Factors Affecting Heated Humidity and Condensation in Neonates Receiving Respiratory Support

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Neonatal and infant mortality rates have drastically declined over the past decades due to technological and medical advances. Development of new respiratory support systems and improvement in neonatal ventilation are primary factors that have impacted infant mortality rates. Despite these tremendous strides, respiratory issues remain a prevalent complication when providing care to premature and sick newborns. In 2008, the Centers for Disease Control and Prevention (CDC, 2011) reported that approximately 7% of newborns (66.7 per 1,000) are admitted to a Neonatal Intensive Care Unit (NICU). In addition, more than 4% (41 per 1,000) of all newborns received assisted ventilation immediately following delivery and that one out of five neonates who required resuscitation in the delivery room remained on assisted ventilation for more than six hours after birth

Assisted ventilation, or the movement of gas into and out of the lung by an external source connected directly to the patient, does not come without risk. The most common complications associated with assisted ventilation in the neonate include bronchopulmonary dysplasia (BPD), chronic lung disease (CLD), and ventilator-induced lung injury (Goldsmith & Karotkin, 2011). In addition, condensation obstacles related to adequate heat and humidity are a challenging problem to manage with this vulnerable population.

The optimal goal when providing heated humidification to neonate's receiving respiratory support is to mimic natural gas conditioning with core temperature at 37°C, 100% saturation with water vapor, and absolute humidity of 44mg/L (Goldsmith & Karotkin, 2011). Despite heated humidification being a widely accepted standard of practice in neonatology, there lacks consensus on the amount of heated humidification and the temperature for adequate

humidification in the neonatal population. Although studies have agreed that ideal humidification aims to simulate normal airway mechanisms and temperatures, minimal acceptable temperature and humidity settings have not been established and there is a gap on how to achieve optimal heated humidification for neonates (Branson & Gentile, 2009; Hanssler, Tennhoff, & Roll, 1992; Solomita, Daroowalla, LeBlanc, & Smaldone, 2009; Tarnow-Mordi, Sutton, & Wilkinson, 1986; Todd, Boyd, Lloyd, & John, 2001; Yamada, et al., 2008).

According to Rodgriuez, et al., (2012), to appropriately regulate respiratory heat and humidification, it is imperative to understand normal physiologic gas conditioning and associated terminology. Humidity is the quantity of water vapor present in air, and can be expressed as absolute or relative values. Absolute humidity is the measured amount of water vapor in a gas mixture whereas relative humidity relates to temperature. Therefore, absolute humidity is the content of total water present in the gas (mg H_2O/L) whereas relative humidity is the amount of water present expressed as a percentage of maximum carrying capacity at a given temperature (Rodriguez, et al.). The ratio between water vapor mass contained in a certain gas volume at a certain temperature and maximum water vapor mass that the same gas volume could contain at the same temperature is another way to describe relative humidity (Gorayb, Braz, Martins, Modolo, & Nakamura, 2004).

At any given temperature, the amount of water that air can hold is limited. Air carrying its maximum capacity of water is referred to as being fully saturated or having 100% relative humidity. Heating air increases its capacity to hold moisture and becomes unsaturated or having less than 100% relative humidity. Unsaturated air absorbs water by evaporation until it reaches an equilibrium at the point of complete saturation or 100% relative humidity. On the contrary, when moist air is cooled, its capacity decreases and condensation may occur until a new

equilibrium is established either by lowering gas temperature or increasing saturation (Williams, Rankin, Smith, Galler, & Seakins, 1996). Consequently, a decrease in temperature of inspired gas that is already saturated with water vapor induces condensation (Yamada, et al., 2008).

In spontaneous breathing, the respiratory tract heats and humidifies inspired gas to assure that the gas entering the alveoli is warmed to body temperature and fully saturated with water vapor (Chikata, Sumida, Oto, Imanaka, & Nishimura, 2011). During normal breathing, inspiratory gases are heated and humidified to 29-32°C and fully saturated with water vapor by the time gas enters the trachea. At mid-trachea, temperature and absolute humidity reach approximately 34°C and absolute humidity is 34-38mg H_2O/L. While breathing through an intact upper airway, by the time air reaches the second bronchial bifurcation located just below the carina, temperature reaches 37°C with 100% relative humidity which correlates to an absolute humidity of 44mg/L (Branson & Gentile, 2010; Chikata, et al.; Goldsmith & Karotkin, 2011). This point is referred to as the isothermic saturation boundary (ISB) and represents the location where humidity and temperature become constant. Above the ISB, the airway acts as a counter-current heat-and-moisture exchanger. Whenever a thermal and moisture difference between the gas and the airway mucosa exists, heat and moisture exchange continues; the greater the difference the greater the transfer of heat and water (Branson & Gentile)

Under certain circumstances, such as hyperventilation or when cold, dry air enters the trachea, the ISB moves further down the bronchial tree. This forces the lower respiratory tract to assist with heat and moisture exchange. During the expiratory phase, gas is cooled when traversing the airway above the IBS, resulting in water condensation (Branson & Gentile, 2010). The upper airway recovers a significant proportion of the moisture and warmth which helps minimize the amount of insensible water and heat loss from the body during exhalation (Cahill,

2012). Under normal breathing conditions the temperature of expired air ranges from 32°C to 34°C at 100% relative humidity (Branson & Gentile).

Although it is widely understood that the optimal and ideal goal for newborn's receiving respiratory support is to deliver gases as close to 37°C and 100% humidity which corresponds to an absolute humidity of 44mg/L, there is discussion and controversy over managing airway temperature and humidity for this population. Mechanically producing heat and humidification similar to that of the natural airway is multifactorial and difficult to manage. The amount of heat and moisture that should be delivered to neonates receiving respiratory support remains unknown and there lacks a clear standard of care in managing heated humidification settings.

Condensation is one of many consequences associated with less than optimal humidification and has become a challenging adverse effect of inadequate humidification in the neonatal population. A major focus of avoiding adverse effects resulting from respiratory rainout is directed towards health professionals and their role in implementing strategies to prevent, reduce, and eliminate condensation. Managing condensation affects respiratory therapists, nurses, neonatal nurse practitioners, and neonatologists.

Past and current research regarding appropriate respiratory heat and humidity continues to address various factors that impact the delivery of optimal humidification. Minimal research has been dedicated to analyzing factors that exacerbate or reduce condensation. The aim of this scholarly project was to examine the environmental, baby, and respiratory factors in the NICU that complicate delivery of optimal humidity. The purpose of this study was to answer the following questions. 1) Which infant factors affect condensation levels in neonates receiving respiratory support? 2) Which environmental factors affect condensation levels in neonates

receiving respiratory support? Which respiratory support factors affect condensation levels in neonates receiving respiratory support?

