10-3-2022

# Exploring Environmental Factors Contributing to Fluid Loss in Diapers Placed in Neonatal Incubators

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## Recommended Citation

Jones-Hepler B, Silva S, Elmore K, Vance A, Harney J, and Brandon D. Exploring Environmental Factors Contributing to Fluid Loss in Diapers Placed in Neonatal Incubators. Adv Neonatal Care 2022.

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# Exploring Environmental Factors Contributing to Fluid Loss in Diapers Placed in Neonatal Incubators

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**ABSTRACT**

**Purpose:** Assessing fluid output for infants in the neonatal intensive care unit is essential to understanding fluid and electrolyte balance. Wet diaper weights are used as standard practice to quantify fluid output; yet, diaper changes are intrusive and physiologically distressing. Less frequent diaper changes may have physiologic benefits but could alter diaper weights following extended intervals.

**Methods:** This pilot study examined the impact of initial diaper fluid volume, incubator air temperature and humidity, and diaper brand on wet diaper weight over time. Baseline fluid volume was instilled, and then diapers were placed in a neonatal incubator. Wet diaper weight was assessed longitudinally to determine changes in fluid volume over time. A factorial design with repeated measures (baseline, 3 hours, and 6 hours) was used to explore the effects of diaper brand (brand 1 vs brand 2), baseline fluid volume (3 mL vs 5 mL), and incubator temperature (28°C vs 36°C) and humidity (40% vs 80%) on the trajectory of weight in 80 diapers.

**Results:** Wet diaper weight was significantly reduced over 6 hours ($P < .005$). However, wet diaper weight increased in 80% humidity, but decreased in the 40% humidity over time ($P < .0001$). Baseline fluid volume, incubator temperature, and diaper brand did not influence wet diaper weight over time (all $P > .05$).

**Implications:** Understanding environmental factors that influence the trajectory of wet diaper weight may support clinicians in optimizing the interval for neonatal diaper changes to balance the impact of intrusive care with need to understand fluid volume loss.

**Key Words:** low birth weight, neonatal, preterm, urine output

Premature infant survival, especially among the most immature, continues to rise due to the ongoing advancement in neonatal care.[1] However, as a result of extreme prematurity, these infants require intense multisystem monitoring and management, including fluid and electrolyte status.[2] These infants are at risk for fluid and electrolyte imbalance due to skin and renal system immaturity; therefore, managing fluid balance has become an essential component of neonatal care.[2,3] A common mechanism for monitoring fluid status is through urine output assessment; however, due to the potential complications with bladder catheterization (eg, infection) and urine collection bags (eg, urinary bagging and leaking), neonatal intensive care units (NICUs) measure urine output via diaper weights before and after use, such that 1 g of weight change = 1 mL of urine.[4] While this provides a less invasive way of monitoring urinary output, many factors, including the infants' environment, have been shown to influence the validity of this method.[4,5]

One core practice to support premature infants is to care for them in an incubator. Incubators provide supplemental heat and, thus, thermal stability since they are unable to maintain normal body temperature.[6] Skin immaturity is a contributing factor to this temperature instability, particularly for very preterm infants.[7,8] The underdeveloped epidermal layer of the premature infant increases skin permeability, which leads to heat and transepidermal water loss (TEWL).[9] TEWL is the diffusion of water across skin that is not associated with sweating.[10] While term infants have a normal TEWL of 4 to 6 g/m²/h, the TEWL of very low birth-weight (VLBW) infants can reach 60 to 75 g/m²/h, particularly in very immature infants (<28 weeks' gestation at birth) in the first

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*Dr Brandon, who is a Co-Editor for* Advances in Neonatal Care, *was not involved in the editorial review or decision to publish this article. The entire process from submission, referee assignment, and editorial decisions was handled by other members of the editorial team for the journal.*

*The authors declare no conflicts of interest.*

*Ethical approval was provided by the Institutional Review Board of Duke University Health System in advance of study initiation. No human subjects were involved in the study and thus this research was deemed exempt.*

