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A Cross-Sectional Study To Examine The Effects Of The Nurse Work Environment On Outcomes Of Very Low Birth Weight Infants

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Abstract

ABSTRACT

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Elizabeth S. Schierholz

Eileen T. Lake

Importance: Extensive variation in rates of mortality, and morbidity, including severe intraventricular hemorrhage, exists across neonatal intensive care units. The neonatal nurse is essential to the care of very low birth weight infants in these units. Extensive evidence in the adult population supports the association of the nurse work environment, nurse qualifications and nurse staffing with patient outcomes. The relationship of these elements, at the NICU unit level, with the outcomes of in-hospital mortality, intraventricular hemorrhage and length of stay for very low birth weight infants, has not been previously evaluated.

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Design, Setting and Patients: This cross-sectional secondary analysis linked data from the RN survey from the Multi-State Nursing Care and Patient Safety Study 2005-2008 to administrative state discharge data of VLBW infants with birth weights 500-1499 grams in California, Pennsylvania, New Jersey and Florida. The nurse work environment, nurse education, certification and patient-to-nurse ratios were aggregated to the hospital level from RN survey responses. Risk-adjusted odds ratios and incident rate ratios were determined by logistic regression and negative binomial regression.

Main Outcomes and Measures: The primary study outcomes were in-hospital mortality, severe intraventricular hemorrhage and length of stay.

Results: There were 17,771 VLBW infants in 170 NICUs. Mortality was 10.8%, severe intraventricular hemorrhage was 5.2% and length of stay 46 days, all varied by category of the work environment. The range of work environment scores across the NICUS was 1.93-3.79. Based on these scores NICUs were categorized as having poor, average and best work environments; 44 NICUs were categorized as best and 36 NICUs were categorized as poor. Patient-to-nurse ratios varied by work environment category. Proportions of BSN educated and nurses with specialty certification did not vary across work environments. In NICUs with poor vs. better environments mortality was 11% vs. 9.8%. In poor compared to better environments sIVH was 6.4% vs. 4.5%. Average length of stay in poor vs. better environments was 53 days and 36 days respectively. In regression models, controlling for patient and hospital characteristics (race, sex, insurance, NICU volume and hospital teaching status), each one unit (1 SD) increase in the work environment score was associated with a 4% lower odds of death (OR = 0.96, 95% CI 0.88-1.05, p=0.36), 23% lower odds of severe IVH (OR 0.88 95% CI 0.79-0.99, p= 0.043) and 4% shorter length of stay (OR 0.96, 95% CI 0.93-0.995, p=0.026). NICUs with the best work environments and higher proportions of BSN educated nurses were associated with lower odds of death (OR 0.94, 95% CI 0.89-0.99, p=0.045) and shorter lengths of stay (IRR 0.97, CI 0.94-0.99 p= 0.01) for very low birth weight infants.

Conclusions: These results indicate that outcomes of VLBW infants vary by the nurse work environment category. VLBW infants cared for in better work environments have significantly lower risk-adjusted rates of severe IVH and shorter lengths of stay. Improving the nurse work environment and increasing the proportion of BSN educated nurses are actionable interventions to improve nursing quality and reduce poor outcomes for very low birth weight infants in neonatal intensive care units.

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A CROSS-SECTIONAL STUDY TO EXAMINE THE EFFECTS OF THE NURSE WORK ENVIRONMENT ON OUTCOMES OF VERY LOW BIRTH WEIGHT INFANTS

Elizabeth Susan Schierholz

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A CROSS-SECTIONAL STUDY TO EXAMINE THE EFFECTS OF THE NURSE WORK ENVIRONMENT ON OUTCOMES OF VERY LOW BIRTH WEIGHT INFANTS

Dedication

For my mom

"For I know the plans I have for you," declares the LORD,

"plans to prosper you, and not to harm you, plans to give

you hope and a future. Then you will call upon me and

come and pray to me and I will listen to you. You will seek

me and find me when you seek me with all your heart."

Jeremiah 29:11-13

For my grandmother, Olivia

Of your many children and grandchildren – your dream

was to have one care for others as a nurse,

I am proud to be that one.

And perhaps, most importantly,

To all the NICU parents

Thank you for entrusting the lives of your precious infants

to my care and the care of NICU nurses

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I would also like to thank my family. To my mom – thank you for your steadfast faith, unconditional love and support, prayers, and encouragement. Thank you for all the sacrifices you have made to support me and my dreams. To my dad – thank you for showing me that you can set almost unachievable goals and work hard to achieve them. To my sisters – Stephanie and Patricia (and Sam), and my brother Ryan (and Rebekah) – you have all provided unwavering support and encouragement, thank you. I am beyond grateful for my fellow doctoral students, past and present, especially Betsy White, Ashley Ritter, Christine Bader, Jackie Boyden, Amanda Bettencourt, Marta Simonetti and Danielle Altares-Sarik – thank you for sharing this journey, for your encouragement and for celebrating the successes. To Erica Deam, Tia Smith, Ruth Mercer, Sarah Bolin, April Jaggi, Tasha Tanner, Amanda Morgan, Lauren Spydell and Melissa Liggins – we have all had mountains to climb in the past few years, thank you for sharing the tears and triumphs, and most of all thank you for your never-ending encouragement and unconditional love and friendship. And to all the NICU nurses and nurse practitioners I have had the honor to work with, thank you for providing excellent care to the littlest of infants and for allowing me to learn and grow with you.

No dissertation can be realized without the inspiration, guidance, support and encouragement of a team, this dissertation was only possible by the faculty and students at Penn, my family and dear friends – thank you for supporting my dream and making it a reality.

I am sincerely grateful. Thank you.

ABSTRACT

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Importance: Extensive variation in rates of mortality, and morbidity, including severe intraventricular hemorrhage, exists across neonatal intensive care units. The neonatal nurse is essential to the care of very low birth weight infants in these units. Extensive evidence in the adult population supports the association of the nurse work environment, nurse qualifications and nurse staffing with patient outcomes. The relationship of these elements, at the NICU unit level, with the outcomes of in-hospital mortality, intraventricular hemorrhage and length of stay for very low birth weight infants, has not been previously evaluated.

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Conclusions: These results indicate that outcomes of VLBW infants vary by the nurse work environment category. VLBW infants cared for in better work environments have significantly lower risk-adjusted rates of severe IVH and shorter lengths of stay. Improving the nurse work environment and increasing the proportion of BSN educated nurses are actionable interventions to improve nursing quality and reduce poor outcomes for very low birth weight infants in neonatal intensive care units.

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Chapter 1: Introduction

The problem

Each year 55,000 very low birth weight (VLBW) infants, those with a birth weight less than 1500 grams (3.2 pounds) require care in the neonatal intensive care unit (NICU) (Martin, Hamilton, Osterman, Driscoll, & Drake, 2018). Survival of VLBW infants has improved significantly in the past 30 years due to the availability of and improvements in neonatal care (Barfield et al., 2012; Callaghan, MacDorman, Rasmussen, Qin, & Lackritz, 2006; Harrison & Goodman, 2015; Mathews, Macdorman, & Thoma, 2015). The Vermont Oxford Network (VON) reports a decrease in average mortality from 14% in 2005 to 10.9% in 2014 (Horbar et al., 2017). Those that survive often experience significant morbidities, including severe intraventricular hemorrhage, that result in neurodevelopmental impairment, increased resource utilization and cost, longer lengths of stay and prolonged separation of infant and family (Butler & Behrman, 2007; Schmidt et al., 2003; Stoll et al., 2004). Despite overall decreases, there is significant variation in mortality and morbidity rates across hospitals (Alleman et al., 2013; Horbar et al., 2017; Stoll et al., 2015). This institutional variation in mortality and morbidity exists both within and across states (Horbar et al., 2017; Rogowski, Staiger, & Horbar, 2004) and is not explained by infant risk factors including gestational age, birth weight, resuscitation at birth, race, sex, multiple birth, type of delivery and prenatal care (Alleman et al., 2013; Stoll et al., 2015).

Of all pediatric patients, VLBW infants have the greatest risk of death and poor health outcomes (Horbar et al., 2012; Soll, 2015; Stoll et al., 2015). While very low birth weight infants, account for only 1-2% of all U.S. births, they represent 56% of all infant deaths, (Martin et al., 2018; Mathews et al., 2015) which currently occur at a rate of 5.9 per 1000 live births (Mathews et al., 2015; Murphy, Xu, Kochanek, Curtin, & Arias, 2017). Despite national efforts to decrease preterm births, the U.S. has experienced an increase in preterm births for the past 2 years (Martin et al., 2018). Reducing mortality and morbidities of very low birth weight infants improves outcomes and contributes significantly to decreasing infant mortality in the U.S.

Nurses constitute the largest workforce of healthcare providers in the hospital and are in the best position to detect complications and problems in care, serving as a surveillance system to minimize and prevent poor patient outcomes (Aiken, Clarke, Cheung, Sloane, & Silber, 2003). Neonatal nurses are essential for optimal care of very low birth weight infants in the NICU. At birth these infants are not ready for survival in the world, and each life is completely dependent on the care and resources available in the NICU. The NICU is well equipped with state-of-the-art technology- incubators, ventilators and infusion pumps, all which sustain the life of each premature infant. This artificial environment provides temperature regulation, nutrition and oxygen. Despite technological advances, none of these machines respond to the infant's changing needs. Each infant may require different temperature levels, oxygen levels and nutritional support – intravenous infusions or enteral feedings in order to provide adequate life support (Blackburn, 2014; Verklan & Walden, 2015). Nurses are necessary to assess the infant's response to each of the current levels of support provided by these machines and intervene as needed to avoid negative outcomes (Kenner & Lott, 2007). Small changes that may be inconsequential to adults may be the first signs of a critical change in a premature infant. The NICU nurse remains at the bedside carefully monitoring and continually watching for subtle cues in order to respond to a decline in clinical status (Cricco-Lizza, 2016). NICU nurses are essential to infant outcomes, providing care that protects and advocates for the life of these vulnerable infants.

The fragile physiology and the availability of advanced technology make the provision of nursing care required for very low birth weight infants complex, intensive and expensive. This care is among the most nurse intensive of all hospital patients with nurse to patient ratios ranging from greater than one nurse per VLBW infant for the most critically ill to one nurse for three to four of the most stable infants (Kilpatrick, Papile, & Macones, 2012, 2017; Schofield, Simpson, Adkins-Bley, Wilson, & Brennan, 2010).

There is considerable evidence suggesting that the ability of nurses to monitor and provide this care maybe largely influenced by the organizational environment in which they practice. Extensive research involving adult patients indicate that favorable nurse work environments are related to better patient health outcomes, including lower mortality and failure to rescue (death following a complication) (Aiken, Cimiotti, et al., 2011; Friese, Lake, Aiken, Silber, & Sochalski, 2008; Lake, de Cordova, et al., 2017). Expanding on this research, there is increasing evidence to suggest that elements of the organization of nursing, including staffing, education, certification and experience of nurses providing care in the neonatal intensive care unit contribute to outcomes of VLBW infants. The significance of these nursing elements and the association to patient outcomes is well supported in the adult literature (Aiken, Cimiotti, et al., 2011; Aiken et al., 2003; Kendall-Gallagher, Aiken, Sloane, & Cimiotti, 2011) demonstrating that patients receiving care in hospitals with better staffing and more BSN educated nurses have better outcomes. There is also evidence that these elements vary across NICUs (Lake, Hallowell, et al., 2016; Rogowski et al., 2015).

Study Overview

The purpose of this study was to examine the empirical relationships among the nurse work environment, the NICU nursing workforce composition and staffing, and the outcomes of very low birth weight infants using cross-sectional data from a four-state nurse survey and infant outcomes from state administrative files of the same states. This study linked unique nurse survey data collected in 2005-2006 from California, Pennsylvania, New Jersey and in 2007-2008 from Florida, to patient level data from administrative databases in each state. The nurse survey included detailed information on nurses and hospitals for virtually all of the hospitals in the four states in which very low birth weight infants receive care. The nurse survey contained a large number of indicators of the nurse work environment and elements of the organization of nursing including patient-nurse ratios, education attainment, nurse experience level and nurse certification. Linking these data with the patient data provided a unique opportunity to examine the effects of the nurse work environment and elements of the organization of nursing in neonatal intensive care units on outcomes of very low birth weight infants in these hospitals. This was a secondary data analysis to address the research question: Are the quality of the work environments and the qualifications of the registered nurses in neonatal intensive care units related, and how are these factors individually or jointly related to mortality, intraventricular hemorrhage and length of stay for very low birth weight infants?

Specific Aims

The following aims were defined in order to address the research question.

Aim 1: To examine the effect of the nurse work environment on outcomes of very low birth weight infants (in hospital mortality, hospital length of stay, and severe intraventricular hemorrhage).

> Hypothesis 1: Hospitals with poorer work environments for nurses, will have higher rates of VLBW infant mortality, longer lengths of stay and higher rates of severe intraventricular hemorrhage).

Aim 2: To examine the direct effects of nurse staffing, education, and certification on the outcomes (in hospital mortality, hospital length of stay, and severe intraventricular hemorrhage) of very low birth weight infants, and to examine the interaction effects of the nurse work environment with staffing, education, and certification on those outcomes.

> Hypothesis 2: Hospitals with higher percentages of bachelor's prepared nurses, better staffing, and higher nurse certification will have better outcomes for VLBW infants, the effect of some or all of these factors will be more pronounced in hospitals with better work environments.

Gaps

This study addressed several gaps in the existing literature. The relationship of the nurse work environment and patient outcomes has not been studied in VLBW infants. The influence and variation of organizational elements of nursing including staffing, nurse education, and specialty certification across the nurse work environment, with regards to infant outcomes also has not been explored.

This study provides new evidence of the relationship of the organization of nursing care in neonatal intensive care units and the nurse work environment on outcomes of very low birth weight infants. Current evidence documents very low birth weight outcomes from several epidemiological reports and extensive research focusing on medical practice and treatment of VLBW infants (Alleman et al., 2013; Horbar et al., 2017; Jensen & Lorch, 2015; Rysavy et al., 2015; Stoll et al., 2015). More recent research has included physician and hospital level factors (Alleman et al., 2013; Glass et al., 2015; Jensen & Lorch, 2015; Stoll et al., 2015) as contributing to outcomes of very low birth weight infants. It is recognized that nurses are a constant presence and provide care and surveillance of very low birth weight infants, however, the contribution of nurses to outcomes of these patients is understudied. There is increasing evidence describing the nurse work environment and nurse staffing in the NICU, but limited research links these elements to outcomes of very low birth weight infants.

This study extended beyond describing outcomes of VLBW infants and physician and hospital factors that influence these outcomes and offers evidence that nurses and their environment contribute to VLBW infant outcomes. Specifically, this study builds on the research of Lake that evaluated hospitals recognized for nursing excellence and outcomes of VLBW infants, the work of Tubbs-Cooley that evaluated hospitals recognized for nursing excellence with missed nursing care and the work of Hallowell and Rogowski that evaluated the nurse work environment with breastfeeding support and availability and nurse staffing with infection rates, respectively (Hallowell et al., 2016; Lake et al., 2015; Rogowski et al., 2013; Tubbs-Cooley et al., 2017). Magnet® status is a hospital level factor. This study followed the work of Hallowell and Rogowski at the NICU unit level to look at the outcomes of mortality, severe intraventricular hemorrhage and length of stay, outcomes not previously studied as associated with the nurse work environment, NICU nurse workforce or nurse qualifications at the NICU level.

The nurse work environment is not static, and thus can be modified in order to decrease variation in outcomes of VLBW infants. This study provides empirical evidence to demonstrate that interventions designed to improve the nurse work environment in NICUs that care for very low birth weight infants would contribute to better patient outcomes.

This study adds to our understanding of nursing care for very low birth weight infants. The nurse work environment, nurse staffing, nurse education and nurse certification are all modifiable system characteristics that when optimized function as an intervention to improve outcomes of very low birth weight infants.

Chapter 2: Background and Significance

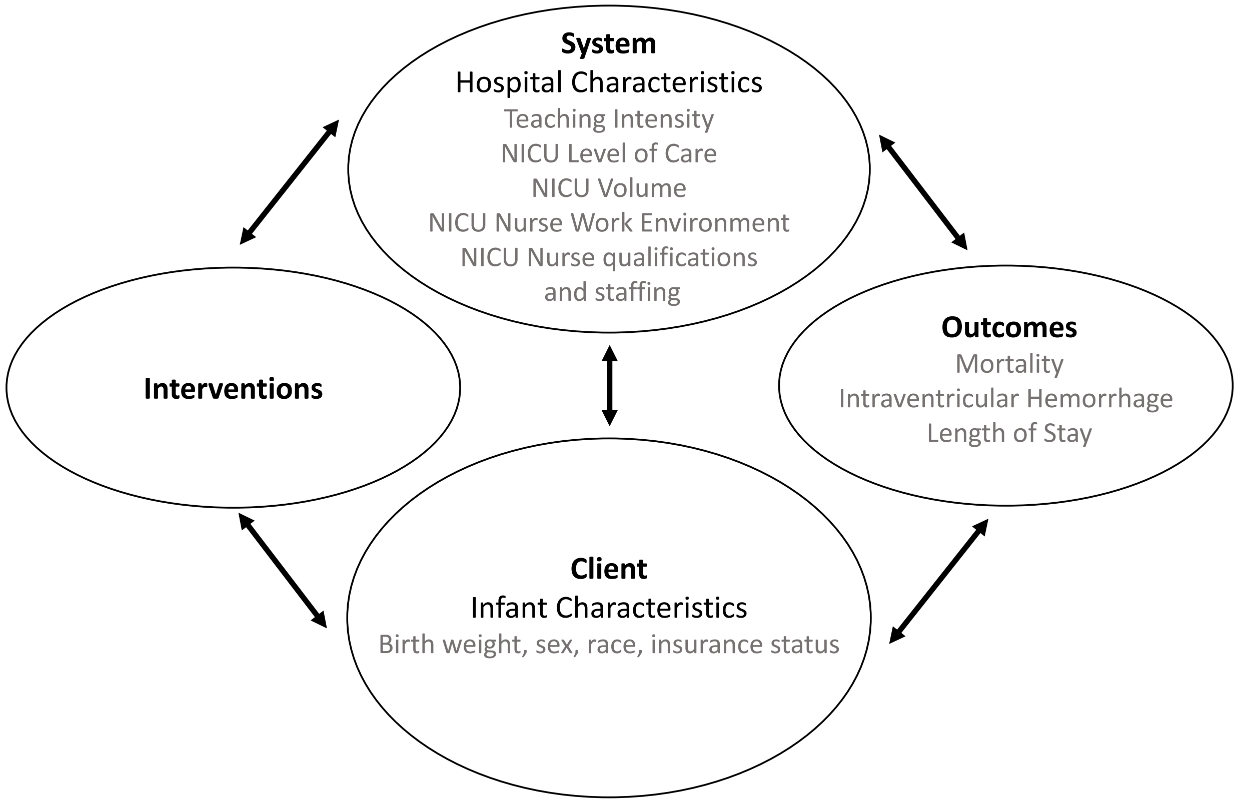
Conceptual Framework

The conceptual framework used in this study is the Quality Health Outcomes Model (QHOM). The QHOM was adapted from the Donabedian framework (Donabedian, 1966) of quality care that demonstrates the relationship of structural factors and patient outcomes as mediated through processes of care. In Donabedian's model, structure consists of having the right things, process is doing the right things and outcomes are having the right things occur. Donabedian's structure-process-outcome model is used in outcomes research to study the relationships of structures and processes of care that influence patient outcomes (Horbar, 1995) and has been used specifically to evaluate the influence of organizational aspects of nursing on patient outcomes (Stimpfel, Sloane, McHugh, & Aiken, 2016). The QHOM model departs from Donabedian's model and allows for more complex relationships between structure-process-outcomes considering the dynamic nature of these components by which interventions are mediated through system and patient characteristics to influence outcomes. The QHOM has been previously used to demonstrate the relationship between the organization of nursing elements within a system of care and patient outcomes (Mitchell & Lang, 2004).

The relationships tested in this study are diagramed in Figure 1. In the QHOM, system characteristics are theorized to be comparable with Donabedian's structure component and represent the characteristics of the organization or hospital that provides care. These characteristics include hospital teaching status, technology and NICU level of care. NICU level of care was classified by the American Academy of Pediatrics (levels II, III and IV), each level represents increasingly complex services (Phibbs, Baker, Caughey, Danielsen, et al., 2007; Profit et al., 2016). The majority of VLBW infants are cared for in level III NICUs (Chung et al., 2010; Profit et al., 2016; Rogowski et al., 2015). This is directly associated with those infants requiring complex nursing and medical care and indicates hospital characteristics that would support that care. In the QHOM process is replaced with interventions and represents the direct and indirect activities necessary to complete care for the patient. For this study, nursing care interventions were not tested directly, but the effects of structural factors, such as the nurse work environment, nurse education, nurse staffing, nurse specialty certification were theorized to incorporate nursing care interventions. For both Aim 1 and Aim 2 the VLBW infant outcomes measured in this study were infant mortality, severe intraventricular hemorrhage and length of stay. The QHOM specifies that outcomes result from both care processes and structures as modified by patient characteristics. In this study each outcome evaluated was controlled for by appropriate infant characteristics.

The study aims define a path represented by the arrows in Figure 1. Aim 1 begins at “system” and measures the relationship of the nurse work environment on infant outcomes as modified by hospital characteristics, nurse qualifications and infant characteristics. Aim 2 also begins at “structure” and measures the relationship of the nurse workforce and qualifications (staffing, education, and certification) on infant outcomes as modified by hospital and infant characteristics. Aim 2 further explored the relationships within “structure" by measuring the interaction of the nurse work environment with nurse workforce and qualifications, staffing, education and certification, on infant outcomes.

Figure 1. Conceptual Framework



Adapted from (Mitchell, Ferketich, & Jennings, 1998) Quality Health Outcomes Model

Background

Advances in technology and specialized care in NICUs have dramatically improved the survival of very low birth weight infants (Horbar et al., 2012; Stoll et al., 2015). In the past 30 years the limits of viability have extended from certain mortality at 26 weeks to survival at 23 weeks of gestation (Glass et al., 2015). Despite these advances there is great variation in the outcomes of infants across hospitals. (Horbar et al., 2012, 2017; Rogowski, Staiger, et al., 2004). Variation in complications and survival are observed across hospitals after adjusting for patient characteristics present at birth including: gestational age, birth weight, resuscitation at birth, race, sex, multiple birth, type of delivery and prenatal care (Alleman et al., 2013; Horbar et al., 2017; Rogowski, Staiger, et al., 2004; Stoll et al., 2010, 2015).

The focus of much neonatal research in the past 20 years has been on medical intervention, the use of mechanical ventilation, non-invasive continuous positive airway pressure, exogenous surfactant, administration of antenatal steroids, treatment of patent ductus arteriosus, delayed cord clamping and use of breastmilk and the effects and association with neonatal outcomes – mortality, chronic lung disease, retinopathy of prematurity, necrotizing entercolitis and intraventricular hemorrhage (Glass et al., 2015; Stoll et al., 2015). According to Stoll and colleagues (Stoll et al., 2015) there is considerable medical practice variation at the institution level that affects neonatal outcomes (Alleman et al., 2013; Stoll et al., 2015). Recognizing this institutional variation in VLBW mortality, more recent studies have evaluated system characteristics such as resident duty-hour restrictions, (Bell et al., 2010; Stoll et al., 2015) health insurance status, (Brandon et al., 2009) level of care available at birth hospital, (Cifuentes et al., 2002; Jensen & Lorch, 2015) NICU volume (Jensen & Lorch, 2015; Phibbs, Baker, Caughey, Danielsen, et al., 2007) and education and training of NICU providers (Karlowicz & McMurray, 2000) on the effect of neonatal outcomes- mainly using mortality in the NICU as a metric of quality.

Many of the system characteristics that have been found to contribute to poor outcomes of very low birth weight infants are difficult to modify. High volume and higher levels of NICU care have been found to be significantly associated with decreased VLBW mortality, yet the solution, additional large perinatal centers, is not simple and requires significant resources (Phibbs, Baker, Caughey, Danielsen, et al., 2007). Better nurse-to-patient ratios and staffing are also associated with better VLBW outcomes, and while it is possible to increase staffing, this too, in an already nurse intense unit in the hospital, is expensive. Finally, hospitals recognized for nursing excellence -Magnet® Hospitals- also are associated with better VLBW outcomes. Magnet® status is costly – requiring years of preparation and both direct and indirect monetary investment (Lake et al., 2012) - and thus may be unachievable for many hospitals. In contrast, elements of the nurse work environment are modifiable and potentially less cost prohibitive. Assuming that the effect of the nurse work environment differs by nurse education, certification and staffing, investment in the work environment and organizational elements of nursing could be optimized to improve outcomes of VLBW infants.

Evidence to support elements of nursing care as a system characteristic with the association of patient health outcomes is demonstrated in several research studies (Lake, de Cordova, et al., 2017; Lake, Hallowell, et al., 2016; Mchugh et al., 2011). Studies of nursing care and the impact of nurses on patient outcomes have focused on staffing, (Aiken, Clarke, Sloane, Lake, & Cheney, 2008; Brooks Carthon, Kutney-Lee, Jarrín, Sloane, & Aiken, 2012; Kane, Shamliyan, Mueller, Duval, & Wilt, 2007) nurse education, (Aiken, Cimiotti, et al., 2011; Aiken et al., 2003; Blegen, Goode, Park, Vaughn, & Spetz, 2013; Stone et al., 2007) nurse certification (Blegen, 2012; Kendall-Gallagher et al., 2011) and the nurse work environment (Aiken et al., 2008; Brooks-Carthon, Kutney-Lee, Sloane, Cimiotti, & Aiken, 2011; Friese et al., 2008). These studies support the positive association between better nurse staffing, nurse education, certification and nurse work environments and better patient outcomes including decreased odds of death and failure to rescue and lower odds of mortality in adult patient populations (Aiken et al., 2008; Brooks Carthon et al., 2012).

Nurse Work Environment and the elements of the Organization of Nursing

Nurse reported positive ratings of safety and quality are associated with better nurse work environments in the neonatal intensive care unit (Lake, Hallowell, et al., 2016). Additional evidence indicates that in hospitals with higher concentrations of black VLBW infants, poor nurse work environment and understaffing, there are poorer infant outcomes- higher rates of infection and lower levels of breast milk at discharge (Lake et al., 2015). Using mortality as the primary outcome, Lake and colleagues (Lake et al., 2012) evaluated infants cared for in hospitals recognized for nursing excellence i.e. Magnet® hospitals. These hospitals are known for exhibiting transformational leadership, structural empowerment, exemplary professional practice, new knowledge, innovations and improvements and empirical outcomes. They found that infants who received care in hospitals with Magnet® designation have better outcomes – lower risk-adjusted 7-day mortality, infection and severe intraventricular hemorrhage - in VLBW infants (Lake et al., 2012).

The characteristics that represent the organization of nursing in the neonatal intensive care unit consist of nurse education, nurse staffing and nurse specialty certification. Levels of nurse staffing, education, and certification have been associated with better patient outcomes (Aiken, Cimiotti, et al., 2011; Kendall-Gallagher et al., 2011; Mark, Harless, & Berman, 2007; Stone et al., 2007). Better nurse staffing and higher nurse education are associated with shorter length of stay in ICU and surgical patients (Kane et al., 2007; Kutney-Lee & Aiken, 2008). Research of VLBW outcomes shows an association of better staffing with decreased ventilation days, decreased days on oxygen (Profit et al., 2010) and lower infection rates (Cimiotti, Haas, Saiman, & Larson, 2006; Profit et al., 2010). Hospital acquired infection rates are associated with higher rates of mortality and longer lengths of stay (Leroyer et al., 1997; Mahieu, Buitenweg, Beutels, & De Dooy, 2001). Small studies evaluating family-centered care and nurse-intense developmental care also have shown decreased length of stay (Als et al., 1994; Ortenstrand et al., 2010).

It is well established that better nurse staffing is associated with lower mortality (Kane et al., 2007; Jack Needleman et al., 2011; Spetz, Donaldson, Aydin, & Brown, 2008) in adult populations. There is also evidence that supports this relationship between better nurse staffing with outcomes of VLBW infants - lower risk of infection, (Rogowski et al., 2013) higher rates of VLBW infants discharged home on human milk (Hallowell et al., 2016) and lower severe intraventricular hemorrhage (sIVH) in the neonatal intensive care unit (Cimiotti et al., 2006; Lake, Hallowell, et al., 2016; Rogowski et al., 2013, 2015). Evidence also evidence that suggests significant understaffing in the NICU exists (Rogowski et al., 2013).

