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Preterm Infant Incubator Humidity Levels

A Systematic Review

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ABSTRACT

Background: Numerous scholars have reported that inconsistent levels of incubator humidity in the neonatal intensive care unit (NICU) require attention. Evidence synthesis was needed to identify optimal incubator humidity levels and duration to decrease transepidermal water loss (TEWL) and the potential for infection.

Purpose: The purpose of this systematic review was to appraise and synthesize the evidence of preterm outcomes related to incubator humidity. The primary aim of this study was to determine how patient outcomes were impacted by incubator humidity levels and duration in premature infants born before $32^0/_7$ weeks cared for in the NICU.

Methods/Search Strategy: The foundation of this systematic review was the Joanna Briggs Institute method for systematic reviews. Mefford's theory of health promotion for the preterm infant was used to address the wholeness of the preterm infant's body system. Evidence was classified using the Johns Hopkins evidence-based practice levels and quality of evidence.

Findings: Twelve studies met inclusion criteria. The evidence demonstrated that the practice of incubator humidity is warranted; however, it does not come without risks. Microbial growth was increased in high levels of incubator humidity. Unnecessary TEWL was prevented by lowering high levels of incubator humidity after the first week of life, improving skin barrier formation.

Implications for Practice: Incubator humidity of 60% to 70% in the first week of life was effective in preventing TEWL in infants born 26 weeks or more.

Implications for Research: Future incubator humidity research is needed for infants born before 26 weeks.

Video Abstract available at https://journals.lww.com/advancesinneonatalcare/Pages/videogallery.aspx?autoPlay=false&videoId=39.

Key Words: humidity, incubator, neonatal intensive care, nosocomial infection, preterm infant, transepidermal water loss

Concern about the humidity conditions in the care of preterm infants dates back to the 1930s when Blackfan and Yaglou [1] suggested the importance of the use of humidity in relation to temperature. In the 1950s, Silverman and Blanc[2] revealed that preterm infants cared for in an incubator set at 80% to 90% relative humidity had a markedly lower death rate versus preterm infants cared for in 30% to 60% relative humidity incubators. These researchers suggested that humidity played an important role in evaporative losses.[2]

As the care of preterm infants improved, preterm infants' immature skin development became a topic of interest. Transepidermal water loss (TEWL) and fluid balance challenges in this population were studied, and it was discovered that incubator humidity was most influential on TEWL in preterm infants.[3] Although 75% relative humidity effectively reduced TEWL during the first days of life, this environment was suggested to prolong skin barrier maturation in preterm infants.[4]

A review of the literature revealed differing opinions on incubator humidity levels between scholars. Recommendations changed as humidity technology improved. Harpin and Rutter[5] conducted a study on the effects of 60% incubator humidity on evaporative losses in infants born before 30 weeks' gestation. They concluded that 60% incubator humidity compared with 30% led to less evaporative losses and better temperature control, but *Pseudomonas aeruginosa* was collected on occasion from the humidity chamber.[5] Given the humidity technology available, these scholars recommended that infants less than 30 weeks' gestation receive 4 to 7 days of incubator humidity.[5]

To further investigate incubator humidity infection risk, Lynam and Biagotti[6] tested microbe contamination in the incubator, Giraffe Omnibed, when 65% humidity was delivered. They determined that the Giraffe Omnibed humidification process to boil water prior to dispersing humidification sterilized the water when contaminated with *P. aeruginosa*, *Serratia marcescens*, *Escherichia coli*, or *Candida albicans*.[6] No microbes were ever found in the patient areas of the

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incubators when the humidity chambers were contaminated.[6] However, *P. aeruginosa* was found in the humidity chamber at 24 hours after contamination and *C. albicans* was found in the humidity chamber up to 48 hours after contamination, suggesting thermal death occurred within the humidification system between 48 and 72 hours after contamination.[6] Lynam and Biagotti[6] found that many neonatal intensive care units (NICUs) use incubator humidity more than 65% and suggested that future studies be conducted on the microbe growth at higher humidity levels.[6]

Knobel[7] published an article describing the thermoregulation process in the care of preterm infants. The author found that there were not any standard guidelines for the amount and duration of incubator humidity and that additional research was needed in this subject.[7] Knobel[7] concluded that, according to the evidence available, high incubator humidity was beneficial in thermal stability, skin integrity, TEWL, and fluid and electrolyte balance in the extremely preterm infant population and suggested lowering humidity to 60% as soon as the infant tolerates this change to minimize risks.[7]

The work of Ludington-Hoe et al[8] provided evidence of thermosynchrony between maternal–preterm infant skin temperatures during skin-to-skin care. However, an additional study revealed that over 50% of paternal–preterm infant pairs resulted in infant hyperthermia during skin-to-skin care.[9] Further research by Abouelfettoh et al[10] suggested that maternal–preterm infant skin-to-skin care increased TEWL, but also improved stratum corneum hydration suggesting that skin-to-skin care may enhance skin barrier formation.