Conceptual Model and Framework

Rosswurm & Larrabee Practice Change Framework

The goal of evidence-based health care is to utilize best current research in making decisions about individual patients or delivery systems. Evidence-based health care affects clinical practices, patients, and health care economics (Cochrane, 2012). To achieve best practices based on research evidence, clinicians, including advanced practice nurses, must challenge opinion-based processes and begin searching literature, critically analyzing findings, and synthesizing evidence (Rosswurm & Larrabee, 1999). Various models have been developed to assist practitioners and other health professionals towards evidence-based practice. The proposed topic will be critically guided by the first three steps of Rosswurm and Larrabee's evidence-based practice model (Appendix A).

Rosswurm and Larrabee's model is derived from theoretical and research literature related to utilizing evidence-based practice, research, and change theory. The model is designed to guide practitioners through the entire process of changing evidence-based practice. The model was originally designed for hospital centers, but can also be applied to primary care settings (Rosswurm & Larrabee, 1999).

Step 1

The initial step outlined by the model is to assess the need for change in practice. Practitioners may derive this interest from multiple aspects such as patient preferences, satisfaction scores, quality improvement data, self-queries, or new research data. During this step, internal data is compared with external data (Rosswurm & Larrabee, 1999). In reference to

the proposed topic of prevent respiratory condensation in the neonatal population, specifically analyzing the impact heater temperatures and location of temperature sensor can be compared with other institutions. The proposed tertiary NICU does not have policies or guidelines for specific heat settings when a neonate is on respiratory support as compared with NICUs from other facilities.

After analyzing internal data, practitioners determine the demand for change based on comparisons from internal data with external data from benchmarking databases. Benchmarking refers to collecting and sharing comparable information that lead to best outcomes (Rosswurm & Larrabee, 1999). The intention of comparing internal and external information is to either substantiate current practice or support the need for a change. Since specific guidelines are not available in the tertiary NICU, analyzing the data is the first step to either support the current practice or recognize that change may be necessary.

Stakeholders are another factor that must be considered in step one of this model. Stakeholders are those involved in the practice and may include discipline-specific or multidisciplinary teams, practitioners, administrations, and/or patients (Rosswurm & Larrabee, 1999). Practitioners, nurses, and respiratory therapists directly participate with hands-on care in regards to invasive and non-invasive ventilator equipment.

Step 2

Linking the problem with interventions and outcomes is the second step in Rosswurm and Larrabee's model. This step warrants practitioners to define the problem using the language of standardized classifications and linking the classification with interventions and outcomes. The classifications serve to define the concepts, organize knowledge, and facilitate communications among health professionals to determine quality and cost of care. Outcomes can

be impacted by issues related to condensation. Condensation can impede adequate ventilation and lead to longer durations of respiratory support and increasing the risk for sepsis (Garland, 2010; Norris, Barnes, & Roberts, 2009).

Step 3

Step three of the model involves synthesizing best evidence and refining interventions and outcomes. This stage focuses on gathering, analyzing, and synthesizing through literature review. Various patient and environmental-related data will be gathered and any correlations with the amount of respiratory rainout will be analyzed.

Step 4

Following the literature synthesis, providers describe the process of desired care change activities. For the proposed topic, those involved in caring for neonates on respiratory support will be educated on what research implementation will be conducted.

Physiologic Conceptual Model

The problem of condensation in the neonate will be conceptualized using a physiologic framework. A visual conceptual model demonstrating the dynamics that affect respiratory condensation will also be used to guide this study (Appendix B). This conceptual model focuses on the physiological and scientific factors associated with humidity and condensation. These elements include 1) baby factors, 2) environmental factors, and 3) respiratory support variances.

Appendix B illustrates various factors that contribute to the potential problem of inadequate respiratory condensation. The three main vectors include patient related factors, environmental aspects, and respiratory requirements. All elements have physiological implications on the proposed outcome of respiratory rainout in the neonatal population. Certain patient factors may impact environmental factors. For example, extremely low birth weight

babies (<1000 grams) may require higher respiratory support and/or more assistance with temperature regulation, and vice versa

Literature Review

Available past and current research literature identifies natural gas conditioning levels as target goals for humidification. The goal of heated humidification begins with warming respiratory gas inside the humidification chamber to a set target temperature. Water vapor is then added from the heated water reservoir. Inspiratory circuit tubing, containing a temperature probe or wire, is utilized to maintain or adjust the gas temperature to prevent water rainout before the gas reaches the infant (Schulze, 2007). Warming inspired gas at body temperature (37°C) and humidifying inspired gas to be thermodynamically saturated with 100% relative humidity or absolute humidity 44mg/L are the optimal condition to provide assisted ventilation to the neonate (Branson & Gentil, 2010; Cahil, 2009; Chikata, et al., 2012; Lellouche, et al., 2004; Nagaya, Okamoto, Nakamura, Hayashi, & Fujieda, 2009; Restrepo & Walsh, 2012; Rodriguez, et al., 2012; Schulze, 2007; Shearman, Hous, Dunster, & Jardine, 2012; Todd, Boyd, Lloyd, & John, 2001; Verta, Schena & Silverstri, 2010; Williams, Rankin, Smith, Galler, & Seakins, 1996; Yamada, et al., 2008). Despite professional agreement on optimal humidification values during assisted ventilation, there are not recommended heat and humidification settings to achieve this ideal environment.

The delivery of heated humidified gases for non-invasive and invasive ventilation is a standard of practice in neonatology (Restrepo & Walsh, 2012). Natural gas conditioning that occurs with normal breathing is interrupted when respiratory support systems are in place. Therefore, artificial humidified heat must be provided when a neonate's upper airway is

bypassed during invasive mechanical ventilation and/or compromised during non-invasive assisted ventilation.

Physiologic benefits and consequences of heated humidification are well established and understood. Optimal humidity maximizes complete gas conditioning, prevents heat and moisture exchange with the mucosa, eliminates systemic heat and moisture loss, maximizes mucociliary clearance, normalizes volume of airway secretions, prevents inflammatory reactions to thermal injury, reduces condensation, sustains airway patency, stabilizes lung compliance, preserves lung mechanics, supports surfactant production, optimizes energy expenditure, and provides comfort to the neonate (Cahill, 2009; Nagaya, et al., 2009; Restrepo & Walsh, 2012; Schulze, 2007; Schearman, Hou, Dunster, & Jardine, 2012; Solomita, et al., 2009; Williams, Rankin, Smith, Galler, & Seakins, 1996; Yamada, et al., 2008). Inadequate or low humidification of inspired gases in the neonate has demonstrated damaging affects including: diminished ciliary activity, increased viscosity of mucus, endotracheal occlusion, reduced respiratory compliance, increased airway resistance, increased risk for hypoventilation and alveolar gas trapping, reduced surfactant activity, prolonged oxygen requirements, induced inflammation, hypothermia, and discomfort (Allan, et al., 2009; Branson & Gentile, 2010; Chikata, et al., 2012; Davies, Dunster, & Cartwright, 2004; Hanssler, Tennhoff, & Roll, 1992; Lellouche, et al., 2004; Nagaya, et al., 2009; Restrepo & Walsh, 2012; Rodriguez, et al., 2012; Schulze, 2007; Schearman, et al., 2012; Solomita, et al., 2009; Tarnow-Mordi, Sutton, & Wilkinson, 1986; Todd, Boyd, LLoyd, & John, 2001; Verta, Schena, & Silvestri, 2010; Williams, Rankin, Smith, Galler, & Seakins, 1996). Over humidification is less frequently reported but carries potential consequences such as respiratory thermal injury, dilution of surfactant, overwhelming secretions, interference with mucociliary transport, and risk for ineffective pressure or volumes generated by assisted ventilation (Allan, et