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*DOI: 10.1097/ANC.0000000000001026*

weeks of life.[9,11] Thus, TEWL can increase infants' risk for fluid and electrolyte imbalance.[9,11] To minimize this risk, very premature infants are cared for in heated and humidified incubators, which have been shown to decrease TEWL and support skin health.[12] In addition, the TEWL of the buttock has been shown to remain elevated, with mean levels of 11 g/m$^2$/h noted at 3 to 4 weeks of life.[11] Premature infant skin is susceptible to irritation related to fluid next to the skin; thus, diapers containing products that enhance absorption are commonly used.[13] However, these fluid-wicking diapers can potentially increase water absorption into the diaper from the infant's skin.[13] While the contribution of TEWL from the infant to the diaper would be difficult to quantify, it should be considered when diaper weights are utilized to manage fluid status, especially during the early days of life.

Incubator humidity levels and TEWL have the potential to influence diaper weights directly. Previous studies have shown that higher humidity levels (>85%) may falsely increase diaper weights through absorption, and lower humidity levels (<40%) may decrease diaper weights due to evaporative loss.[3,6,14] High evaporative losses may lead to clinical underestimation of urine output.[15] Furthermore, the greatest evaporative losses occurred with smaller urine volumes,[3,6,14] most common in very premature infants (0.5-2 mL/kg/h).[16] In addition, the temperature of the incubator may influence the absorption and/or evaporation of fluid in the diaper. Because the air temperature of the incubator influences its capacity to carry water (eg, at a relative humidity of 85%, an air temperature of 37°C carries more water vapor [mg/L] than an air temperature of 34°C degrees),[17] warmer incubator air has the potential to increase water vapor inside the incubator. Furthermore, since cooler air temperatures are unable to carry as much water, water vapor may be released from the incubator air during infant care.

While safe clinical assessments are essential, there is also a need to balance assessments with minimizing intrusive interventions to ensure neonatal physiologic stability. One of the most stressful routine activities performed in the NICU is diaper changes,[18] which typically occurs every 2 to 4 hours. The frequency of diaper changes may vary depending on infant acuity or weight to reduce the risk of short- and long-term physiologic effects associated with adverse outcomes. Postponing diaper changes to assessment times with less stressful tasks may improve physiologic stability.[19] However, the incubator environment, along with less frequent diaper changes, may impact diaper fluid volume loss via evaporation, therefore affecting the accuracy of calculated urine outputs. This can lead to inaccurate conclusions of the infant's overall fluid and electrolyte status.

While previous studies have compared different incubator humidity settings,[3,15] instilled volumes,[4,5] time frames,[3-5,14] and diaper types,[5,14] in relation to diaper volumes, no study has evaluated the influence of incubator temperature and humidity together. Further, while limited studies examined urine output evaporative loss during extended timeframes and in the varied incubator environments, no studies evaluated environments with co-occurring factors or greater than 2 time points. Improving our awareness of factors that alter the accuracy of estimated urine output can help guide the timing of caregiving activities, allowing for greater physiologic stability. Thus, the purpose of this study was to evaluate the potential impact of instilled diaper fluid volume, incubator air temperature, incubator air humidity, and diaper brand on the accuracy of very premature infant diaper weights across time. The goal of this study was to evaluate wet diaper weight longitudinally over 6 hours under varied laboratory conditions, by answering the following research questions:

1. How does wet diaper weight vary by water volume in the diaper (3 mL vs 5 mL) over time?
2. How does wet diaper weight vary by incubator temperature (28°C vs 36°C) over time?
3. How does wet diaper weight vary by incubator humidity level (40% vs 80%) over time?
4. How does wet diaper weight vary by diaper brand (brand 1 vs brand 2) over time?

**What This Study Adds**

- This study provides insight into changes in wet diaper weight related to fluid volume gains or losses over time during exposure to various incubator conditions (ie, incubator temperature and humidity differences).