Because of the lack of large clinical trials, variations occur in incubator humidity practices.[11,12] The inconsistent use of incubator humidity in the care of preterm infants has been a concern of many scholars; yet, strong evidence was lacking for specific recommendations or national guidelines to be generated. This inconsistent practice was a gap in knowledge warranting evaluation and improved management. Therefore, a detailed analysis of what was known about preterm infant outcomes in relation to incubator humidity was constructed.

Although some evidence existed related to best practices for humidity use in the preterm infant, no systematic reviews were identified that addressed patient outcomes related to humidity levels. The goal of this systematic review was to compile and analyze the evidence on preterm infant skin maturation, incubator humidity research, and humidity-related contamination risks to develop provider guidance on the levels and duration of incubator humidity in the care of preterm infants. The research question was: In premature infants born before 32 $^{0}/_{7}$ weeks' gestation, what impact does incubator humidity level and duration have on patient outcomes?

What This Study Adds

- A systematic review on preterm infant incubator humidity levels and duration.
- What the evidence reveals on preterm skin maturation with differing humidity levels.
- A direction of future research needs on preterm infant incubator humidity.

METHODS/SEARCH STRATEGY

The systematic steps outlined by Joanna Briggs Institute[13] were followed during the development of this systematic review. Mefford's[14] theory of health promotion for preterm infants was also used as a foundation in this project, which allowed us to formulate a plan that concisely addressed the wholeness of health by administering precision and thoroughness to each aspect of health in the preterm infant. The health aspects of physical immaturity, structural immaturity, neurological immaturity, and disruption in family systems depicted in Mefford's model guided the organization of data. The evidence was collected by completing a comprehensive and exhaustive search of the literature using the following 8 databases: CINAHL, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, MEDLINE, Ovid, Science Direct, UpToDate, and ProQuest. A search to include articles published in the last 15 years was conducted between January 1, 2004, and August 1, 2019, using the following keywords: *incubator, humidity, humidification*, or *humid* in conjunction with *neonate, newborn, neonatal intensive care, preterm, premature,* and *infant*. Available in-use hospital NICU incubator humidity policies were obtained, which were used for citation searching to assure the evidence search was comprehensive and exhaustive. High-quality published quantitative journal articles, textbook information, incubator manufacturing manuals, and institutional protocols were assessed and reviewed for this review of the literature. The Joanna Briggs Institute[13] approach provided a rigorous process that ensured that the critical appraisal and synthesis of the literature included diverse forms of evidence.

Inclusion criteria included peer-reviewed, full-text, journal articles available in the English language that addressed outcomes of using incubator humidity in preterm infants less than 32 weeks that were published in the past 15 years. The search was expanded to this timeframe due to the lack of existing humidity evidence. Exclusion criteria included articles that were not available in full text, those that were not available in English, studies published over 15 years prior to the search, and those that did not address the study question. Low-quality evidence articles according to the Johns Hopkins levels and