al., 2009; Davies, Dunster, & Cartwright, 2004; Hanssler, Tennhoff, & Roll, 1992; Lellouche, et al., 2004; Restrepo & Walsh, 2012; Schearman, Hou, Dunster, & Jardine, 2012; Todd, Boyd, Lloyd, & John, 2001; Williams, Nigel, Smith, Galler, & Seakins, 1996).

Condensation, or rainout, in the neonatal population has been identified and reported as a clinical problem associated with various modes of assisted ventilation, both invasive and non-invasive. Condensation occurs when ventilator gases are fully humidified and warmer than body temperature (Cahill, 2009; Yamada, et al., 2008). Another condition that induces condensation is a drop in temperature of inspired gas that is already saturated with water vapor. This causes excess water in the unheated part of the circuit and tube, decreases absolute humidity of the gas, and limits the delivery of optimal humidified gas to the lungs (Yamada, et al., 2008). Tubing condensation, also referred to as rainout, can filter back into the neonate's airway causing difficulties with ventilation, apneic and bradycardic episodes, and false ventilator pressure measurements (Cahill; Schulze, 2007). Condensation creates particulate water formation in the respiratory circuit increasing the risk for unintentional lavage in the neonate. Physiologically, condensation interferes with cilia's close contact with mucous, leading to low viscosity and the inability to transport mucous. There is a higher correlation between over humidification and condensation. However, it occurs when administering above or below optimal gas conditioning (Cahill, 2009; Todd, Boyd, Lloyd, John, 2001; Restrepo & Walsh, 2012; Schulze, 2007; Williams, Ranke, Smith, Galler, & Seakins, 1996).

As health providers, it is prudent to avoid excessive accumulation of condensate in the circuit, especially near the neonate. Conscious efforts should be taken towards avoiding accidental drainage of condensate into the neonate's airway (Cahill, 2009; Hess, 2003; Nagaya, Okamoto, Nakamura, Hayashi, & Fujieda, 2009; Schulze, 2007; Lellouche, et al., 2004; Yamada,

et al., 2008). Life threatening events, such as bradycardia or apnea episodes, can occur from inadvertent delivery of accumulated rainout into the neonate's airway impeding adequate oxygenation and ventilation (Rodriguez, et al., 2012).

Clinical studies have not provided evidence for the establishment of guidelines on how to achieve optimal gas conditioning. In addition, standards of practice are not available on how to appropriately manage, prevent, or reduce respiratory circuit condensation when ventilating premature and sick neonates. Previous studies have identified environmental factors that potentially influence rainout, but there lacks consensus on how to translate these findings into clinical practice.

Environmental Factors

Fluctuations in heated humidification and the development of rainout have been associated with changes in ambient air. The inventions of radiant warmers and incubators have improved survival rates by promoting neutral thermal environments and decreased insensible water loss (Schulze, 2007). Because the respiratory circuit must pass through two different environments: the room and the incubator or radiant warmer, heated humidification is more complex (Nagaya, Okamoto, Nakamura, Hayashi, & Fujieda, 2009; Schulze; Todd, Boyd, Lloyd, & John, 2001; Yamada, et al., 2008).

Respiratory circuit temperature and humidification are dependent on ambient temperature. High ambient air temperature correlates to decreased heated humidification performance; the higher the ambient temperature the lower the relative and absolute humidity (Davies, Dunster, & Cartwright, 2004; Lellouche, et al., 2004; Nagaya, Okamoto, Nakamura, Hayashi, & Fujieda, 2009; Schulze, 2007; Todd, Boyd, Lloyd, & John, 2001; Yamada, et al., 2008). The rationale for poor humidification with high ambient air temperature is that when the

inlet chamber is above normal the heater stops heating, supposedly maintaining the set outlet chamber temperature. In other words, the temperature probe for the respiratory support system is located as close to the patient connection to monitor the respiratory gas temperature. The heater aims to maintain the set gas temperature at the Y adaptor by controlling the circuits heated power output. If the temperature probe is in the presence of a heated field, such as a radiant warmer, it may register at a higher temperature than the actual respiratory gas temperature due to radiation or convection from the warmer environment. This may potentially signal the respiratory servo control to decrease the heating output of the ventilator circuit and lead to loss of gas temperature. Consequently, this produces rainout. The water contained in the chamber remains too cold for evaporation, leading to extreme low levels of relative and absolute humidity. The inlet chamber temperature of respiratory support systems were most affected by ambient air temperature. Higher incubator temperatures are required for extremely premature neonates, creating inspiratory circuit condensation and delivering lower humidity (Todd, Boyd, Lloyd, & John; Yamada, et al., 2008). Condensation and inadequate humidification arise when the incubator temperature or heat output from a radiant warmer is higher than the targeted gas temperature (Davies, Dunster, & Cartwright, 2004; Lellouche, et al., 2004; Schulze, 2007).

Clinical studies and article reviews support the theory that heated humidification and condensation are dependent on ambient or incubator temperatures (Davies, Dunster, & Cartwright, 2004; Lellouche, et al., 2004; Nagaya, Okamoto, Nakamura, Hayashi, & Fujieda, 2009; Schulze, 2007; Todd, Boyd, Lloyd, & John, 2001; Yamada, et al., 2008). Despite this concept being widely accepted, small variances have been analyzed and reported. One study that was conducted in a laboratory utilizing simulated lungs, reported both condensation and inadequate humidification at high and low ambient temperatures. Temperature drop and moisture

loss, rainout, occur as a result when incubator temperature is lower than Y-piece temperature creating relatively dry gas being delivered to the lungs due to the decreased temperature and subsequent drying of inspired gas (Yamada, et al., 2008). Whereas, another study found that a lower incubator temperature compared to the temperature setting on the heated humidifier lead to condensation of water in the respiratory circuit. Changes in relative and absolute humidity were not discussed in this instance (Nagaya, Okamoto, Nakamura, Hayshi, & Fujieda, 2009). One bench study measured humidity with three different humidifiers under several conditions including varying ambient air temperatures, varying ventilators with different gas temperatures, and varying ventilator tidal volumes. The researchers obtained data on three different days on 20 ventilated patients in the NICU. The results found that visual condensation is not a reliable clinical marker for adequate humidification when the ambient air temperature is high. When ambient air temperature is normal, between 22°C and 24°C, there was a good correlation between inspired gas and condensation on the chamber wall. The correlation did not exist for high ambient temperatures due to the inability for gas to cool and condense. The researchers concluded that condensation remains a clinical problem and that visual evaluation may only be useful in cases where ambient temperature is not too high (Lellouche, et al., 2004).