## METHODS

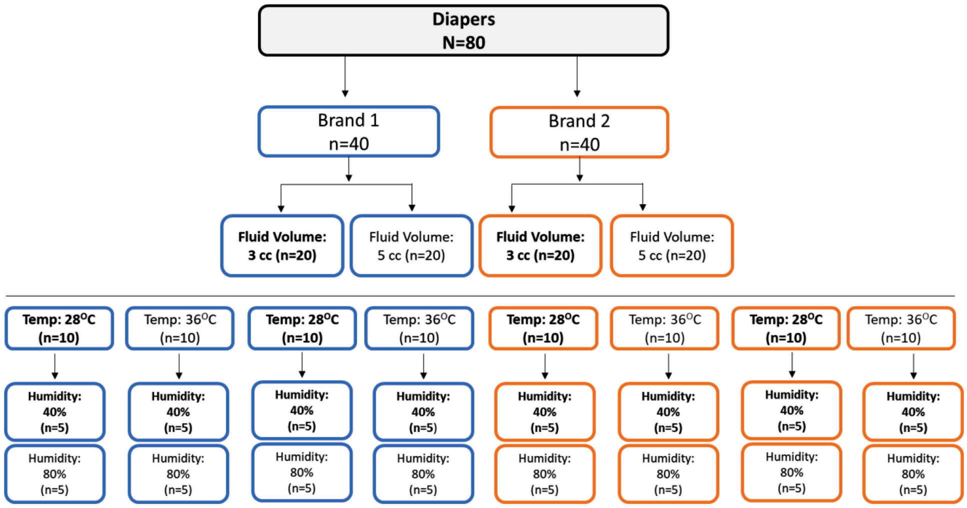
### Design

This experiment was a balanced factorial design with repeated measurements to evaluate changes in baseline sterile water volume instilled in the diaper, incubator temperature, incubator humidity level, and diaper brand on diaper weight across 6 hours in 80 diapers. At baseline, each diaper's dry weight and weight after instilling sterile water into the diaper (wet weight) was determined. Evaporation loss or condensation gains (eg, diaper weight) across the 6 hours was assessed using the wet weight of each diaper at baseline, 3 hours post-baseline, and 6 hours post-baseline. Figure 1 details the study design.

### Procedures and Measures

The sample size was 80 diapers. Two common diaper brands were used (40/brand). Each brand included 5 different sizes of diapers: 3 sizes of diapers intended for preterm infants of various weights,

FIGURE 1




Study design.

a newborn infant size, and one size larger than newborn. A Sartorius scale was used for the diaper weights. At baseline, the diaper's dry weight, in grams, was determined by weighing the diaper twice to confirm accuracy of the weight. Each diaper was instilled with 3 or 5 mL of fluid volume instilled into the dry diaper and the wet weight (g) of the diaper was recorded at baseline.

For each brand of diaper, 50% received a 3-mL volume of water (n = 40) and 50% received a 5-mL volume of water at baseline (n = 40). Each diaper was then immediately placed inside a Giraffe OmniBed Carestation (ie, infant incubator). The Air Boost function was used to maintain the specified temperature and humidity for the diaper. For each diaper brand and water volume subgroup, half were placed in an incubator set at 28°C and half were placed in an incubator set at 36°C. Additionally, half of the diapers within each brand, fluid volume, and temperature subgroup had the incubator humidity level set at 40% and the other half had the humidity set at 80% at the start of the study. Higher versus lower temperature and humidity settings were selected based on guidelines at a level IV NICU for management of very preterm infants over time.

The impact of the 4 different factors (fluid volume, incubator temperature, incubator humidity, and diaper brand) on wet diaper weight was examined by one trained research nurse. Of the 80 diapers, 40 were assessed within each level of each factor and 10 were measured under each level of the combined factors. The wet diaper weight was assessed at baseline (0 hour), 3 hours after the diaper was placed in the incubator (3 hours), and 6 hours after the diaper was placed in the incubator (6 hours). The assessment points of 3 and 6 hours were selected to simulate typical duration of care times in NICU settings.

### Statistical Analysis

Descriptive statistics were used to describe the dry diaper weight at baseline and wet diaper weights for each factor at each assessment point (Table 1). Nondirectional statistical tests were performed with significance set at .05 for each test. Independent *t* tests were performed to test for factor-level differences in dry and wet diaper weight at baseline.