Patient outcomes are optimized when the care received from nurses completely meets the patient's needs (according to the Synergy Model of Nursing) (Curley, 2007). This requires that in addition to adequate staffing, the nurse's knowledge, skills and experience is aligned with the patient's individual needs. Using this model as a framework, Rogowski and colleagues (Rogowski et al., 2015) evaluated nurse staffing, accounting for the infants needs using infant acuity levels. In this study nurse education, experience and specialty certification were used to account for nurse competence. They found that infant acuity was associated with staffing ratios, but there was no relationship of infant acuity to nursing competence as indicated by education, experience or nurse certification (Rogowski et al., 2015).

Extensive research provides evidence that hospitals with more highly educated nurses – nurses who hold a BSN or higher degree - have better outcomes for both adult medical and surgical patients, including lower mortality, lower failure to rescue (death after a complication) fewer readmissions and shorter stays (Aiken, Cimiotti, et al., 2011; Aiken, Sloane, et al., 2011; Aiken et al., 2003; Kutney-Lee & Aiken, 2008). The fragile physiology of VLBW infants and the technology required to meet their care needs make the provision of nursing care for very low birth weight infants clinically complex. Nurses are essential to monitor these infants for changes in clinical status and intervene to prevent complications. The nurse's ability to provide this care is dependent on education and clinical experience provided in BSN programs which emphasize patient assessment, critical thinking, collaboration with interdisciplinary teams and resource utilization.

The highly specific and clinically complex nursing care necessary for very low birthweight infants requires specialized knowledge, skills and experience in addition to nursing education. One method for demonstrating clinical expertise, knowledge and competence is nurse specialty certification. The American Academy of Pediatrics (AAP) and the American College of Obstetricians and Gynecologists (ACOG) recommend that all nurses caring for infants in the neonatal intensive care unit should have "specialty certification or advanced training." Despite recommendations from national nurse and medical organizations including the AAP, the National Association of Neonatal Nurses (NANN) and the Association of Women Health, Obstetrics and Neonatal Nursing (AWHONN) (Kilpatrick et al., 2017; Schofield et al., 2010), there are no standardized requirements for training, education or certification of nurses providing care in neonatal intensive care units. Nurse specialty certification has been associated with patient safety (Kendall-Gallagher & Blegen, 2009) and when combined with higher nurse education (BSN or greater) is associated with better patient outcomes in adult surgical patients (Kendall-Gallagher et al., 2011). Based on findings in these studies nurse experience (years of work as a nurse) is not considered a substitute for nurse certification (Kendall-Gallagher et al., 2011; Kendall-Gallagher & Blegen, 2009).

The effect of nurse education and nurse certification on outcomes in the neonatal intensive care unit has been understudied. There are no studies evaluating either nurse education or nurse certification on outcomes of very low birth weight infants. In a study evaluating acuity based patient ratios researchers found no relationship of nurse certification to infant acuity, but in nurse level analysis, the study results did show that nurses with specialty certification increased the average nurse's percentage of high-acuity infants (Rogowski et al., 2015). It is known that better nurse staffing is associated with better patient outcomes. However, it is unlikely that nurse staffing alone accounts for the effect of nurse resources on patient outcomes. It is also known that nurse experience, education and competence of the nursing staff are associated with better patient outcomes (Aiken, Cimiotti, et al., 2011; Aiken, Sloane, et al., 2011; Aiken et al., 2003; Kendall-Gallagher et al., 2011; Kutney-Lee & Aiken, 2008). The relationship of these organizational elements of nursing and nurse staffing is previously unstudied in this patient population.

Nurse Work Environment interaction with Organizational Elements of Nursing

The relationship of better work environments and nursing elements, including staffing and education, with lower mortality is well established in adult populations (Aiken, Cimiotti, et al., 2011; J. Needleman, Buerhaus, Stewart, Zelevinsky, & Mattke, 2006; Jack Needleman et al., 2011; Stone et al., 2007). Based on the research of Rogowski (Rogowski et al., 2013) significant improvement in staffing ratios and acuity based staffing would improve outcomes of very low birth weight infants. Improving the work environment may have an effect on infant outcomes as demonstrated by Aiken in which the research team demonstrated that for hospitals with the best work environments the effect of better staffing had a greater effect on patient outcomes than in poor work environments (Aiken, Cimiotti, et al., 2011). For hospitals with understaffing and poor work environments, improving staffing singularly may not improve patient outcomes (Aiken, Cimiotti, et al., 2011).

Summary

Despite the growing knowledge supporting relationships of elements of nursing organization in adults, less information is available validating these relationships in outcomes of VLBW infants. Very low birth weight infants, highly sensitive to and totally dependent on the care they receive are theorized to also experience poor outcomes when elements of the organization of nursing -nurse education, certification, and staffing- are low and the nurse work environment is poor.

The extensive research of the significance of the nurse work environment on adult outcomes, the evidence of nurse-to-patient ratios on outcomes in the neonatal intensive care unit and the limited knowledge of the effect of the nurse work environment and nursing qualifications on outcomes of very low birth weight infants, provided the opportunity to more fully explore the impact of the nurse work environment and the association of the organization of nursing in the NICU - nurse education, certification and nurse-to-patient ratios - on outcomes of very low birth weight infants.

In order to better understand the relationship of staffing and outcomes of very low birth weight infants, nurse education and certification was evaluated; additionally, the interaction of these elements with the known positive effect of the nurse work environment was also evaluated.

Outcomes of Very Low Birth Weight Infants

Identifying appropriate outcomes for comparison of quality of care in the neonatal population is challenging. There are very few outcomes that are identified and endorsed at the national level. The Agency Healthcare Research and Quality (AHRQ) first identified Pediatric Quality Indicators in 2006. There are twenty-four hospital-level and area-level pediatric quality indicators. Of these 24, three are specific to neonates: iatrogenic pneumothorax, neonatal mortality and bloodstream infections in neonates. In 2010 an expert panel met to identify and expand on these three pediatric quality indicators using state inpatient datasets from the health care cost and utilization project (HCUP). Based on expert consensus and review of the literature potential neonatal quality indicators have been recommended these include intraventricular hemorrhage, retinopathy of prematurity, necrotizing enterocolitis, meconium aspiration syndrome, nosocomial bacterial sepsis infection and neonatal mortality. The highest rated and agreed upon were intraventricular hemorrhage, necrotizing enterocolitis, nosocomial bacterial sepsis infection and neonatal mortality.

Mortality

The primary outcome of interest in this study is neonatal mortality. Mortality of very low birth weight infants contributes significantly to the US infant mortality rate (Butler & Behrman, 2007) and varies across US states and across institutions. Decreasing VLBW mortality is a national priority and is addressed in the Institute of Medicine's report on Preterm Birth (Butler & Behrman, 2007) and the Secretary's Advisory Committee on Infant Mortality for the Department of Health and Human Services

(*Report of the Secretary' s Advisory Committee on Infant Mortality*, 2013). (*Report of the Secretary' s Advisory Committee on Infant Mortality*, 2013) In the neonatal outcomes research literature, the most frequently measured outcome in infant health is mortality. Mortality rates are the preferable measure of quality because mortality is clearly delineated. Mortality is a measure that is established rigorously and has been used extensively to measure system characteristics (Jensen & Lorch, 2015; Lake et al., 2012). Infant characteristics strongly influence mortality rates. Known risk factors for mortality of very low birth weight infants include gestational age, birth weight, sex and race. Risk adjustment using these infant characteristics allows for comparison of hospitals with differing infant populations.

Morbidities

The primary outcome evaluated in neonatal outcomes research is mortality. Secondary outcomes include the neonatal morbidities of necrotizing enterocolitis (NEC), chronic lung disease (CLD), retinopathy of prematurity (ROP) and intraventricular hemorrhage (IVH). Individually, each of these morbidities contribute to increased risk of mortality and are associated with neurodevelopmental impairment (Bassler et al., 2009; Schmidt et al., 2003; Schmidt, Roberts, Davis, Doyle, Asztalos, Opie, Bairam, Solimano, et al., 2015). These secondary outcomes contribute to significantly longer lengths of stay and hospital cost. Longer hospital stays, hospital cost and each morbidity adds tremendous lifetime financial, social and emotional cost and burden for the patient and family (Butler & Behrman, 2007; Hintz, Kendrick, Vohr, Poole, & Higgins, 2008;

Schmidt et al., 2003; Schmidt, Roberts, Davis, Doyle, Asztalos, Opie, Bairam, Solimano, et al., 2015). All very low birth weight infants regardless of morbidity(ies) are eligible for early intervention services. These services are estimated to cost $611 million annually ($1200 per preterm infant) (Butler & Behrman, 2007). Special education services are necessary for infants with neurodevelopmental impairment as a result of IVH, ROP, NEC and CLD. The cost of these services is estimated at $1.1 billion or $2200 per preterm infant (Butler & Behrman, 2007).

Severe Intraventricular hemorrhage

Advances in care that have resulted in better survival for these infants have only modestly improved morbidities including intraventricular hemorrhage (Lea, Smith-Collins, & Luyt, 2017). The Vermont Oxford Network recently evaluated performance variation in US NICUs, finding that only 64.4% of NICUs achieve the lowest rates of severe intraventricular hemorrhage (Horbar et al., 2017). Studies evaluating the long-term neurodevelopmental impairment in these infants indicate that there is little improvement in severe disability among the surviving infants and the number of children with disability is increasing (Lea et al., 2017; Schmidt et al., 2003; Schmidt, Roberts, Davis, Doyle, Asztalos, Opie, Bairam, Solimano, et al., 2015). In a recent evaluation of five year outcomes for VLBW survivors, Schmidt and colleagues (Schmidt, Roberts, Davis, Doyle, Asztalos, Opie, Bairam, Solimano, et al., 2015) demonstrate that the smallest infants are at greatest risk for poor outcomes due to the risk of complications (IVH, NEC, CLD and ROP). If, however, the smallest infants survive without these complications their long-term outcomes are more similar to those of the more mature infants (Schmidt, Roberts, Davis, Doyle, Asztalos, Opie, Bairam, Solimano, et al., 2015).

Very low birth weight infants (<1500grams), and extremely low birth weight infants (<1000 grams), are at the greatest risk for intraventricular hemorrhage (Volpe, 1989a, 1989c, 1989b). The very immature microvasculature of the germinal matrix predisposes the premature brain to hemorrhage into and beyond the ventricles. (Ballabh, 2014) Development of intraventricular hemorrhage is associated with hypoxia after birth, respiratory distress, mechanical ventilation, fluctuation in cerebral perfusion in response to changes in systemic blood pressure, blood transfusion and fluid replacement, hypothermia leading to cold stress, head positioning and pain (Bassan, 2009; Bolisetty et al., 2014; Vohr & Ment, 1996; Wells & Ment, 1995).

Changes in hemodynamic regulation place an infant at risk for IVH. A recent study evaluating cerebral hemodynamic changes of very low birth weight infants indicates that nursing activities are associated with significant systemic mean blood pressure changes and changes in cerebral oxyhemoglobin saturations (Limperopoulos et al., 2008). Routine and necessary nursing interventions including diaper changes, endotracheal tube positioning, suctioning, general assessment and tactile stimulation were evaluated. Changes in systemic blood pressure and cerebral oxyhemoglobin saturations experienced by these VLBW infants were also associated with intraventricular hemorrhage (Limperopoulos et al., 2008).

Hypothermia is both a risk factor for IVH and a predictor of IVH and has been independently associated with infant mortality (Hazan, Maag, & Chessex, 1991; Miller, Lee, & Gould, 2011; Profit et al., 2013). Several research studies indicate that nursing care practices are key to maintain normothermia and significantly reduce hypothermia in this population (Cramer, Wiebe, Hartling, Crumley, & Vohra, 2005; Knobel, Wimmer, & Holbert, 2005; Leadford et al., 2013; Vohra, Roberts, Zhang, Janes, & Schmidt, 2004). Despite this knowledge, recent analysis from the Vermont Oxford Network (n=454,617) indicates that 25% of infants are hypothermic on admission to the NICU, placing them at increased risk for intraventricular hemorrhage and other complications (Edwards, Greenberg, & Soll, 2017).

Additional studies demonstrate that unit specific collaborative efforts using better practices to reduce hypothermia and intraventricular hemorrhage (Harer et al., 2017; McLendon et al., 2003) result in improvements in rates of sIVH. Research demonstrates that reductions in sIVH are possible. Collaborative efforts of nursing and medical teams applying best practice and standardizing care of very low birth weight infants (Fanaroff et al., 2007; Harer et al., 2017; Horbar et al., 2017; McLendon et al., 2003) can protect the premature brain.

In several studies, nursing resources and organizational elements within the neonatal intensive care units have been associated with variation of the incidence of severe intraventricular hemorrhage. High patient volume and high neonatologist to patient ratios are associated with lower rates of sIVH (Synnes et al., 2006). In a small regional study of organizational factors that influence outcomes in NICUs, an overall higher organizational score, and higher scores in leadership and coordination were associated with lower incidence of sIVH (Pollack & Koch, 2003). Better nurse staffing and hospitals known for quality nursing care – hospitals with Magnet® designation – have also been associated with lower rates of IVH (Lake et al., 2012; Profit et al., 2010).

Nursing education and certification – nursing factors that are associated with quality, would indicate the nurse's knowledge and dedication to best care practices to prevent hypothermia, monitor hemodynamic status and actively take measures to maintain a neutral thermal environment and hemodynamic stability, have not been previously studied in association to the outcome of sIVH.

Length of Stay

Very low birth weight infants, the most fragile and vulnerable of all pediatric patients, require care in neonatal intensive care units. Infants receiving care in the neonatal intensive care unit are completely dependent on nursing care and technology for all of their needs. They also have some of the longest hospital stays ranging from 51-79 days (Butler & Behrman, 2007). The combination of intensity of care and long hospital stay make their hospitalization among the most expensive of any hospital stay (Butler & Behrman, 2007; Gardner, Woollett, Daly, Richardson, & Aitken, 2010; Richardson et al., 2001). The combination of resource intensity and long lengths of stay make these stays financially costly (Richardson et al., 2001) and are estimated to be a total of $26.2 billion annually or $51,000 per infant (in 2005 dollars) (Butler & Behrman, 2007).

Long NICU length of stays not only contribute to large financial cost but neonatal intensive care stays are stressful for both the infant and the family (Carter, Mulder, Bartram, & Darlow, 2005; Franck, Cox, Allen, & Winter, 2005; Miles, Funk, & Kasper, 1991; Obeidat, Bond, Lynn, & Callister, 2009) and prolong separation of the infant with its mother and family. Additionally, longer hospital stays are associated with increased risk of complications, including infection. There is extensive literature demonstrating the devastating effects of hospital acquired infection (HAI) in this population and the additional length of stay required to treat HAIs (Payne, Carpenter, Badger, Horbar, & Rogowski, 2004; Rogowski et al., 2013).

Length of stay is an important outcome to study; it is an indirect representation of hospital cost (Ho, Zupancic, Pursley, & Dukhovny, 2017) and is considered a value-based measure of hospital quality (Brasel, Lim, Nirula, & Weigelt, 2007; Ho et al., 2017; Lee, Bennett, Schulman, & Gould, 2013). As a quality measure, appropriate length of stay reflects adequacy of resources, best care practices and efficient and effective utilization of resources (Brasel et al., 2007).

Nursing factors including favorable staffing, more BSN prepared nurses and nurse certification have been associated with better patient outcomes (Aiken, Cimiotti, et al., 2011; Mark et al., 2007; Jack Needleman et al., 2011; Stone et al., 2007). The intensity of care required for each VLBW infant varies throughout the hospital stay. The American Academy of Pediatrics and American College of Obstetrics and Gynecology outline acuity definitions in their Guidelines for Perinatal Care. Acuity ranges over five levels from nurse intense, complex critical care to lower acuity of continuing care (Kilpatrick et al., 2012, 2017). During complex critical care periods the NICU nurse is responsible for identification and response to acute changes in the patient's status – monitoring carefully and acting in a timely manner to prevent complications such as infection or sIVH that may directly increase length of stay. For infants requiring intermediate care or continuing care, the role of the bedside nurse also includes support and preparation of both the infant and the family for the care transition from hospital to home (Griffin & Abraham, 2006; Weiss et al., 2008). The nurse provides parent education including infant care of a medically fragile infant, home management that includes medications, devices and anticipation of and recognition of potential problems (Griffin & Abraham, 2006; Tubbs-Cooley, Cimiotti, Silber, Sloane, & Aiken, 2013; Weiss et al., 2008). Nurse staffing levels would likely reflect the nurses ability to complete parent education, (Tubbs-Cooley et al., 2013) while nurse education and certification levels would reflect the quality of education and preparation provided.

In general, length of stay is difficult to study. There are several factors that account for the challenges in studying length of stay as an outcome of low birth weight infants. Length of stay in VLBW infants varies by infant characteristics, financial considerations, (Lee et al., 2013; Morriss, 2013) parent confidence and competence in care (Griffin & Abraham, 2006; Weiss et al., 2008) and provider practice variation (Weiss et al., 2008). Length of stay is significantly different for infants that die or are transferred to another facility early in their stay, which is likely not reflective of the quality of care and is often challenging and complicated to model in regression analysis. Methodologically length of stay has a non-normal, skewed distribution that "suffers" from over dispersion, partially due to early deaths and transfers. With adequate risk adjustment, infant characteristics, mortality and transfers can be accounted for in statistical analyses; financial incentives and parental variation are harder to account for.

Interpretation of length of stay is also challenging. A longer stay may not necessarily be negative. A long length of stay may represent higher quality of care that requires more time or may also represent inefficient utilization of resources with equal quality of care. Long lengths of stay may also reflect poor quality and inefficient utilization of resources or poor quality that results in complications, such as infection that lengthens stays.

The association of the nurse work environment, nurse staffing, education, and certification with length of stay for very low birth weight infants has not been studied. This will be one of the first studies to examine these relationships.

Chapter 3: METHODS

Overview

This cross-sectional study linked hospital nurse survey data from California, Pennsylvania, New Jersey and Florida to administrative data for patients in the same hospitals in the same four states. This was a secondary data analysis of linked datasets. The data sources for this study included the RN Survey from the *Multi-State Nursing Care and Patient Quality Study*, administrative patient discharge data from California, New Jersey, Pennsylvania and Florida and the American Hospital Association Annual Survey of Hospitals.

Parent Study

The nurse survey data was obtained from the parent study, the RN survey from the *Multi-State Nursing Care and Patient Safety Study*. This study was conducted in 2005-2008, by Dr. Linda Aiken at the Center for Health Outcomes and Policy Research (CHOPR) at the University of Pennsylvania. Permission for use was granted by Dr. Linda Aiken, the Director of the Center for Health Outcomes and Policy Research at the School of Nursing and Principal Investigator. The data are owned and secured "in house" at the Center for Health Outcomes and Policy Research at the School of Nursing, University of Pennsylvania. The University of Pennsylvania Investigational Review Board provided approval prior to implementation of *Multi-State Nursing Care and Patient Safety Study*.

In the nurse survey study, a random sample of 272,783 RNs in California, Pennsylvania, New Jersey and Florida that appeared on state licensure lists received the RN Survey from the *Multi-State Nursing Care and Patient Safety Study* at their home addresses by mail. These four states represent approximately 20% of the US population and are large and geographically diverse states. Nurse survey data were collected in California, Pennsylvania and New Jersey between September 2005 and August 2006 and in Florida between November 2007 and April 2008. The nurses were asked whether they currently worked in a hospital, and those that did, identified their hospital by selecting it from a list provided or wrote in their hospital name and address. The study was designed to use nurses as key informants in order to obtain organizational information about the hospitals in each state (Aiken, Cimiotti, et al., 2011). To accomplish this, nurses were contacted directly through their state boards of nursing. This method of contacting the nurses directly prevents selection bias from the hospital. The response rate from a random sample of 272,783 registered nurses was 39%. A resurvey of 1300 of the original non-responders yielded a 91% response rate. Comparison of results from the responses from the original sample and with the non-responder sample indicated no significant difference in nurse reports of organizational features of nursing at the hospital level (Aiken, Cimiotti, et al., 2011; Smith, 2008). In order to evaluate the care received by very low birth weight infants, this study utilized the nurse responses from those who reported that they work in direct patient care in the neonatal intensive care unit. To create aggregate hospital-level measures of nursing resources (i.e. the nurse work environment, patient-to-nurse ratios, education and certification) responses from all nurses who reported they work in direct patient care were used.

Data sets

RN Survey from the Multi-State Nursing Care and Patient Safety Study, 2005-2008

The *Multi-State Nursing Care and Patient Safety Study* survey was designed to obtain key information from nurses in order to inform public policy, improve nurse working conditions and provide safer health care for patients. The nurses responded to a vast array of questions and statements on the 12-page questionnaire, including questions about their education, certification, workload, and questions about the work environment, quality of care and patient safety in their hospital (Aiken, Cimiotti, et al., 2011).

Administrative Patient Data

Patient discharge data were obtained from the Office of Statewide Healthcare Planning and Development for California, the Pennsylvania Health Care Cost Containment Council in Pennsylvania, the Department of Health and Senior Services in New Jersey and the Agency for Health Care Administration in Florida for the years 2005-2006. Data from these states were linked to the 2005 Annual Survey of the American Hospital Association.

Patient discharge data are derived from hospital discharge files and are comprised of data from the Uniform Hospital Discharge Data Set (UHDDS) and a summary of data from the uniform bill (claims data) and reflects the hospital inpatient component of care (Schwartz, Gagnon, Muri, Zhao, & Kellogg, 1999). The UHDDS is mandated for Medicare and Medicaid by the federal government (Schwartz et al., 1999). All patient information is de-identified by the state agencies. The hospital discharge files contain de-identified patient information including: a hospital identifier, a patient identifier, date of birth, sex, race, residence, admission date, discharge date, attending physician identifier, operating physician identifier, diagnosis, discharge disposition of the patient and expected source of payment. Specific information regarding diagnosis and procedures are captured in the data through the International Classification of Disease, 9th Edition and Clinical Modification (ICD-9-CM) coding scheme.

American Hospital Association Annual Survey of Hospitals, 2006-2007

The American Hospital Association is a national organization dedicated to advance the health of individuals and communities. Each year the AHA Annual Survey of Hospitals collects data from over 6400 United States hospitals. The survey contains data on hospital organizational structure, facility and service lines, inpatient and outpatient utilization, expenses, physician arrangements, staffing, and corporate and purchasing affiliations (American Hospital Association, 2015). Data on hospital characteristics, including teaching status, were used to adjust for hospital-level differences that may be correlated with infant outcomes.

Preliminary work

While many of the outcomes research studies in adults utilize administrative data to evaluate patient outcomes (Forrest, Shipman, Dougherty, & Miller, 2003; Forrest, Simpson, & Clancy, 1997) there is limited outcomes research that solely uses administrative data to evaluate infant, specifically VLBW infant outcomes. The majority of VLBW outcomes are reported from network data, including the Neonatal Research Network (NRN) or the Vermont Oxford Network (VON) (Alleman et al., 2013; Horbar et al., 2017; Rogowski et al., 2013; Stoll et al., 2015), or from administrative data linked to birth certificate data i.e. epidemiological studies. This method of linking hospital discharge records to birth certificate data is considered the "gold standard" when using administrative data to evaluate infant outcomes (Jensen & Lorch, 2015; Lorch, Baiocchi, Ahlberg, & Small, 2012).

Prior to this study's analysis, the administrative patient data from 2005-2006 in PA, CA, NJ and FL were evaluated in order to identify and describe VLBW infants and outcomes. The Agency for Health Research Quality (AHRQ) quality indicators that specify low birth weight infants according to their corresponding categories of birth weight by ICD-9-CM codes were used to identify infants in the dataset. This preliminary work identified 25,469 infants with birth weights 500-1499 grams in California, Pennsylvania, New Jersey and Florida. Mortality was identified by the variable "death" as the "discharge disposition," indicating that rather than surviving for a live discharge, the infant died prior to discharge. Not accounting for infant severity of illness, there was significant variation in mortality in this sample, ranging from 0-30% across hospitals with a mean mortality rate of 11.2%. The sample of VLBW infants was compared to the National Vital Statistics (NVS) records of all infant births and deaths for the years 2005 and 2006 in order to validate the sample for accuracy and completeness. The NVS files contain data from birth and death certificates. In the four states included in the sample, NVS reports 28,998 infants between 500-1499 grams, the sample for this study identified 25,469 infants, or 88% of the total United States reported VLBW population. Table 1 provides a comparison of data used for this study with published results from the National Vital Statistics database (Martin et al., 2007, 2009).

Table 1. Comparison of 4 State Infant Sample with National Vital Statistics (NVS) Data						
	California	**Florida**	**New Jersey**	**Pennsylvania**	total	% of population represented
2005	n (%)	n (%)	n (%)	n (%)		
4 state	5882 (47)	3216 (26)	1447 (12)	1981 (16)	12526	
NVS	6749 (47)	3603 (25)	1751 (12)	2286 (16)	14389	
				difference =	1863	0.87
2006						
4 state	5962 (46)	3456 (27)	1509 (12)	2016 (16)	12943	
NVS	6597 (45)	3752 (26)	1838 (13)	2422 (17)	14609	
				difference =	1867	0.89

% for each state is the proportion of the total for each state

Samples

Infants

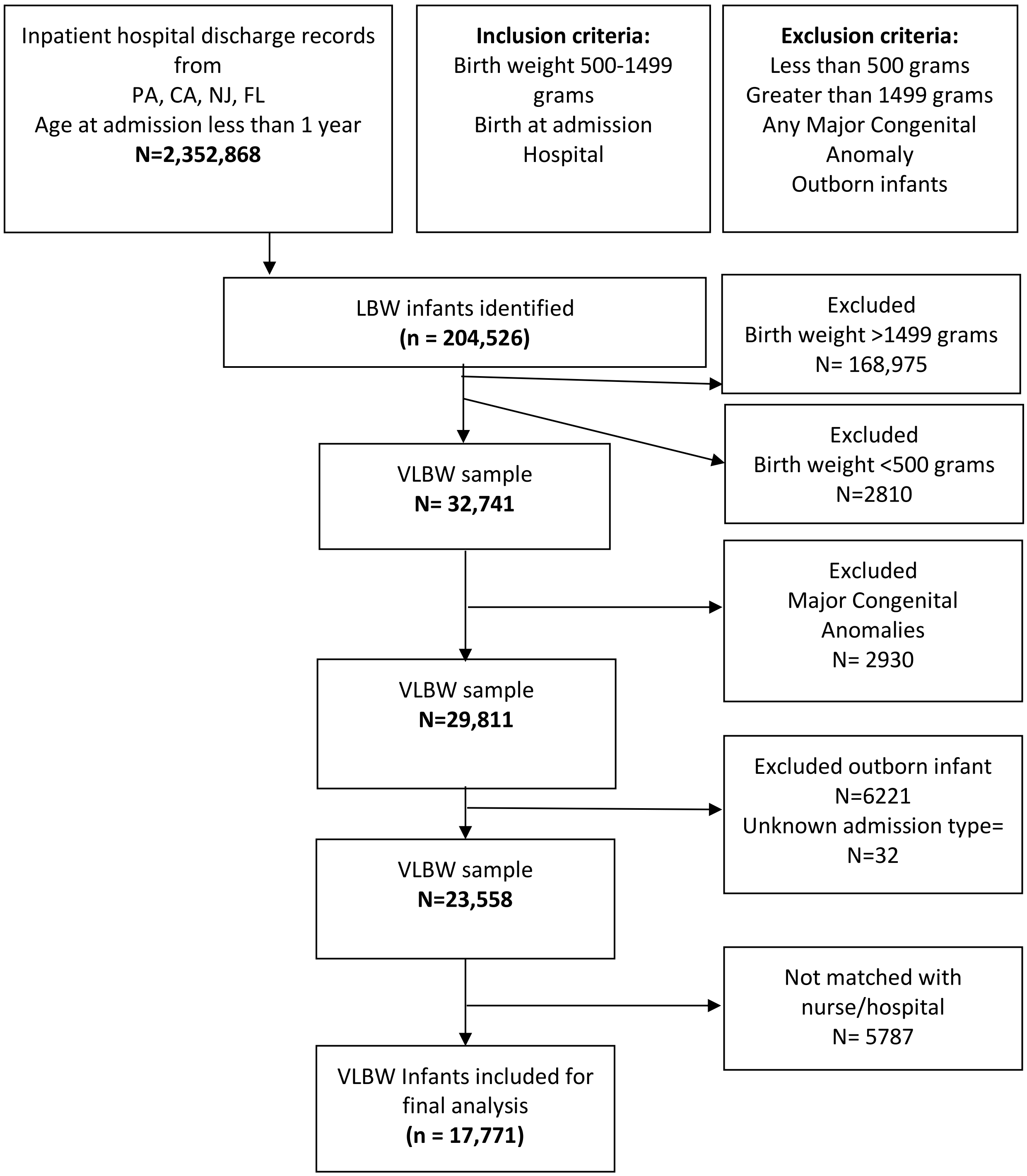
Administrative patient discharge data from hospital patient discharge files (PA, CA, NJ, FL) were used to create the infant sample. This data provided individual patient level characteristics and outcome variables. The patient discharge data files for all four states contained all hospital discharges for the years provided. The infant sample was constructed using the following inclusion criteria: age at admission less than one year, birth weight 500-1499 grams and primary hospital admission after birth.

