Advances in technology have improved the survival of small, low birthweight infants. Due to their prematurity, these infants are at significant risk of acquiring infection during their hospitalization. In fact, surveillance cultures have shown infection rates of 15-20% in some neonatal intensive care units (NICUs). Knowledge of risk factors, etiology, and some fundamental principles of microbiology is a first step in prevention.

Nosocomial, hospital-acquired, or late onset neonatal infection are all terms used to describe those infections which generally occur after the first week of life and are acquired from the postnatal environment. Nosocomial infections are differentiated from early or congenital infections not only by the timing of disease onset, but also by the common offending microorganisms. Nosocomial infections are acquired from direct contact (eg caregiver hands) and indirect contact (eg contaminated objects) with organisms found in the nursery macro-environment. So how are nosocomial infections and the micro-environments in which sick infants are cared for related? In order to answer this question, let’s briefly review the history of incubator care.

The Closed Microenvironment

Experts have recognized the importance of a closed micro-environment as a means of achieving warmth for preterm infants since the late 19th century when significant decreases in infant mortality were realized with the regular use of this technology. Large body surface area relative to mass, decreased subcutaneous fat, and limited ability to produce heat secondary to poorly developed brown fat stores, predispose the preterm infant to large heat losses if exposed to cool ambient temperatures. Incubators were the first micro-environment designed to provide the infant with a thermally neutral environment. Present-day incubators provide convective heat as means of achieving thermoneutrality. In theory, the thermal neutral zone is defined by specifications of an environment in which the preterm infant can minimize energy usage for heat production and maximize his or her energy expenditure for growth and development. For many preterm infants though, even maximum convective air temperature settings approaching 39 degrees C may be insufficient to maintain core body temperatures of 36.5 to 37 degrees C. This phenomenon generally occurs because the heat partition through which the infant is losing excessive heat is that of evaporation by way of transepidermal water loss (TEWL) and it can be difficult for convective heat to offset the evaporative losses.

Humidity and the Closed Microenvironment

So how does one counterbalance evaporative losses? Use of supplemental humidity is one method to be considered by the clinician. However, just as with all therapies there are benefits and risks. The use of high humidity in an enclosed micro-environment offers several benefits. Among these advantages are reduced evaporative heat losses, decreased insensible water loss, improved fluid and electrolyte balance, and enhanced skin integrity. High levels of humidity can be especially beneficial during the first few days and/or weeks of life before skin of the very low birthweight infant matures.

Researchers have shown that as the air temperature of the enclosed micro-environment increases, the relative humidity decreases unless a source of humidity is provided (See Fig. 1). This phenomenon happens because warmer air has an increased capacity for water vapor. In effect, raising the air temperature within an enclosed micro-environment without a concomitant increase in water vapor increases the potential for TEWL and hence, evaporative heat loss which may be difficult for the convective heat supply of an enclosed micro-environment to overcome. For example, let’s say that point A represents the temperature of a typical labor and delivery suite at 68 degrees F, with a relative humidity of 50%. If that baby is sick and requires care in a 90 degrees F incubator, notice that the RH that the baby is subjected to drops to 25%. This factor may be particularly important in the case of a small preterm infant’s first days and/or weeks of life, as their immature skin with little or no subcutaneous fat and stratum corneum, yields a large surface area for evaporative heat loss. Hence, the need for humidity as a therapeutic intervention to protect against evaporative heat loss.

Risks Associated with Humidity

There is a concern that the thermoneutral environment within an enclosed micro-environment coupled with high relative humidity may pose a significant risk for nosocomial infection in low birthweight infants. However, in light of design modifications to current infant microenvironments, that data may be dated and require re-examination by clinicians.