Hierarchical linear mixed-effects models for the repeated measurements of wet diaper weight were conducted for each factor to test for group differences in their trajectory of change over time. The mixed-effects model used a random-coefficients regression model for longitudinal data. A separate random regression model was conducted for each factor to examine the individual effects of each factor on the trajectory of change in wet diaper weight across time (0, 3, and 6 hours). Fixed effects were time, factor of interest, and their interaction, while random effects were diaper and diaper by time. The outcome was the trajectory of the wet diaper weight, determined by the wet diaper weight at each of the 3 time points. When there was a significant interaction effect at the .05 level for a factor, a posteriori independent *t* test was used to test for a factor group difference in wet diaper weight at each assessment point. Effect sizes and their 95% confidence intervals (CIs) were determined to address clinical significance.

## RESULTS

### Baseline Characteristics

Dry diaper weight and wet diaper weight were assessed at baseline for the 4 factors (fluid volume,

TABLE 1. Descriptive Statistics: Wet Diaper Weight at Each Assessment Point

| Model | Factor | n | 0 h | 3 h | 6 h |
|---|---|---|---|---|---|
| 1 | *Time* | 80 | | | |
| | Mean (SD) | | 16.1 (6.6) | 15.9 (6.8) | 15.7 (6.9) |
| | Min, max | | 7.0, 28.0 | 6.0, 29.0 | 5.0, 30.0 |
| 2 | *Fluid volume instilled* | | | | |
| | 3 mL | 40 | | | |
| | Mean (SD) | | 15.1 (6.6) | 15.0 (6.7) | 14.8 (6.8) |
| | Min, max | | 7.0, 26.0 | 6.0, 28.0 | 5.0, 28.0 |
| | 5 mL | 40 | | | |
| | Mean (SD) | | 17.1 (6.6) | 16.8 (6.8) | 16.7 (6.9) |
| | Min, max | | 9.0, 28.0 | 8.0, 29.0 | 7.0, 30.0 |
| 3 | *Incubator temperature* | | | | |
| | Temperature 28°C | 40 | | | |
| | Mean (SD) | | 16.1 (6.6) | 16.0 (7.0) | 15.8 (7.0) |
| | Min, max | | 7.0, 28.0 | 6.0, 29.0 | 6.0, 30.0 |
| | Temperature 36°C | 40 | | | |
| | Mean (SD) | | 16.1 (6.6) | 15.9 (6.7) | 15.6 (6.8) |
| | Min, max | | 7.0, 28.0 | 6.0, 29.0 | 5.0, 29.0 |
| 4 | *Incubator humidity* | | | | |
| | Humidity 40% | 40 | | | |
| | Mean (SD) | | 16.1 (6.6) | 15.5 (6.6) | 15.0 (6.6) |
| | Min, max | | 7.0, 28.0 | 6.0, 29.0 | 5.0, 28.0 |
| | Humidity 80% | 40 | | | |
| | Mean (SD) | | 16.1 (6.6) | 16.3 (7.1) | 16.5 (7.1) |
| | Min, max | | 7.0, 28.0 | 6.0, 29.0 | 6.0, 30.0 |
| 5 | *Diaper brand* | | | | |
| | Brand 1 | 40 | | | |
| | Mean (SD) | | 17.0 (6.8) | 17.0 (7.1) | 16.8 (7.0) |
| | Min, max | | 7.0, 28.0 | 7.0, 29.0 | 7.0, 30.0 |
| | Brand 2 | 40 | | | |
| | Mean (SD) | | 15.2 (6.3) | 14.9 (6.4) | 14.7 (6.6) |
| | Min, max | | 7.0, 25.0 | 6.0, 25.0 | 5.0, 25.0 |

*Abbreviations: max, maximum; min, minimum; SD, standard deviation.*

incubator temperature, incubator humidity, and diaper brand). The dry diaper weights ranged from 4 to 23 g, reflecting the range of diaper sizes for the 2 brands. Importantly, the levels of each factor did not differ significantly by diaper size on dry or wet weights (all factors $P \geq .1773$). Thus, baseline dry diaper weight was not used as a covariate in the subsequent trajectory analyses examining change in wet diaper weight.

## Trajectory Analyses

The mean wet diaper weight for each factor at each assessment time point is provided in Table 1, and the results of the trajectory analyses are presented in Table 2. The first model examined the effects of time alone on wet diaper weight. Model 1 shows a significant reduction in wet diaper weight across the 6 hours ($P = .0046$), indicating significant overall evaporation loss over time (Figure 2a).