All patients with a hospital admission by age at admission of less than one year for each respective year i.e. 2005, 2006 were included. The complete patient discharge files contained data on 2,352,868 infants. From this sample, all low birth weight (<2500 grams) and very low birth weight infants (<1500grams) were identified using the low birth weight category specifications from AHRQ Patient Quality Indicators. The AHRQ Patient Quality Indicators are presented in Appendix A. Infants were included if this was their primary hospital admission after birth. The primary hospital admission was determined by the earliest occurrence of admission for an infant as designated by each unique patient identification number (if there were multiple admission dates for a single infant as determined by multiple occurrences of an infant's unique patient identification number in the data, only the first occurrence was retained for the infant sample.)

Infants were excluded if their birth weight was less than 500 grams, if they were transferred after birth or if they had any congenital anomalies. Infants with birth weights less than 500 grams have mortality rates of 75-90% (Phibbs, Baker, Caughey, Danielsen, et al., 2007; Stoll et al., 2015). The leading cause of all infant mortality is congenital anomalies (Murphy et al., 2017) and VLBW infants with congenital anomalies have mortality rates of 75-100% (Mathews et al., 2015). These mortality rates do not vary across institutions and are not randomly distributed (Callaghan et al., 2006; Phibbs, Baker, Caughey, Danielsen, et al., 2007). These infants are a very small number of all very low birth weight infants however, their significantly high mortality rate disproportionately inflates mortality of the study sample when included. Infants transferred from their hospital of birth are excluded because of the challenge and potential bias of attributing mortality to the birth hospital versus the hospital in which they received NICU care and ultimately died (Chung et al., 2011; Phibbs, 2013).

This dataset also provided infant characteristics that were used for risk adjustment. Birth weight, sex, race/ethnicity and insurance status are available in this dataset and have been used in prior studies for risk adjustment (Jensen & Lorch, 2015; Lorch et al., 2012; Phibbs, Baker, Caughey, Danielsen, et al., 2007). Many additional infant and maternal characteristics have been studied as potential important characteristics to be included in risk adjustment, however degree of prematurity by birth weight is the strongest and most important predictor of mortality (Brandon et al., 2009).

Figure 2. Creating an Infant sample of VLBW Infants



Nurses

The original RN survey from the Multi-State Nursing Care and Patient Quality Study (Pennsylvania, New Jersey, Florida and California) included 39,038 hospital nurses. In order to create the nurse sample for this study, nurses that met the following criteria were included: all nurses who report that they work 1) in a neonatal intensive care unit 2) describe their current position as a staff nurse and 3) provide direct patient care part-time or full-time. All three criteria correspond to questions directly from the RN survey. Nurses were excluded if they reported caring for greater than seven patients on their last shift were because it is likely that these nurses had a unit leadership role rather than providing direct patient care.

Hospitals

The hospital sample was derived from the aggregated responses of the NICU nurse respondents from the RN survey from the Multi-State Nursing Care and Patient Quality Study. Aggregated responses from the individual nurses allowed for a unit of measurement at the hospital level. In order to justify aggregation there must be an adequate number of nurse respondents and there must be agreement of the nurses (Estabrooks, Midodzi, Cummings, Ricker, & Giovannetti, 2011). Intraclass correlation coefficients (ICC [1(*k*]) or Cronbach's alphas of both the composite PES-NWI and each of its subscales were calculated in order to examine internal consistency of the nurse respondents. A minimum number of nurse respondents per hospital was determined using established criteria for ICC [1(*k*)] coefficients of 0.60 as providing stable estimates of nurse agreement from each hospital (Cicchetti, 1994). In prior work using these nurse data, it was determined that a minimum of 3 nurse respondents per hospital was required to achieve coefficients of 0.60 for both the composite PES-NWI and each of its subscales (Lake, Hallowell, et al., 2016). Also in prior sensitivity analysis using both three and five nurse respondents yielded almost identical results (Lake, Hallowell, et al., 2016). The intraclass correlation coefficients (ICC[1,*k*]) were calculated for each subscale and the composite, they are provided in Appendix B. The ICCs (1,*k)* range from 0.58 for Nursing Foundations for Quality of Care to 0.68 for Nurse Manager Ability, Leadership and Support of Nurses. For this study, a minimum of three NICU nurse respondents per hospital was used to identify the hospital sample.

Major Study Variables

Nurse Work Environment

The nurse work environment is the primary independent variable in Aim 1 and is used as an interaction variable in Aim 2. The nurse work environment will be measured using the Practice Environment Scale of the Nursing Work Index (PES-NWI). The PES-NWI expands from previous work of the Nursing Work Index (NWI) (Kramer & Hafner, 1989) and the Revised Nursing Work Index (NWI-R) (Aiken & Patrician, 2000). The NWI was designed to capture all elements that influenced job satisfaction and perception of an environment conducive to quality of nursing care. Characteristics discussed in the Magnet® Hospital study and extensive review of the job satisfaction and work value instruments available in the literature from 1962-1986 were used to develop items included in the NWI (Kramer & Hafner, 1989). The NWI was designed to evaluate staff nurse job satisfaction and perception of an environment conducive to quality nursing care while accounting for the degree of importance the nurse placed on measured organizational characteristics. The primary aim of the Revised Nursing Work Index (NWI-R) was to create an instrument, using the NWI as the foundation, to study hospital organizational characteristics (Aiken & Patrician, 2000). The primary distinction of the NWI-R is it retained a single statement for each item asking the nurses to report on the presence of a characteristic within their organization and omitted the statement on the importance of the characteristic (Aiken & Patrician, 2000). The goal of the PES-NWI was to "develop a parsimonious, psychometrically sound scale with empirically derived subscales to measure the practice environment and its components (Lake, 2002, 2007).

The PES-NWI consists of 31 items and is scored based on a 4-point Likert scale. Examples of the items include a "director of nursing is highly visible and accessible to staff,' there is "a clear philosophy of nursing that pervades the patient care environment" and there are "enough registered nurses to provide quality patient care." Nurses are asked to indicate the extent to which they agree with of the organizational features, the four response categories are strongly disagree, disagree, agree and strongly agree. The PES-NWI has five subscales 1) nursing foundations for quality care, 2) nurse participation in hospital affairs 3) staffing and resource adequacy, 4) nurse-physician collegial relations and 5) nurse manager leadership (Lake, 2002). Higher scores correspond with nurse agreement of the presence of the organizational traits in their current job. The complete PES-NWI is shown in Appendix C. The PES-NWI is included in the RN survey from the Multi-State Nursing Care and Patient Quality Study 2006. The PES-NWI is endorsed by the National Quality Forum ("National Quality Forum. Practice Environment Scale-Nursing Work Index PES-NWI Composite and Five Subscales," 2015).

The 31 items are unequally distributed across the five subscales, and so, rather than calculating the sum score for each of the five subscales which would complicate comparison of the subscales, the mean score is calculated. A composite score is then calculated from the mean of the five subscale scores.

For aim 1 and 2 of this study, a composite PES-NWI score was calculated by aggregating the individual nurse subscale scores to the hospital level and then calculating the mean of the subscale means. Aggregate scores are only a reliable measure reflecting the organizational features of the hospital if there is consistent agreement of nurses within the hospital. Internal consistency coefficients were calculated to assess nurse agreement. The intraclass correlation coefficient (ICC) should be at least 0.60 to justify use of a aggregate score. Values greater than 0.60 are consistent with sufficient reliability of the hospital mean (Cicchetti, 1994; Glick, 1985). The ICC for 4 of the 5 subscales exceeded this criteria and the 5th is accepted as satisfactory at 0.58 because ratings 0.40-0.59 indicate "fair" agreement (Cicchetti, 1994). Prior work using aggregated nurse response data has demonstrated significant relationships between the nurse work environment and patient outcomes (Aiken, Cimiotti, et al., 2011; Brooks Carthon, Lasater, Sloane, & Kutney-lee, 2015; Kutney-Lee, McHugh, et al., 2009; Sochalski, 2004).

The composite work environment score is a continuous variable with potential values 1-4. Regression models tested both a continuous variable and a categorical variable for work environment. In models that used the continuous work environment variable, work environment was standardized to have a mean of 0 and standard deviation of 1. To create a categorical variable, the subscale scores were used to create three work environment categories: better, average and poor. Two methods have previously been used to create these categories. In the first, hospitals with scores above the median for 4 of the 5 subscales were classified as “better or good” work environments. Hospitals with scores above the median for 2 or 3 subscales were classified as having “average or mixed” work environments; and hospitals with scores above the median for 1 or no subscales were classified as “poor” work environments (McHugh & Ma, 2013). A second method divided the work environment composite score into quartiles. Hospitals in the lowest 25% are classified as “poor” work environments, the 2 quartiles that constitute the 26-75% percentile are classified as “average” and the hospitals greater than the 75% percentile are classified as “better or good” environments.

This study also used the individual subscales as predictors of outcomes. Evidence indicates that individual subscales are associated with outcomes (Baggs et al., 1999; Shortell et al., 1994; Shortell, Rousseau, Gillies, Devers, & Simons, 1991). The care of infants in the neonatal intensive care unit depends on the collaboration of knowledge and skills of both physicians and nurses. Research indicates that collaborative care efforts of these providers are linked with better outcomes for VLBW infants (McLendon et al., 2003). Previous research in the NICU has correlated the subscales of “staffing and resource adequacy” and “nurse manger ability, leadership and support” to breastfeeding support (Hallowell, Spatz, Hanlon, Rogowski, & Lake, 2014). Leadership and management of nurses would also be likely to influence outcomes of infants (Shortell et al., 1994). The variable for each of these subscales will be measured as a continuous variable at the NICU level representing the mean of the aggregated individual subscale of the PES-NWI.

Organization of Nursing in neonatal intensive care units.

Nurse staffing, education, and certification have been evaluated in previous studies and demonstrate a positive association with patient outcomes (Aiken, Cimiotti, et al., 2011; Kendall-Gallagher et al., 2011; Rogowski et al., 2015).

Nurse Education

The Multi-State Nursing Care and Patient Quality Study includes questions about nurses' educational attainment. Nurses are asked to identify the highest degree they hold in nursing. A variable indicating a bachelor's degree of higher level of education in nursing will be created. This variable will represent the proportion of nurses at the hospital level with a bachelor's degree or higher.

Nurse Certification

The Multi-State Nursing Care and Patient Quality Study includes a question about specialty nurse certification. Nurses are asked if they are "currently certified in specialty practice by the American Nurses Association or a national nursing specialty organization?" The nurses respond either with a "yes or a "no." This variable was used to represent the proportion of nurses at the hospital level with specialty certification.

Nurse Certification by Nurse Education

A variable that allows for the measurement of the effect of Nurse Certification by Education was created from the variables of education and specialty certification. Nurses who have a BSN or higher education and also have a specialty certification were coded "1" and nurses with less than a BSN degree in nursing but had a specialty certification were coded "0."

Nurse Staffing

In the RN survey nurses report the number of patients they cared for on their last shift. This number will be used to measure and account for staffing directly. Previous studies have considered staffing as an independent nursing characteristic and have evaluated the effect of staffing on outcomes (D. M. Kelly, Kutney-Lee, Lake, & Aiken, 2013; Rogowski et al., 2013, 2015). In this study staffing was directly accounted for from the nurse report of the number of patients they care for on their last shift and indirectly accounted for in the composite score of the PES-NWI which includes the subscale: staffing and resource adequacy. These two measures are highly correlated and conceptually similar. This relationship was tested statistically for correlation. Each measure was modeled separately to test the effect as a covariate in the association of the nurse work environment with infant outcomes (mortality, sIVH and LOS). Additionally, the subscale of staffing and resource adequacy was included in the composite work environment score in order to measure the nurse work environment because of the integrity of the score as demonstrated in previous studies (Hallowell et al., 2016). The direct measure of staffing was used as a covariate.

Previous work indicates that patient outcomes differ based on the interaction of the work environment and staffing, results indicate that the effect for staffing is contingent on the work environment (Aiken, Clarke, Sloane, Sochlaski, & Silber, 2002). Based on this knowledge, an interaction variable of the work environment and staffing was created by multiplying the mean NICU staffing level with the mean composite nurse work environment score. This interaction term was used to test the effect of staffing dependent on each increase in scores of the nurse work environment and subsequently the effect of the nurse work environment dependent on each increase in the patient-to-nurse ratio, on the infant outcomes.

Outcomes

VLBW mortality

The primary dependent variable for Aims 1 and 2 is infant mortality among VLBW infants. In studies on VLBW outcomes, mortality is defined as death after a live birth and is measured by 7 day, 28 day (known as neonatal mortality) and in hospital mortality (death prior to 1 year in all infants continuously hospitalized after a live birth) (Alleman et al., 2013; Bell et al., 2010; Horbar, 1995; Horbar et al., 2017; Lorch et al., 2012). VLBW mortality was obtained from the 4-state administrative patient data using the variable *disp*, labeled "discharge disposition standardized." This variable has eight possible responses: routine, short-term hospital, skilled nursing facility, intermediate care, another type of facility, home health care, AMA and died in the hospital. In order to capture death prior to a live discharge, the response of "died in the hospital" as "discharge disposition" was used to represent mortality of VLBW infants. This variable was captured and coded as a binary variable death: yes/no and coded 0=no death, 1=death. While it would be ideal to exclude mortality that occurs in the delivery room or at time of birth because it does not reflect care received in the NICU, it is difficult to delineate delivery room versus the NICU as place of death in the data.

Severe Intraventricular Hemorrhage

A secondary dependent variable for Aims 1 and 2 was severe intraventricular hemorrhage (sIVH) among VLBW infants. In studies on VLBW outcomes, severe intraventricular hemorrhage is defined as grade 3 or 4 intraventricular hemorrhage (Jensen & Lorch, 2015; Lake et al., 2012). Severity of intraventricular hemorrhage is measured on cranial ultrasonography and given a Grade I-IV as determined by a pediatric radiologist (McCrea & Ment, 2008; Volpe, 1989a). In administrative data ICD-9-CM codes 772.13 and 772.14 specify grade 3 and grade 4 intraventricular hemorrhage (Jensen & Lorch, 2015). A variable was created that includes all cases of both grade 3 and 4 intraventricular hemorrhage. This variable was captured and coded as a binary variable for severe intraventricular hemorrhage: no sIVH=0 and grade 3/grade 4 sIVH =1.

Hospital Length of Stay

An additional secondary dependent variable for Aims 1 and 2 was hospital length of stay for VLBW infants. Hospital length of stay represents the total number of days from birth to hospital discharge as reported in the 4-state administrative patient data using the variable “los.” This variable was continuous but has a lower bound that is constrained by zero and is thus considered a count variable.

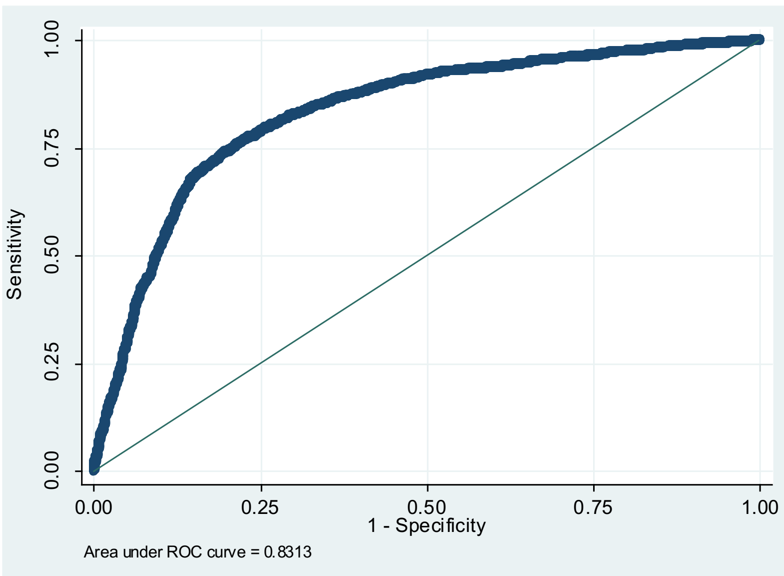
Covariates

Infant characteristics

Infant characteristics are directly associated with infant outcomes including mortality, severe intraventricular hemorrhage and length of stay. In order to adequately evaluate the association of the nurse work environment on VLBW infant mortality, risk adjustment with appropriate infant characteristics was included in model analysis. Use of administrative data limited the available infant characteristics used for risk adjustment. A simple parsimonious group of infant characteristics most associated with infant outcomes was used. Extensive work in prior studies have evaluated infant characteristics association with mortality (Harrison & Goodman, 2015; Horbar, Soll, & Edwards, 2010). In prior use of administrative data infant characteristics used for risk adjustment include gestational age, birth weight, small for gestational age, race, sex, single versus multiple birth and insurance status. Maternal characteristics have also been added for risk adjustment when available from birth certificate data (Jensen & Lorch, 2015; Lorch et al., 2012; Phibbs, Baker, Caughey, Danielsen, et al., 2007). Variables used in the AHRQ Quality Indicators risk adjustment for neonatal mortality include: sex, birth weight categories, congenital anomalies, and transfer status. Infant characteristics available in the 4-state dataset used for this study included birth weight category, race, sex, and insurance status, the sample excluded congenital anomalies and transferred infants.

Bivariate analysis of each of these characteristics with the primary study outcome was evaluated. Multivariate logistic analysis including all of these characteristics to predict mortality produced a c-statistic or area under the curve = 0.83. Figure 2 graphs the receiver operating characteristic (ROC) curve using birth weight category, race, sex and insurance status to predict VLBW infant mortality.

Figure 3. ROC curve



Hospital characteristics

Studies have evaluated hospital characteristics including NICU volume and NICU level of care as associated with neonatal mortality (Chung et al., 2010; Jensen & Lorch, 2015; Lorch et al., 2012; Profit et al., 2013; Rogowski, Horbar, et al., 2004). These characteristics were incorporated into the models for analysis. NICU volume was obtained from the administrative data. NICU volume was measured as the number of VLBW infants admitted to the hospital each year. NICU level of care was classified by definitions from the American Academy of Pediatrics (AAP) (Barfield et al., 2012; Stark, 2004). A policy statement from the AAP designates standardized levels of care. For this study the 2004 guidelines were used to be consistent with the data years of 2005-2007. Definitions for level of care according to the 2004 AAP guidelines are as follows: Level 1: community hospital with no NICU, well baby nursery, Level 2: intermediate NICU, provides care for mildly ill infants but does not provide sustained mechanical ventilation, Level 3A: Provides assisted mechanical ventilation, but limited to conventional mechanical ventilation and only for infants >1000 grams, Level 3B: no restrictions on assisted mechanical ventilation, may have more advanced options of mechanical ventilation and provides major surgery and Level 3C: in addition to all the capabilities and services of a 3B the NICU also provides cardiac surgery to repair congenital heart anomalies that require ECMO extracorporeal membrane oxygenation (ECMO) or cardio-pulmonary bypass. These levels were used in studies by Phibbs et al. and Jensen & Lorch (Jensen & Lorch, 2015; Phibbs, Baker, Caughey, Danielsen, et al., 2007) in their studies of level of care and very low birth weight mortality and therefore were used to define levels of care for this study. In order to identify level of care by hospital, ICD-9-CM procedure codes were used. ICD-9-CM codes were used to identify hospitals that provide longer duration of mechanical ventilation and those that provide cardiac surgery and ECMO. ICD-9-CM codes for mechanical ventilation were used to identify hospital's capacity and use of mechanical ventilation, codes are specified as <96hours, >96hrs and duration unknown. Those with codes < 96hrs were designated as Level 3A, those with codes >96 hours were designated as Level 3B and those with codes that indicated provision of cardiac surgery and ECMO were designated 3C. Hospitals with no use of mechanical ventilation will be classified as Level 2 (Phibbs, Baker, Caughey, Danielsen, et al., 2007; Phibbs, Baker, Caughey, Danielson, et al., 2007). Final designation was confirmed by expert opinion and agreement with the American Academy of Pediatrics Directory (Bhatt et al., 2011). Definitions and designation of levels of care are provided in Appendix D.

Additional information about the hospitals was obtained from the American Hospital Association Annual Survey (AHA). Due to the association with patient outcomes, teaching status was used to control for hospital characteristics in the statistical analysis (Brennan et al., 1991; Hartz et al., 1989; Rogowski, Horbar, et al., 2004). Teaching hospitals were classified into three categories based on the ratio of medical trainees to beds: major (1:4 or greater), minor (less than 1:4) and non-teaching (no trainees).

In similar adult studies of hospitals, the capacity for open heart surgery and/or organ transplantation is classified as high technology (Silber et al., 2016) and controlled for in statistical analysis; this hospital characteristic was tested for correlation with the highest NICU level of care as this designation accounts for pediatric open heart surgery. It was found to be highly correlated and therefore was not included in the model.

Missing Data

All study variables, including the primary independent and dependent variables and variables used as covariates were evaluated for missing data. Missingness on each variable is described in Appendix E. Prior to choice of handling missing data, it was first necessary to describe missingness for each variable used and then determine the mechanism of the missingness. Missing data mechanisms include missing completely at random, missing at random and not missing at random. Preliminary work indicated no missingness on the dependent variable of mortality. All VLBW infants in the dataset have a discharge disposition as either "died in the hospital," indicating mortality or were placed in one of the other seven categories indicating their disposition at discharge. Missing data on covariate variables used for risk adjustment such as infant characteristics including infant race are included in Appendix E. Significant missingness of covariate variables threatens the ability to adequately risk adjust based on those infant characteristics. The risk adjustment variables used in this study included birth weight category, sex, race and insurance status. There was minimal missing data for the variables of birth weight category, sex and insurance status. It was undetermined if the missing for race was nonignorable, and despite the minimal missingness, 3.7%, in order to account for this missingness, a dummy variable was created and added to the risk adjustment model (Allison, 2001). Dummy variables are used in order to minimize bias, maximize the use of available information and get good estimates of uncertainty (accurate standard errors, p-values and confidence intervals) (Allison, 2001). Models using the dummy variable for missing race were compared to those without the dummy variable. There was no significant difference between models. In order to maximize all available patient information, the final model used for regression analysis included the dummy variable for race (Allison, 2001).

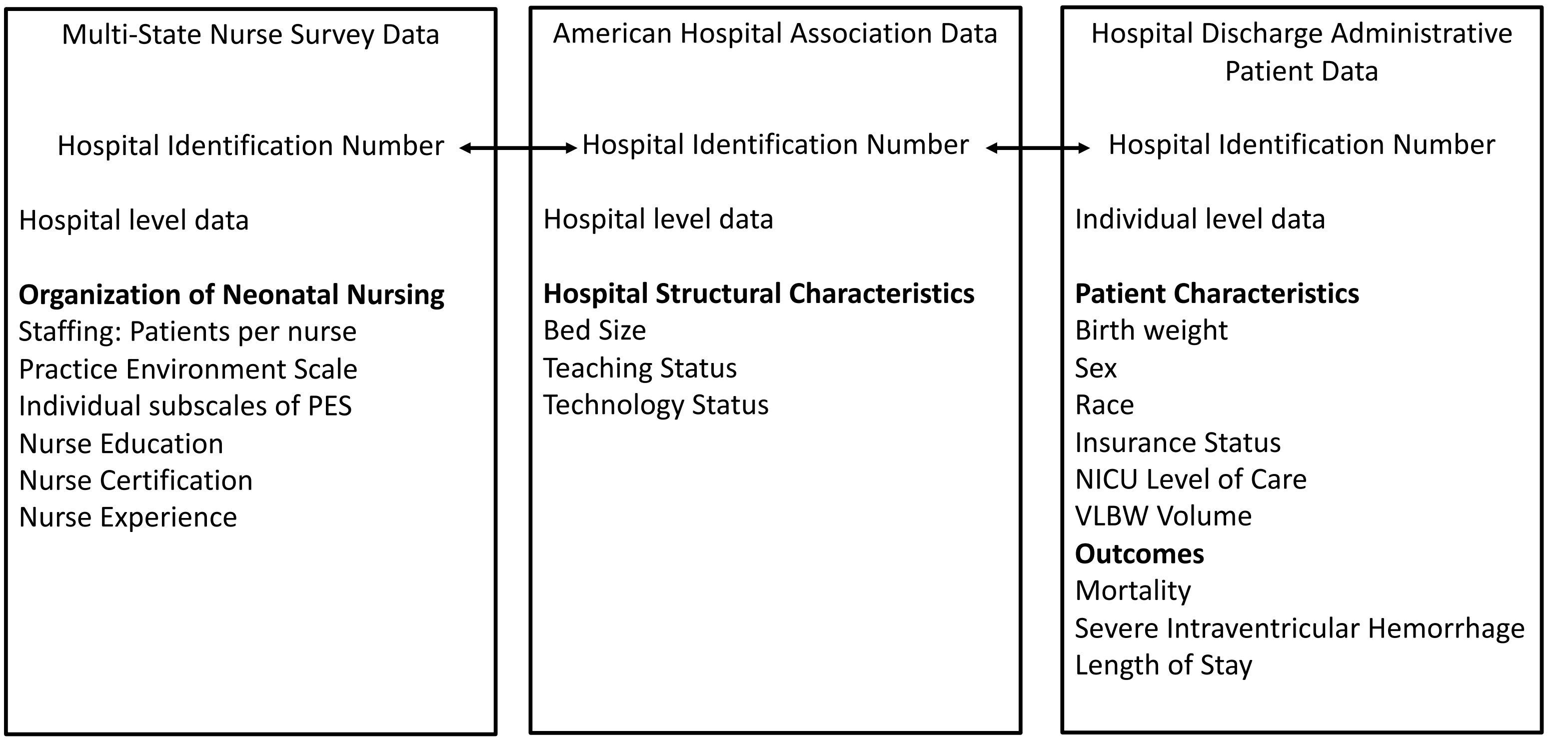
Missing data for nursing characteristics was minimal; nurse certification 1.8%; nurse staffing 1.2% and nurse work environment 2.5%. Responses from the nurses were aggregated to the hospital level. Missing data from the nurse variables did not result in missing hospital level variables.

Construction of the dataset

In order to undertake the analysis for this study, a single dataset that allowed for evaluation of the association of the nurse work environment and the organization of nursing with infant outcomes was constructed. The individual nurse survey responses related to the Practice Environment Scale of the Nursing Work Index (PES-NWI), nurse education, nurse certification and staffing were aggregated to the hospital by taking the mean of the nurse responses within each hospital. The individual infant level data were merged with the aggregated nurse data using a common hospital identifier. The final dataset included infants nested within hospitals, each hospital was represented by aggregated nurse responses. Figure 2 diagrams how the three data sources were linked. This diagram also provides the original source for each of the variables used in the study.

The final dataset used for analysis contained both hospital-level and individual-level measures from the nurse surveys and the AHA dataset and individual measures related to VLBW infants from the same hospitals. The nurse reports were from nurses working in these hospitals during 2005-2006 and infant data were for infants who were born and had their hospital stays in the same hospitals during this same period of time. The nurses were considered expert informants of the care that was delivered in their hospitals and the care that the infants received, rather than being able to specifically report on the care of any one of the infants in the data (Aiken & Patrician, 2000).

Figure 4. Data Linkage



Analysis of Specific Aims

Aim 1: To examine the effect of the nurse work environment on outcomes of very low birth weight infants (in hospital mortality, hospital length of stay, and severe intraventricular hemorrhage).

First, descriptive statistics (percentages, means, standard deviations, variances, etc.) and graphs and plots (bar graphs and histograms) were used to analyze the distribution of both the dependent variables of interest - mortality, severe intraventricular hemorrhage, length of stay,- and the independent variables, including variables for risk adjustment: infant characteristics, nurse work environment, nurse education, nurse certification, nurse staffing and hospital characteristics including NICU volume and level of care.

The unit of analysis for Aim 1 was the infant (individual patient level data). The dependent variable(s) were mortality, severe intraventricular hemorrhage and length of stay. The infant outcome variables of mortality and severe intraventricular hemorrhage were binary: death/not death, and sIVH/no sIVH; the infant outcome variable of length of stay was continuous with a non-normal distribution prone to over-dispersion and a lower bound of zero.