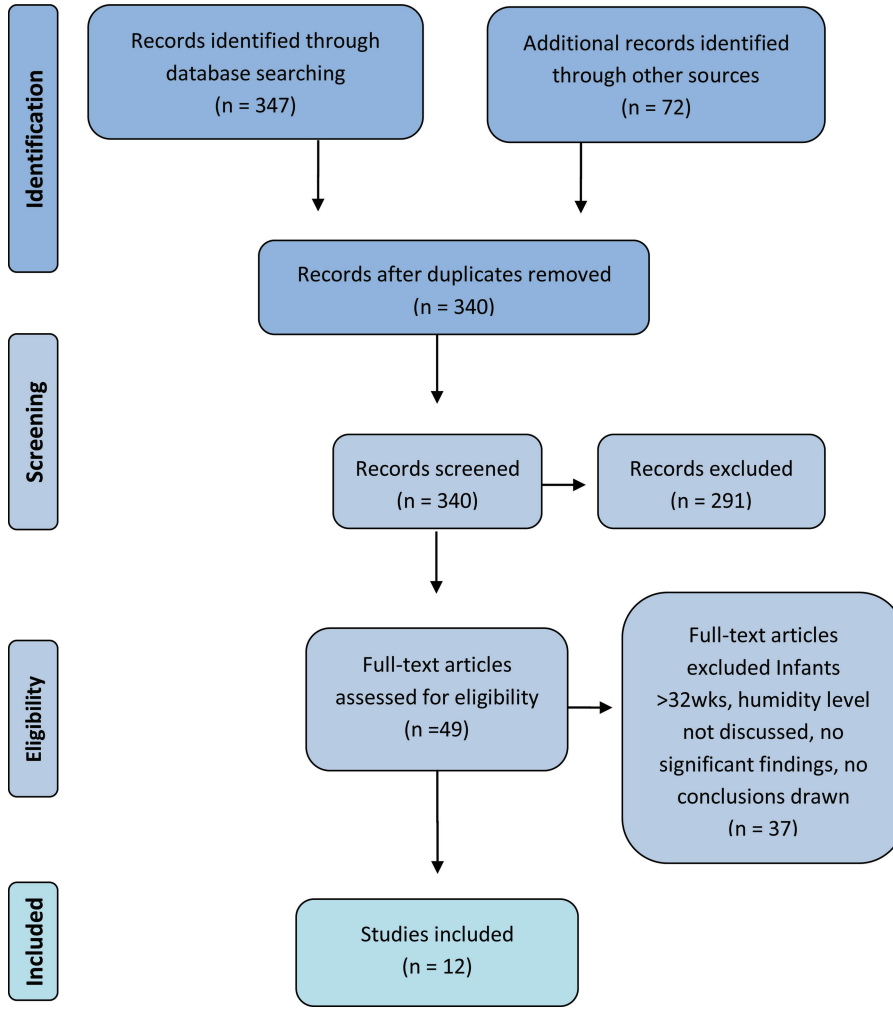
quality of evidence that did not produce significant results about incubator humidity levels or duration in the NICU were not included in this systematic review. To minimize the risk of bias, 2 reviewers independently completed a comprehensive literature search and conducted an appraisal of studies that met inclusion criteria. Any discrepancies were resolved through discussion and forming consensus.

RESULTS

There were 347 articles identified that were published in the last 15 years. An additional 72 articles were identified through other sources, such as citation searching. After removing duplicate articles, 340 articles remained out of the 419 total articles identified. After abstract review, 291 articles were excluded. The authors examined 49 full-text articles, and of these, 37 were excluded. Most of these articles were excluded due to incubator humidity levels not being discussed as leading to an effect on the outcomes of the study. Other articles were excluded because no significant findings or conclusions on incubator humidity levels or duration were drawn, leading to a low-quality rating according to the Johns Hopkins levels and quality of evidence.[15] Twelve quantitative studies were included in this systematic review. Due to the lack of heterogeneity of the studies identified for inclusion, a meta-analysis was not performed (Figure 1).

Following the evidence search, the Johns Hopkins levels and quality of evidence method was applied to rate the evidence. Level I evidence included randomized controlled trials or systematic reviews of randomized controlled trials, level II evidence included quasiexperimental studies or systematic reviews that included quasiexperimental studies, level III evidence included nonexperimental or mixed-method design systematic reviews or studies, level IV

FIGURE 1



Selection of included articles.

evidence included the opinion of respected authorities or nationally recognized committees, and lastly, level V evidence was identified as an interrogative or literature review or an expert opinion that was based on experiential evidence.[15] After determining the level of evidence according to the guidance of the Johns Hopkins levels and quality of evidence, assignment of the quality of the evidence was made as (*a*) high, (*b*) good, or (*c*) low quality.

Studies included in this systematic review were a mix of level I (n = 2), level II (n = 4), level III (n = 3), and level V (n = 3). Following appraisal and synthesis of the studies included in this systematic review, the evidence was then organized by themes of skin-to-skin care, infection, dermatology, fluid and electrolyte balance, and other incubator humidity-related articles. Each article was carefully analyzed for the strength of the findings and the implications for the practice of incubator humidity use in the NICU. The selected studies were all relevant to the level and duration of incubator humidity and its effects, risks, benefits, and conclusions that assisted the synthesis of evidence and necessity for future research. Table 1 provides a summary of the studies that were included in this systematic review.