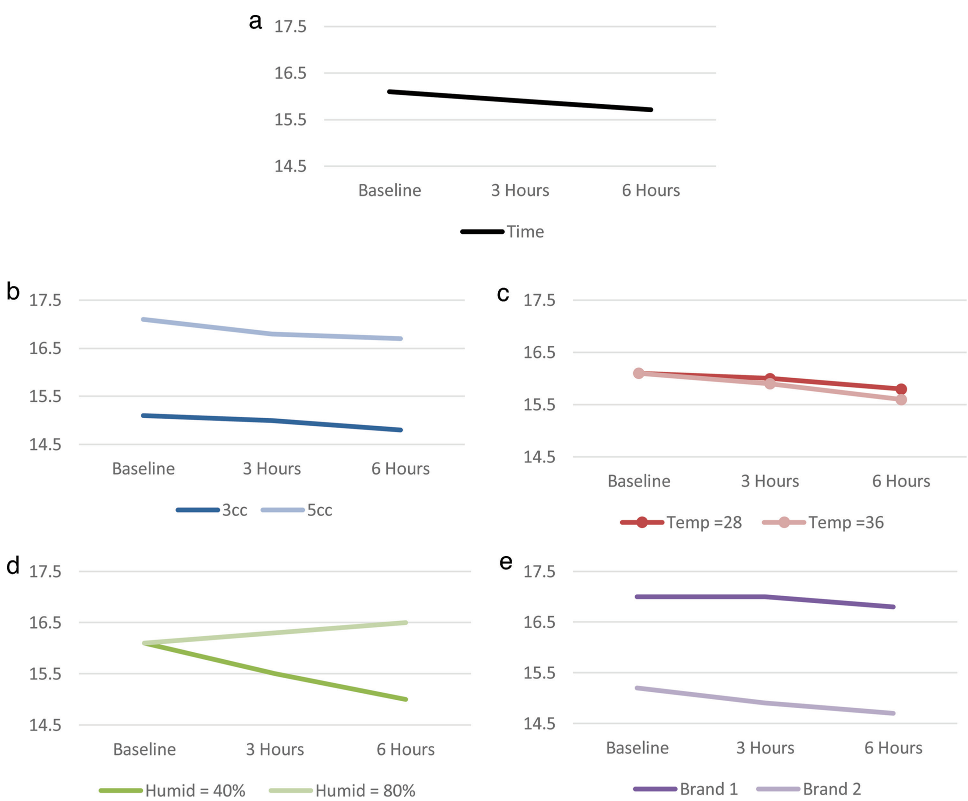
Models 2 to 5 examine the impact of each factor on rate of reduction in wet diaper weight. The results indicate no significant main effect of any factors (all main effects: $P \geq .1182$). That is, the 2 levels of each factor (eg, 3 mL vs 5 mL) did not significantly differ in terms of mean wet diaper weight across all 3 assessment points. The trajectory of reduction in wet diaper weight over time did not differ for the 2 levels of fluid volume instilled, incubator temperature, or diaper brand (factor-by-time interaction effects: all $P \geq .3114$; Figures 2b, 2c, and 2e). However, a significant humidity-by-time interaction effect was observed ($P < .0001$). Specifically, the wet diaper

Table 2. Changes in Diaper Weight Over 6-Hour Results

| Model | Factors | *F* | *df, df* | *P* Value |
|---|---|---|---|---|
| 1 | Time only | 5.78 | 2, 78 | *.0046* |
| 2 | Time | 5.71 | 2, 77 | *.0049* |
| | Fluid volume instilled | 1.56 | 1, 78 | .2157 |
| | Fluid volume instilled by time | 1.37 | 2, 77 | .2608 |
| 3 | Time | 5.79 | 2, 77 | *.0046* |
| | Temperature | 0.01 | 1, 78 | .9433 |
| | Temperature by time | 0.56 | 2, 77 | .5747 |
| 4 | Time | 13.15 | 2, 77 | *<.0001* |
| | Humidity | 0.26 | 1, 79 | .6103 |
| | Humidity by time | 50.22 | 2, 77 | *<.0001* |
| 5 | Time | 5.74 | 2, 77 | *.0048* |
| | Brand | 1.76 | 1, 78 | .1882 |
| | Brand by time | 1.18 | 2, 77 | .3114 |

weight increased over time in the 80% humidity level, while the wet diaper weight decreased over time in the 40% humidity level (Figure 2d). A posteriori simple-effects test (independent *t* tests) comparing the mean wet diaper weight for the 40% and 80% humidity conditions at each assessment point indicated no significant difference at baseline ($P$ = 1.000, Cohen's $d$ = 0.00, 95% CI = −0.43,

