in mask leak.[6,10,11] Also, the observed significant reduction in mask leak after training in optimal mask technique was similar to that in a previous study on mask training.[10] The observed reduction in leak is likely to be clinically relevant. In addition, we have demonstrated that the positive effect remained when participants were retested three weeks after training. The third recording of the consultants did not show a significant reduction in leak. However, with a fairly low percentage leak in the first recording, a large improvement was less likely to occur. Nevertheless, the reduction in the variation of their leak suggests the consultants with the highest percentage leak benefitted from the training. It is possible that the consultants' high level and years of experience in their own mask technique made it more difficult for them to use a different technique.

The mask technique used during training was adopted from the studies of Wood et al.[10] During training in this mask technique there is an emphasis on reducing leak. However, we have demonstrated that in order to minimise leak, participants frequently cause obstruction. This was confirmed by our finding of increased obstruction after training. During resuscitation of human infants, obstruction can be caused by fluid in the oropharynx, the position of the head, neck or tongue or by pressing down too hard on the mask leading to obstruction of the nose and mouth. This cannot occur with the manikin but obstruction is mimicked by a flexible jaw that obstructs the artificial airway. The downward pressure could lead to an inefficient chin lift or too much flexion of the head, which causes obstruction of the artificial airway in the manikin. It is also possible that, when concentrating on mask seal, too much flexion or extension occurred when less attention was paid to the head position. Additionally, the material of the manikin is stiff and therefore more downward pressure on the mask may be needed to obtain an airtight seal.

Ventilating a manikin cannot be compared with clinical resuscitation, which is more stressful and involves unpredictable infant response. However, it is likely that leak and obstruction as observed in resuscitation studies using a manikin occur during neonatal mask ventilation. Mask ventilation of human infants may be more difficult than with a manikin and leak and obstruction occur at least as often as shown in this study, especially in preterm infants. Mask ventilation in the preterm infant is often hampered by inadequate mask size or difficulty in seeing chest rise, and obstruction can occur very easily.[9] It is extremely important in training to demonstrate good mask technique so clinicians can rely on their technique during stressful and unpredictable clinical situations.

The occurrence of leak and obstruction is an underestimated problem and most clinicians are unaware of the effect of their ventilation. It is necessary to increase awareness and reduce the incidence of leak and obstruction by emphasising proper mask ventilation in training. During the study we observed that very few clinicians used the mask technique as advised in resuscitation training manuals. The majority of participants stated in the questionnaire that they would prefer visual input of mask leak and obstruction during neonatal resuscitation. Using a respiratory monitor during training and during real resuscitations will provide direct feedback and could be useful to correct mask hold and positioning techniques to diminish leak and obstruction.[8] Some participants could not be reached for a third recording during this study: one registrar in the academic hospital had been transferred to another hospital, while some participants in the regional hospital were not available during our visit. Therefore, inclusion of participants in the third recording was not affected by selection bias. A repeat test after a longer period would have been useful to see whether the effect of training was sustained.

Conclusion

We have demonstrated that optimal neonatal mask ventilation is difficult and gas leak between the mask and face often occurs. Airway obstruction occurred frequently when participants tried to minimise leak, but severe obstruction did not occur. Training in face mask hold and positioning techniques reduced leak and the effect remained three weeks later. As airway obstruction occurs frequently, even after training, the training methods should be modified and also focus on preventing airway obstruction. Further studies are needed to examine if similar findings occur during resuscitation of infants.

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