Skin-to-Skin Care

In a prospective, interventional study, Maastrup and Greisen[23] evaluated 22 preterm infants who were less than 28 weeks' gestation in a Denmark level III NICU. The purpose of their study was to determine whether preterm infants in skin-to-skin care could maintain their temperature outside of the humidified incubator. Limitations of their study included the small sample size, inconsistent humidity levels with the mean of 63% incubator humidity, and the inconsistency of the family member who provided the skin-to-skin care. Maastrup and Greisin's study included 16 mothers, 1 father, and 1 female sibling who were skin-to-skin with the preterm infant. Mean infant skin temperatures were increased by 0.1°C with the mother and decreased by 0.3°C when skin-to-skin with other family members ($P = .01$). This study resulted in evidence that extremely preterm infants were able to maintain stable temperatures while outside of the humidified incubator during skin-to-skin care with their mother when proper transferring techniques were used. The identified area for future study was the evaluation of temperature control when preterm infants are skin-to-skin care with other family members.

Karlsson et al[20] prospectively studied 26 preterm infants born in Sweden who were less than 27 weeks' gestation within their first 9 days of life. The purpose of their study was to evaluate the thermal balance and the physical environment of extremely preterm infants during skin-to-skin care. Limitations of their study included a small sample size, differing skin-to-skin positions, and techniques to transfer the infant to the mother were not optimized. The mean incubator humidity level of 68% was significantly higher than outside the incubator in the skin-to-skin environment humidity of 42% ($P < .001$). The results of this study revealed that extremely preterm infants had increased insensible water loss of 1 g per kg during skin-to-skin care. Extremely preterm infants were able to maintain stable temperatures outside of the humidified incubator environment according to the nonsignificant differences between the infant's pre- and posttest temperatures ($P = .32$). Karlsson and colleagues[20] concluded that the amount of increased insensible water loss did not outweigh the recognized benefits of skin-to-skin care.

Incubator Humidity Effects on Infection

de Goffau et al[18] investigated whether microbe contamination level could be predicted from incubator temperature and humidity settings in the Netherlands. Twenty-three previously occupied NICU incubators were divided into 2 groups of 60% or less incubator humidity and 60% or more incubator humidity to evaluate temperature distribution and microbe contamination. The study lacked a strict systematic swab method for all of the incubators, with the first 11 incubators being swabbed more often than the last 12 incubators. The results of their study showed that there was increased microbe growth in the cooler regions of the incubators when incubator humidity was 60% or more ($P = .002$), while incubator humidity of 60% or less did not meet statistical significance ($P = .27$) for increased microbe growth in the cooler regions of the incubator. Future research of a larger correlation study that evaluates the relationship between microbial growth and humidity level was suggested.

Etienne et al[19] conducted a case study to investigate the cause of 3 primary diagnoses of cutaneous aspergillosis in extremely preterm infants with the gestational ages between $23^4/_7$ and $24^3/_7$ weeks in a UK NICU. The limitations identified in their article were the case study design, retrospective analysis, and environmental sampling. The results of their case study revealed that *Aspergillus fumigatus* was found in the humidity chambers of 3 infected neonates, one of whom died. The microsatellite typing concluded that a genotypical relationship existed between the humidity chambers and the infected infants. Etienne et al[19] provided insight that future research is needed in the area of real-time strain typing during outbreaks or cluster infections in the NICU.

Dermatologic Incubator Humidity Studies

Visscher and Narendran[26] performed a literature review in the United States with the purpose of reviewing the skin ontogeny related to fetal

TABLE 1. Study Characteristics

Author	Study Design, Method	Purpose	Sample Characteristics and Setting	Limitations	Key Findings	Level and Quality
Allwood[16]	Literature review	Develop evidence-based skin care guidelines for infants 23-30 wk	23- to 30-wk infants in 6 articles, totaling 4145 patients in Australia	Some studies included well infants and infants >30 wk	Preterm infants had increased risk for skin injury Majority of epidermal development was complete by 32 wk Skin barrier formation and increased strength of dermis–epidermis connection occurred with increased gestational age Recommendations were to begin humidity at 85% for the first week, and then wean to 50%	V A
Agren et al[4]	Randomized controlled trial	Test how the level of incubator humidity influences postnatal skin maturation	22 infants 23-27 wk in Sweden	Small sample size Not all infants assessed for TEWL at d 0, 3, and 7	Extremely preterm infants in 75% incubator humidity after the first week of life exhibited increased TEWL when compared to infants in 50% incubator humidity ($P < .001$) No difference in temperature stability, weight gain, or sodium levels was found Findings suggested that increased incubator humidity may delay skin barrier formation	I B
de Carvalho et al[17]	Experimental data collection study	Measure the irradiance level of phototherapy in humidified incubators	3 levels of humidity with 3 phototherapy devices in Brazil	Unknown whether results were influenced by the distance between the light source and the irradiance meter The irradiance meter only measured to 1 $\mu W/cm^2/nm$ 1 incubator was studied	Incubator humidity of 60%-70% did not alter phototherapy irradiance Incubator humidity of ≥80% decreased LED and halogen phototherapy by 10%-45% Fluorescent phototherapy irradiance was unaltered by humidity	II A
de Goffau et al[18]	Observational data collection study	Investigate whether microbial contamination could be predicted from temperature and humidity	23 previously occupied incubators in 2 groups in the Netherlands	All 23 incubators were not swabbed the same amount of times	Increased bacteria growth was observed in cooler areas of incubator when humidity was ≥60% ($P = .002$)	II B
Etienne et al[19]	Case study	Investigate 3 primary diagnoses of cutaneous aspergillosis	3 extremely preterm infants in the UK	Study design Retrospective environmental sampling	*Aspergillus fumigatus* was found in humidity chambers of 3 infected neonates	V C