FIGURE 2




Trajectories for wet diaper weight across 6 hours. (a) Mean wet diaper weight over time. (b) Mean wet diaper weight over time by fluid volume instilled. (c) Mean wet diaper weight over time by temperature. (d) Mean wet diaper weight over time by humidity. (e) Mean wet diaper weight over time by brand.

TABLE 3. Change in Wet Diaper Weights Across Time[a]

| Factor | n | 0-3 h Mean (SD) | 3-6 h Mean (SD) | 0-6 h Mean (SD) |
|---|---|---|---|---|
| Time | 80 | −0.2 (0.9) | −0.2 (0.6) | −0.4 (1.1) |
| Fluid volume instilled | | | | |
| 3 mL of water | 40 | −0.1 (0.7) | −0.3 (0.6) | −0.1 (0.7) |
| 5 mL of water | 40 | −.3 (1.1) | −0.1 (0.5) | −0.3 (1.1) |
| Effect size (95% CI) | | −0.22 (−0.66, 0.22) | 0.36 (−0.08, 0.80) | −0.22 (−0.66, 0.22) |
| Temperature | | | | |
| Temperature 28°C | 40 | −0.2 (1.1) | −0.1 (0.6) | −0.3 (1.2) |
| Temperature 36°C | 40 | −0.3 (0.6) | −0.3 (0.5) | −0.5 (0.9) |
| Effect size (95% CI) | | −0.11 (−0.55, 0.33) | −0.36 (−0.80, 0.08) | −0.19 (−0.63, 0.25) |
| Incubator humidity | | | | |
| Humidity 40% | 40 | −0.6 (0.7) | −0.6 (0.5) | −1.2 (0.6) |
| Humidity 80% | 40 | 0.2 (0.9) | 0.2 (0.4) | 0.4 (0.9) |
| Effect size (95% CI) | | 0.99 (0.53, 1.46) | 1.77 (1.25, 2.28) | 2.09 (1.55, 2.64) |
| Diaper brand | | | | |
| Brand 1 | 40 | −0.1 (0.8) | −0.2 (0.6) | −0.3 (0.9) |
| Brand 2 | 40 | −0.4 (1.0) | −0.2 (0.6) | −0.5 (1.2) |
| Effect size (95% CI) | | −0.33 (−0.77, 0.11) | 0.00 (−0.44, 0.44) | −0.19 (−0.63, 0.25) |

*Abbreviations: CI, confidence interval; SD, standard deviation.*

[a]*Cohen's d effect size and 95% CI: small = 0.20, medium = 0.50, large = 0.80; positive score = wet diaper weight increases due to absorption; negative score = wet diaper weight decreases due to evaporative loss. Diaper weights are calculated in grams.*

0.43), at 3 hours ($P$ = .6017, Cohen's $d$ = 0.12, 95% CI = −0.32, 0.55), or 6 hours ($P$ = .3246, Cohen's $d$ = 0.22, 95% CI = −22.0, 0.66).

Table 3 compares the difference in wet diaper weight loss from 0 to 3 hours, 3 to 6 hours, and 0 to 6 hours for each factor. A more negative score indicated volume loss (decrease in wet diaper weight), while a more positive score indicated volume gain (increase in wet diaper weight). For each factor, Cohen's $d$ effect sizes are provided to indicate the magnitude of the difference in the mean difference (volume change) between the 2 levels of each factor. With exception of humidity level, the effect sizes for the volume change for each interval were minimal to small (Cohen's $d \leq 0.49$). The effect sizes were large when comparing the 40% and 80% humidity (Cohen's $d \geq 0.99$) and the effects increased as time progressed due to the increasing diaper weight (volume gain) across time in the 80% humidity condition and the decreasing diaper weight across time due evaporation in the 40% humidity condition (Figure 2d).