American studies conducted in the 1950’s and 1960’s suggested a high correlation between use of humidity and an increasing incidence of necrotizing pneumonia in low birthweight infants. Environmental studies of incubators suggested that water basins of nebulizing units used to provide humidity were harbingers of gram-negative colonies.
microbial species or fungi. Organisms such as Pseudomonas aeruginosa, Escherichia coli, Serratia marcescens, or Candida albicans were found to colonize not only the water basins but the internal mechanisms of the unit as well. In this location, sterilization would be almost impossible. Furthermore, whenever a nebulization method was used to provide micro-environmental humidity, the potential existed for any bacterial contaminant within the water basin to become airborne on water droplets as the nebulizing device broke a larger water molecule into smaller liquid particles. In addition, the manufacturers’ design of these devices at the time did not involve any active heating of the water pool, as a method of bacterial control. Thus, the correlations between infection rates and humidity were probably real rather than artifact.8,9,10,11

ORGANISMS OF CONCERN

Currently, four organisms seem to cause most concern for human newborns.2 Three are gram negative microbes and one is a yeast.1,2,8 However, nosocomial infections in neonatal intensive care environments are not limited to the geimrs. All gram negative organisms secrete numerous toxic exoproducts from their cell walls. These endotoxin are lethal compounds that initiate secretion of several inflammatory mediators felt to be responsible for the pathogenesis of sepsis. Infections caused by gram negative rods can be severe and fulminant, progressing rapidly to multisystem organ failure.

Escherichia coli is the most prevalent gram negative organism (see Fig. 2). E. coli colonizes the lower intestinal tract soon after birth and remains the predominant fcal flora throughout life. Sepsis with E. coli may occur after colonization from the environment or from translocation of the bacterial across the intestinal tract. Strains of E. coli containing the K1 antigen are among the most common organisms responsible for purulent meningitis. Invasions of the bloodstream by organisms that have colonized mucosal surfaces usually precede both sepsis and/or meningitis.12

Pseudomonas aeruginosa is a water-loving, gram negative, aerobic rod that can be found in moist areas (see Fig. 3). It is an opportunistic infection, as infection is rare in healthy individuals. However, it is a virulent organism that infects the vulnerable host. Therefore, immune compromised newborns contract systemic infections that occur through contaminated equipment, aqueous solutions, and, at times, the hands of health care personnel. It can infect all types of wounds, particularly burns. The underdeveloped stratum corneum of the preterm newborn makes them highly susceptible to this microbe. Pseudomonas can cause sepsis, severe conjunctivitis, necrotizing pneumonia, endocarditis, meningitis, and death. It is also known to be resistant to multiple antibiotics.12

Serratia marcescens can cause rapidly spreading outbreaks of severe infections in neonatal intensive care units and is frequently multiresistant to antibiotics (see Fig. 4). Outbreaks in NICUs have been attributed to contamination of various equipment and supplies (e.g. ventilators, IV solutions, breast pumps, soap dispensers). Recently, studies have concluded that colonized and infected infants are the most frequent reservoir of Serratia marcescens and are potential sources of horizontal transmission via the hands of healthcare personnel. Control of outbreaks requires cohorting and isolation of infected and colonized infants with strict handwashing, gowing, and gloving procedures. Because Serratia marcescens has been shown to survive on the hands of healthcare personnel despite use of a strict handwashing protocol, gloves are cruically important in preventing the spread of infection.12

Candida albicans (ovoid budding yeast) is the most frequent cause of fungal sepsis in the low birthweight preterm infant (see Fig. 5). It has become more prevalent since the introduction of widespread antibiotic use and the threshold of viability has been progressively challenged down to 22 to 23 weeks gestation. In most infants, colonization from Candida occurs in utero or at the time of delivery. Other infants may acquire fungus from caregivers during hospitalization. In fact, colonization of the skin generally precedes an opportunistic systemic yeast infection.12

HUMIDITY AND CURRENT TECHNOLOGICAL ADVANCES

Humidity may have other benefits in addition to protection against evaporative heat loss and stabilization of the neutral thermal environment. Other research shows that these same environmental conditions also act to stabilize fluid and electrolyte balance, and to preserve skin integrity. Optimizing these aspects of newborn care may enhance utilization of metabolic substrates to promote growth and development of the infant.