The primary predictor (independent variable) for Aim 1 was the nurse work environment. The nurse work environment was a continuous standardized variable with the mean set to zero and a one-unit change that is equivalent to one standard deviation. Logistic regression allowed for clustering at the hospital level was used to estimate the effect of the relationship between the nurse work environment and infant outcomes. Due to concerns that infants treated by the same physicians and nurses working in the same hospital tend to share similar characteristics with their respective peer groups which, if ignored could lead to an underestimation of standard errors (SE); a robust standard errors were used for better estimation (Vittinghoff, Glidden, Shiboski, & McCulloch, 2011) and clustering of patients was accounted for using the Huber-White sandwich estimator (Huber, 1967; White, 1980). Logistic regression was used for models involving binary outcomes (mortality and sIVH), and negative binomial regression models were used for the continuous and over-dispersed outcome (length of stay). Goodness of the fit statistics were employed to estimate the correspondence between the observed data and predicted data and how well the models predict this outcome. The Hosmer-Lemeshow test was used where a value greater than 0.5 predicts the outcome better than chance (Hosmer Jr, Lemeshow, & Sturdivant, 2013; Lemeshow & Hosmer, 1982).

The first model used for analysis is an unadjusted or bivariate logistic regression model in which no covariates were included. Equation 1 depicts the unadjusted bivariate model.

$$(1)\ \log\left({}^{P_{ij}}/_{(1-P_{ij})}\right) = \alpha + N'_j \beta N + \varepsilon_{ij}$$

In this simple model, P is the probability of the binary outcome (sIVH or mortality) for the i^{th} patient in the j^{th} hospital, α is the intercept term in the regression, N_j is a vector representing the nurse work environment for the j^{th} hospital, and βN is a vector of coefficients representing the effect of the nurse work environment and ε_{ij} is the error term. This bivariate model provided an unadjusted estimate of the effect of the nurse work environment on the likelihood (or odds) of the outcome, before accounting for infant and hospital characteristics that may also explain the likelihood of the outcome.

The subsequent models used for analysis were multivariate logistic regression models. The second model controlled for infant characteristics, the third model controlled for both infant and nurse organizational characteristics. The final model controlled for infant, nursing and other hospital characteristics. Equation 2 depicts the fully adjusted multivariate logistic model used to evaluate Aim 1: the association between the nurse work environment and infant outcomes (mortality and sIVH).

$$\text{(2)}\ \mathbf{log}\ (^{\mathbf{P}ij}/_{(\mathbf{1-P}ij)}) = \boldsymbol{\alpha} + \mathbf{N}'j\boldsymbol{\beta}N + \mathbf{H}'j\boldsymbol{\beta}H + \mathbf{X}'ij\boldsymbol{\beta}X + \mathbf{O}'ij\boldsymbol{\beta}O + \boldsymbol{\varepsilon}ij$$

In this model, P is the probability of a binary outcome for the i^{th} patient in the j^{th} hospital, α is the intercept term in the regression, N*j* is a vector representing the nurse work environment for the j^{th} hospital, β*N* is a vector of coefficients representing the effect of the nurse work environment, H*j* is a vector of (hospital) attributes for the j^{th} hospital, β*H* is a vector representing the effect of the hospital attributes, β*O* is a vector representing the effect of nursing characteristics, X*ij* is a vector of characteristics for the i^{th} VLBW infant in the j^{th} hospital, and β*X* is a vector of coefficients representing the effect of VLBW infant characteristics.

Odds ratios were calculated to express how the likelihood of mortality (or sIVH) would change if an infant had been cared for at a hospital with a nurse work environment that is more favorable. Odds ratios are derived by exponentiating the regression coefficients for the nurse work environment ($e^{\beta N}$) and indicate the effect of a one standard deviation increase in nurse work environment on the likelihood, or odds, on the outcome.

Hospital length of stay was analyzed utilizing a negative binomial regression model due to the violation of normality of the distribution. Length of stay is best described as a count variable because it is constrained to a lower bound of zero (i.e. there are no stays less than zero). Negative binomial models account for over-dispersion with a left skewed distribution and provide efficient estimates of the standard errors (Allison, 1999). Sensitivity analysis evaluated differences in length of stay for those who survived and those who were transferred. Additionally, zero-inflated Poisson and zero-inflated negative binomial models were estimated and evaluated to ensure model fit.

Aim 2: To examine the direct effects of nurse staffing, education, and certification on infant outcomes and to examine the interaction effects of the nurse work environment with staffing, education and certification on outcomes of very low birth weight infants (in hospital mortality, hospital length of stay, and severe intraventricular hemorrhage).

First, descriptive statistics (percentages, means, standard deviations, variances, etc.) were used to analyze the distribution of the independent variables of interest: nurse education, nurse certification, and nurse staffing.

The unit of analysis for Aim 2, as in aim1, was the infant (individual patient level data). The dependent variable(s) were mortality, severe intraventricular hemorrhage and length of stay. The infant outcome variables of mortality and sIVH were treated as binary outcomes: death/not death and sIVH/no sIVH. Nurse education, certification and staffing were each evaluated as the predictor variables (independent variable) for Aim 2.

Aim 2 also further explored the interaction of each of the nurse variables with the nurse work environment.

Here too, the logistic regression models allowed for clustering of infants within hospitals, in this case to estimate the relationship between the various organizational elements of nursing and infant mortality and sIVH. Equation 3 depicts the model for the association between organizational elements of nursing and infant outcomes.

$$(3)\ \mathbf{log}\ (^{P_{ij}}/_{(1\,-\,P_{ij})}) = \boldsymbol{\alpha} + \mathbf{N}'j\boldsymbol{\beta}N + \mathbf{H}'j\boldsymbol{\beta}H + \mathbf{X}'ij\boldsymbol{\beta}X + \boldsymbol{\varepsilon}ij$$

This model is very similar with the model for Aim 1 with one exception, in this model **N*j*** is a vector representing the nurse work environment for the j^{th} hospital, and **β*N*** is a vector of coefficients representing the effect of one of the following: nurse education, nurse certification or NICU staffing. Using nurse education and the nurse work environment as an example, the interaction term of these variables allows the slope for each category of the nurse work environment to vary by the proportion of BSN educated nurses. The product of nurse education and the nurse work environment represents the multiplicative effect of nurse education at each level of the nurse work environment.

Interpretation: Results were interpreted as the multiplicative effect of education for each category of the nurse work environment on the odds of VLBW mortality or sIVH.

As in Aim 1, negative binomial regression was used to account for the over-dispersion in hospital length of stay.

The initial models were unadjusted. Additional models allowed for risk adjustment with infant characteristics and hospital level characteristics including NICU volume and level of care. Sensitivity analysis evaluated controlling for nurse characteristics in models that evaluated nursing factors as the independent variable.

Data Integrity

Data were stored on a password secured computer network. A server in the School of Nursing at the University of Pennsylvania was designated for storage of all study data, which includes nurse survey data, de-identified patient-level data, and data on hospital characteristics. The data analyzed for this study were retained on a secure computer server maintained by the Office of Technology and Information Services (OTIS) at the University of Pennsylvania, School of Nursing. OTIS was responsible for daily backing up all computer-generated information, which is stored at an off-site secure location. OTIS uses state-of-the-art security protocols, firewalls, and antiviral software patches which were all routinely updated on all computers within the School of Nursing. Study datasets were accessible only to specifically-authorized members of the research team using passwords. No breach in data security occurred.

Human Subjects and Ethical Considerations

This study used secondary data sources. No primary collection of data occurred for this study. All data from this survey was de-identified at the individual level. The Center for Health Outcomes and Policy Research (CHOPR) maintains an IRB protocol for the RN nurse survey data collection. Data for the neonates were extracted from state administrative data files from 2005-2006 and contained de-identified patient data. Names, social security numbers, birth dates, address and zip codes had been removed from the analytic dataset. Information from the data was not able to be linked to individual infants or nurses. No identifiable information was available to the research team.

This study was evaluated based on Emanual and colleagues' systematic framework of seven requirements designed to guide ethical development and evaluation of studies (Emanuel, Wendler, & Grady, 2000). It is believed that this study provided valuable information in understanding nurse factors that contribute to neonatal outcomes. The tools used for measurement of work environment have been validated and used extensively in previous studies. The requirement for fair subject selection was met. Nurses were randomly selected and willingly participated in the survey. The neonatal subjects were identified from all infants within the 4-state database rather than a subset of neonates from a specific designated group. There was no risk to subjects and while there was no direct benefit to subjects from this study, it is believed that the results aid in decisions made for future benefit for nurses and neonates in neonatal intensive care units.

The research team recognizes that nurses are vitally significant to the necessary care of neonates, and this study was designed to seek better outcomes for neonatal patients. All information was aggregated and individual subjects were not identifiable. The research team handled data about these subject groups with utmost respect.

The research team recognized that information reported by nurses about their organization of nursing and the nurse work environment is sensitive and has potential risk professionally and legally if data were identifiable at the individual level. Additionally, neonatal patients are considered a vulnerable population and any study that involves neonatal patients requires special consideration under Federal Regulations Part 46.205 "Research involving neonates." The special considerations include appropriate assessment of potential risk to both viable and nonviable neonates, fully informed consent, and specify that the research team has no part in determining viability of the neonate. This study did not include any of these areas requiring special consideration. Because the data for both the nurses and infants was de-identified and used for secondary data analysis, there was no risk to the infants or nurses.

Chapter 4: RESULTS

Introduction

The purpose of this study was to examine the effect of the organization of nursing within neonatal intensive care units – nurse staffing, nurse education, nurse certification and the nurse work environment- on VLBW infant outcomes – mortality, severe intraventricular hemorrhage and length of stay – of very low birth weight infants. The characteristics of the samples of very low birth weight infants, the nurses in neonatal intensive care units, and the hospitals and neonatal care units are described. Each of these sets of characteristics are then described across the differing nurse work environments. Finally, the results from the regression analyses as specified in both Aim 1 and Aim 2 are discussed.

Characteristics of the patient population

The final sample included 17,771 VLBW infants. Characteristics of the infant sample are shown in Table 2. The number of VLBW increases with each increase in birth weight category. The largest number of infants have birth weights 1250-1499 grams. The study sample is majority white. There are equal numbers of male and female infants. Almost half (48%) of the infants have private insurance. The sample contained large numbers of infants from all four states; the largest percentages were from California (39%), followed by Florida (29%).

Table 2. Infant Characteristics n=17,771	
	n (%)
Birth Weight	
500-749 grams	3613 (20)
750-999 grams	3983 (22)
1000-1249 grams	4599 (26)
1250-1499 grams	5576 (31)
Race	
White	6948 (39)
Black	4404 (25)
Hispanic	4163 (23)
Other	1599 (9)
Sex	
Male	8919 (50)
Female	8848 (50)
Insurance	
Private	8554 (48)
Medicaid	7775 (44)
Other	1439 (8)
State	
California	6870 (39)
New Jersey	2546 (14)
Pennsylvania	3259 (18)
Florida	5096 (29)
Not all Percentages add to 100% due to missing data as follows: Race 3.7% Sex <1% Insurance <1%	

Table 3. Infant Characteristics by Very Low Birth Weight Category						
Birth Weight Category	**500-1499 grams**	**500-749 grams**	**750-999 grams**	**1000-1249 grams**	**1250-1499grams**	**p-value**
Race						
White	6948 (39)	1209 (35)	1514 (39)	1876 (42)	2350 (44)	0.000
Black	4404 (25)	1058 (31)	1044 (27)	1081 (24)	1221 (23)	
Hispanic	4163 (23)	892 (26)	932 (24)	1077 (24)	1262 (24)	
Other	1599 (9)	302 (9)	354 (9)	407 (9)	536 (10)	
Sex						
Male	8919 (50)	1777 (49)	2065 (52)	2286 (50)	2791 (50)	0.097
Female	8848 (50)	1836 (51)	1917 (48)	2311 (50)	2784 (50)	
Insurance						
Private	8554 (48)	1658 (46)	1902 (48)	2215 (48)	2779 (50)	0.005
Medicaid	7775 (44)	1668 (46)	1753 (44)	2025 (44)	2329 (42)	
Other	1439 (8)	286 (8)	326 (8)	359 (8)	468 (8)	

For categorical variables (race, sex, insurance), the p-value of the Pearson chi-squared statistic comparing these infant characteristics by birth weight category is shown.

Table 3 provides information about the infant sample across birth weight categories. Overall, the largest percentage of infants are white (39%), followed by black (25%) and Hispanic (23%) infants. White infants are found disproportionately in the largest birth weight category (1250-1499 grams), which represent the largest and theoretically the most mature infants. The proportion of black infants is slightly larger in the birth weight categories 500-749 grams and 750-999 grams which represent the smallest infants and theoretically the least mature infants. The distribution of the infant characteristics of sex and insurance are consistent with the overall infant sample, fifty-percent of the infants are female and just under fifty-percent of all VLBW infants have private insurance (46-50%). The greatest difference in insurance status is present in the 1250-1499 grams infant group, here fifty-percent of infants have private insurance and forty-two percent have Medicaid.

Table 4. Infant Characteristics, Overall and by Nurse Work Environment					
		Work Environments Categories			
	All Work Environments n=17,771	**Poor Work Environments n=4461**	**Average Work Environments n=8919**	**Best Work Environments n=4391**	**p-value**
Birth Weight					
500-749 grams	3613 (20)	945 (26)	1797 (50)	871 (24)	0.272
750-999grams	3983 (22)	1039 (26)	1968 (49)	976 (25)	
1000-1249grams	4599 (26)	1115 (24)	2329 (51)	1155 (25)	
1250-1499 grams	5576 (31)	1362 (24)	2825 (51)	1389 (25)	
Race					
White	6948 (41)	1707 (25)	3585 (52)	1656 (24)	0.000
Black	4404 (26)	1474 (34)	2053 (47)	877 (20)	
Hispanic	4163 (24)	904 (22)	2037 (49)	1222 (29)	
Other	1599 (9)	210 (13)	880 (55)	509 (32)	
Sex					
Male	8919 (50)	2188 (25)	4485 (50)	2246 (25)	0.136
Female	8848 (50)	2272 (26)	4432 (50)	2144 (24)	
Insurance					
Private	8554 (48)	1609 (19)	4472 (52)	2473 (29)	0.000
Medicaid	7775 (44)	2430 (31)	3858 (50)	1487 (19)	
Other	1439 (8)	421 (29)	588 (41)	430 (30)	

The p-values in the last column indicate the significance of Pearson chi-square statistics testing whether the nurse work environment is independent of birth weight, race, sex and insurance.

Infant characteristics across work environment categories are presented in Table 4. There is an equal distribution of birth weight categories across hospitals with differing nurse work environments. White infants are equally distributed across work environments. There is an unequal distribution of black infants across work environments. Thirty-four percent of black infants receive care in the poorest work environments and only 20% receive care in the best work environments. There is an equal distribution of male and female infants across work environments, but an unequal distribution of insurance type is present. In the best work environments 29% of infants have private insurance, and in poor work environments only 19% have private insurance.

Table 5. Characteristics of Nurses n=1285	
Age in years, mean (SD)	45 (10)
Race, white, n (%)	784 (77)
Black, n (%)	26 (3)
Hispanic, n (%)	65 (5)
Filipino, n (%)	112 (9)
Asian, n (%)	52 (4)
Sex, female, n (%)	1228 (98)
Years of experience, mean (SD)	11 (9)
BSN is Highest RN degree, n (%)	630 (50)
Specialty Certification, n (%)	491 (40)

Table 5 describes the characteristics of neonatal intensive care nurses in the sample. There were 1285 nurses that responded that they work in a hospital neonatal intensive care unit. The average age of the nurses working in NICUs is 45 years. The vast majority of NICU nurses are white (77%), while Black (3%) and Hispanic (5%) are poorly represented. Of the minority groups Filipino nurses are the largest, 9%. The neonatal intensive care nurses are predominantly female (98%). The average years of experience is 11 years. Fifty-percent of neonatal intensive care nurses have a BSN or higher degree in nursing. Forty-percent report having specialty certification.

Table 6. Characteristics of Nurses, Overall and by Nurse Work Environment

	Distribution of nurse characteristics across different work environments				
	All Nurses	Poor Work Environments n=307	Average Work Environments n=609	Best Work Environments n=304	p-value
Age in years, mean (SD)	45 (10)	46 (10)	44 (10)	46 (11)	0.0029
Race, white, n (%)	784 (63)	173 (56)	385 (63)	204 (67)	0.851
Sex, female, n (%)	1228 (98)	300 (99)	595 (98)	301 (99)	0.085
Years of experience, mean (SD)	11 (9)	12 (9)	11 (9)	12 (9)	0.1542
BSN is Highest RN degree, n (%)	630 (50)	142 (46)	314 (52)	161 (53)	0.195
Specialty Certification, n (%)	491 (40)	130 (43)	224 (38)	123 (41)	0.247

For categorical variables (race, sex, BSN, specialty certification), the p-value of the Pearson chi-squared statistic comparing these infant characteristics by nurse work environment category is shown. For the continuous variables (age and years of experience) F-tests were used to test the differences across nurse work environment categories.

Percentages may not equal 100% due to missing data

Table 6 describes the distribution of nurse characteristics across the nurse work environment categories. The only nurse characteristic that differed significantly across hospitals with difference work environments was age, and even that difference is slight. There are fewer white nurses in poor work environments 56% compared with 67% in the best work environments. In the best work environments there are more nurses with higher education, 53% compared to 46% in the poor work environments.

Table 7. Characteristics of Hospitals by Nurse Work Environment					
	Distribution of Hospital Characteristics across work environments				
	All Hospitals	**Poor Work Environments**	**Average Work Environments**	**Best Work Environments**	p-value
Hospital Characteristics	N=170	n=36	n=90	n=44	
Volume, n (%)					
Less than 50 VLBW admissions	51 (30)	8 (22)	27 (30)	16 (36)	0.330
50-99 VLBW admissions	46 (27)	8 (22)	25 (28)	13 (30)	
Greater than 100 VLBW admissions	73 (43)	20 (56)	38 (42)	15 (34)	
NICU Level of Care, n (%)					
Level 2	7 (4)	2 (6)	4 (4)	1 (2)	0.940
Level 3	138 (81)	28 (78)	73 (81)	37 (84)	
Level 4	25 (15)	6 (17)	13 (14)	6 (14)	
Size, Number of Hospital Beds, n (%)					
Small (<100)	5 (3)	2 (6)	2 (2)	1 (2)	0.880
Medium (100-250)	37 (22)	8 (22)	19 (21)	10 (23)	
Large (>250)	127 (75)	26 (72)	69 (77)	32 (74)	
Teaching, n (%)					
Non-teaching - No residents	59 (35)	13 (36)	29 (32)	17 (39)	0.790
Minor teaching - Less than 1:4 residents per bed	76 (45)	14 (39)	44 (49)	18 (42)	
Major teaching - Greater than 1:4 residents per bed	34 (20)	9 (25)	17 (19)	8 (19)	
High technology, n (%)					
Any transplant	114 (67)	22 (61)	64 (71)	28 (65)	0.520

For categorical variables (Volume, Level of Care, Size, Teaching, Technology), the p-value of the Pearson chi-squared statistic comparing these infant characteristics by work environment category is shown.

Hospital characteristics and the distribution of these characteristics by the work environment are presented in Table 7. The majority of hospitals (70%) have high volumes of VLBW infants and forty-three percent care for greater than 100 infants each year. The majority of hospitals (81%) are designated as providing level 3 NICU care. The majority of hospitals (75%) are large with bed size >250. Only 20% of the sample was classified as a major teaching hospital, as indicated by the proportion of postgraduate residents per bed. Two-thirds (67%) were classified as high technology hospitals, indicating that they have the capacity to perform organ transplantation and/or open cardiac surgery.

Table 7 further presents the distribution of each of the hospital characteristics across the work environments. There is minimal variation by quality of the nurse work environment. By category no significant differences were found. The highest volume NICUs, those with greater than 100 admissions per year have the poorest work environments. There is a slight increase in the proportion of Level of Care 4 hospitals in the poor environment category – 17% compared with 14% in the best work environment. Only 19% of hospitals in the best work environments are designated as major teaching hospitals.

Table 8. NICU Nursing Organizational Characteristics

Distribution of NICU Nursing Organizational Characteristics across Nurse Work Environments

	All Work Environments n=170	**Poor Work Environments n=36**	**Average Work Environments n=90**	**Best Work Environments n=44**	p-value
NICU Nursing Organizational Characteristics					
Staffing					
Patient to Nurse Ratio, mean (SD)	2.6 (0.59)	2.9 (0.73)	2.6 (0.52)	2.4 (0.5)	0.003
range	1.25-6	2.0-6	1.25-4	1.4-3.6	
Nurse Work Environment					
scale 1-4, mean (SD)	2.88 (0.33)	2.4 (0.19)	2.87 (0.12)	3.3 (0.18)	<0.001
range	1.9-3.79	1.92-2.6	2.64-3.07	3.07-3.79	
Education					
Percentage of BSN or higher degree in Nursing, mean (SD)	49 (0.23)	45 (0.2)	50 (0.24)	51 (0.23)	0.422
range	0-10	0-0.79	0-10	0-10	
Nurse Specialty Certification					
Percentage of Nursing Staff with Specialty Certification, mean (SD)	42 (0.42)	43 (0.27)	39 (0.23)	46 (0.24)	0.350
range	0-10	0-10	0-10	0-10	
Nurse Experience					
Years of NICU experience, mean (SD)	12 (4.8)	12 (3.8)	11 (5.1)	12 (4.7)	0.868
range	0.5-22	5.25-22	0.5-22	1.25-22	

For categorical variables, the p-value of the Pearson chi-squared statistic comparing these characteristics by nurse work environment category is shown. For the continuous variables F-tests were used to test the differences across nurse work environment categories.

Table 8 presents the Characteristics of the Organization of Nursing in neonatal intensive care units as a whole and as distributed across work environments. The average number of patients per neonatal nurse was 2.6. The overall average nurse work environment score was 2.88 on a scale of 1-4, ranging from 1, indicating the poorest work environments, to 4 as the best. A score of 2.88 is considered above average, with 2.50 the midpoint of the scale range and 3.00 indicating nurses "agree" that valued organizational traits are present in their job. On average, 49% of the neonatal nurses had a bachelor's degree in nursing (BSN) or higher. At the NICU unit level the average percentage of nurses across hospitals with specialty certification was 42%.

The right side of the table shows the distribution of nursing characteristics across the nurse work environment categories. The average patient to nurse ratio is the highest in the poor work environment, 2.9, and the lowest in the best work environment, 2.4. This is a statistically significant difference (p=0.0032). Differences in the percentage of BSN nurses and specialty-certified nurses, as well as the differences in experience across hospitals with different work environments are statistically significant.

Table 9. Pearson Correlations

A Pearson's correlation was performed to assess the relationship between the hospital level variables in the sample. The composite work environment score and the individual subscale scores were highly and significantly positively correlated (ρ= 0.5-0.86, $p < 0.001$). The subscales Nurse Manager Ability, Leadership and Support and Foundations for Quality of Care had the strongest correlations ($\rho=0.86$, $p < 0.001$). Nurse staffing (i.e patients-to-nurse ratio) only correlated weakly with the composite work environment score ($\rho= -0.276$, $p<0.001$) but this was significant and moderately correlated with the individual staffing and resource adequacy subscale ($\rho= -0.357$, $p<0.001$) also significant. Specialty certification had a positive but weak correlation with Nurse Participation in Hospital Affairs, this correlation was significant, $\rho=0.1819$, $p= 0.018$. NICU volume was negatively correlated with the composite work environment $\rho= -0.1533$, $p=0.045$ and positively correlated with staffing $\rho=0.1605$, $p=0.037$). Hospital teaching status was positively correlated with nurse education $\rho=0.1942$, $p=0.114$ and NICU volume $\rho=0.1587$, $p=0.039$. NICU level of care was negative correlated with staffing $\rho= -0.2483$, $p=0.001$ and positively correlated with NICU volume $\rho=0.2021$, $p=0.008$ and teaching status $\rho=0.3022$, $p=0.001$. Overall, the correlations were weak ρ -0.3-0.3 but several were significant with p-values <0.05.

Table 9. Pearson Correlations between Nursing Organizational Characteristics and Hospital Characteristics

	1	1a	1b	1c	1d	1e	2	3	4	5	6	7	8	9
1. Nurse Practice Environment	1.000													
a. Nurse-Physician Relations	**0.764**	1.000												
b. Nurse Manager Ability, Leadership and Support	**0.860**	**0.516**	1.000											
c. Staffing and Resource Adequacy	**0.757**	**0.500**	**0.564**	1.000										
d. Foundations for Quality of Care	**0.865**	**0.584**	**0.679**	**0.542**	1.000									
e. Nurse Participation in Hospital Affairs	**0.831**	**0.486**	**0.689**	**0.472**	**0.796**	1.000								
2. Staffing	**-0.276**	**-0.194**	-0.150	**-0.357**	**-0.249**	**-0.205**	1.000							
3. Education	0.088	-0.043	0.094	0.148	0.027	0.125	-0.305	1.000						
4. Certification	0.085	0.020	0.051	0.013	0.108	**0.182**	0.063	0.012	1.000					
5. NICU Volume	**-0.153**	**-0.200**	-0.024	**-0.246**	-0.092	-0.068	**0.161**	0.117	-0.067	1.000				
6. Bed size	0.010	-0.059	0.085	-0.097	0.062	0.050	-0.027	0.042	-0.103	**0.201**	1.000			
7. Teaching Status	-0.043	-0.115	-0.013	-0.072	0.036	0.007	-0.067	**0.194**	0.015	**0.159**	**0.176**	1.000		
8. Technology Status	0.022	-0.072	-0.013	0.065	0.041	0.087	-0.046	0.142	-0.077	**0.172**	**0.364**	0.050	1.000	
9. Level of Care	-0.040	-0.098	-0.012	-0.102	0.004	0.060	**-0.248**	0.131	**-0.154**	**0.202**	0.138	**0.302**	0.145	1.000

Weak Correlation -0.3-0.3 Moderate Correlation -0.6- -0.3 or 0.3-0.6 Strong Correlation -1.0 - -0.6 or 0.6 -1.0

Bolded values indicate p<0.05

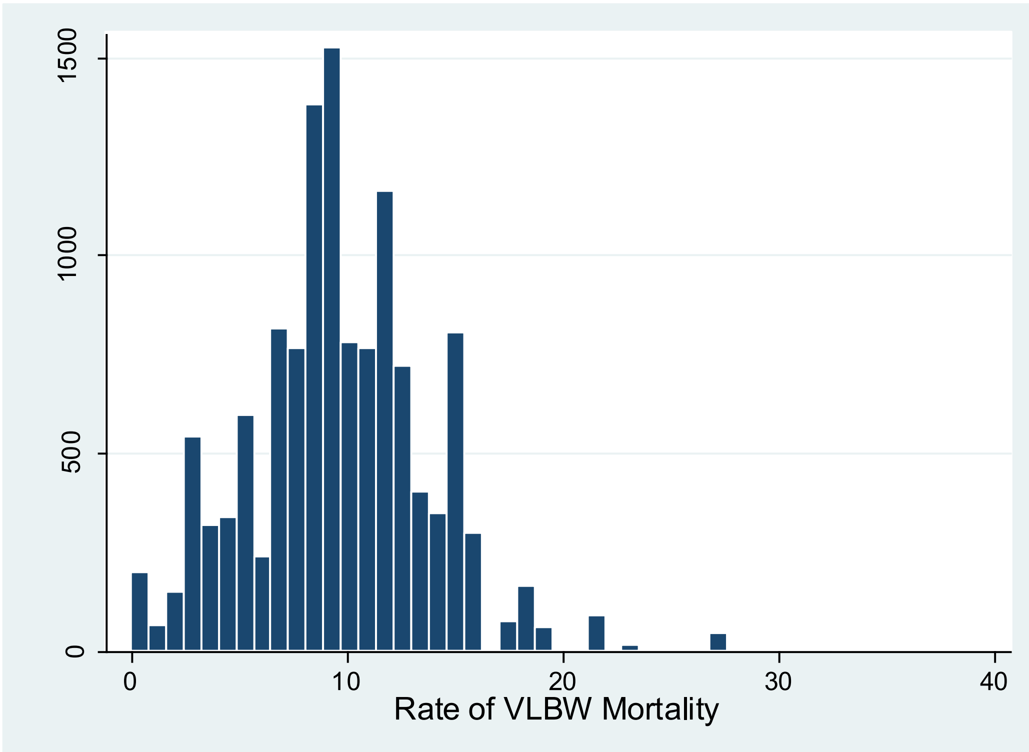
Outcome Distribution

The distribution of VLBW infant outcomes evaluated for this study is displayed in Table 10. The in hospital mortality rate was 10.8% (death in the hospital prior to 1 year of age) and Neonatal Mortality (death prior to 28 days of life) was 9.7%. The incidence of severe intraventricular hemorrhage was 5.2%. The mean NICU length of stay was 46 days. NICU length of stay ranged from 0-359 days, with a median of 41 days. Figures 3, 4 and 5 graphically depict the distribution of each of these outcomes at the infant level.