## DISCUSSION

This study extends previous findings of evaporative water loss and absorption in absorbent diapers by examining 2 different fluid volumes, incubator temperatures, humidity levels, and diaper brand. Findings from this study indicate that wet diaper weight declines significantly over 6 hours. However, instilled fluid volume, incubator temperature, and diaper brand did not significantly influence wet diaper weight over time. Instilled fluid volume showed small effect size changes and incubator temperature as well as diaper brand showed small or medium effect size changes over time (Table 3). However, incubator humidity over time had a significant effect, with high humidity increasing wet diaper weight over time, whereas low humidity had the opposite effect (Table 2). Effect sizes for humidity changes over time ranged from small to large (Table 3). Similar studies have demonstrated variations in diaper fluid volumes due to evaporative loss or absorption based on varying incubator humidity levels.[15]

The smaller volumes of urine output from very premature infants may be more vulnerable to evaporative loss in low humidified environments. In the presence of high humidity, an increase in weight may occur from the diaper absorbing moisture from the infant and environment. Therefore, there may be an overestimation of urine output in very preterm infants in higher humidity environments and an underestimation in low humidity environments. Thus, diaper weight alone (eg, without the context

## Summary of Recommendations for Practice and Research

| | |
|---|---|
| **What we know:** | • Fluid output for infants in the neonatal intensive care unit is essential to understanding fluid and electrolyte balance.<br>• Measurement of diaper weights is used as standard practice to quantify urine output.<br>• Diaper changes are psychologically distressing for infants. |
| **What needs to be studied:** | • Conduct study exploring the impact of environmental factors (eg, incubator temperature and humidity) on diaper weights when an infant is wearing the diaper.<br>• Explore whether there are any unintended consequences (eg, skin breakdown, excess transepidermal water loss in diapers, and changes in microbiota) of less frequent diaper changes among infants in a neonatal intensive care setting.<br>• Explore infant physiologic responses to less frequent diaper changes in a neonatal intensive care unit setting. |
| **What we can do today:** | • Monitor incubator temperature and humidity levels between diaper changes. |

of humidity levels) may not afford clinicians an accurate assessment of fluid and electrolyte balance. Strategies to reduce these types of measurement errors require further evaluation.

### Limitations

This study has limitations worth noting. The sample size of 80 (40 per level of each factor) did not provide at least 80% statistical power when small effect sizes were observed. In addition, the wide range of diaper sizes also added variability that decreased statistical power. Finally, this study did not include infants wearing the diapers. Thus, there may be unaccounted for effects of infant TEWL over time, which could affect measured fluid volume in the diapers.

### Implications

There was no clinically meaningful difference in evaporative loss between 3 and 6 hours based on environmental factors such as fluid volume instilled, incubator temperature, or diaper brand (Table 1). Therefore, less frequent diaper changes should not impact assessed urine output. Some caution might be appropriate with very high or low incubator humidity levels because there were large effect sizes related to fluid volume over time in high and low humidity environments despite no statistically significant change in fluid volume based on humidity alone. Thus, in clinical practice, neonates in incubators with high or low humidity levels might experience greater changes in diaper weight relating to extending periods between diaper changes. These findings may support a more developmentally appropriate infant environment and less intrusive care that fosters healthier physiologic outcomes. However, unintended consequences such as skin breakdown or increased microbial colonization of the urinary tract due to extended periods between diapering should be explored prior to adopting longer diaper changing intervals. Further study, with a larger cohort and infants wearing the diapers, is needed to determine whether adjustments in normal clinical fluid management are necessary. Clinicians can, however, implement rigorous control of outside contributing factors. Varying initial weights of dry diapers of the same sizes were found throughout the study. To ensure accuracy with weighing, dry diapers should consistently be weighed prior to placing them on the infant, particularly for the extremely low-birth weight (ELBW)/VLBW population. Stringent standards for monitoring the reliability of diaper scales are also needed to ensure consistency and accuracy of diaper weights, given the need for strict fluid management of this population.

The use of diaper weighing in high-humidity infant environments may not be an accurate measure of actual urine output in the very premature infant. This study demonstrates the need for caution when interpreting this measure, and we discussed some possible clinical approaches to ameliorate this difficulty.

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