(continues)

TABLE 1. Study Characteristics (*Continued*)

Author	Study Design, Method	Purpose	Sample Characteristics and Setting	Limitations	Key Findings	Level and Quality
Karlsson et al[20]	Prospective data collection study	Evaluate thermal balance and the physical environment during skin-to-skin care in extremely preterm infants	26 preterm infants 22-26 wk during postnatal d 2-9 in Sweden	Small sample size Infants were in 2 positions during the study Generalized term of parent was used Transferring techniques were not optimized	Extremely preterm infants had increased insensible water loss outside the humidified incubator equaling 1 g/kg Infant skin temperatures remained stable with no significant difference between pre- and posttest ($P = .32$) Skin-to-skin care did not significantly impact fluid balance The benefits of skin-to-skin care outweighed the minimal insensible water loss	II B
Kim et al[21]	Retrospective data collection study	Compare extremely preterm infants in humidified and nonhumidified incubators to identify changes in temperature, fluid and electrolyte management, and growth	182 extremely low-birth-weight infants <1000 g in a US medical center	Study design may have allowed for unrecognized practice changes in the time differences of the study (humidified group 2002-2005, nonhumidified group 2002-2003) Inclusion criteria did not include gestational age	2 groups of infants <1000 g were studied comparing 70%-80% week 1, then 50%-60% vs no incubator humidity Significant findings in the humidified group were increased growth velocity, a decreased severe bronchopulmonary dysplasia, less fluid intake, less urine output, less insensible water loss, less weight loss, lower incidence of hypernatremia, less electrolyte sampling No significant differences found for temperature instability, intraventricular hemorrhage, patent ductus arteriosus, necrotizing enterocolitis, mild and moderate bronchopulmonary dysplasia, or sepsis between the 2 groups More infants in humidified group were diagnosed with bacterial sepsis (adjusted OR 1.6) Positive correlation between hypernatremia and intraventricular hemorrhage	III A
Kong et al[22]	Randomized controlled trial, single center	Compare the effect of 80% and 70% incubator humidity	50 preterm infants ≤28 wk in the first 2 wk of life in Australia	Nurses not blinded Single center Sample size Selection bias was present for infants <26 wk (9 in group A vs 4 in group B)	Infants randomized to 70% or 80% incubator humidity No statistical significance was discovered in skin integrity, body temperature, fluid requirement, sodium levels, sepsis, patent ductus arteriosus, chronic lung disease, or intraventricular hemorrhage Microbial growth was more prominent in 80% humidity 85%-100% humidity was not recommended	I A

(continues)

TABLE 1. Study Characteristics (*Continued*)