Table 10. VLBW Infant Outcome Distribution n =17,771

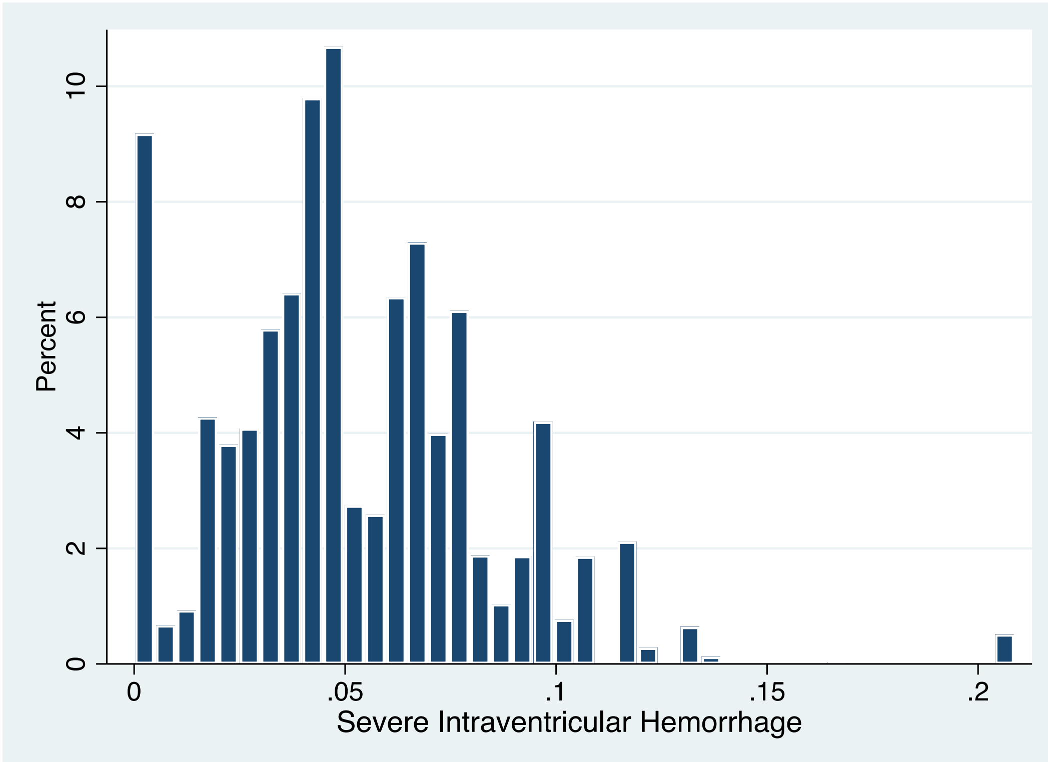
In Hospital Mortality	mean	0.108 (0.31)
	range	0-1
Neonatal Mortality (28 day Mortality)	mean (SD) range	0.0965 (.295) 0-1
Severe IVH	mean (SD)	0.052 (0.22)
	range	0-1
NICU Length of Stay	mean (SD)	45.5 (35)
	range	0-359
	median	41

Figure 5. Distribution of in hospital VLBW mortality.



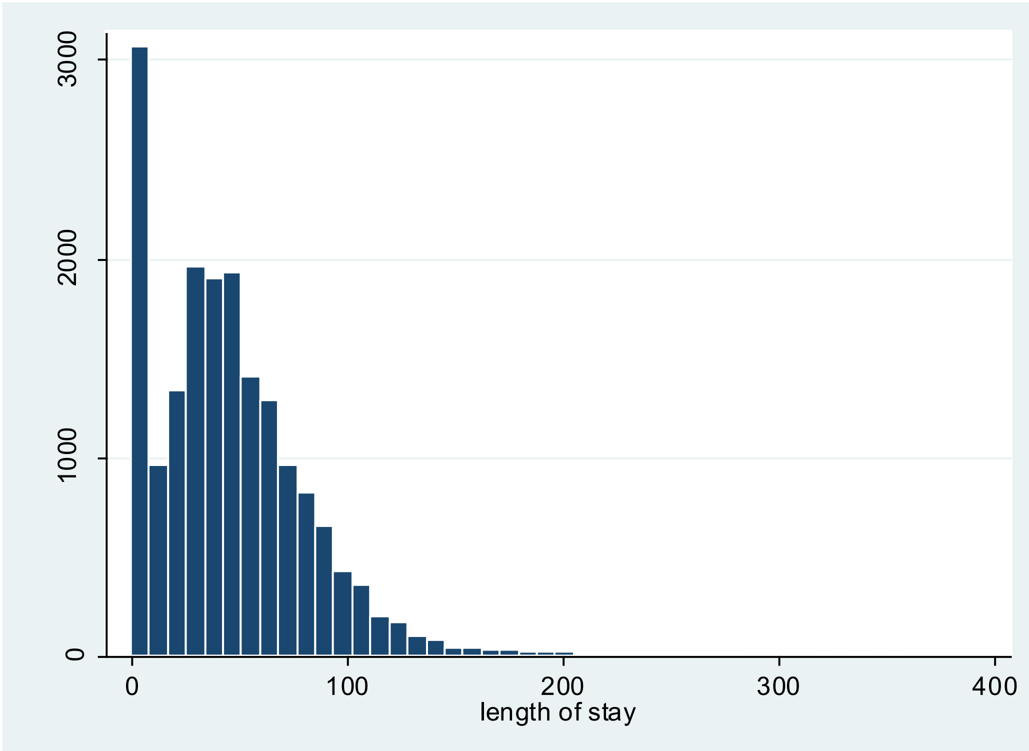
The distribution of in-hospital mortality ranges from zero to just less than thirty percent. The greatest number of infants have mortality rates 9-10%. Overall, the distribution appears to be fairly normal with a central tendency of approximately 10%,

Figure 6. Distribution of Severe Intraventricular Hemorrhage



The distribution of severe intraventricular hemorrhage ranges from zero to just over twenty percent. There is a large percent of the infant population with rates of severe intraventricular hemorrhage equal to zero. The greatest percentage of infants have rates of severe intraventricular hemorrhage 3-4%. After accounting for the large percentage of zeros the distribution of severe intraventricular hemorrhage appears to be normal with a central tendency of approximately 4%.

Figure 7. Distribution of NICU length of stay



The distribution of length of stay is significantly right skewed with many zeros. The range of length of stay is zero days to 359 days. Almost all of the very low birth weight infants have length of stays less than 200 days, and the majority have length of stays less than 100 days.

Table 11. Length of Stay Distribution of VLBW Infants that Died within 28 days, survived greater than 28 days and those with Severe Intraventricular Hemorrhage					
		All VLBW Infants	Died within 28 days	Survived to 28 days	Diagnosis of sIVH
		n=17,771	n=1715	n=16,056	n=922
NICU Length of Stay	mean	45.5 days	4.3 days	49.9 days	53 days
	median	41 days	1 day	45 days	46 days
	Range	0-359 days	0-27 days	0-359 days	0-277 days

Table 11 displays the distribution of length of stay by neonatal mortality (death prior to 28 days of life) and includes length of stay for those infants diagnosed with severe intraventricular hemorrhage. VLBW infants that died prior to 28 days of life had considerably shorter lengths of stay that those that survived to greater than 28 days of life in the neonatal intensive care unit. This accounts for a change in average length of stay from 45.5 days for all VLBW infants regardless of outcome to 49.9 days for those infants that survived greater than 28 days.

Infants with a diagnosis of sIVH had an average length of stay equal to 53 days. Infants with a diagnosis of sIVH had average lengths of stay longer than all VLBW infants regardless of mortality and longer than the average length of stay for those that survived greater than 28 days.

Analysis of Specific Aims

Specific Aim 1: To examine the effect of the nurse work environment on outcomes of very low birth weight infants (in hospital mortality, hospital length of stay, and severe intraventricular hemorrhage).

To address Specific Aim 1, the relationship of the nurse work environment, as measured using the composite work environment variable, standardized so that the mean is equal to 0, on each outcome – in hospital mortality, severe intraventricular hemorrhage and length of stay was evaluated. Logistic regression models that accounted for clustering of infants within hospitals were used to estimate the effect of the nurse work environment on the outcomes of mortality and severe intraventricular hemorrhage. A negative binomial regression model was used to analyze the association of the nurse work environment on neonatal intensive care unit length of stay.

The regression results analyzing the effect of the nurse work environment on the odds of mortality for very low birth weight infants and the incident rate ratio (IRR) for length of stay are displayed in Table 12. The regression results are presented and organized by outcomes: neonatal mortality, in hospital mortality and length of stay.

Mortality

Model 1 analysis is of the unadjusted bivariate logistic regression of the nurse work environment on mortality. Model 2 and Model 3 are multivariate models that account for infant characteristics (VLBW, sex, race and insurance status), and nursing characteristics (education, certification and staffing), respectively. The fully adjusted multivariate model – Model 4 accounts for infant, nursing and hospital characteristics (VLBW volume, NICU level, and teaching status).

The unadjusted model of the effect of the nurse work environment on neonatal and in hospital mortality indicates that infants cared for in hospital/neonatal intensive care units with increasingly better work environments have lower odds of death. After adjusting for infant, nurse and hospital characteristics each one standard deviation increase in the nurse work environment is associated with a 4.2% lower odds of in hospital mortality for very low birth weight infants (OR 0.96, p=0.356) and a 3.7% lower odds of neonatal mortality (OR 0.963, p=0.443). These models demonstrate that the relationship between the nurse work environment and mortality of very low birth weight infants is in the hypothesized direction but does not reach statistical significance.

The nurse work environment was a strong predictor of severe intraventricular hemorrhage, indicating that after adjusting for infant, nurse and hospital characteristics each one standard deviation increase in the nurse work environment is associated with an 11.6% lower odds of severe intraventricular hemorrhage for very low birth weight infants (OR 0.884, $p<0.05$).

The nurse work environment was also a predictor of length of stay. In Model 3, after accounting for infant and nurse characteristics each one standard deviation increase in the nurse work environment was associated with a 4.8% lower IRR in length of stay (IRR 0.952, $p<0.05$.). After adjusting for hospital characteristics, this relationship maintained significance, (IRR 0.961, $p<0.05$) indicating that one unit standard deviation increase in the nurse work environment is associated with a 3.9% lower IRR length of stay.

Table 12. Odds Ratios and Incident Rate Ratios Estimating the Association of the Nurse Work Environment[a] with Outcomes of Very Low Birth Weight infants

	Model 1			Model 2			Model 3			Model 4		
	Unadjusted			Adjusted for patient characteristics[b]			Adjusted for patient and nurse characteristics[c]			Adjusted for patient, nurse and hospital characteristics [d]		
	Odds Ratios	95% CI	p-value	Odds Ratios	95% CI	p-value	Odds Ratios	95% CI	p-value	Odds Ratios	95% CI	p-value
Mortality												
Within 7 days	1.02	0.946-1.10	0.563	1.06	0.97-1.16	0.181	1.055	0.967-1.15	0.228	1.03	0.95-1.13	0.374
Within 28 days	0.947	0.88-1.01	0.135	0.965	0.881-1.05	0.433	0.962	0.88-1.04	0.389	0.963	0.876-1.06	0.443
Before discharge	0.936	.87-1.01	0.074	0.965	0.88-1.05	0.433	0.962	0.88-1.04	0.389	0.958	0.88-1.05	0.356
Morbidity												
Severe IVH	0.863	0.777-0.959	0.006	0.865	0.775-0.966	0.01	0.87	0.775-0.977	0.019	0.884	0.79-0.99	0.043
Length of Stay												
NICU length of stay	0.946	0.896-0.99	0.045	0.956[e]	0.917-0.997	0.038	0.952	0.917-0.988	0.009	0.961	0.929-0.995	0.026

[a] work environment standardized so that 1 unit = 1 SD
[b] patient risk adjustment: birth weight, race, sex, insurance
[c] nursing risk adjustment: education, certification, staffing
[d] hospital risk adjustment: NICU volume, NICU level of care, teaching status

In order to look completely at the nurse work environment bivariate and multivariate models looked at the effect of each of the nurse work environment subscales on each of the outcomes. Table 13 provides odds ratios and incident rate ratios for each of the subscales effect on each of the outcomes.

Mortality

In bivariate analysis each of the domains of the nurse work environment were in the hypothesized direction with OR 0.91-0.98. The only domain that significantly predicted mortality was nurse-physician relations, OR 0.91, p=0.002. After controlling for infant and additional nurse characteristics this relationship remained significant, but failed to reach significance after controlling for the hospital characteristics of NICU volume, level of care and teaching status, OR 0.92, p= 0.059.

Severe Intraventricular Hemorrhage

In the unadjusted models four of the five domains of the nurse work environment were significantly associated with severe intraventricular hemorrhage. Nurse manager ability, leadership and support was in the hypothesized direction, but this was not significant (OR 0.92, p=0.11). After controlling for infant and additional nurse characteristics three domains remained significantly associated with sIVH; nurse-physician relations (OR 0.88, p=0.037), staffing and resource adequacy (OR 0.88, p=0.033) and foundations of quality of care (OR 0.86, p=0.008). After controlling for hospital characteristics, the only domain that achieved significance was foundations for quality of care (OR 0.87, p=0.027).

Length of Stay

In unadjusted models the bivariate analysis for each of the nurse work environment domains was in the hypothesized direction, indicating that better subscale scores were related to reduced lengths of stay. The only domain in which this unadjusted relationship was significant however was nurse-physician relations (OR 0.94, p=0.021). After controlling for infant and additional nurse characteristics this domain maintained significance (OR 0.95, p=0.005) and the staffing and resource adequacy achieved significance (OR 0.95, p=0.01). When controlling for hospital characteristics the staffing and resource adequacy domain failed to achieve significance, while the nurse-physician relations domain did achieve significance (OR 0.96, p=0.03).

Specific Aim 2: To examine the direct effects of nurse staffing, education and certification and to examine the interaction effects of the nurse work environment with staffing, education and, certification on outcomes of very low birth weight infants (in hospital mortality, hospital length of stay, and severe intraventricular hemorrhage).

To address Specific Aim 2, the relationship of each of the following elements of the organization of nursing, nurse education, nurse staffing and nurse certification, and the outcomes were analyzed. Logistic regression models that accounted for clustering of infants within hospitals were used to assess the relationship of nursing factors and the outcomes of mortality and severe intraventricular hemorrhage and negative binomial regression was used to assess the association of nursing factors on length of stay. The regression results are presented by outcome, mortality, severe intraventricular hemorrhage and length of stay.

Mortality

The results of analyzing the effect of nurse education, nurse certification, BSN nurses with certification and nurse staffing on the odds of mortality for very low birth weight infants are displayed in Table 14. Model 1 presents the unadjusted bivariate logistic regression of nursing factors on morality. Model 2 shows a multivariate model that accounts for infant characteristics and Model 3 accounts jointly for infant and hospital characteristics. None of the nursing elements of the organization of nursing in neonatal intensive care units were significantly associated with infant mortality in bivariate or multivariate regressions. Nurse BSN education and nurse certification showed no relationship with infant mortality. The odds ratios for BSN nurses with specialty certification indicate for each 10% increase in the proportion of BSN nurses with certification in hospitals is associated with a lower odds of mortality, this relationship was not significant in the fully adjusted model (OR 0.767, p=0.51). The odds ratios for nurse staffing indicate that for each additional patient per nurse the odds of mortality increases. In the fully adjusted model one additional infant per nurse is associated with a 3% increase in mortality, these results are in the hypothesized direction, however this relationship is not significant (OR 1.03, p=0.849).

Severe Intraventricular Hemorrhage

The results of analyzing the effect of nurse education, nurse certification, BSN nurses with certification and nurse staffing on the odds of severe intraventricular for very low birth weight infants is displayed in Table 15. None of the nursing elements of the organization of nursing in neonatal intensive care units were significantly associated with severe intraventricular hemorrhage in bivariate or multivariate regressions. Nurse education was not a predictor of sIVH in the regression models (OR 1.00, p =0.85). Nurse certification has a very weak effect on the association of sIVH. In the fully adjusted model, hospitals with higher proportions of certified nurses are associated with a 2% lower odds of sIVH, this relationship is not statistically significant (OR 0.98, p =0.579). The model estimating the effect of BSN nurses with specialty certification with sIVH, indicates that hospitals with higher proportions of BSN nurses with specialty certification are associated with decreased odds of sIVH. In the fully adjusted model for each additional 10% increase in the proportion of BSN nurses with certification in hospitals is associated with a 6% decrease in sIVH, while in the hypothesized direction this relationship is not significant (OR 0.94 p =0.157, CI 0.86-1.02). No evidence of a relationship is demonstrated in the regression model estimating the effect of nurse staffing on sIVH.

Length of Stay

The negative binomial model results analyzing the effect of organization elements of nursing on length of stay for very low birth weight infants are presented in Table 16. Interpretations of the incident rate ratios (IRR) focus on the fully adjusted model that accounts for infant and hospital characteristics. Nurse education was not associated with length of stay (IRR 1.00, p=0.822). Nurse certification was not associated with length of stay (IRR 1.00, p=0.77). The model that estimates the relationship of hospital proportion of BSN nurses with specialty certification indicates that each 10% increase in the proportion of BSN nurses with specialty certification is associated with a decrease incident rate ratio of 1% for length of stay, this is not statistically significant (IRR 0.99, p=0.511, CI 0.96-1.02). The effect of staffing was modeled in two ways. As a continuous variable staffing ranges from a mean of 1.25 to 6 patients per nurse at the hospital level. As a categorical variable the base category represents less than 2 patients per nurse, category 1 represents an average of 2 patients per nurse, category 2 represents an average of greater than 2.5 patients per nurse and category 3 represents greater than 3 patients per nurse. In models that analyzed the effect of nurse staffing on length of stay, no significance was found. Interestingly the effect size is in the opposite of the hypothesized direction, this was consistent in bivariate models and models accounting for patient and hospital characteristics. This suggests that for each unit increase in patients per nurse the average length of stay decreases.

Table 13. Odds Ratios and Incident Rate Ratios Estimating the Association of the Nurse Work Environment Subscales[a] with Outcomes of Very Low Birth Weight infants

	Model 1			Model 2			Model 3			Model 4		
	Unadjusted			Adjusted for patient characteristics[b]			Adjusted for patient and nurse characteristics[c]			Adjusted for patient, nurse and hospital characteristics [d]		
Mortality	**Odds Ratios**	**95% CI**	**p-value**	**Odds Ratios**	**95% CI**	**p-value**	**Odds Ratios**	**95% CI**	**p-value**	**Odds Ratios**	**95% CI**	**p-value**
Nurse-Physican Relations	0.907	0.85-0.96	**0.002**	0.92	0.85-0.988	**0.023**	0.913	0.845-0.986	**0.021**	0.92	0.84-1.00	0.059
Nurse Manager Ability, Leadership and Support	0.979	0.9-1.06	0.621	1.00	0.9-1.1	0.989	1.00	0.9-1.1	0.983	0.992	0.899-1.09	0.884
Staffing and Resource Adequacy	0.952	0.89-1.02	0.15	0.97	0.89-1.05	0.516	0.959	0.88-1.04	0.349	0.97	0.88-1.06	0.546
Foundations for Quality of Care	0.94	0.87-1.02	0.121	0.94	0.86-1.03	0.192	0.939	0.86-1.02	0.154	0.94	0.86-1.02	0.171
Nurse Participation in Hospital Affairs	0.96	0.89-1.03	0.282	0.983	0.9-1.07	0.694	0.98	0.91-1.06	0.69	0.986	0.9-1.07	0.75
Severe Intraventricular Hemorrhage	**Odds Ratios**	**95% CI**	**p-value**	**Odds Ratios**	**95% CI**	**p-value**	**Odds Ratios**	**95% CI**	**p-value**	**Odds Ratios**	**95% CI**	**p-value**
Nurse-Physican Relations	0.87	0.78-0.97	**0.015**	0.87	0.77-0.97	**0.017**	0.877	0.78-0.99	**0.037**	0.89	0.79-1.00	0.06
Nurse Manager Ability, Leadership and Support	0.92	0.83-1.01	**0.11**	0.926	0.83-1.03	0.161	0.929	0.837-1.03	0.174	0.94	0.84-1.04	0.254
Staffing and Resource Adequacy	0.88	0.78-0.985	**0.027**	0.88	0.78-0.997	**0.045**	0.876	0.776-0.989	**0.033**	0.898	0.79-1.01	0.09
Foundations for Quality of Care	0.86	0.78-0.95	**0.003**	0.85	0.77-0.95	**0.003**	0.86	0.77-0.96	**0.008**	0.87	0.77-0.98	**0.027**
Nurse Participation in Hospital Affairs	0.896	0.81-0.99	**0.036**	0.9	0.813-0.99	**0.04**	0.9	0.82-1.00	0.053	0.9	0.82-1.00	0.065
Length of Stay	**IRR**	**95% CI**	**p-value**	**IRR**	**95% CI**	**p-value**	**IRR**	**95% CI**	**p-value**	**IRR**	**95% CI**	**p-value**
Nurse-Physican Relations	0.94	0.89-0.99	**0.021**	0.947	0.91-0.986	**0.008**	0.95	0.92-0.98	**0.005**	0.96	0.93-0.99	**0.03**
Nurse Manager Ability, Leadership and Support	0.94	0.89-1.00	0.053	0.968	0.93-1.00	0.12	0.967	0.93-1.00	0.082	0.967	0.94-1.00	0.062
Staffing and Resource Adequacy	0.97	0.92-1.03	0.341	0.967	0.93-1.00	0.111	0.95	0.92-0.98	**0.01**	0.968	0.93-1.00	0.073
Foundations for Quality of Care	0.94	0.89-1.01	0.105	0.964	0.92-1.01	0.125	0.96	0.91-1.01	0.122	0.97	0.92-1.01	0.236
Nurse Participation in Hospital Affairs	0.96	0.91-1.02	0.187	0.97	0.93-1.01	0.172	0.97	0.93-1.00	0.061	0.97	0.94-1.00	0.058

[a] work environment subscales standardized so that 1 unit = 1 SD
[b] patient risk adjustment: birth weight, race, sex, insurance
[c] nursing risk adjustment: education, certification, staffing
[d] hospital risk adjustment: NICU volume, NICU level of care, teaching status

Table 14. Odds Ratios Estimating the Association of Nurse Education, Nurse Staffing and Nurse Certification with Mortality of Very Low Birth Weight infants

	Model 1			Model 2			Model 3		
	Unadjusted			Adjusted for patient characteristics[b]			Adjusted for patient and hospital characteristics [d]		
	Odds Ratios	95% CI	p-value	Odds Ratios	95% CI	p-value	Odds Ratios	95% CI	p-value
Education	1.000	0.96-1.04	0.867	1.000	0.96-1.06	0.819	0.997	0.95-1.04	0.929
Certificaton	0.999	0.99-1.00	0.694	0.998	0.99-1.00	0.662	0.998	0.99-1.00	0.690
Certified BSN Nurses	0.851	0.44-1.63	0.631	0.85	0.37-1.96	0.703	0.767	0.35-1.67	0.506
Staffing	1.08	0.82-1.42	0.567	1.089	0.82-1.45	0.561	1.03	0.77-1.36	0.849

[b] patient risk adjustment: birth weight, race, sex, insurance
[d] hospital risk adjustment: natural log of volume, NICU level of care, teaching status

Table 15. Odds Ratios Estimating the Association of Nurse Education, Nurse Staffing and Nurse Certification with sIVH of Very Low Birth Weight infants

	Model 1			Model 2			Model 3		
	Unadjusted			Adjusted for patient characteristics[b]			Adjusted for patient and hospital characteristics [d]		
	Odds Ratios	95% CI	p-value	Odds Ratios	95% CI	p-value	Odds Ratios	95% CI	p-value
Education	1.000	0.95-1.06	0.85	1.010	0.96-1.07	0.566	1.00	0.939-1.055	0.881
Certificaton	0.984	0.93-1.04	0.604	0.98	0.92-1.04	0.572	0.98	0.92-1.05	0.579
Certified BSN Nurses	0.958	0.88-1.03	0.299	0.965	0.88-1.05	0.425	0.94	0.86-1.02	0.157
Staffing	1.00	0.78-1.29	0.998	0.98	0.78-1.28	0.898	0.956	0.76-1.19	0.694

[b] patient risk adjustment: birth weight, race, sex, insurance
[d] hospital risk adjustment: NICU volume, NICU level of care, teaching status

Table 16. IRRs Estimating the Association of Nurse Education, Nurse Staffing and Nurse Certification with Length of Stay of Very Low Birth Weight infants

	Model 1			Model 2			Model 3		
	Unadjusted			Adjusted for patient characteristics[b]			Adjusted for patient and hospital characteristics[d]		
	Odds Ratios	95% CI	p value	Odds Ratios	95% CI	p value	Odds Ratios	95% CI	p value
Education	1.01	0.98-1.05	0.391	1.01	0.99-1.04	0.153	1.00	0.98-1.02	0.822
Certification	1.00	0.96-1.04	0.911	1.00	0.98-1.02	0.717	1.00	0.98-1.02	0.77
Certified BSN Nurses	0.99	0.94-1.04	0.721	1.00	0.98-1.03	0.708	0.99	0.96-1.02	0.511
Staffing (cont)	0.91	0.79-1.05	0.233	0.95	0.86-1.05	0.34	0.92	0.94-1.00	0.08
Staffing (categorical)	0.96	0.9-1.04	0.317	0.98	0.93-1.03	0.45	0.97	0.93-1.01	0.17

[b] patient risk adjustment: birth weight, race, sex, insurance
[d] hospital risk adjustment: NICU volume, NICU level of care, teaching status

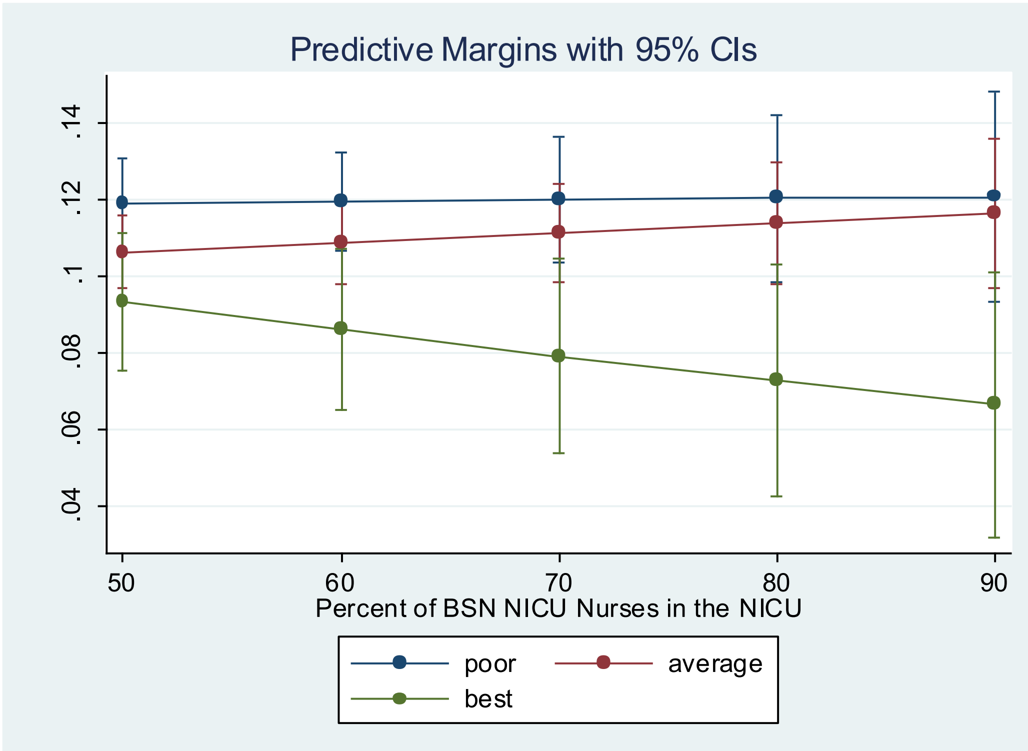
Aim 2 further examines the effects of the interaction of the nurse work environment with each nursing element: nurse education, nurse certification and nurse staffing, on each of the very low birth weight outcomes. Results of these interactions are presented in Tables 17-28 and are organized by outcome: mortality, severe intraventricular hemorrhage and length of stay. All models accounted for clustering of infants within hospitals and control for infant and hospital characteristics.