Risks versus benefits is critical to the decision making process before implementing any therapeutic intervention such as humidity. The clinician should be guided by clear evidence that the benefit outweighs the risk. When one considers the research, it is important to know that as a result of the infectious outbreaks in the 1950s and 1960s, Ohmeda Medical changed its methodology of providing micro-environmental humidity. The main part of the Giraffe® Humidification System consists of an immersion heater that sits within a bath of sterile, distilled water. The temperature of this water bath reaches a temperature of 52 degrees C to 58 degrees C which by itself is bactericidal to most mesophilic microorganisms (that is, organisms which tend to thrive at moderate temperatures of 20 to 45 degrees C and act as pathogens in the human body). However, this temperature is insufficient to protect the infant from a potential source of infection should accidental contamination of the reservoir take place.12 As an added measure of safety, engineers designed the immersion heater so that a small aliquot of water is boiled just before the humidity is disbursed into the air circulation within the infant
compartment. By using this technology, sterile humidity is created and offered to the infant in a gaseous vapor state, leaving no airborne water droplets to act as vectors of infectious microorganisms.

As with any humidification system, proper cleaning and routine changing of water will reduce the potential for bacterial propagation. The design of the Giraffe® humidification system allows for the reservoir to be accessed from the front of the bed without disturbing the infant. This facilitates ease of changing the water and cleaning of the water reservoir on a routine basis, as determined by unit policy. This study indicates that the Ohmeda Medical Giraffe® humidification system will not promote bacterial growth.

EVIDENCE-BASED PRACTICE

Purpose
Due to concerns over bacterial or fungal propagation, this study was conducted to evaluate the Ohmeda Medical Giraffe Humidification System. Specifically, the product’s ability to provide specified levels of humidity and ease of operation and cleaning are important. However, the risk of bacterial propagation with high levels of micro-environmental humidity must be fully described.

Equipment
3 Giraffe units with Active Humidification System
Sterile, distilled water
American Type Culture Collection (ATCC) microorganisms: P. aeruginosa, E. coli, S. marcescens, C. albicans
Appropriate culture media
Calibrated thermometer

Procedure
Clean 3 Giraffe® units, including humidifier with Cavicide.
Giraffe #1 (experimental)—humidity condition, reservoir contaminated.
Giraffe #2 (control)—humidity condition, no reservoir contamination.
Giraffe #3 (control)—no humidity condition, no reservoir contamination.
Reconstitute freeze dried microorganism ($10^3$ to $10^6$ cfu/ml).
Fill humidifiers of Giraffe #1, #2 with 1 liter sterile, distilled water.
Prewarm all 3 Giraffe units in air control mode @ 35 degrees C for 1 hour.
Set humidity levels of Giraffe #1, #2 @ 65% RH for 1 hour.
Record water bath temperature @ time of inoculation.
Culture site(s) of all 3 beds just prior to inoculation: humidity reservoir at immersion heater, reservoir injector seal, points of airflow at midpoint of east and west doors, center of bed, servO2 system (6 sites, see Fig. 6).
Inoculate humidity reservoir of Giraffe #1 (time 0h) with P. aeruginosa (or E. coli,
S. marcesens, C. albicans @ sequential 1 week intervals) with 10 cc of reconstituted microorganism (10^3 to 10^6 cfu/ml).

Culture site(s) @ time 0h: humidity reservoir at immersion heater, reservoir injector seal, points of airflow at midpoint of east and west doors, center of bed, servO2 system (6 sites, see Fig. 6).

Refill humidifiers of Giraffe® #1, #2 q 12 hours or prn with 1 liter sterile, distilled water.

Record water bath temperature at time of each culture session @ 24h, 48h, 72h, 168h. Reculture sites @ 24h, 48h, 72h, 168h post-inoculation.

Site(s) of post-inoculation cultures: humidity reservoir at immersion heater, reservoir seal, points of airflow at midpoint of east and west doors, center of bed, servO2 system (sites, see Fig. 6).

Each microorganism was studied separately at one-week intervals.