Another frequently mentioned element that is taken into consideration when analyzing heated humidification is the location of the thermometer probe that regulates the respiratory heat temperature and humidity. Varying data and discussions have been presented regarding location of the airway temperature probe in order to optimize humidification. Proximity of the temperature probe to the patient and the location of the probe in reference to the incubator (inside or outside) are relevant factors that need to be considered when analyzing the position of the probe and its influence on heated humidification (Davies, Dunster, & Cartwright, 2004; Nagaya,

Okamoto, Nakamura, Hayashi, & Fujieda, 2009; Schulze, 2009; Todd, Boyd, Lloyd, & John, 2001).

Similar studies agreed that ambient air temperature affects the output of heat and humidification (Davies, Dunster, & Cartwright, 2004; Nagaya, Okamoto, Nakamura, Hayashi, & Fujieda, 2009). However, one emphasized the importance of optimizing management of respiratory humidification by measuring both temperature and humidity as close to the patient as possible (Davies, Dunster, & Cartwright). On the contrary, Nagaya et al. (2009) discovered the temperature at the Y piece fluctuated regardless of the temperature setting of the probe placed near the patient. Researchers concluded that the circuit temperature was independent of the airway temperature probe location and dependent on incubator temperature (Nagaya, Okamoto, Nakamura, Hayashi, & Fujieda). As referenced earlier, many studies allude to alterations in controlling the heat of inspiratory gases when the temperature probe is exposed to heat or cool sources. For example, when a temperature probe is in the presence of a radiant warmer or inside a high temperature incubator, the airway temperature probe may sense that the inspired gas temperature is at the set temperature and temporarily switch to an "off" position. This in turn will actually cool the inspired gases and deliver inadequate heat and humidity to the neonate (Schulze, 2007; Todd, Boyd, Lloyd, & John, 2001). Placing the airway temperature probe outside the heated field, or outside the incubator, is one recommended solution to alleviate this problem. To complicate the issue further, despite positioning the probe outside the warmed area, once the gas enters the inspiratory circuit within the warmed environment, the temperature falls and results in particulate water formation and rainout in the respiratory tubing (Schulze; Todd, Boyd, Lloyd, & John).

Respiratory Support Factors

Gas flow rates delivered via various types of ventilation impact the temperature and degree of relative and absolute humidity. A management guideline for pediatric patients receiving heated, high-flow nasal cannula recommended in order to prevent excess water accumulating within the circuit to keep a minimum of 2L/min of gas flow (Northern Sydney Local Health District, 2012). Higher flow rates (>20 L/min) decreased heated humidification performance in comparison with low (10L/min) rates (Lellouche, et al., 2004). Similarly, flow rates were inversely related to temperature, absolute, and relative humidity (Rodriguez, et al., 2012; Tarnow-Mordi, Sutton, & Wilkinson, 1986). Since neonate's require minimal flow rates compared to adults, studies recognize the difficulty in transposing research analyzing such high flow rates. In regards to typical neonatal air flow rates, Verta, Schena, and Silvestri (2010) found that humidity decreased faster at low flow settings, than at higher flow settings. Low flow rates also presented another drawback: relative humidity values equal to 100% lead to a presence of condensed water in the breathing circuit that increased risk for accidental rainout lavage or ETT occlusion (Verta, Schena, & Silvestri).

Baby Factors

Weight of the neonate and required thermal support to maintain an appropriate neutral environment are two additional components that need to be evaluated. Mechanically ventilated neonates weighing less than 1,500 grams at birth displayed significantly more chronic lung disease if exposed to inspired gas at less than 36.6°C during the first four days of life (Nagaya, Okamoto, Nakamura, Hayashi, & Fujieda, 2009; Schulze, 2007; Yamada, et al., 2008). Typically temperature requirements are related to weight in neonates; the smaller or more premature the neonate the higher the incubator temperature. A strong correlation between temperature and weight in newborns is due to a strong correlation between weight and incubator temperature,

with heavier infants having lower incubator temperatures. Such measurements would help predict potential drops in inspired temperature (Davies, Dunster, & Cartwright, 2004).

Adequate humidification leads to optimal outcomes for the neonatal population while inappropriate heated humidification carries minor to severe consequences. Humidification remains a standard of practice in the field of neonatology, despite the lack of recommendations on minimally accepted settings for heat and humidification. Past and current research has acknowledged various environmental elements that impact delivery of humidification to the neonate. A gap exists between providing appropriate humidification and avoiding condensation. There is still a dire need to establish consistency for managing heat and humidification in the neonatal population.

Methods

Sample

A convenience sample of seven hospitalized neonates from a level III Neonatal Intensive Care Unit who received invasive and/ or non-invasive respiratory support (N=7) were selected for inclusion in this study. Patient identifiers were excluded. Exclusion criteria included babies undergoing head or total body cooling and those infants who extubated to room air and received no assisted ventilation.

During one month, seven babies were enrolled in the study after parental consent was obtained. Two sets of twins were enrolled. Gestational ages at birth ranged from $27^{1/7}$ weeks to 30 weeks (mean=$28^{2/7}$). Birth weight was 780 grams to 1670 grams (mean=1100 grams). Data was collected during the first to tenth days of life.

Design & Procedure

This was an observational study. Descriptive analysis of the factors that contribute to respiratory condensation was completed. Approval for this study was obtained from the facility's nursing research committee and institutional review board.

Data Collection

Data collection included multiple patient and environmental factors. Parental consent was obtained and documented prior to data collection. Patient characteristics were obtained from chart reviews and environmental factors were obtained by the investigator at the bedside. The primary investigator was the sole data collector. The primary investigator was utilized to ensure consistency and reliability. Repeated measures were utilized by the observer collecting data on the same patient for three consecutive days in an attempt to follow changes in patient or environmental elements. Following the same patient for numerous days and at different times of the day assisted in identifying which environmental or respiratory factors contribute to condensation since the baby's demographic related factors remained stable (i.e. weight and gestational age).

Patient characteristics included gestational age at birth, current day of life, and current weight in grams. Environmental elements analyzed included bed type, temperature control mode, temperature control setting, incubator environmental temperature, ambient room temperature, baby's axillary temperature, and incubator humidity percentage. Respiratory support information collected included respiratory support types, settings, flow, amount of secretions, respiratory heater temperature, heat sensor location, proximity of heat sensor to baby, and condensation amount (Appendix C, D, & E).