Mortality

Nurse education and the nurse work environment interacted significantly in the effect on in hospital mortality with an odds ratio of 0.944 (p= 0.045, CI 0.89-0.99). To further investigate the interaction of nurse education with the nurse work environment, the effect of the nurse work environment at each 10% increase in proportion of BSN educated nurses was estimated. In hospitals with poor or average nurse work environments there was no significant difference in mortality with increasing proportions of BSN nurses. In the best nurse work environments the probability of mortality decreased (OR 0.935) with each incremental increase in the proportion of BSN prepared nurses. In the best nurse work environments with an 80% proportion of BSN nurses the probability of mortality is 0.07 compared with a 0.12 probability of mortality in poor work environments with the same proportion of BSN nurses (Figure 7). In the best work environments there is additional benefit when the proportion of BSN nurses increases to 90%. The probability of mortality decreases to 0.065, while in poor work environments is remains at 0.12. This is visually represented in a graph in Figure 7.

Table 17. Interaction Effect of the Nurse Work Environment and Education				
	NICU Mortality			
	Main Effect Model		Interaction Model	
	Odds Ratio	p-value	Odds Ratio	p-value
Education	0.998	0.93	1.049	0.07
Nurse Work Environment	0.975	0.72	1.296	0.06
Education x Nurse Work Environment			0.944	0.045
Implied Effect of Education when the Work Environment is -				
Poor	1.049			
Mixed	0.990			
Better	0.935			
Implied Effect of the Work Environment when %BSN is -				
0	1.296			
10	1.223			
20	1.155			
30	1.090			
40	1.029			
50	0.972			
60	0.917			
70	0.866			
80	0.817			
90	0.772			

Figure 8. Interaction of the Nurse Work Environment and BSN Education on NICU Mortality



The interaction terms for the nurse work environment and nurse certification and the nurse work environment and nurse staffing were not significantly associated with in hospital mortality, as shown in Tables 18 and 19.

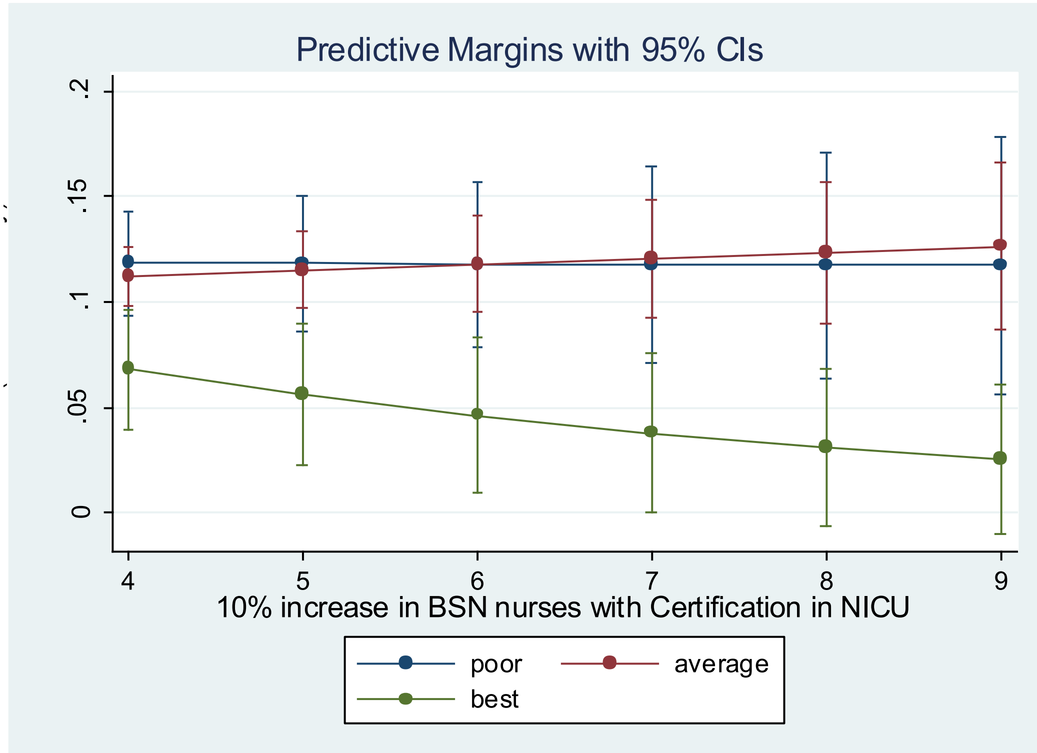
Table 18. Interaction Effect of the Nurse Work Environment and Specialty Certification				
	NICU Mortality			
	Main Effect Model		**Interaction Model**	
	Odds Ratio	**p-value**	**Odds Ratio**	**p-value**
Specialty Certification	0.998	0.69	1.04	0.25
Nurse Work Environment	0.958	0.356	1.2	0.127
Specialty Certification x Nurse Work Environment			0.95	0.114

Table 19. Interaction Effect of the Nurse Work Environment and Staffing				
	NICU Mortality			
	Main Effect Model		Interaction Model	
	Odds Ratio	p-value	Odds Ratio	p-value
Staffing	1.030	0.849	0.911	0.536
Nurse Work Environment	0.958	0.356	1.02	0.953
Staffing x Nurse Work Environment			0.978	0.852

The interaction term for the nurse work environment and BSN certified nurses was also not significantly associated with in hospital mortality, as shown in Table 20. The odds ratio is in the hypothesized direction and the p-value of 0.079 is significant at a p-value of less the 0.1. Figure 9 graphically depicts the relationship across the work environments. There appears to be a distinct difference in the effect of increasing proportions of BSN certified nurses in the best work environments that favors lower mortality rates for very low birth weight infants.

Table 20. Interaction Effect of the Nurse Work Environment and BSN + Certification				
	NICU Mortality			
	Main Effect Model		Interaction Model	
	Odds Ratio	p-value	Odds Ratio	p-value
BSN + Certification	0.767	0.506	1.1	0.076
Nurse Work Environment	0.958	0.356	1.11	0.344
BSN + Certification x Nurse Work Environment			0.893	0.079

Figure 9. Interaction of the Nurse Work Environment and BSN + Specialty Certification



Severe Intraventricular Hemorrhage

In the regression model estimating the effect of the interaction of nurse education and the nurse work environment with severe intraventricular hemorrhage, no relationship was found (OR 0.978, p=0.58). The predicted rate of severe intraventricular hemorrhage did not vary by increased proportions of nurses with BSN education across any of the 3 work environment groups. This is visually represented in the graph displayed as Figure 10. Consistent with results from Aim 1, the rate of severe intraventricular hemorrhage is lowest in the best work environments with no variation based on proportion of nurses with BSN or greater education.

Table 21. Interaction Effect of the Nurse Work Environment and Education

	Severe Intraventricular Hemorrhage			
	Main Effect Model		**Interaction Model**	
	Odd Ratio	**p-value**	**Odds Ratio**	**p-value**
Education	1.000	0.881	0.887	0.504
Nurse Work Environment	0.884	0.043	0.999	0.991
Education x Nurse Work Environment			0.998	0.949

Figure 10. Interaction of the Nurse Work Environment and BSN Education on Severe Intraventricular Hemorrhage

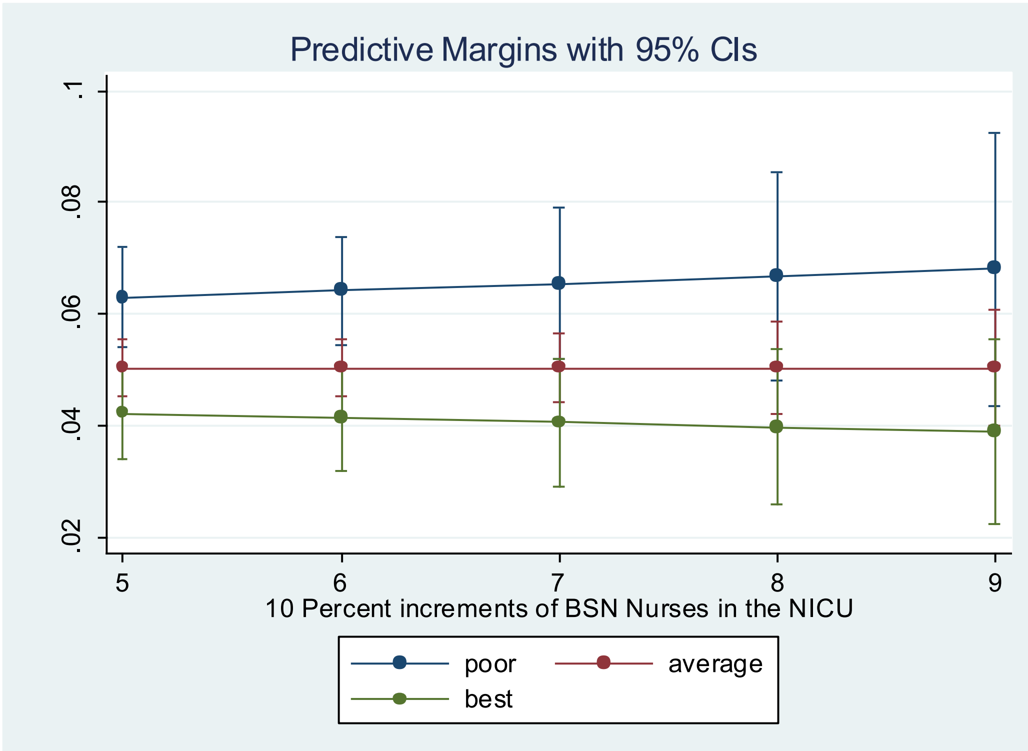


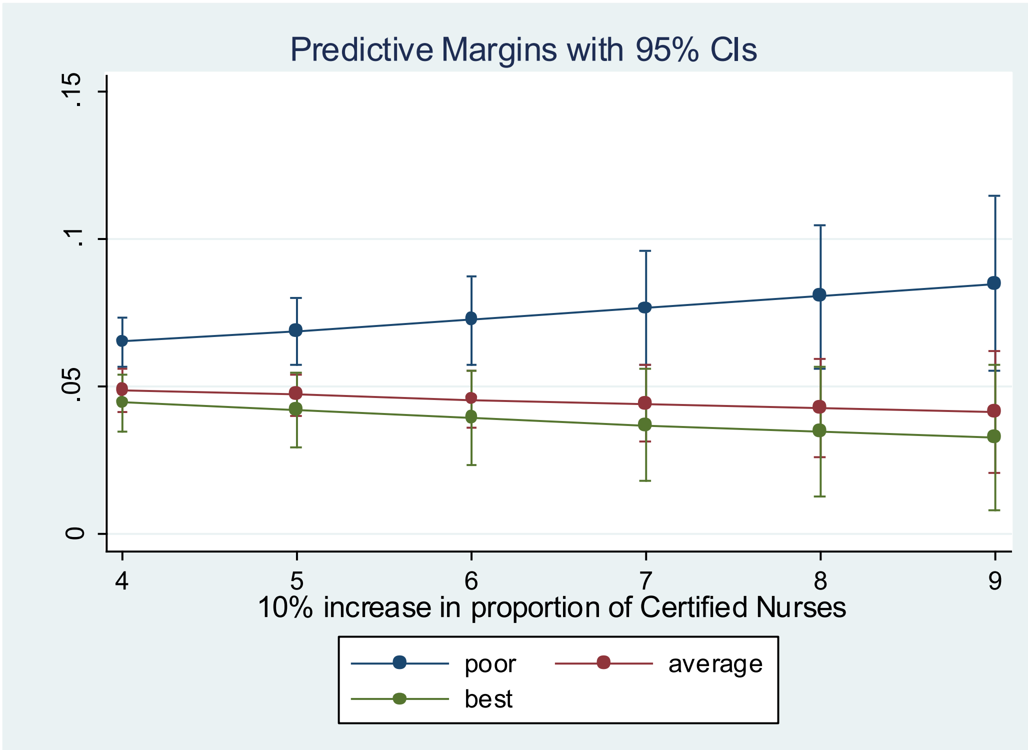
Table 22. Interaction Effect of the Nurse Work Environment and Specialty Certification				
	Severe Intraventricular Hemorrhage			
	Main Effect Model		Interaction Model	
	Odds Ratio	p-value	Odds Ratio	p-value
Specialty Certification	0.980	0.579	0.983	0.626
Nurse Work Environment	0.884	0.043	1.15	0.211
Specialty Certification x Nurse Work Environment			**0.938**	**0.038**

Table 23. Interaction Effect of the Nurse Work Environment and Staffing				
	Severe Intraventricular Hemorrhage			
	Main Effect Model		Interaction Model	
	Odds Ratio	p-value	Odds Ratio	p-value
Staffing	0.956	0.694	1.06	0.697
Nurse Work Environment	0.884	0.043	**1.8**	**0.028**
Staffing x Nurse Work Environment			**0.769**	**0.007**

The interaction terms for the product of the nurse work environment and nurse certification and the nurse work environment and nurse staffing were both statistically significant in models that estimated the association with severe intraventricular hemorrhage.

The effect for nurse specialty certification and the nurse work environment had an odds ratio of 0.938, p=0.038. This effect is in the hypothesized direction, indicating that there is an added benefit of nurse specialty certification by quality of the nurse work environment that is associated with a reduction in incidence of severe intraventricular hemorrhage. This benefit favors the average and best work environments as depicted in Figure 11.

Figure 11. Interaction of the Nurse Work Environment and Specialty Certification on Severe Intraventricular Hemorrhage



The effect for staffing and the nurse work environment had an odds ratio of 0.769, p=0.007. While highly significant, based on these values it appears that this is in the opposite of the hypothesized direction indicating that for each additional patient in a nurse's assignment the probability of sIVH decreases. When looking at a visual graph of this relationship (Figure 12) we see that in the poor and average work environments the effect is in the hypothesized direction indicating that there is an increased risk of sIVH with each additional infant assigned to a nurse in these work environments.

Figure 12. Interaction of the Nurse Work Environment and Nurse Staffing on Severe Intraventricular Hemorrhage

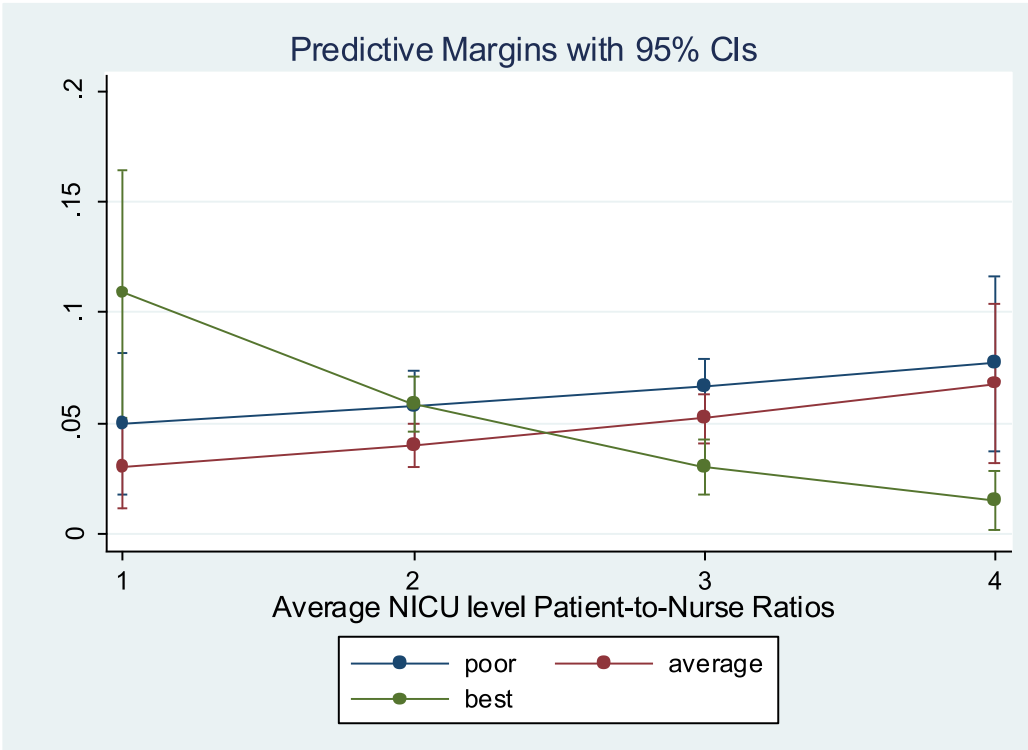


Table 24. Interaction Effect of the Nurse Work Environment and BSN + Certification				
	Severe Intraventricular Hemorrhage			
	Main Effect Model		Interaction Model	
	Odds Ratio	p-value	Odds Ratio	p-value
BSN + Certification	0.940	0.157	0.957	0.273
Nurse Work Environment	0.884	0.043	1.02	0.849
BSN + Certification x Nurse Work Environment			0.934	0.116

The interaction term for the product of the nurse work environment and BSN certified nurses was not statistically significant in the model that estimated the association with severe intraventricular hemorrhage.

Length of Stay

In the negative binomial regression model estimating the effect of the interaction of nurse education and the nurse work environment with length of stay, the interaction term was significant indicating that the slope for the effect of the nurse work environment varies by proportion of nursing education (IRR 0.968, p=0.012). Table 25 provides estimates of the multiplicative effect of both the work environment and BSN or higher nurse education. Figure 13 provides a visual representation of the predicted event rate based on the quality of the nurse work environment. The predicted event rate for length of stay was 40 days in the best work environments when the proportion of BSN nurses was 60% and incrementally decreased to less than 40 days when the proportion of BSN nurses increased to 80%. This effect is not seen in average or poor work environments indicating that there is not an additional benefit of increasing BSN nurses in hospitals with average or poor work environments. These results are consistent with results from Aim 1. Overall, at all levels of proportions of BSN nurses, length of stay is shorter in the best work environments. This interaction term indicates that in the best work environments there is an added benefit of increasing the proportion of BSN nurses.

Table 25. Interaction Effect of the Nurse Work Environment and Education				
	Length of Stay			
	Main Effect Model		Interaction Model	
	IRR	p-value	IRR	p-value
Education	1.002	0.82	1.04	.0.04
Nurse Work Environment	0.960	0.19	1.127	0.03
Education x Nurse Work Environment			0.97	0.01
Implied Effect of Education when the Work Environment is -				
Poor	1.040			
Mixed	1.009			
Better	0.979			
Implied Effect of the Work Environment when %BSN is -				
0	1.127			
10	1.093			
20	1.060			
30	1.029			
40	0.998			
50	0.968			
60	0.939			
70	0.911			
80	0.883			
90	0.857			

Figure 13. Interaction of the Nurse Work Environment and BSN Education on Length of Stay

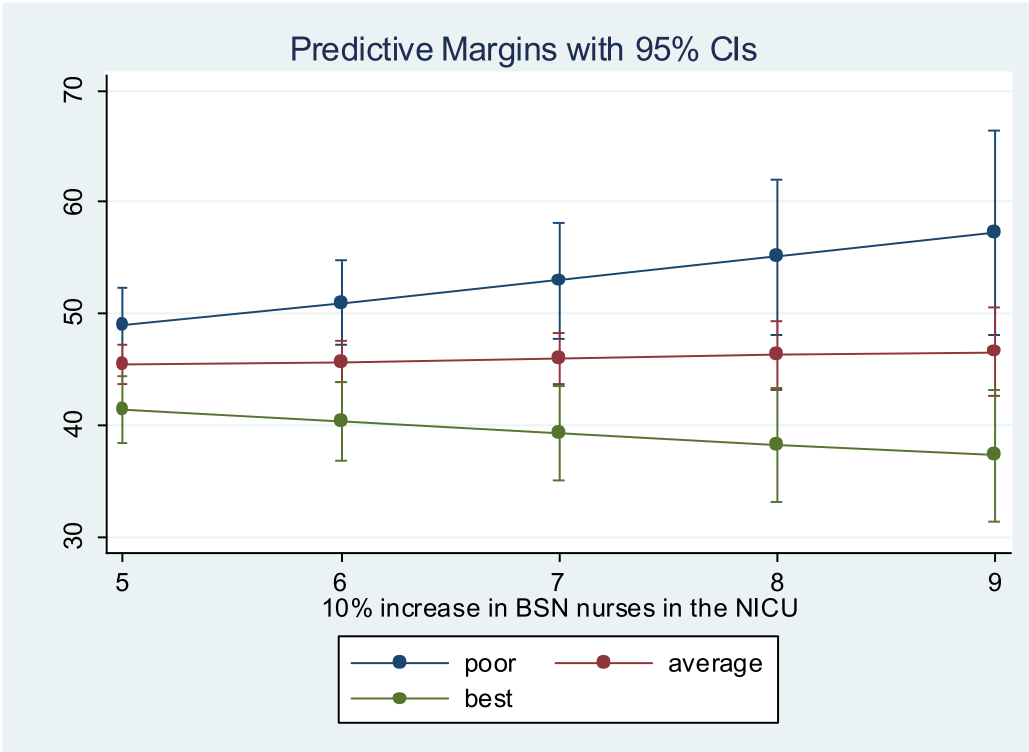


Table 26. Interaction Effect of the Nurse Work Environment and Specialty Certification				
	Length of Stay			
	Main Effect Model		Interaction Model	
	IRR	p-value	IRR	p-value
Specialty Certification	1.000	0.77	1	0.698
Nurse Work Environment	0.961	0.026	0.961	0.32
Specialty Certification x Nurse Work Environment			1	0.8

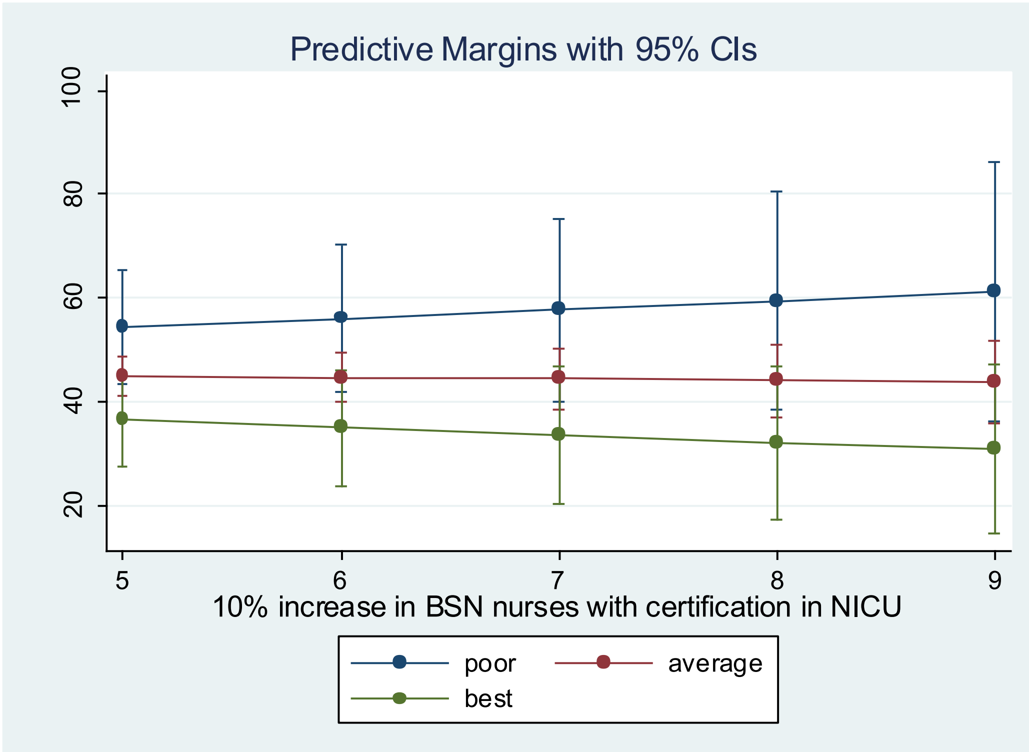
Table 27. Interaction Effect of the Nurse Work Environment and Staffing				
	Length of Stay			
	Main Effect Model		Interaction Model	
	IRR	p-value	IRR	p-value
Staffing	0.920	0.08	0.9	0.041
Nurse Work Environment	0.961	0.026	0.894	0.391
Staffing x Nurse Work Environment			1.03	0.571

Tables 26 and 27 provide incident rate ratios for the interaction terms of the product of the nurse work environment and nurse certification and the nurse work environment and nurse staffing. Neither were significantly associated with length of stay in the negative binomial regression models.

Table 28. Interaction Effect of the Nurse Work Environment and BSN + Certification				
	Length of Stay			
	Main Effect Model		Interaction Model	
	IRR	**p-value**	**IRR**	**p-value**
BSN + Certification	0.990	0.511	0.99	0.698
Nurse Work Environment	0.961	0.026	1	0.709
BSN + Certification x Nurse Work Environment			0.98	0.164

The effect of the product of the proportion of BSN nurses with specialty certification with the nurse work environment was also not statistically significant (IRR 0.98, p=0.164). Consistent with Aim 1 length of stay is shorter in hospitals with the best work environments. The effect is in the hypothesized direction, with the predicted number of events for length of stay equal to 38 days in hospitals with a proportion of 50% BSN nurses with specialty certification and less than 35 days in hospitals with a proportion of over 80% BSN nurses with specialty certification. In poor work environments length of stay is predicted as greater than 50 days with minimal to no change with increasing proportions of BSN nurses with specialty certification. This is graphically depicted in Figure 14.

Figure 14. Interaction of the Nurse Work Environment and BSN Education + Specialty Certification on Length of Stay



Summary

Aim 1: To examine the effect of the nurse work environment on outcomes of very low birth weight infants (in hospital mortality, hospital length of stay, and severe intraventricular hemorrhage).

Mortality

- A better nurse work environment is associated with a lower odds of mortality for very low birth weight infants in the hypothesized direction, but is not statistically significant. The odds ratio of 0.958 indicates that in better work environments mortality is decreased by 4.2%, this may be clinically significant.
- The domain of nurse-physician relations was individually predictive of lower odds of mortality after controlling for infant characteristics (OR 0.92, p=0.023 CI 0.849-0.987) but failed to reach significance after accounting for hospital characteristics (OR 0.92, p=0.059, CI 0.84-1.00).

Severe Intraventricular Hemorrhage

- A better nurse work environment is a significant predictor of lower odds of severe intraventricular hemorrhage. In better work environments the odds of severe intraventricular hemorrhage is decreased by 11.6% after controlling for infant, nurse and hospital characteristics.
- In bivariate analysis the domains of nurse-physician relations, staffing and resource adequacy, nurse participation in hospital affairs and foundations for quality care were all predictors of lower odds of severe intraventricular hemorrhage. After controlling for infant characteristics all remained significant.

After controlling for NICU volume, level of care and hospital teaching status the only domain that reached significance was nursing foundations for quality of care (OR 0.87, p=0.027 CI 0.77-0.98).

Length of Stay

- The nurse work environment was significantly associated with shorter NICU lengths of stay. This relationship was maintained after accounting for mortality and transfers which decrease average length of stay.
- The only domain that predicted shorter length of stay is nurse-physician relations. After controlling for early stay mortality and transfers this relationship was significant with a 5.3% lower incident rate ratio for length of stay. This remained significant after accounting for nurse and hospital characteristics (IRR 0.96, p=0.03 CI 0.93-0.99). The domains of nurse manager ability, leadership and support, staffing and resource adequacy and nurse participation in hospital affairs were marginally significant.

Aim 2: To examine the direct effects of nurse staffing, education and certification and to examine the interaction effects of the nurse work environment with staffing, education and, certification on outcomes of very low birth weight infants (in hospital mortality, hospital length of stay, and severe intraventricular hemorrhage).

Mortality:

- Educational preparation, specialty certification and nurse staffing were not predictors of very low birth weight mortality.

- A higher proportion of bachelor's prepared nurses in better nurse work environments was significantly associated with lower odds of mortality for very low birth weight infants. This interaction was not significant in poor and average work environments. The interactions of nurse certification and nurse staffing with the nurse work environment did not have a significant effect on mortality. The interaction of BSN educated and certified nurses approached significance.

Severe Intraventricular Hemorrhage:

- Nurse education, specialty certification and nurse staffing were not predictors of severe intraventricular hemorrhage in very low birth weight infants.
- The interactions of nurse education with the nurse work environment was not significant. The interactions of specialty certification and nurse staffing with the nurse work environment were significant. There is added benefit of nurse specialty certification to the effect of the nurse work environment on the risk of severe intraventricular hemorrhage. The interaction effect for staffing and the nurse work environment is complicated.

Length of Stay

- No relationship between nurse education, specialty certification or nurse staffing and length of stay was demonstrated.
- The interaction of the nurse work environment and nurse education was significant. Length of stay is shorter in NICUs with better work environments and with higher proportions of BSN educated nurses.