Methods

To determine the role of humidity in microbial colonization of an enclosed micro-environment. As a condition of this laboratory research, a Giraffe micro-environment was cleaned with a germicidal detergent utilizing a dilution of one ounce per gallon of water at the start of the study (Cavicide, active disinfecting ingredient: diisobutylphenoxyethyl dimethyl benzyl ammonium chloride). The enclosed micro-environment was run in air control mode at 35 degrees C and actively humidified at 65% RH through a servo-controlled mechanism. Sterile, distilled water was added at the start of the study and as needed to the water reservoir. After reaching temperature and humidity equilibration, a known inoculum of one of four different micro-organisms (P. aeruginosa, S. marcesens, E. coli, or C. albicans) reconstituted to 10^6 to 10^8 cfu/ml H2O was placed into the reservoir on day 0 and baseline cultures were obtained. Bacterial cultures were taken at five points including the humidification reservoir near the immersion heater, the reservoir seal at entry to the Giraffe®, along the path of airflow at both the east and west doors, and the center of the mattress. Semi-quantitative bacterial swabs were repeated at 24h, 48h, 72h, and 168h. The testing of each micro-organism was done serially over a four week period.

Discussion

Risks versus benefits is critical to the decision making process before implementing any therapeutic intervention such as humidity. The clinician should be guided by clear evidence that the benefit outweighs the risk. When one considers the research, it is important to know that as a result of the infectious outbreaks in the 1950’s and 1960’s, Ohmeda Medical changed its methodology of

### Results: PSEUDOMONAS AERUGINOSA

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<tr>
<td>Giraffe® #1 Contaminated, Humidity</td>
<td>Positive¹</td>
<td>Negative</td>
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* Positive in reservoir culture only; negative at all sites beyond humidifier

### Results: CANDIDA ALBICANS

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### Results: Serratia Marcescens

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### Results: Eschericia coli

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providing micro-environmental humidity.

It is not surprising that purposeful inoculation of the patented Giraffe Humidification System yielded no pathway for conduction of infectious microorganisms into the infant’s micro-environment. No microorganisms were ever collected from the patient environment during the entire course of the study. Microorganisms were cultured from the humidifier reservoirs at 24 hours under the Pseudomonas aeruginosa and Candida albicans conditions but at a colony count that was reduced to 10^2 cfu/ml. This suggests that the thermal death time to kill these two microorganisms at the water bath temperature within the system is between 24 and 48 hours.

The results are also not surprising in light of the fact that every component of the system was designed to protect the infant from potentially harmful pathogens when the infant’s own primary barrier, the skin, may be compromised due to conditions surrounding prematurity. Results of this study showed that the temperature of the water bath in the humidification reservoir typically reached 52 degrees C at the most distal point from the immersion heater to 58 degrees C beside the device. These temperatures are probably bactericidal to most mesophilic microorganisms (that is, organisms which tend to thrive at human body temperature and act as pathogens). Yet this intentional design feature is insufficient to protect the infant from a potential source of infection should accidental contamination of the reservoir happen.

As an added measure of safety, engineers designed the immersion heater so that a small aliquot of water is boiled just before the humidity is disbursed into the air circulation within the infant compartment. By using this technology, sterile humidity is created and offered to the infant in a gaseous vapor state, leaving no airborne water droplets to act as vectors of infectious microorganisms.

Furthermore, some clinicians have reported that traditional boiler type humidification systems have tubing distal to the boiler to conduct “sterile” steam from the boiler to the infant chamber. Principles of physics suggest that such tubing would permit re-condensation of water vapor into a liquid state, thereby acting as a possible focal point for bacterial overgrowth.

As with any humidification system, proper cleaning and routine changing of water with reduce the potential for bacterial propagation. The design of the Giraffe® Humidification System allows for the reservoir to be accessed from the front of the bed without disturbing the infant. This facilitates ease of changing the water and cleaning of the water reservoir on a routine basis, as determined by unit policy. This study indicates that the Ohmeda Medical Giraffe® humidity system will not promote bacterial growth.

Conclusion

This study indicates that the humidity system in the Ohmeda Medical Giraffe family of products will not promote bacterial or fungal growth. The humidification system of the Giraffe family of products can provide an adequate level of relative humidity which can be extremely beneficial to the low birthweight infant. The system was found to be easy to operate, to fill, and to clean without disturbing the infant. This means that the clinician can provide a therapy without concern for an increased risk of infection to the infant when the reservoir is filled daily with sterile distilled water and the bed is routinely cleaned, according to the protocol described within this study.

REFERENCES