Measurement of the respiratory rainout according to the scale of significant, moderate, or none by the observer was used to evaluate the problem and its significance. The patient and environmental data was analyzed to recognize condensation amounts to identify whether any correlations exist. The bedside registered nurses' perception of respiratory rainout was also included in the study and the nurse's perception increased the validity in regards to the amount of condensation.

Data Analysis

Due to a minimal number of participants the study results were not large enough to perform a Chi-square statistical analysis. Correlations between baby factors, environmental elements, and respiratory support were explored to identify any associations with the amount of condensation. The dependent variable throughout this study was respiratory rainout.

Results

In regards to environmental factors, all seven participants were in isolettes on ISC (skin) temperature control mode at a setting of 36.5 Celsius (C). Incubator environmental temperatures ranged from 28.4°C to 36.7°C (mean=31.75) with axillary temperatures of 36°C to 37.4°C (mean=36.66). The baby's individual room temperatures were between 22.2°C (72°F) to 24.4°C (76°F) (mean=73.7). Five out of the seven participants were receiving 70% humidity inside their isolette at the time of data collection. The remaining two were not on any humidity support. Supplemental humidity was not always associated with condensation.

Various respiratory support modes were utilized. Invasive types of ventilation included synchronized intermittent mandatory ventilation (SIMV) and high-frequency oscillatory ventilation (HFOV). Non-invasive modes of ventilation included continuous positive airway pressure (CPAP) via SiPAP machine, noninvasive intermittent mandatory ventilation (NIMV)

via RAM cannula, and BiPhasic CPAP via SiPAP machine. None of the babies received heated high-flow nasal cannula (HFNC) during the study. There were two settings for the respiratory heater temperatures, 31˚C for non-invasive and 37˚C for invasive respiratory support. Respiratory heater temperature settings ranged from 30.9˚C to 37.1˚C. The location of the heat sensor on the respiratory tubing was outside the isolette for all support modes, except for HFOV in which it was inside the isolette. One baby who received CPAP via SiPAP machine was the only baby who did not have any secretions, which were reported as dry. The remainder of the patients had small to large oral and/or endotracheal secretions. With invasive ventilation, the temperature differences between the respiratory heater temperature and the incubator/environmental temperature were 0.4 -7.7 degrees C., with a mean of 4.8 degrees. With non-invasive ventilation, the temperature differences were 0.3-4.0 degrees C., with a mean of 1.9 degrees.

Condensation was associated with all infants on invasive ventilation with the exception of one. One baby placed on HFOV less than 30 minutes prior to data collection had no condensation, probably due to the recent change in ventilation mode. One outlier was an invasively ventilated baby with the heater temperature setting at 31˚C (noninvasive) which still resulted in a large amount of condensation. Higher ventilator settings were not necessarily associated with more condensation. Condensation occurred in the same patient who received both HFOV and SIMV types of ventilation. Another baby had condensation when receiving SIMV ventilation, but on the consecutive days of receiving BiPhasic CPAP condensation was not present. A third baby received NIMV, SIMV, and BiPhasic CPAP and the only day condensation appeared was when the baby was invasively ventilated. The nurses perceived

condensation as an issue for all the babies who received invasive respiratory support, except the new HFOV baby.

There is a consistent relationship between condensation and invasive ventilation. All babies on invasive ventilation (intubated) had scant to significant condensation, with most babies having moderate condensation. Overall, intubated babies have more condensation in the respiratory tubing than those babies treated with non-invasive ventilation (nasal prongs). In addition, dry secretions were reported with non-invasive CPAP via SiPAP machine and little to no condensation with non-invasive ventilation.

Condensation and dry obstructive secretions are clinical problems that affect babies receiving respiratory support. There were higher differences in temperatures between the respiratory heater and the isolette in the babies on invasive ventilation (see Appendix F). These intubated babies also had more condensation. The one baby with no condensation had a temperature difference of 0.4˚C, the baby with scant condensation had a temperature difference of 4.4˚C., and the babies with moderate condensation (n=8) had temperature differences between 4.6-7.1. There was one baby with significant condensation which had a low temperature difference, but also had a very low temperature of both the respiratory heater and the isolette. Therefore, it appears that infants with a higher isolette temperature (close to the baby's actual temperature) with a lower heater temperature had the least amount of condensation. The higher the difference in temperatures appeared to cause more condensation than the lower temperature differences. Therefore, keeping the isolette temperatures closer to the respirator heater temperature may decrease the amount of condensation. Since the isolette temperatures of these babies were based on their actual skin temperature (ISC control), the nurse may have no control over this variation.

With infants on non-invasive ventilation (CPAP or BiPhasic), these infants had smaller differences in temperatures between the respiratory heater and the isolette temperature, and most of them also had the isolette temperatures which were higher than the heater temperatures. This was not the case with the invasively ventilated patients. All of the invasively ventilated babies had higher respiratory heater temperatures than isolette temperatures. So babies on non-invasive ventilation with CPAP or BiPhasic have lower respiratory heater temperatures, but similar isolette temperatures due to the heater settings for these types of devices. This resulted in no condensation in any of the tubing.

Limitations of this study make it difficult to suggest or recommend changes in practice to reduce the amount of condensation or prevent dry secretions. Primary limitations of this study include the small number of babies in the sample. The limited amount of participants hinders the ability to conduct a statistical analysis and determine relationships between the variables. Also, the heat temperature settings of the respiratory support equipment had only two available setting options, 31˚C or 37˚C. This limited the control of the nursing or respiratory staff over temperatures of the air provided to the patient.

Implications for Education and Practice

Education of all healthcare providers, including neonatal nurse practitioners, nurses, respiratory therapists, and neonatologists is imperative to provide optimal, artificial humidification that mimics natural gas conditioning. Being vigilant about controlling and disposing of condensation may be helpful in preventing accidental lavage into a baby's endotracheal tube or into his/her oral cavity. Side effects and adverse events such as life-threatening episodes of bradycardia or apnea can result from excessive respiratory support condensation or from dry obstructive secretions that occlude the airway. Healthcare providers

should also be conscious of environmental factors that may affect increased condensation or dryness. For example, if a term baby is invasively ventilated on a radiant warmer and there is increased condensation, transferring the baby to an isolette may decrease condensation. Rotating the respiratory heater temperature settings from 31˚C to 37˚C every designated number of hours for both invasive and noninvasive ventilation may assist in controlling the amount of condensation or prevent dryness while providing adequate heat.

Conclusion

Recommendations for future research include expanding the participant database to include a large portion of subjects at various gestational ages, weights, heat support, and respiratory support. Also, controlling the isolette temperatures to stay closer to the respiratory heater temperature may decrease the amount of condensation. Following subjects for more than three days would be another consideration to improve the reliability of the results.