Author	Study Design, Method	Purpose	Sample Characteristics and Setting	Limitations	Key Findings	Level and Quality
Maastrup and Greisen[23]	Data collection, prospective intervention study	Determine whether preterm infants in skin-to-skin care could maintain temperature out of humidified incubator	22 preterm infants <28 wk in Denmark	Small sample size Differing humidity levels Inconsistent family member (1 sister and 5 fathers)	Extremely preterm infants were able to maintain stable temperature while outside the humidified incubator during skin-to-skin care with their mother if proper transferring techniques were used Other family members who provided skin-to-skin care led to a decrease in temperature ($P = .011$)	II B
Prazad et al[24]	Observational, descriptive data collection study	Quantify 45 volatile compounds in various incubator modes	10 unoccupied incubators,45 compounds in 4 operational settings in the United States	Concentrations were below OSHA exposure limits for adults; however, no data exists for neonates therefore, unknown clinical implications	Airborne volatile organic compound concentrations were increased when 50% incubator humidity was added	III A
Sung et al[25]	Retrospective, exploratory data collection study	To investigate fluid and electrolyte balance during the first week of life under high humidification	218 extremely low-birth-weight preterm infants 22 to >26 wk in Korea	Infants in the 25-wk group were excluded due to varying humidity levels, comparing groups were different gestational ages	22- and 23-week infants exhibited increased insensible water loss, fluid intake, and electrolyte imbalance despite 95% incubator humidity 24-week infants in 95% humidity for the first 3 d did not have a significant increase in insensible water compared with infants ≥26 weeks' gestation in 60% incubator humidity Infants ≥26 weeks in 60% incubator humidity did not exhibit increased insensible water loss when compared with infants in 80% humidity	III B
Visscher and Narendran[26]	Literature review	Review skin ontogeny of fetal development and after birth	Term and preterm infants in the United States	Details of the literature search were not revealed	Extremely premature infants had a rapid skin barrier formation within 5 d after birth Full stratum corneum maturation was estimated to occur between 2 and 9 postnatal wk	V B

Abbreviations: OR, odds ratio; OSHA, Occupational Safety and Health Administration; TEWL, transepidermal water loss.

development, preterm infant skin, and the effects after birth. Their review detailed the relationship of environmental factors after delivery on the skin barrier formation in preterm infant skin. Visscher and Narendran[26] added valuable information toward answering the practice problem in this systematic review by explaining that even extremely premature infants have a rapid skin barrier formation within 5 days after birth, with full stratum corneum maturation estimated to occur between 2 and 9 postnatal weeks. A significant increase in involucrin and albumin was noted in preterm infants 32 weeks' or less gestation, suggestive of barrier disruption, inflammation, and TEWL. A limitation of their study was that the details of the literature search were not revealed. Future areas of investigation included the relationship between gestational age and the maturation of the stratum corneum to provide evidence on microflora, susceptibility to injury, permeability, structure, and composition.

In a randomized controlled trial, Agren et al.[4] tested how the level of incubator humidity influences the postnatal skin maturation. This study was conducted in Sweden and included 22 preterm infants between 23 and 27 weeks' gestation. Limitations included a small sample size and the fact that not all the infants were evaluated for TEWL on days 0, 3, and 7 because of patient instability. Agren et al[4] provided evidence that extremely preterm infants who were cared for in 75% incubator humidity after the first week of life exhibited increased TEWL when compared with infants cared for in 50% incubator humidity after the first week of life ($P < .001$). Significant differences in temperature stability, weight gain, and serum sodium levels were not found. Study findings suggested that use of 75% incubator humidity beyond the first week of life delayed skin barrier formation without benefiting other body systems. Identified areas in need of future investigation were the level of humidity in skin barrier formation related to microbe and environmental toxins.

Allwood[16] composed a literature review in Australia to develop evidence-based skincare guidelines for infants between 23 and 30 weeks' gestation. Six articles from the previous 10 years were included, with a total sample size of 4145 patients. A limitation of the applicability of findings for the purpose of this review was that some of the articles included infants more than 30 weeks' gestation. Allwood[16] concluded that preterm infants were at increased risk for skin injury, that most of the epidermal development was completed by 32 weeks' gestation, and that skin barrier formation and increased strength of the dermis–epidermis connection occurred with increased gestational age. Incubator humidity recommendations were to begin use of humidity at 85% for the first week, and then wean to 50%; however, the duration to extend humidity was not evident in the literature.

Incubator Humidity Effect on Fluid and Electrolyte Balance

Sung et al[25] completed a retrospective exploratory study in Korea that investigated the fluid and electrolyte balance of 218 extremely low-birth-weight preterm infants during the first week of life while in high humidity incubators. Infants who were 24 weeks' or less gestation in 95% incubator humidity levels were compared with 26 weeks' or more gestation infants in 60% incubator humidity. A major limitation of the study was that infants in the 25-week gestational group were excluded due to varying humidity levels. Another limitation of the study was that the groups were not of equal gestational ages. Sung et al[25] found that 22- and 23-week infants exhibited an increased insensible water loss, fluid intake, and electrolyte imbalance despite 95% incubator humidity. Infants who were 24 weeks' gestation cared for in 95% humidity did not have a significant increase in insensible water loss compared to infants 26 weeks' or more gestation in 60% incubator humidity. The 3 days of 95% incubator humidity, which was then gradually decreased, may have sufficiently compensated for insensible water loss, fluid intake, and electrolyte balance in the 24-week gestational age group. Infants 26 weeks' or more gestation in 60% incubator humidity did not exhibit increased insensible water loss when compared with those in 80% humidity, concluding that in this population, 60% incubator humidity was sufficient. The future direction of study included insensible water loss investigation of 22- and 23-week infants.