Chapter 5: Discussion

Introduction

The purpose of this study was to develop a better understanding of the relationship between the organization of nursing within the neonatal intensive care unit, specifically the nurse work environment and outcomes of very low birth weight infants. The study further investigated the association of very low birth weight infant outcomes with the nurse workforce and nurse qualifications, and finally, examined the interaction of each of these with the nurse work environment. This is the first study to examine the relationship of the nurse work environment with mortality, severe intraventricular hemorrhage and length of stay in very low birth weight infants. The results of this study indicate that the nurse workforce and nurse qualifications within the neonatal intensive care unit, specifically the nurse work environment and nurse education and certification, have the potential to contribute to improvement in outcomes of very low birth weight infants. This chapter discusses the study's primary findings, the limitations of the research study and implications of these findings including recommendations for future research.

Main Findings: Specific Aim 1

The primary aim of this study was to explore the relationship of the nurse work environment and three outcomes of very low birth weight infants: mortality, severe intraventricular hemorrhage, and length of stay. The study findings are as follows: 1) better nurse work environments were associated with lower odds of mortality; each one standard deviation unit increase in the nurse work environment score was associated with a 4.6% lower odds of mortality, although this association was not significant in the fully adjusted model, 2) better work environments were significantly associated with lower odds of severe intraventricular hemorrhage; each one standard deviation unit increase in the nurse work environment score was associated with a 11.6% lower odds of severe intraventricular hemorrhage and 3) a better nurse work environment was significantly associated with shorter length of stay; each one standard deviation unit increase in the nurse work environment score was associated with a two day shorter length of stay for very low birth weight infants receiving care in neonatal intensive care units.

These findings are consistent with extensive work in adult outcomes that have established the relationship between better nurse work environments and lower rates of mortality (Aiken, Cimiotti, et al., 2011; Aiken, Sloane, et al., 2011; Lake et al., 2015; Lake, Hallowell, et al., 2016; McHugh & Ma, 2013) and expands from research that establishes the relationship of hospitals known for nursing excellence- Magnet® designation- and lower rates of mortality and severe intraventricular hemorrhage in very low birth weight infants (Lake et al., 2012). In these studies, the nurse work environment or Magnet® designation, the intervention, is measured at the hospital level. It is evident that there is a hospital effect that permeates the populations studied. It is plausible that the effect of these interventions on patient outcomes may not be uniformly distributed in all hospital units, i.e. favorable nurse environments in the adult cardiac care unit, or surgical intensive care units may not effect outcomes of very low birth weight infants in the neonatal intensive care unit (Ma & Park, 2015). This study adds to this previous work in two primary ways.

First, the nurse work environment was measured from nurses working in the same hospital units – neonatal intensive care units –as the very low birth weight infants and second, the nurse work environment is a composite measure of five subscales, offering the potential to investigate within the nurse work environment the components that have the greatest impact on outcomes of very low birth weight infants receiving care in neonatal intensive care units. This could provide a better understanding of what elements of the nurse work environment contribute most to VLBW infant outcomes and allow for targeted interventions to improve these aspects of the nurse work environment.

The Nurse Work Environment and Mortality

Mortality of very low birth weight infants is a national priority (Butler & Behrman, 2007; *Report of the Secretary' s Advisory Committee on Infant Mortality*, 2013) and is identified as a quality indicator by the Agency for Healthcare Research and Quality (AHRQ). Contemporary literature has focused predominantly on medical interventions, NICU level of care, and NICU volume and has hypothesized that variation in care practices may explain variations in mortality. Despite recognition that nurses trained in the specific care of very low birth weight infants are critical to their survival, there is limited research that evaluates nursing factors as contributing to mortality. Research evaluating nursing factors as contributing to outcomes of low birth weight infants has focused on nurse staffing and linked the nurse work environment with other VLBW outcomes, including breastmilk provision and breastfeeding support (Hallowell et al., 2016, 2014, Rogowski et al., 2013, 2015).

The hypothesized mechanism that explains the association between the nurse work environment and mortality of VLBW infants is nurse surveillance. Nurse surveillance is defined as the nurse's continuous process of observation, assessment, recognition, interpretation of clinical information and decision-making based on the on-going accumulation of patient information gathered (Kutney-Lee, Lake, & Aiken, 2009). Kutney-Lee et al. propose that nurse surveillance is a function of both individual nurses and a collective effort of nurses over time. As a collective surveillance system, nurses monitor and intervene when there are changes or deterioration in the infants' condition. The ability to astutely observe and act in a timely manner requires patient specific knowledge, adequate staffing, support and collaboration with colleagues and unit policies that support nursing care and intervention (Kutney-Lee, Lake, et al., 2009). By creating the Hospital Nurse Surveillance Capacity Profile (Kutney-Lee, Lake, et al., 2009) the authors proposed that the collective of better nurse work environments, lower patient to nurse ratios, a better educated nurse workforce, nurse specialty certification and nurse experience are associated with better quality of care and fewer adverse events.

In addition to testing the impact of the nurse work environment, the final model in Aim 1 accounted for nurse education, nurse specialty certification and staffing. Evaluation of the nurse work environment subscales further point to key aspects of the nurse work environment that contribute to the nurse's ability to provide surveillance and thereby prevent complications and death. The subscales with the greatest effect on mortality are nurse-physician relations (OR 0.92, p=0.059, CI 0.84-1.00) and foundations for quality of care (OR 0.94, p= 0.171, CI 0.86-1.02). The nurse-physician relations domain reflects nurse physician teamwork, positive relationships and collaborative care. The foundations for quality of care domain reflects organizational support of nursing care, prioritizes patient assignments with a focus on continuity of care, clinical competence of nursing through preceptor programs, on-going nursing education and an organizational expectation of high nursing standards. Each of these elements fosters the nurse's ability to know the infant's needs, focus on subtle changes that may be specific to the infant and require intervention, confidently act as an advocate for the infant and contribute to a collaborative team effort to prevent adverse events and poor outcomes. While each of these components is vital, in the neonatal intensive care unit with long infant lengths of stay (median 41 days), patient assignments focused on continuity of care would have more significance than units with shorter hospital stays. Recent research evaluated missed nursing care in neonatal intensive care units and pediatrics generally (Lake, de Cordova, et al., 2017; Tubbs-Cooley, Pickler, Younger, & Mark, 2015). In these studies, it was found that one of the most frequent reported care activities missed is daily attendance at rounds. Broadly, daily rounds is a discussion led by a physician or nurse practitioner about the individual patient's care. In the NICU participation in daily rounds by the bedside nurse, respiratory therapist, pharmacist and parents is highly encouraged. Daily rounds provide the opportunity for nurse physician teamwork and collaboration. An adult study of organizational characteristics associated with ICU patient outcomes found that daily rounds by an ICU physician was associated with decreased patient mortality and not having an ICU physician on daily rounds was associated with an increase in risk of cardiac arrest, renal failure, infection, platelet transfusion and reintubation (Pronovost et al., 1999). This study emphasized the presence of an ICU physician daily for rounds. Direct correlation cannot be made here, but evidence does suggest and is possibly implied that daily nurse physician discussion of the patient's status and care needs may result in better patient outcomes.

The Nurse Work Environment and Severe Intraventricular Hemorrhage

Severe intraventricular hemorrhage is a major morbidity of preterm birth and contributes significantly to mortality and long term neurodevelopmental impairment. The variation in rates across NICUs after adjusting for infant risk suggest variation in unit care practices. Current research identifies medical interventions- caffeine, prophylactic indomethacin, delayed cord clamping and volume ventilation, (Lea et al., 2017; Schmidt et al., 2003) care practices – delivery room resuscitation by an experienced team, thermoregulation with temperature >= 36C, cardiorespiratory stability with surfactant administration, minimize pain and stress, minimize, noise, handling and lighting, use optimal positioning including neutral or midline head positioning, prevention of hypocapnia, blood pressure regulation and care clustering (Carteaux et al., 2003) and NICU characteristics, high volume, high neonatologist to staff ratio (Synnes et al., 2006) and better organizational process scores of leadership and coordination (Pollack & Koch, 2003)- are associated with lower rates of severe intraventricular hemorrhage. The evidence supporting indomethacin is inconclusive, (Foglia et al., 2018) and there is underutilization and lack of consistency in practice for other medical interventions (Lea et al., 2017). The support for care practices – expertise in delivery room resuscitation, thermoregulation, midline head positioning, decreased noise and lighting, minimal handling and care clustering - are widely accepted, but there is tremendous variation in care practices among nurses, physicians and neonatal intensive care units (Carteaux et al., 2003; McLendon et al., 2003). All of these care practices directly involve nursing, both through active surveillance and intervention, and require both independent nurse practice and care and as well as collaboration with physician colleagues.

In order to assure that such care is delivered, the nurse work environment must support nurses providing this care and recognize the value, ability and contribution of nursing and facilitate collaboration with physician colleagues. Lake and colleagues (Lake et al., 2012) found that Magnet® designation was associated with a lower incidence of sIVH. Magnet® designation is earned though the American Nurses Credentialing Center (ANCC) when hospitals demonstrate a commitment to nursing excellence in five components: transformational leadership, structure empowerment, exemplary professional practice, new knowledge, innovation and improvements and empirical quality results. Magnet® hospitals are associated with better nurse-physician relationships, (L. A. Kelly, McHugh, & Aiken, 2011) better nurse work environments (Mchugh et al., 2013) and lower nurse dissatisfaction and burnout.

The results from two NICU network studies, the Canadian Neonatal Network and the District of Colombia Neonatal Network that evaluated outcomes of VLBW infants with NICU characteristics and NICU organizational characteristics (Pollack & Koch, 2003; Synnes et al., 2006) suggest that characteristics within the NICU, including expert practitioners, managerial practices and organizational processes are associated with lower rates of sIVH. These results and the results from Lake and colleagues support the finding of this study that found a lower incidence of sIVH was associated with better nurse work environments. Pollack and colleagues evaluated VLBW infant outcomes as influenced by institutional organizational features, the instrument used in their study had seven constructs: leadership, communication, coordination, effectiveness, problem solving, authority and job satisfaction (Pollack & Koch, 2003). They found a lower incidence of intraventricular hemorrhage and periventricular leukomalacia (PVL) was associated with higher overall organizational ratings and specifically, in the constructs of leadership, coordination and conflict resolution. This finding was from a composite score analyzed jointly across nurses, physicians and respiratory therapists. In analysis of the individual provider groups, the findings were only significant in the nurse group. McLendon, Carteaux and colleagues identified similar concepts -collaboration, communication, education and dedicated leadership, as necessary when implementing improvement in care practices associated with decreased IVH (Carteaux et al., 2003; McLendon et al., 2003).

In this study, additional examination of the nurse work environment subscales showed that three domains most influenced the outcome of severe intraventricular hemorrhage. The domain foundations for quality of care was significantly associated with lower odds of severe intraventricular hemorrhage after adjusting for infant, nursing and hospitals characteristics (OR 0.87, CI 0.77-0.98, p=0.027). Hospitals and units that have high ratings of foundations of quality of care recognize nursing care as independent of a medical care model, prioritize assignments for continuity of care to encourage and foster the nurse- patient relationship, offer patient specific or unit specific preceptorship for new nurses and provide on-going nursing education and administration recognizes nursing's influence by demanding high standards of care and assuring a clinically competent nursing workforce.

The domains nurse physician relations (OR 0.89, CI 0.79-1 p= 0.06), and staffing and resource adequacy (OR 0.989 CI 0.79-1.01, P =0.09) also showed an effect on severe intraventricular hemorrhage, although in the fully adjusted models neither achieved statistical significance. Nurse agreement with domains indicate the presence of adequate nurse staffing, adequate supportive staff that allow the nurses to provide quality care, assure that nurses have the time and opportunity to discuss patient care with other nurses, foster teamwork with physicians, positive relationships with physician colleagues and encourage care collaborations. The summation of these qualities are evident in Magnet® hospitals and interdisciplinary, quality collaboratives (Grover et al., 2015; Horbar et al., 2001; Lake et al., 2012). The Vermont Oxford Network (VON) and Children's Hospital Neonatal Consortium (CHNC) facilitate collaboration of quality improvement projects across NICUs, each focusing on evidence based interdisciplinary work targeted for specific outcomes. Magnet® Hospitals and NICU care collaboratives are associated with better patient outcomes (Barnes, Rearden, & Mchugh, 2016; Grooms, Froehle, Provost, Handyside, & Kaplan, 2017; Grover et al., 2015; Lake et al., 2012; Ma & Park, 2015; Mchugh et al., 2013; McLendon et al., 2003). It would be likely that NICUs that are within a Magnet® Hospital and those that actively participate in these NICU specific care collaboratives would have better nurse work environments, although this has not been studied.

The Nurse Work Environment and Length of Stay

There is little research using length of stay as an outcome in NICU studies. There is even a smaller volume of research that links nursing factors to length of stay in the NICU. It is known that higher proportions of BSN nurses are associated with shorter lengths of stay for adults with serious mental illness (Kutney-Lee & Aiken, 2008). It is also known that NICU lengths of stay are long and directly related to cost (Russell et al., 2007; Schmitt, Sneed, & Phibbs, 2006).

It is hypothesized that nurses contribute to shorter lengths of stay through two mechanisms. Quality nursing care decreases complications that lead to longer lengths of stay (Russell et al., 2007) and nurses contribute significantly to preparation of the infant and family for discharge (Weiss et al., 2008; Weiss, Yakusheva, & Bobay, 2011). The American Academy of Pediatrics (AAP) in a published policy statement entitled "Hospital Discharge of the High-Risk Neonate" provides uniform guidelines for infant discharge. The recommendations include readiness of the infant, the family and home environment and the community and health care system. Infant readiness is determined by the physician based on the infant's clinical status. Family and home readiness is determined jointly by the health care providers and the family when the following capabilities have been demonstrated: – parents and caregivers have knowledge and skills of the infant's care including feeding, bathing, skin care, temperature measurement, infant cardiopulmonary resuscitation, assessment of infant's clinical status with identification of early signs and symptoms of illness, safety precautions and medication administration (Committee on Fetus and Newborn, 2008). The preparation of the family's readiness is most often the responsibility of the nurse. Recent studies indicate that in the neonatal intensive care unit, nursing care is left undone and that care is more frequently left undone in poor work environments (Lake et al., 2015; Lake, de Cordova, et al., 2017; Tubbs-Cooley et al., 2015). In one study, discharge teaching was reported as left undone by 15% of the nurses on their previous shift, this increased to 20% in poor work environments (Lake, De Cordova, et al., 2017). A second study reported that parent education was one of the most frequent activities left undone (Tubbs-Cooley et al., 2015). Parent education and discharge teaching left undone would likely delay family readiness for discharge and result in longer lengths of stay.

This is the first known study to link the nurse work environment to length of stay in this population. The findings of this study that support the association of better nurse work environments with shorter lengths of stay is consistent with previous research associating better nurse staffing and higher nurse education with shorter lengths of stay in adult ICU and surgical patients (Kane et al., 2007; Kutney-Lee & Aiken, 2008). There is some literature that focuses on the nurse's role in facilitation of discharge (Weiss et al., 2008, 2011), but studies on length of stay are limited. Outcomes associated with increased length of stay include sepsis and necrotizing enterocolitis (Bisquera, Cooper, & Berseth, 2002; Stoll et al., 2002). There is evidence to support the nurse's role in decreasing both sepsis and necrotizing enterocolitis, but these studies did not evaluate length of stay (Cimiotti et al., 2006; Gephart, McGrath, & Effken, 2011; Rogowski et al., 2013).

In a recent quality improvement project focused on decreasing length of stay for infants treated for neonatal abstinence syndrome (NAS), the most effective interventions included establishing a standardized treatment protocol, enhancing communication between physicians and registered nurses and nursing education specific to the patient population and treatment protocol (Asti, Magers, Keels, Wispe, & McClead, 2015). Infants with NAS are not VLBW infants, however establishing a standardized treatment protocol, i.e. having a standard pathway to discharge, enhancing communication between physicians and registered nurses and providing or requiring nursing education specific to not only the intensive care required by very low birth weight infants, but also the preparation for discharge and transition to home, all align with elements of the nurse work environment, specifically nurse-physician relations, which independently predicted lower IRR for length of stay.

It could be that VLBW infants cared for in the better work environments are less ill and therefore have shorter lengths of stay. Based on available infant characteristics at birth, this does not seem to be the case. It is known that infants with complications such as sepsis, necrotizing enterocolitis and severe intraventricular hemorrhage have longer lengths of stay, but it is also hypothesized that these complications could be a reflection of poorer quality of care observed in poor work environments.

Main Findings: Specific Aim 2

The second aim of this study was to explore the effects of nurse education, nurse certification and nurse staffing on infant outcomes and to evaluate the interaction of each of these nursing factors with the effect of the nurse work environment. It was hypothesized that the effect of these nursing factors would be different in varying nurse work environments.

Nurse Education, Certification and Staffing and Infant Outcomes

The effect of nurse education, nurse certification and nurse staffing on outcomes of very low birth weight infant was minimal. These findings differ from those in adult studies that found higher nurse education and better nurse staffing were statistically associated with better patient outcomes (Aiken, Cimiotti, et al., 2011; Aiken et al., 2002; Kutney-Lee & Aiken, 2008). There are no previous studies that evaluated nurse education and infant outcomes in the neonatal intensive care unit. Studies of staffing within the NICU have associated understaffing and increased workload with increased infection for VLBW infants (Cimiotti et al., 2006; Rogowski et al., 2013). While the hypothesis was that better nurse staffing would be associated with better outcomes, there was little variation observed in staffing ratios in this sample. At the hospital level, sixty-five percent of the hospitals had an average patient-to-nurse ratio that ranged between 2 and 3, less than 9 percent had an average ratio below 2 and 24% had an average ratio greater than 3. The Guidelines for Professional Registered Nurse Staffing for Perinatal Units Executive Summary allow for patient/nurse ratios that range from less than one to four based on the infant's care needs (Schofield et al., 2010). In this sample, of the 24% that had ratios greater than 3, less than 3% of hospitals had average ratios of greater than 4 patients/nurse. This is consistent with recent studies of NICU nurses that found that neither nurse staffing nor nurse education were associated with infant outcomes (Hallowell et al., 2016; Lake et al., 2015). Additionally, in the study by Rogowski and colleagues that found an association of nurse understaffing and higher rates of infection, the researchers calculated nurse-to-patient ratios by infant acuity. Given that there was little variation in staffing, and infant acuity was not accounted for in this study, the non-significant results for the effect of staffing are not entirely unexpected. Interestingly, the subscale of staffing and resource adequacy was statistically significant in an association with sIVH (OR 0.88, p=0.03) and length of stay (IRR 0.95, p=0.01) after accounting for patient and nurse characteristics, but before accounting for the hospital characteristic of teaching intensity. For the outcome length of stay, the effect was in the opposite direction from the hypothesis. For each additional patient per nurse there was a decrease in length of stay. This may not initially or intuitively make sense; however, there is evidence that staffing ratios differ based on infant acuity (Rogowski et al., 2015; Schofield et al., 2010). Infants that are clinically stable and ready for discharge would score lower on acuity measures and therefore would be "eligible" for a higher patient-to-nurse ratio. So, while we may not see the hypothesized effect in this study, the results may reflect appropriate acuity adjusted staffing.

The Interaction of the Nurse Work Environment and Nurse Education, Certification and Staffing on Infant Outcomes

The final analysis of aim 2 was to explore the interaction effect of the nurse work environment with nurse education, nurse certification and nurse staffing with the hypothesis that in better environments the effect for each element, better nurse education, nurse certification and nurse staffing would be associated with better infant outcomes. The findings provide evidence that these nursing factors exhibit effects in the context of varying nurse work environments. This is consistent with evidence from adult populations (Aiken, Cimiotti, et al., 2011; Aiken et al., 2008; Aiken, Sochalski, & Lake, 2017; Nicely, Sloane, & Aiken, 2013). The results show that for each 10% increase in the proportion of BSN educated nurses that work in NICUs with the best nurse work environments, the likelihood of mortality is incrementally reduced. This effect is not seen in average or poor work environments. Despite increased proportions of BSN educated nurses, the likelihood of mortality is unchanged in average and poor nurse work environments. For both the outcomes of mortality and length of stay, the effect of this relationship was statistically significant. This is the first study to demonstrate this relationship on outcomes of VLBW infants. In aim 1 there was no independent effect of nurse education on either of these outcomes. The impact of education is contingent on the quality of the nurse work environment. This implies that increasing the proportion of BSN educated nurses in poor or average work environments without also improving the nurse work environment may not have an effect on patient outcomes.

There was also an effect seen for nurse specialty certification and the nurse work environment with the outcome of severe intraventricular hemorrhage. There are no prior studies in this population that have evaluated this relationship. Adult studies examining the effect of nurse specialty certification have mixed results. There are some studies that show an association between nurse specialty certification and better patient outcomes. Kendall-Gallagher and colleagues showed that nurse specialty certification is inversely related to patient falls, and in a second study showed that nurse specialty certification contingent upon BSN education is associated with lower rates of mortality and failure to rescue (Kendall-Gallagher et al., 2011; Kendall-Gallagher & Blegen, 2009). The results of this study also show that nurse specialty certification is contingent on other nursing factors, specifically the nurse work environment. No significant effect either independent or an interaction effect of specialty certification with BSN education and the nurse work environment was seen, although the effects were consistently in the hypothesized direction. The care of very low birth weight infants is complex and requires clinical competence and specialized knowledge of the patient population. And as discussed in the main findings for aim 1, specific knowledge and care is necessary in the prevention of severe intraventricular hemorrhage in very low birth weight infants. Knowledge specific to this population and the timing of prevention is necessary to achieve reductions of this neonatal complication. NICU nurses with specialty certification represent nurses with a validated level of clinical knowledge in combination with experience and formal education (Kendall-Gallagher & Blegen, 2009). NICU nurses with the combination of clinical knowledge, formal education and experience would be more likely to be able to provide specific and specialized care and work both independently and collaboratively with nurse and physician colleagues to achieve lower rates of severe intraventricular hemorrhage.

Limitations

There are several limitations to be acknowledged. Key limitations in the study include 1) the infant data set is extracted from hospital discharge data and is not linked to birth certificates, which would increase the coverage of the true population sample, 2) the use of hospital discharge data limits risk adjustment, 3) the cross-sectional study design limits causal inference, 4) the nurse survey data are self-reported, which introduces the potential for bias, and 5) the survey had a 39% response rate and 6) the data are from 2005 and 2006.

The infant sample extracted from hospital discharge data yielded 25,049 infants and represents 86% of the population of very low birth weight infants for the study years. This limitation is due to use of inpatient hospital discharge data. When this data is linked with birth certificate data, greater than 98% of the population is identified (Jensen & Lorch, 2015). Missing 14% of the population is not ideal. However, the infant sample is believed to be a fair, representative sample and mirrors the entire population based on known infant characteristics. Additionally, the hospital sample, derived from responses of random samples of licensed nurses, avoids the biases introduced by hospitals' ability to "opt in" as is the case in network data (e.g., VON and Neonatal Research Network).

Use of hospital discharge records, i.e. administrative data, challenges the researcher's capacity for risk adjustment. Infant characteristics used for risk adjustment were identified using ICD-9-CM codes. The reliability of ICD-9-CM code use in neonatal studies has previously been studied. These studies assessed accuracy and completeness of ICD-9CM coding for lower birth weight infants. Based on the findings, use of ICD-9-CM codes was determined to have high specificity and accuracy, and thus provides validity to research relying on use of ICD-9-CM codes (Barrett, Sevick, Conlin, Gumbs, & Lee, 2012; Phiri et al., 2015). The distribution of infant characteristics in this sample is consistent with distributions based on NVS data and Vermont Oxford Network data published from the same time period (Horbar et al., 2012; Martin et al., 2009).

Risk adjustment in this study was limited by the available infant characteristics in the data. Birth weight category, race, gender and insurance status were used for risk adjustment (all infants with outborn status or with congenital anomalies were excluded). Variables representing these characteristics were first used in a model to predict mortality. Published area under the curve (AUC) values for mortality prediction in infants less than 1500 grams using the VON risk adjustment (VON-RA) and physiologic risk scores are 0.85 and 0.86 (Zupancic et al., 2007). The VON risk adjustment (VON-RA) method is one of the most widely used and accepted risk adjustment models for neonatal infants. The VON-RA includes variables for gestational age, gestational age squared, multiple gestation, outborn status, Apgar score, gender, cesarean section and presence of congenital anomalies (Zupancic et al., 2007). The VON risk adjustment has been compared to physiologic risk scores and was found to predict mortality similarly. There are no comparisons of VON-RA with risk adjustment using administrative data.

The AUC using birth weight category, race, gender and insurance status for this study was 0.83. Using all infants the AUC was 0.94 when including congenital anomalies and outborn infants, which is consistent with the VON-RA model that has an AUC of 0.93 (Zupancic et al., 2007). The standardized risk adjustment used by AHRQ for neonatal mortality includes variables for birth weight category, sex, congenital anomalies. The AUC using this model ranges from 0.879 - 0.92 (Agency for Health Care Research and Quality, 2017). The risk adjustment in this study additionally accounted for race and insurance status.

The observational, cross-sectional design limits inference of causation. In the future, a longitudinal approach would strengthen the ability to make causal inference with such observational data.

In order to evaluate for potential low response bias, Aiken and colleagues followed the initial survey with a non-responder survey of 1300. The response rate was 91% and evaluation of results indicated no significant bias on job related variables including the work environment (Smith, 2008).

The data used for this study are from the years 2005 and 2006. The use of data from more than a decade ago may present certain issues, including, the current relevance of the data, concern that the data does not represent contemporary issues, concern that secular trends or new interventions have not been accounted for, and concern that the relationships in the results are no longer relevant to the current population. In order to address these concerns, current outcomes of very low birth weight infants, secular trends and evidence of new technology or interventions available for very low birth weight infants were considered. The average mortality rate in this study was 10.8%. Recent analysis from VON reports mortality in 2014 as 10.9% with a reduction from 14% in 2005. While an overall improvement in mortality is observed, the current rate of mortality still contributes significantly to infant mortality (Mathews et al., 2015) and does not differ with the observed mortality rate in this study. Perhaps more importantly, the significant variation in outcomes observed across institutions in this study persists in more contemporary studies (Horbar et al., 2017). An additional concern is whether technology or new interventions are contributing to the overall improvement in observed outcomes. In several recent studies, experts acknowledge that no new major care practices, technology or treatments that have significantly affected mortality of very low birth weight infants in the past 10 years (Stoll et al., 2010, 2015). Despite overall improvements, with lower rates of mortality and morbidities, institution-level variation in mortality and morbidities still exists and long-term outcomes have not improved (Schmidt, Roberts, Davis, Doyle, Asztalos, Opie, Bairam, Scapinello, et al., 2015). The population also has not changed; the proportion of VLBW infants in 2016, the most recent year available from National Vital Statistics, is similar to that of 2005-2006, representing ~2% of all live births (Martin et al., 2018). Insurance status might also be a concern if changed over this period. However, in this sample, 48% had private insurance and 44% had Medicaid coverage, which matches the current landscape, where 49% have private insurance and 42% are supported by Medicaid (Martin et al., 2018).

In summary, these large linked datasets provided a unique opportunity to examine the nursing workforce, nurse qualifications and the nurse work environment in the neonatal intensive care units and their relationships with infant outcomes. The significance of the nurse relationship to infant outcomes remains unchanged over time. Nurses are recognized both historically and presently as essential to care of these vulnerable infants (Gartner et al., 2001). This study provided an opportunity to evaluate the relationship of nursing in the neonatal intensive care unit using variables from the nurse survey on outcomes of very low birth weight infants. This new knowledge of these relationships establishes an approach for future research studies.

Implications for Practice and Policy

The findings of this study have important implications for very low birth weight infants, their families, nurses, physicians, hospital administrators and policy makers. Unfortunately, preterm births have not decreased. For each of the past two years the rate of preterm births has increased (Martin et al., 2018). As the number of preterm births rise there will be an increased demand for specialized neonatal care providers, including nurses. Care of these infants requires specialized knowledge, the ability to work with technology and collaboration with physicians and the entire interdisciplinary NICU care team. While this study did not evaluate the specific mechanisms or processes of nursing care that may contribute to the findings of reductions in mortality, severe intraventricular hemorrhage and length of stay, the evidence that nursing qualifications and the quality of the nurse work environment are associated with better outcomes for very low birth weight infants should resonate with NICU leadership, including nurse managers and NICU directors. These findings suggest that efforts to improve nursing quality through better nurse work environments and increasing the proportions of BSN educated and specialty certified nurses have the potential to reduce mortality, severe intraventricular hemorrhage and length of stay for very low birth weight infants.