Despite the study's limitations, the data reinforced that condensation obstacles related to adequate heat and humidity are a challenging problem to manage in the neonatal population. The study also emphasized that although heated humidification is a standard of practice in neonatology, there is still a gap in how to achieve optimal heated humidification for neonates (Branson & Gentile, 2009; Hanssler, Tennhoff, & Roll, 1992; Solomita, Daroowalla, LeBlanc, & Smaldone, 2009; Tarnow-Mordi, Sutton, & Wilkinson, 1986; Todd, Boyd, Lloyd, & John, 2001; Yamada, et al., 2008).

References

AARC Evidence-Based Clinical Practice Guidelines. (2003). Care of the ventilator circuit and its relation to ventilator-associated pneumonia. Respiratory Care, 48(9), p. 869-879.

Allan, P., Hollingsworth, M.J., Maniere, G.C., Rakofsky, A.K., Chung, K.K., Naworol, G.A., Ward, J.A., … Morris, M.J. (2009). Airway humidification during high-frequency percussive ventilation. Respiratory Care, 54(3), p. 350-358.

Branson, R.D., & Gentile, M.A. (2010). Is humidification always necessary during noninvasive ventilation in the hospital. Respiratory Care, 55(2), p. 209-215.

Cahill, S. (2009). Humdification of inspired gases in the neonatal unit. NHS Forth Valley.

Centers for Disease Control and Prevention: US Department of Health and Human Services. (2011). Expanded data from the new birth certificate, 2008. National Vital Statistics Reports, 59(7).

Chikata, Y., Sumida, C., Oto, J., Imanaka, H., & Nishimura, M. (2012). Humidification performance of heat and moisture exchangers for pediatric use. Critical Care Research and Practice.

Cochrane Collaboration. (2011). Evidence-based healthcare and systemic reviews. The Cochrane Library. Retrieved from: http://www.cochrane.org/about-us/evidence-based-health-care/

Davies, M.W., Dunster, K.R., & Cartwright, D.W. (2004). Inspired gas temperature in ventilated neonates. Pediatric Pulmonology, 38, p. 50-54.

Garland, J.S. (2010). Strategies to prevent ventilator-associated pneumonia in neonates. Clinical Perinatology, 37(3), 629-643.

Goldsmith, J.P. & Karotkin, E.H. (2011). Assisted Ventilation of the Neonate, (5th ed.). Saunders-Elsevier.

Gorayb, S.B., Braz, J.R., Martins, R.H., Modolo, N.S., & Nakamura, G. (2004). Inhaled gases humidification and heating during artificial ventilation with low flow and minimal fresh gases flow. Brazilian Journal of Anesthesiology, 54(1), p. 28-36.

Hanssler, L., Tennhoff, W., & Roll, C. (1992). Membrane humidification – a new method for humidification of respiratory gases in ventilator treatment of neonates. Archives of Disease in Children, 67, p. 1182-1184.

Lellouche, F., Taille, S., Maggiore, S.M., Qader, S., L'Her, E., Deye, N., & Brochard, L. (2004). Influence of ambient and ventilator output temperatures on performance of heated-wire humidifiers. American Journal of Respiratory Critical Care Medicine, 170, p. 1073-1079.

Nagaya, K., Okamoto, T., Nakamura, E., Hayashi, T., & Fujieda, K. (2009). Airway humidification with a heated wire humidifier during high-frequency ventilation using babylog 8000 plus in neonates. Pediatric Pulmonology, 44, p. 260-266.

Northern Sydney Local Health District. (2012). Procedure: heated & humidified oxygen via nasal cannula (HHNC): administration and management of pediatric patients. NSW Government.

Norris, S. C., Barnes, A.K., & Roberts, T.D. (2009). When ventilator-associated pneumonias haunt your NICU – One unit's story. Neonatal Network, 28(1), 59-66.

Restrepo, R.D., & Walsh, B.K. (2012). Humidification during invasive and noninvasive mechanical ventilation: AARC Clinical practice guideline. Respiratory Care, 57(4), p. 782-788.

Rodriguez, A.M., Scala, R., Soroksky, A., BaHammam, A., Klerk, A., Valipour, A., Chiumella, D., Martin, C., & Holland, A.E. (2012). Clinical review: humidifiers during non-invasive ventilation – key topics and practical implications. Critical Care, 16, p. 203-208.

Rosswurm, M. A., & Larrabee, J. H. (1999). A model for change to evidence-based practice. Journal of Nursing Scholarship, 31(4), p. 317-322.

Schulz, A. (2007). Respiratory gas conditioning and humidification. Clinics in Perinatology, 34, p. 19-33.

Shearman, A.D., Hou, D., Dunster, K.R., & Jardine, L. (2012). Heating of gases during neonatal resuscitation: a bench study. Resuscitation, 83, p. 369-373.

Solomita, M., Palmer, L.B., Daroowalla, F., Liu, J., Miller, D., LeBlanc, D.S., & Smaldone, G.C. (2009). Humidification and secretion volume in mechanicall ventilated patients. Respiratory Care, 54(10), p. 1329-1335.

Tarnow-Mordi, W.O., Sutton, P., & Wilkinson, A.R. (1986). Inadequate humidification of respiratory gases during mechanical ventilation of the newborn. Archives of Disease in Childhood, 61, p. 698-700.