Kim et al[21] conducted a retrospective study on 182 infants who were less than 1000 g in a US medical center. The purpose of the study was to compare extremely preterm infants in humidified and nonhumidified incubators to identify changes in temperature, fluid and electrolyte management, and growth. Secondary outcomes included mortality, bronchopulmonary dysplasia, necrotizing enterocolitis, patent ductus arteriosus, sepsis, and intraventricular hemorrhage. A limitation in this study was that the inclusion criteria did not include gestational age, a known determinant of skin maturation.[27] Another limitation was that the study design may have allowed for unrecognized practice changes in the time differences (humidified group 2002-2005, nonhumidified group 2002-2003) of the study.[21] Two groups of infants less than 1000 g at birth were studied (70%-80% for week 1, then 50%-60% week 2 until corrected to 32 weeks) versus no incubator humidity. Significant findings in the humidified group were increased growth velocity ($P = .02$), a decreased incidence of severe bronchopulmonary dysplasia ($P = .003$), less fluid intake ($P < .0001$), less urine output ($P < .0001$), less insensible water loss ($P < .0001$), less weight loss ($P < .0001$), lower

incidence of hypernatremia ($P = .003$), higher incidence of hyponatremia ($P = .01$), and less electrolyte sampling ($P = .02$). No significant differences were found for mortality ($P = .15$), intraventricular hemorrhage ($P = .89$), patent ductus arteriosus ($P = .88$), necrotizing enterocolitis ($P = .71$), mild and moderate bronchopulmonary dysplasia ($P = .90$), or sepsis ($P = .19$) between the 2 groups. However, more infants in the humidified group were diagnosed with bacterial sepsis (adjusted odds ratio 1.6) and there was a positive correlation between hypernatremia and intraventricular hemorrhage, which warrants future study in these areas.

Kong et al[22] conducted a single-center randomized controlled trial in Australia that included 50 preterm infants 28 weeks' or less gestation within the first 2 weeks of life. Limitations were that the nurses were not blinded, it was performed at a single center, a larger sample size may have led to more statistically significant findings, and selection bias between groups was present for infants less than 26 weeks with 9 infants less than 26 weeks in group A versus 4 infants less than 26 weeks in group B. Infants 28 weeks or less were randomized to 70% or 80% incubator humidity for the first 14 days of life. No statistical significance was discovered between the 2 groups in skin integrity, body temperature ($P = .80$), fluid requirement, sodium levels, sepsis ($P = .55$), patent ductus arteriosus ($P = .39$), chronic lung disease ($P = .09$), or intraventricular hemorrhage (equal cases among the groups). Microbial growth was more prominent in the incubators with 80% humidity, suggesting not offering levels more than 70% incubator humidity unless necessary. More research is needed comparing humidity levels in patients less than 26 weeks.

Additional Incubator Humidity Study Findings

An experimental study by de Carvalho et al[17] aimed to measure the irradiance level of phototherapy in humidified incubators in Brazil. The 3 levels of 60% to 70%, 80%, and 90% or more were studied in a double-walled neonatal incubator with 3 different phototherapy devices. The study had limitations of using one incubator and that the irradiance meter measured to 1 $\mu W/cm^2/nm$, which may not have been strong enough to make conclusions on the low irradiance of the fluorescent phototherapy device. Key study findings concluded that incubator humidity of 60% to 70% did not alter phototherapy irradiance, while incubator humidity 80% or more decreased LED and halogen phototherapy by 10% to 45%. Fluorescent phototherapy irradiance was unaltered by humidity levels.

Prazad et al[24] collected data in a US observational descriptive study with the purpose to identify and quantify 45 volatile compounds in 4 differing incubator operational modes. Ten unoccupied NICU incubators were used to study what effect the different operational modes had on the airborne compounds. One limitation in this study was that the incubators were unoccupied, possibly increasing the compounds inside the incubator compared with occupied incubators that would have the portholes opened during care times. There was also uncertainty of the clinical implications to the developing preterm infant due to no reference points available from the occupational safety and health administration on safe exposure levels of the studied compounds in the fetal or newborn population, although the levels were below the exposure limits for adults and animals. The results revealed that when 50% incubator humidity was added, airborne volatile organic compounds were increased ($P < .0001$ to $P < .0006$). The conclusions of this study revealed the need for future research in the area of neonatal exposure limits of airborne volatile organic compounds.