Birth of a new human is supposed to be a joyous event, but an extremely preterm birth and the subsequent struggle to maintain life are tragedies. Each VLBW infant requires extensive care aided by technology, treatments, procedures, and medical and nursing care in order to fight for survival. Despite sophisticated technology and advances in care, complications are frequent. The cost of this care is tremendous and billions of dollars are spent each year on hospitalizations and throughout the first years of life due to complications. This cost is a burden for hospitals, payers and families. It cannot be denied that technology and innovations in care have contributed greatly to survival in this population. Unfortunately, despite the considerable resources including technology and medical innovation, extensive variation in complications and long-term outcomes exist.

Access to hospitals with sophisticated technology and expert care providers varies greatly and explains some variation in outcomes (Jensen & Lorch, 2015; Phibbs, Baker, Caughey, Danielsen, et al., 2007). Infants born with birth weights less than 1500 grams should be delivered in a hospital with appropriate level of care. The current AAP Level of Care guidelines state that Level 3 NICUs are equipped to comprehensively provide care for these infants (Barfield et al., 2012). In this sample, 96% of all infants received care in a Level 3 or 4 NICU, indicating that the majority of very low birth weight infants had access to the appropriate level of care. It is well established that efforts should be made to ensure that infants delivered preterm are born in facilities with the technology and clinical team to support their care. The National Quality Forum endorses delivery at appropriate level of care as a measure of perinatal quality (Weireter, 2012). This study highlights variation in the nursing workforce, nurse qualifications and quality of nurse work environments in NICUs with similar technology and physician access. In order to improve outcomes of very low birth weight infants, it is necessary that we maximize the nurses' contribution within these neonatal intensive care units.

This study adds to the evidence that nursing qualifications and the professional nurse work environment contribute to outcomes of very low birth weight infants. This is now the fourth study that evaluates structural elements including the nurse work environment, organizations known for nursing excellence or organizations with high ratings of leadership, communication and conflict resolution as identified from nurses that has provided evidence of statistically lower incidence of severe intraventricular hemorrhage. Based on this evidence NICU leadership and hospital administration should prioritize efforts for improvement in the professional nurse work environment. Specifically, NICU unit efforts should focus on nurse-physician relations, improving staffing and resources and foundations of quality of care. Such programs and policies would encourage teamwork and communication between physicians and nurses and prioritize unit care practices that are collaborative and focused on patient outcomes and prioritize continuity in-patient care assignments. Nurse education and certification should be prioritized. NICU leadership should make intentional and actionable efforts to increase the proportion of BSN nurses by requiring BSN education of new staff and by offering financial support and incentives for current staff to obtain a BSN degree. Education in neonatal care should also be a priority. The neonatal curriculum in BSN degree programs is minimal. New nurses in the NICU need formal didactic education and preceptorship in order to have the skills and knowledge to provide nursing care for this specific patient population. In-service and continuing education for all staff is also necessary as our knowledge and research in this field progresses. The Association of Women, Obstetric and Neonatal Nurses, the National Association of Neonatal Nurses, the Academy of Neonatal Nurses and the National Certification Corporation all provide extensive evidence-based practice education and guidelines for care for these infants. Nurse membership and use of these guidelines should be encouraged and financial incentives offered by NICU leadership and hospital administration.

State and national efforts should also be made to recognize these findings and support and promote research and policy that gives equal attention to the quality of nursing care as is placed on technology, medical intervention and pharmaceutical therapy. The availability and development of technology for these infants has changed considerably in the past 50 years. Unfortunately, there has been little change in the requirement of training and education for the nurses providing care for these infants. Registered nurse licensure is regulated at the state level, initial requirements are minimal and on-going licensure requirements vary by state. Some nursing state boards require self-reported continuing education, however, auditing and verification of this requirement is highly variable. At the advanced practice level some state boards of nursing require specialty certification for licensure, but this is also inconsistent. Nurses are eligible for registered nurse (RN) nurse specialty certification (from various agencies and associations) after 2 years of experience in their specialty field. This also corresponds to state licensure renewal. This provides an opportunity for state boards to encourage on-going patient specific education by requiring specialty certification for each subsequent licensure renewal. In addition to the specialty education and demonstration of knowledge required for the initial certification, continued certification requires on-going education specific to the field of specialty. If this was accomplished at the hospital level, it would continue to create variation in nursing care across hospitals rather than ensure that nursing quality is consistent throughout the state for all VLBW infants. At the national level, the Centers for Medicare and Medicaid Services (CMS) and the National Institutes of Health should increase funding support for research and programs that demonstrate quality through nurses and nursing care.

In this study 44% of all very low birth weight infants were covered by Medicaid. It would be expected that 75% of these infants are born in hospitals with average and poor work environments, however, infants with Medicaid are born disproportionately (81%) in these hospitals. Improving the nurse work environment is not without cost, but the comorbidities potentially associated with poor and average work environments are even more costly. In a recent study evaluating the cost and length of stay for a central line-associated bloodstream infection, Goudie and colleagues found that neonates experiencing a central line-associated bloodstream infection (CLABSI) during their hospital stay had a mean cost difference of $90,221 and length of stay of 31.5 days compared to neonates without a CLABSI ($206, 982 vs. $116,761 and 91.8 vs. 60.2 days) (Goudie, Dynan, Brady, & Rettiganti, 2014).

While this current study did not evaluate infection, previous research has tied better nurse staffing and Magnet® hospitals to decreased infection rates (Cimiotti et al., 2006; Lake et al., 2012; Rogowski et al., 2013). The Centers for Medicare and Medicaid Services no longer reimburse for additional hospital cost as a result of hospital-associated infection. Vascular Catheter-Associated Infections are considered a provider preventable condition and according to section 2701 of the Patient Protection and Affordable Care Act of 2010, (*Patient Protection and Affordable Care Act*, 2010) federal payment to states for health care-acquired conditions is prohibited. The Children's Health Insurance Program Reauthorization Act (CHIPRA) signed by President Obama in 2009 placed dual emphasis on the transformation of children's health in the United States through quality of care and coverage of care. Quality of care efforts were specified as standardized quality measures, reporting of quality measures and alignment of incentives to focus on quality and child health outcomes (HHS Secretary's Efforts to Improve Children's Health Care Quality in Medicaid and CHIP, Kathleen Sebelius, December 2010). Pediatric central line-associated bloodstream infection is identified as a quality measure by CMS and is endorsed by the by the National Quality Forum as one of the Child Core Set of measures focused on improving health care for children. At this time reporting is not mandatory, and so non-payment is likely not enforced. CMS has recently partnered with AHRQ to establish and implement new pediatric quality measures. One of the new quality measures for management of acute conditions is temperature of low birthweight newborns. This measure is based on the research that has linked hypothermia with poor outcomes including mortality and intraventricular hemorrhage. As Medicaid continues to invest in quality through identification of pediatric quality measures and reporting, it would be plausible that reporting of quality measures including pediatric central-line infections and hypothermia be mandatory and could in the future, be linked to reimbursement.

The state of Texas recently passed through the legislative process a bill that links Medicaid reimbursement to a verified Neonatal Level of Care designation (*Texas Administrative Code Title 25 Chapter 133*, 2016). In order to receive any Medicaid reimbursement all hospitals caring for infants requiring specialized neonatal care must provide evidence of a verified level of care designation by September 1, 2018. In response to the Texas rule, the American Academy of Pediatrics (AAP) and the National Association of Neonatal Nurses (NANN) have collaborated to establish the AAP NICU Verification Program with the mission to "improve outcomes for high-risk newborns by supporting a system that ensures that every high-risk newborn received care in a facility with the personnel and resources appropriate for the newborn's need and condition" (AAP NICU Verification Program). The AAP NICU Verification Program, as a joint effort of the AAP and NANN, evaluates each hospital based on the Texas state rules and the AAP Levels of Care standards. The state bill broadly requires that all institutions "have skilled medical staff and personnel with documented training, competencies and continuing education specific for the patient population served," (*Texas Administrative Code Title 25 Chapter 133*, 2016) and the AAP policy on Levels of Neonatal Care recognize that "specialized neonatal nurses" should be continuously available for designation as a Level 2-4 NICU. While both the AAP and state of Texas specify specialized education, training, and competencies for neonatal nursing, there are no standards for evaluating these at the nurse or unit level. The AAP and NANN include nursing within the NICU in their evaluation of Level of Care designation based on the current research that shows that well educated nurses, organizations that value and support nursing and optimize staffing are associated with better outcomes for NICU patients (Blegen et al., 2013; Lake et al., 2012). It is unknown if this state level policy will have an impact on outcomes of infants requiring NICU care, but it is the first state policy that ties reimbursement to some degree of standardized NICU care that includes nursing quality and requires independent validation. It also suggests that Level of Care designation should integrate objective measures of nursing quality.

Investment in improving the nurse work environment aligns with the Institutes of Medicine's report *Keeping Patient Safe: Transforming the Work Environment of Nurses* and should have considerable appeal to hospital executives, payers and policy makers, as this investment has potential to increase quality of care and reduce costly comorbidities and lengths of stay and realize considerable cost savings.

Future Research Directions

The purpose of this study was to examine the relationships among the nurse work environment, the qualifications of NICU nurses and the NICU nurse workforce, and the outcomes of VLBW infants. The findings of this study have provided a foundation for future work. The primary finding of the link between the nurse work environment and the outcome of mortality is in the hypothesized direction but did not reach statistical significance in the fully adjusted model. The outcomes of sIVH and LOS were significant. This study evaluated 170 neonatal intensive care units. There are over 1,000 neonatal intensive care units in the United States (Bhatt et al., 2011). It is possible that this study of 170 NICUs was not sufficiently powered to detect a significant effect of the nurse work environment on NICU mortality. Future work should repeat this analysis with a larger sample of NICUs. In the study of Magnet® Hospitals the sample included 558 hospitals and was able to detect significance with similar odds ratios (Lake et al., 2012).

The literature on staffing in NICUs reports mixed results. In this study, evaluation of staffing using the nurse work environment subscale - Staffing and Resource Adequacy - showed that higher scores were associated with lower odds of severe intraventricular hemorrhage and shorter length of stay. These results were statistically significant before adjusting for hospital characteristics. The subscale measure and the direct patient-to-nurse ratio measure of staffing are not the same. In this study the direct patient-to-nurse ratio is an objective measure that does not account for infant acuity. The staffing and resource adequacy subscale indirectly accounts for infant acuity by asking the nurse to report on the extent to which he/she agrees that there is adequate staff to complete care. It is assumed that the nurse considers the complexity of the infant's care when responding to this statement. Evaluation of staffing using the direct staffing measure (patient-to-nurse ratio) in this study's main effect models, showed that staffing had no relationship with outcomes. However, in the interaction of staffing (patient-to-nurse ratio) and the nurse work environment on the outcome of severe intraventricular hemorrhage, there was also a significant finding. These findings require further investigation. This study did not evaluate acuity adjusted staffing in the direct staffing measure of patient-to-nurse ratios.

Based on this study's findings and the evidence from prior studies (Rogowski et al., 2013, 2015), detailed exploration of staffing, adjusted for infant acuity, on these outcomes is warranted. Prior studies have also not evaluated the mandated patient-to-nurse ratio in California on outcomes in this population. Future work relevant to state policy should evaluate the impact of these ratios in this population.

This study departed from more widely used data sources of outcomes research evaluating very low birth weight infants, which uses either large network data such as the Vermont Oxford Network or linked birth certificate and hospital records. This study used hospital discharge records. Hospital discharge records are used extensively in other patient population studies. The primary concern in any use of any administrative data is adequate risk adjustment. Methods for predicting outcomes in adult populations have been studied extensively. For the population of infants in the NICU, risk adjustment models that have been studied are based primarily on network data or clinical and physiological parameters available in the patient's clinical record (Patrick, Schumacher, & Davis, 2013). VON-RA and the physiological based risk adjustment models have been previously compared and found to predict mortality similarly (Zupancic et al., 2007). The adequacy of risk adjustment in the data used in this study as compared with the additional measures available in clinical registry or birth certificate data warrants evaluation.

This is the first known study to link the nurse work environment to length of stay for very low birth weight infants. Research on the contribution of nurses to length of stay is minimal, specifically in this population. The relationship between the nurse work environment and length of stay requires further investigation. Future analysis of this relationship should account for readmissions to better understand if length of stay is related to readmissions, especially as readmissions are a Pediatric Quality Measure identified by CMS and endorsed by AHRQ (*Pediatric All-Condition Readmission Measure*, 2018). Additionally, use of newer measures of length of stay, including prolonged length of stay and conditional length of stay, may be helpful to understand whether VLBW infants with shorter lengths of stay are less critically ill and therefore expected to have shorter lengths of stay or if the shorter length of stay as observed in this study is truly lower than the expected length of stay.

The relationship of the nurse work environment and the outcome of severe intraventricular hemorrhage was statistically significant and is clinically meaningful. Evaluation of the subscale domains indicate that Nurse-Physician Relations, Staffing and Resource Adequacy and Foundations for Quality of Care contribute most to this finding. Returning to the conceptual framework for this study, nursing care interventions are a result of these structural factors. The Institute for Healthcare Improvement (IHI) defines "a bundle" of care, as "a structured way of improving the processes of care and patient outcomes [through] a small set of evidence-based interventions, for a defined patient population and care setting, that when performed collectively and reliably, improve patient outcomes" ("Institute for Healthcare Improvement: Evidence-Based Care Bundles," 2018). Care "bundles" have been well studied and exist for preventing central line infections, ventilator-associated pneumonia and obstetrical adverse events (Resar R, Griffen, & Haraden, 2012). The Vermont Oxford Network, through collaborative work aimed to reduce long-term morbidities associated with prematurity, identified care practices focused on consistent care, minimizing stress and complications and improving teamwork in the first hour of life. This "bundle" of care practices has been coined "the golden hour" (Reynolds, Pilcher, Ring, Johnson, & McKinley, 2009; Sharek et al., 2003). There is evidence that the nurse work environment, centers of nursing excellence, team communication, and specific nurse and physician care practices are associated with lower incidence of severe intraventricular hemorrhage in VLBW infants (Carteaux et al., 2003; Lake et al., 2012; McLendon et al., 2003; Pollack & Koch, 2003). This previous work in VLBW infants and improvement in outcomes demonstrated by "bundles" of care provides the opportunity for integration of evidence-based interventions associated with lower rates of severe intraventricular hemorrhage into practice settings. Future work may evaluate NICU unit practices and policies that integrate these evidence-based interventions, including nurse interventions and nurse-physician teamwork, to reduce severe intraventricular hemorrhage.

Summary

Better nurse work environments and higher proportions of nurses with baccalaureate degree preparation and specialty certification in hospitals with better nurse work environments were associated with lower odds of mortality for very low birth weight infants receiving care in neonatal intensive care units.

The primary study hypothesis stated that variation in the nurse work environment in neonatal intensive care units may explain variation in outcomes for this highly vulnerable and fragile population of preterm infants. The findings of this study support the hypothesis statement that there is variation in the nurse work environment. Nurse qualifications also explain some of this variation.

As the demand for neonatal nursing care continues, it is essential that medical and nursing leadership in the neonatal intensive care, as well as hospital, system health care administrators and policymakers prioritize investment in supportive environments for highly qualified nurses to care for specialized patient populations, such as very low birth weight infants, to have the greatest impact on outcomes of very low birth weight infants.

Health outcomes research focusing on the organization of care within hospitals has consistently demonstrated that investment targeted to optimize the organization of care results in better patient and staff outcomes. The results of this study specifically support that such initiatives to optimize the organization of nursing and increase nurse qualifications in neonatal intensive care units would have beneficial effects for very low birth weight infants requiring care.

APPENDIX A

AHRQ Quality Indicators: Low Birth Weight Categories

ICD-9-CM Birth Weight Category 1 (less than 500 grams) diagnosis codes:			
	76401, 76411, 76421, 76491, 76501, 76511, V2131		
ICD-9-CM Birth Weight Category 2 (500-749 grams) diagnosis codes:			
	76402, 76412, 76422, 76492, 76502, 76512, V2132		
ICD-9-CM Birth Weight Category 3 (750-999 grams) diagnosis codes:			
	76403, 76413, 76423, 76493, 76503, 76513, V2132		
ICD-9-CM Birth Weight Category 4 (1000-1249 grams) diagnosis codes:			
	76404, 76414, 76424, 76494, 76504, 76514, V2133		
ICD-9-CM Birth Weight Category 5 (1250- 1499 grams) diagnosis codes:			
	76405, 76415, 76425, 76495, 76505, 76515, V2133		
ICD-9-CM Birth Weight Category 6 (1500-1749 grams) diagnosis codes:			
	76406, 76416, 76426, 76496, 76506, 76516, V2134		
ICD-9-CM Birth Weight Category 7 (1750-1999 grams) diagnosis codes:			
	76407, 76417, 76427, 76497, 76507, 76517, V2134		
ICD-9-CM Birth Weight Category 8 (2000-2499 grams) diagnosis codes:			
	76408, 76418, 76428, 76498, 76508, 76518, V2135		
ICD-9-CM Birth Weight Category 9 (> 2500 grams) diagnosis codes:			
	76409, 76429, 76429, 76499, 76509, 76519		

APPENDIX B

ICD-9-CM codes for Congenital anomalies

1. Gastrointestinal	
756.70	Anomaly of abdominal wall, unspecified
756.79	Other congenital anomalies of abdominal wall
750.3	Tracheoesophageal fistula, esophageal atresia and stenosis
750.4	Other specified anomalies of esophagus
750.5	Congenital hypertrophic pyloric stenosis
750.7	Other specified anomalies of stomach
750.8	Other specified anomalies of upper alimentary tract
750.9	Unspecified anomaly of upper alimentary tract
751.1	Atresia and stenosis of small intestine
751.5	Other anomalies of intestine
751.8	Other specified anomalies of digestive system
751.9	Unspecified anomaly of digestive system
560.2	Volvulus
751.4	Anomalies of intestinal fixation
751.0	Meckel's diverticulum
751.2	Atresia and stenosis of large intestine, rectum, and anal canal
751.3	Hirschsprung's disease and other congenital functional disorders of colon
771.1	Congenital cytomegalovirus infection
751.61	Biliary atresia
751.7	Anomalies of pancreas
751.60	Unspecified anomaly of gallbladder, bile ducts, and liver
751.69	Other anomalies of gallbladder, bile ducts, and liver
2. Genitourinary	
753.0	Renal agenesis and dysgenesis
753.12	Polycystic kidney, unspecified type
753.14	Polycystic kidney, autosomal recessive
753.15	Renal dysplasia
753.10	Cystic kidney disease, unspecified
753.19	Other specified cystic kidney disease
753.3	Other specified anomalies of kidney
753.4	Other specified anomalies of ureter
753.21	Congenital obstruction of ureteropelvic junction
753.22	Congenital obstruction of ureterovesical junction
753.23	Congenital ureterocele
753.6	Atresia and stenosis of urethra and bladder neck
753.7	Anomalies of urachus
753.8	Other specified anomalies of bladder and urethra
753.9	Unspecified anomaly of urinary system
753.20	Unspecified obstructive defect of renal pelvis and ureter
756.71	Prune belly syndrome

3. CNS	
741.00 741.01 741.02 741.03 741.90 741.91 741.92 741.93 742.59 742.0	With hydrocephalusm, unspecified region With hydrocephalusm, cervical region With hydrocephalusm, dorsal (thoracic) region With hydrocephalusm, lumbar region Without mention of hydrocephalus, unspecified region Without mention of hydrocephalus, cervical region Without mention of hydrocephalus, dorsal (thoracic) region Without mention of hydrocephalus, lumbar region Other specified anomalies of spinal cord, Other Encephalocele
742.1 742.4 742.2 742.3 742.8 742.9	Microcephalus Other specified anomalies of brain Reduction deformities of brain Congenital hydrocephalus Other specified anomalies of nervous system Unspecified anomaly of brain, spinal cord, and nervous system
4. Pulmonary	
519.4 553.3 750.6 756.6	Disorders of diaphragm Diaphragmatic hernia Congenital hiatus hernia Anomalies of diaphragm
748.3 748.9	Other anomalies of larynx, trachea, and bronchus Unspecified anomaly of respiratory system
748.4 748.60 748.69 748.8	Congenital cystic lung Other anomalies of lung, anomaly of lung, unspecified Other anomalies of lung, other Other specified anomalies of respiratory system
5. Cardiovascular	
746.3 746.4 424.1	Congenital stenosis of aortic valve Congenital insufficiency of aortic valve Aortic valve disorders
747.10 747.21 747.29 747.11 747.22 746.81	Coarctation of aorta (preductal) (postductal) Other anomalies of aorta, anomalies of aortic arch Other anomalies of aorta, other Interruption of aortic arch Other anomalies of aorta, atresia and stenosis of aorta Subaortic stenosis
746.7	Hypoplastic left heart syndrome
425.3	Endocardial fibroelastosis
746.5 424.0 746.6 746.84	Congenital mitral stenosis Mitral valve disorders Congenital mitral insufficiency Obstructive anomalies of heart, NEC
745.10 745.19 745.12	Complete transposition of great vessels Transposition of great vessels, other Corrected transposition of great vessels
746.85 425.1	Coronary artery anomaly Hypertrophic obstructive cardiomyopathy
745.3 745.11	Common ventricle Double outlet right ventricle

745.0	Common truncus
746.01 746.83	Atresia, congenital Infundibular pulmonic stenosis
746.2 746.09 745.2 746.1	Ebstein's anomaly Anomalies of pulmonary valve, other Tetralogy of Fallot Tricuspid atresia and stenosis, congenital
745.60 745.61 745.69	Endocardial cushion defect, unspecified type Ostium primum defect Endocardial cushion defects, other
746.82 747.41 747.42	Cor triatriatum Total anomalous pulmonary venous connection Partial anomalous pulmonary venous connection
747.40 747.49	Anomaly of great veins, unspecified Other anomalies of great veins
6. Skeletal	
756.50 756.51 756.55 756.59	Osteodystrophy, unspecified Osteogenesis imperfecta Chondroectodermal dysplasia Osteodystrophies, other
7. Chromosomal Syndromes	
758.3 758.5 758.89 758.9 759.89 759.9 759.7 759.4	Autosomal deletion syndromes Other conditions due to autosomal anomalies Other conditions due to chromosome anomalies, other Conditions due to anomaly of unspecified chromosome Other specified anomalies, other Congenital anomaly, unspecified Multiple congenital anomalies, so described Conjoined twins
8. Other	
778.0 759.6 776.5	Hydrops fetalis not due to isoimmunization Other hamartoses, NEC Congenital anemia

APPENDIX C

Practice Environment Scale of the Nursing Work Index Subscale and Items

1. Nurse Participation in Hospital Affairs
    - Staff nurses are involved in the internal governance of the hospital
    - Opportunity for staff nurses to participate in policy decisions
    - Many opportunities for advancement of nursing personnel
    - An administration who listens to and responds to employee concerns
    - A director of nursing highly visible and accessible to staff
    - Career development/clinical ladder opportunity
    - Nursing administrators consult with staff on daily problems and procedures
    - Staff nurses have the opportunity to serve on hospital and nursing department committees
    - A chief nursing executive equal in power and authority to other top level hospital executives
2. Nursing Foundations for Quality of Care
    - Use of nursing diagnoses
    - An active quality assurance program
    - A preceptor program for newly hired RNs
    - Nursing care is based on a nursing, rather than medical model
    - Patient care assignments that foster continuity of care, i.e. the same nurse cares for the patient from one day to the next
    - A clear philosophy of nursing that pervades the patient care environment
    - Written, up-to-date nursing care plans for all patients
    - High standards of nursing care are expected by the administration
    - Active in-service/continuing education programs for nurses
    - Working with nurses who are clinically competent
3. Nurse Manager Ability, Leadership and Support of Nurses
    - A head nurse who is a good manager and leader
    - A head nurse/supervisor who backs up the nursing staff in decision making if the conflict is with a physician
    - Supervisors use mistakes as learning opportunities, not criticism
    - A supervisory staff that is supportive of the nurses
    - Praise and recognition for a job well done
4. Staffing and Resource Adequacy
    - Enough staff to get the work done
    - Enough registered nurses to provide quality patient care
    - Adequate support services allow the nurse to spend time with his/her patients
    - Enough time and opportunity to discuss patient care problems with other nurses
5. Collegial Nurse- Physician Relations

- A lot of teamwork between nurses and doctors
- Physicians and nurses have good relationships
- Functional collaboration (joint practice) between nurses and physicians

APPENDIX D

ICD-9-CM codes for NICU Level of Care

American Academy of Pediatrics Level of Care Definitions:

Level 1: community hospital with no NICU, well baby nursery

Level 2: intermediate NICU, provides care for mildly ill infants but does not provide sustained mechanical ventilation.

Level 3A: Provides assisted mechanical ventilation, but limited to conventional mechanical ventilation and only for infants >1000 grams

Level 3B: no restrictions on assisted mechanical ventilation, may have more advanced options of mechanical ventilation and provides major surgery

Level 3C: in addition to all the capabilities and services of a 3B the NICU also provides cardiac surgery to repair congenital heart anomalies that require ECMO extracorporeal membrane oxygenation (ECMO) or cardio-pulmonary bypass.

Level of Care designation for this study was as follows:

Level 2: all infants that did not meet criteria for Level 3B or 3C

Level 3B (or 3): all infants with ICD-9-CM code 967.2 indicating mechanical ventilation duration greater than 96 hours

Level 3C (or 4): all infants with ICD-9-CM codes for congenital cardiac disease (see table below) or that received extracorporeal membrane oxygenation, ICD-9-CM code 396.1.

ICD-9-CM Codes for Congenital Cardiac Disease

ICD-9-CM Codes for Congenital Cardiac Disease	
Aortic Valve	746.3, 746.4, 424.1
Aortic Arch	747.10, 747.21, 747.29, 747.11, 747.22, 746.81
Hypoplastic left heart syndrome	746.7
Endocardial fibroelastosis	425.3
Mitral Valve, stenosis and other	746.5, 424.0, 746.6, 746.84
Transpositions	745.10, 745.19, 745.12
Coronary/ Myocardial	746.85, 425.1
Common right ventricle, etc.	745.3, 745.11, 745.0
Pulmonary valve- tricuspid	746.01, 746.83, 746.2, 746.09, 745.2 746.1
Cushion defects	745.60, 745.61, 745.69
Pulmonary veins	746.82, 747.41, 747.42
Anomaly of great veins	747.40, 747.49

APPENDIX E

Missing Data description and plan

Missing Data			
Variables	Expected	Actual	Missing
Infant Characteristics			
VLBW	17771	17771	0
Race	17771	17114	657
Sex	17771	17767	4
Insurance	17771	17768	3
Nurse Characteristics			
Education	1285	1284	1
Certification	1285	1262	23
Staffing	1285	1269	16
Nurse Work Environment	1285	1253	32
Hospital Characteristics			
NICU volume	170	170	0
Level of Care	170	170	0
Teaching Status	170	169	1

Missing data for the infant characteristics of sex and insurance status was considered ignorable due to the very small number of missing cases. The missingness for race was considered non-ignorable and the decision was made to create a dummy variable that accounted for this missingness. Both the prediction model for mortality and the regression models with and without this variable yielded identical results and so final models did not include the dummy variable for missing data on race.

Missing data on nurse characteristics was minimal. Nurse characteristics were used to aggregate each of these components to the hospital level, no individual nurse characteristic was used in analysis and so no adjustments were made for missing data.

APPENDIX F

Practice Environment Scale- Nursing Work Index (PES-NWI) Subscale Scores

Practice Environment Scale- Nursing Work Index (PES-NWI) Subscale Scores n= 1253				
	Number of Items	Mean	Median	Range
Nurse Manager Ability, Leadership & Support	4	2.65	2.75	1-4
Nurse Participation in Hospital Affairs	9	2.71	2.75	1-4
Nurse Foundations for Quality of Care	9	3.08	3.11	1-4
Collegial nurse/physician relations	3	3.07	3	1-4
Staffing and Resource Adequacy (SRA)	4	2.89	3	1-4
Composite score (with SRA)		2.88	2.9	1.11-4
Composite score (without SRA)		2.88	2.9	1.08-4
Scale scores from 1-4 with a higher score representing a more positive work environment				

APPENDIX G

Intraclass correlation coefficients of the nurse work environment

Intraclass correlation coefficients (1,*k*) of Nursing measures in Hospitals with 3 or more neonatal nurse respondents	
Nurse Manager Ability, Leadership & Support	0.67757
Nurse Participation in Hospital Affairs	0.62713
Nurse Foundations for Quality of Care	0.58033
Collegial Nurse/Physician relations	0.64296
Staffing and Resource Adequacy	0.61225

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