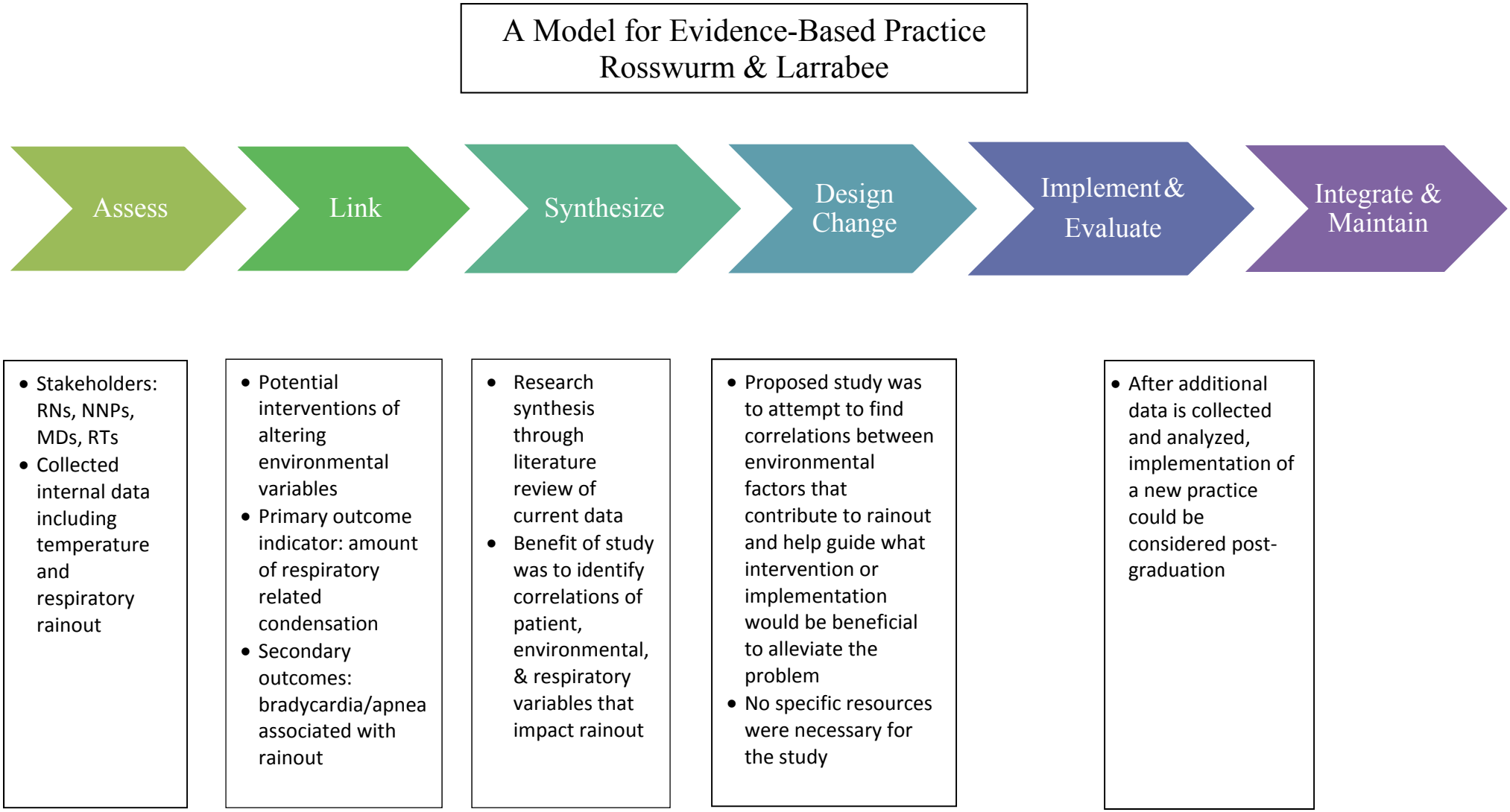
Todd, D., Boyd, J., Lloyd, J., & John, E. (2001). Inspired gas humidity during mechanical ventilation: effects of humidification chamber, airway temperature probe position and environmental conditions. Journal of Pediatrics and Child Health, 37, p. 398-494.

Verta, A., Schena, E., & Silvestri, S. (2010). Mathematical model and minimal measurement system for optimal control of heated humidifiers in neonatal ventilation. Medical Engineering and Physics, 32, p. 475-481.

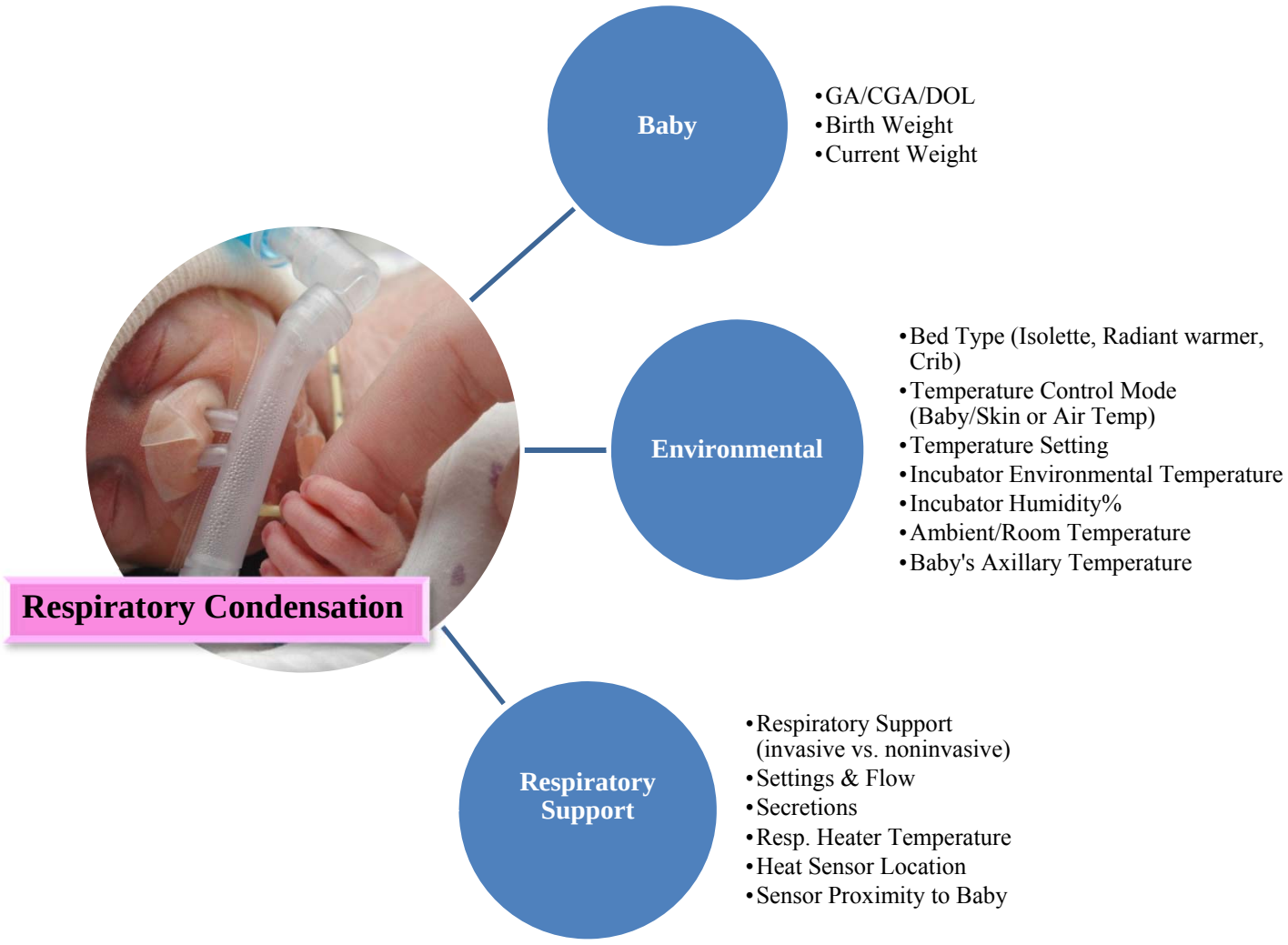
Williams, R., Rankin, N., Smith, T., Galler, D., & Seakins, P. (1996). Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa. Critical Care Medicine, 24(11), p. 1920-1929.

Yamada, Y., Kyuno, T., Suzuki, S., Ito, T., Kato, I., & Togari, H. (2008). A drop in gas temperature in the external part of the endotracheal tube is problematic during neonatal respiratory support. Pediatric Pulmonology, 43, p. 666-673.