DISCUSSION

The gap in practice of unknown optimal incubator humidity levels and duration has been addressed in the findings of this systematic review. Although some conclusion can be drawn, more research on incubator humidity levels and duration focused on infants less than 26 weeks is needed. The evidence in this review suggests that the benefits of skin-to-skin care outweigh the additional insensible water loss that preterm infants exhibit when outside the humidified incubator.[20] Extremely premature infants have been shown to maintain stable temperature regulation when skin-to-skin with their mother,[23] concluding this to be a safe and beneficial practice for the population of infants less than $32^0/_7$ weeks' gestation who are cared for in humidified incubators.

The evidence concludes that skin barrier formation and maturation of the stratum corneum is nearly complete by 32 weeks' gestation,[16,26] offering the implication to limit incubator humidification for infants born before $32^0/_7$ weeks. Agren et al[4] demonstrated that preterm infants who remained in incubator humidity of 75% after the first week of life had delayed skin barrier maturation when compared with 50% incubator humidity after the first week of life. This evidence, along with the work by Visscher and Narendran,[26] suggests that preterm infants have a rapid skin barrier formation in the first 5 days of life and additional high levels of humidity might impede skin maturation after delivery leading to increased TEWL.[4] Clear evidence has demonstrated that 60% to 70% incubator humidity for the first week of life followed by 50% to 60% incubator humidity compared with no incubator humidity positively impacted preterm infant outcomes, such as decreasing severe bronchopulmonary dysplasia, electrolyte imbalance, weight loss, and insensible water loss.[21]

Summary of Recommendations for Practice and Research	
What we know:	• Incubator humidity is a necessary practice to prevent TEWL and manage fluid and electrolyte balance. • Variations exist among incubator humidity practice. • Incubator humidification presents an infection risk.
What needs to be studied:	• Comparing patient outcomes related to incubator humidity levels and duration of infants less than 26 weeks will be beneficial to the management of this population. • Large randomized controlled trials that evaluate preterm infant skin barrier formation and how humidity affects this formation will significantly assist practice guidelines on the levels and duration of incubator humidity. • Future research on microbial growth in more than 80% incubator humidity is warranted.
What we can do today:	• Limit incubator humidity to infants born before 32 weeks' gestation. • Begin to wean high humidity levels after 1 week of life. • Discontinue unnecessary incubator humidity once the infant has developed a skin barrier at approximately 2 weeks' postnatal age.

Sung et al[25] demonstrated that infants born before $24^{0}/_{7}$ weeks had increased TEWL even when supported with 95% incubator humidity, compared with 24 weeks' infants who demonstrated that 95% humidity for the first 3 days compensated the TEWL, while infants 26 weeks' or more gestation did not exhibit increased insensible water loss when in 60% versus 80% incubator humidity. The evidence supported by Kong et al[22] suggested that no patient benefits were found when incubator humidity was set to 80% versus 70%, while microbial growth was more prominent in the 80% group, although this was not statistically significant. Other studies provided evidence that microbe growth was increased in cooler incubator regions when incubator humidity was 60%[18] or more and humidity chambers were found to be contaminated during the investigation of neonatal infections leading to 1 death.[19] In addition, Prazad et al[24] found a significant increase in volatile airborne compounds when 50% humidity was added to the neonatal incubator. Additional evidence revealed that phototherapy was found to be affected by incubator humidity, with levels 80% or more decreasing the irradiance by 10% to 45%.[17]

The evidence suggests that careful consideration be given when providing preterm infants with incubator humidity more than 70% who may have developed a skin barrier and do not require the humidity protection for TEWL as demonstrated in the first days of life. The evidence surrounding the benefits of continuing incubator humidity at 50% to 60% beyond 2 weeks after birth remains limited. However, several studies have demonstrated that microbes and toxins thrive in humid conditions.[18,19,22,24]

FUTURE RECOMMENDATIONS

Investigating the practice issue of inconsistent incubator humidity in the NICU has led to the conclusion that future studies are needed comparing incubator humidity levels and duration correlated with gestational age. Future incubator humidity research of infants less than 26 weeks' gestation will be beneficial to the management of this population. Large randomized controlled trials that evaluate preterm infant skin barrier form ation and how humidity affects this formation will significantly assist practice guideline formation on the levels and duration of incubator humidity in the NICU. The research area of incubator humidity holds great opportunity for additional evidence to be collected that can further clarify the precise incubator humidity levels and duration according to gestational and postnatal age.

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