Appendix A


A Model for Evidence-Based Practice
Rosswurm & Larrabee
Assess
Link
Synthesize
Design Change
Implement & Evaluate
Integrate & Maintain
• Stakeholders: RNs, NNPs, MDs, RTs
• Collected internal data including temperature and respiratory rainout
• Potential interventions of altering environmental variables
• Primary outcome indicator: amount of respiratory related condensation
• Secondary outcomes: bradycardia/apnea associated with rainout
• Research synthesis through literature review of current data
• Benefit of study was to identify correlations of patient, environmental, & respiratory variables that impact rainout
• Proposed study was to attempt to find correlations between environmental factors that contribute to rainout and help guide what intervention or implementation would be beneficial to alleviate the problem
• No specific resources were necessary for the study
• After additional data is collected and analyzed, implementation of a new practice could be considered post-graduation

Appendix B


Baby
•GA/CGA/DOL
•Birth Weight
•Current Weight
Environmental
•Bed Type (Isolette, Radiant warmer, Crib)
•Temperature Control Mode (Baby/Skin or Air Temp)
•Temperature Setting
•Incubator Environmental Temperature
•Incubator Humidity%
•Ambient/Room Temperature
•Baby's Axillary Temperature
Respiratory Condensation
Respiratory Support
•Respiratory Support (invasive vs. noninvasive)
•Settings & Flow
•Secretions
•Resp. Heater Temperature
•Heat Sensor Location
•Sensor Proximity to Baby

Appendix C

Demographic Data Table

Baby	GA	DOL	CGA	BW (g)	Wt (g)
1a	28.1	1	28.2	780	820
b		2	28.3		760
c		3	28.4		780
2a	28.1	1	28.2	970	950
b		2	28.3		940
c		3	28.4		850
d		4	28.5		840
3a	27.1	3	27.4	770	760
b		4	27.5		780
c		5	27.6		770
4a	28.6	8	30.0	1100	1000
b		9	30.1		1010
c		10	30.2		1020
5a	30.0	3	30.3	1670	1460
b		4	30.4		1360
c		5	30.5		1450
6a	27.6	1	28.0	1230	1230
b		2	28.1		1160
c		3	28.2		1200
7a	27.6	1	28.0	1180	1180
b		2	28.1		1070
c		3	28.2		1010

Appendix Key

GA: gestational age weeks at birth
DOL: current day of life at time of data collection
CGA: corrected gestational age at time of data collection
BW: weight in grams at birth
Wt: current weight in grams at time of data collection

Appendix D

Environmental Data Table

Baby	Incub. Environ. Temp	Ambient Temp	Axillary Temp
1a	32.4	23.9C (75F)	36.9
b	30.8	23.9C (75F)	36.2
c	28.4	24.4C (76F)	36.9
2a	31.2	23.9C (75F)	37.4
b	31	23.9C (75F)	36.9
c	36.7	24.4C (76F)	37.2
d	31.5	23.9C (75F)	36.9
3a	32.3	22.2C (72F)	36.8
b	31.8	22.2C (72F)	36.1
c	31.9	22.8C (72F)	36.6
4a	34	22.8C (72F)	36.5
b	32.3	23.3C (74F)	36.8
c	32	23.9C (75F)	36
5a	29.6	22.8C (73F)	36.5
b	28.7	23.3C (74F)	36.9
c	28.7	22.8C (73F)	36.7
6a	32.5	22.8C (73F)	36.2
b	33	22.8C (73F)	36.8
c	30.6	22.8C (73F)	36.7
7a	32.3	22.8C (73F)	36.7
b	31.9	22.8C (73F)	36.2
c	34.9	22.8C (73F)	36.7

Appendix Key

Incubator Environmental Temperature: Celsius
Ambient Temperature: Room temperature in Fahrenheit
Axillary Temperature of Baby: Celsius

Appendix E

Respiratory Support Data Table

Baby	Resp. Type	Settings	Resp. Heater Temp	Condensation	RN Percep
1a	I	16/5, 15, +6	36.8	Scant	Y
b	I	17/6, 20, +6	36.9	Moderate	Y
c	I	22/5, 40, +8	36.1	Moderate	Y
2a	I	18/6, 25, +8	37.1	Moderate	Y
b	I	20/6, 30, +8	37.1	Moderate	Y
c	I	Δ27, MAP10, Hz12	37.1	None (new)	N
d	I	Δ20, MAP11, Hz10	37	Moderate	Y
3a	I	Δ27, MAP12, Hz11	36.9	Moderate	Y
b	I	Δ26, MAP12, Hz11	37.1	Moderate	Y
c	I	Δ27, MAP12.5, Hz11	37	Moderate	Y
4a	NI	6 (SiPAP)	31	None/ Dry	N
b	NI	5 (SiPAP)	30.8	None	N
c	NI	5 (SiPAP)	31	None	N
5a	I	19/6, 25, +8	31	Significant	Y
b	NI	9/6, 30	31.1	None	N
c	NI	9/6, 20	30.9	None	N
6a	NI	20/6, 20 (RAM)	30.9	None	N
b	NI	20/6, 20 (RAM)	31.1	None	N
c	NI	20/6, 20 (RAM)	30.9	None	N
7a	NI	18/6, 20 (RAM)	30.9	None	N
b	I	15/4, 30, +6	36.6	Moderate	Y
c	NI	9/5, 20	30.9	None	N

Appendix Key

Respiratory Support Type: Invasive (I); Non-invasive (NI)
Secretions: Scant (SC); Small (SM); Moderate (M); Large (L); Copious (C)
Respiratory Heater Temp: Celcius
*Condensation: Significant, Moderate, Scant, None
RN perception: condensation as a clinical factor: Yes (Y); No (N)

Appendix F

Condensation and Temperature Differences

Invasive			
Resp Heater Temp	Incubator Environ Temp	Condensation	Temperature Difference
36.8	32.4	Scant	4.4
36.9	30.8	Moderate	6.1
36.1	28.4	Moderate	7.7
37.1	31.2	Moderate	5.9
37.1	31	Moderate	6.1
37.1	36.7	None (new)	0.4
37	31.5	Moderate	5.5
36.9	32.3	Moderate	4.6
37.1	31.8	Moderate	5.3
37	31.9	Moderate	5.1
31	29.6	Significant	1.4
36.6	31.9	Moderate	4.7

Non-Invasive			
Resp Heat Temp	Incubator Environ Temp	Condensation	Temperature Difference
31	34	None/Dry	-3
30.8	32.3	None	-1.5
31	32	None	-1
31.1	28.7	None	2.4
30.9	28.7	None	2.2
30.9	32.5	None	-1.6
31.1	33	None	-1.9
30.9	30.6	None	0.3
30.9	32.3	None	-1.4
30.9	34.9	None	-4