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Evaluation of Key Factors Impacting Feeding Safety in the Neonatal Intensive Care Unit

A Systematic Review

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ABSTRACT

Background: Individualized feeding care plans and safe handling of milk (human or formula) are critical in promoting growth, immune function, and neurodevelopment in the preterm infant. Feeding errors and disruptions or limitations to feeding processes in the neonatal intensive care unit (NICU) are associated with negative safety events. Feeding errors include contamination of milk and delivery of incorrect or expired milk and may result in adverse gastrointestinal illnesses.

Purpose: The purpose of this review was to evaluate the effect(s) of centralized milk preparation, use of trained technicians, use of bar code-scanning software, and collaboration between registered dietitians and registered nurses on feeding safety in the NICU.

Methods/Search Strategy: A systematic review of the literature was completed, and 12 articles were selected as relevant to search criteria. Study quality was evaluated using the Downs and Black scoring tool.

Findings/Results: An evaluation of human studies indicated that the use of centralized milk preparation, trained technicians, bar code-scanning software, and possible registered dietitian involvement decreased feeding-associated error in the NICU.

Implications for Practice: A state-of-the-art NICU includes a centralized milk preparation area staffed by trained technicians, care supported by bar code-scanning software, and utilization of a registered dietitian to improve patient safety. These resources will provide nurses more time to focus on nursing-specific neonatal care.

Implications for Research: Further research is needed to evaluate the impact of factors related to feeding safety in the NICU as well as potential financial benefits of these quality improvement opportunities.

Key Words: NICU, nutrition, preterm infants, quality improvement, safety

While human milk is well established as the optimal choice for nourishing all infants, its composition is insufficient to meet the nutritional needs of very low birth-weight (<1500 g) infants and many high-risk newborns without multinutrient fortification. Multinutrient fortification can include the addition of human milk fortifiers, other nutrient modifiers, or concentrated formula to human milk in order to meet expert-level nutrient recommendations for the preterm infant. Other infant-feeding products often require additional steps in the preparation process to optimize nutrition as well. Nutrient deficiencies must be prevented to allow for adequate growth and health of neonates.[1,2] Therefore, it is important that preterm infants receive individualized feeding plans with the appropriate constituents to address each patient's unique nutritional needs.[3-7]

Preparation and delivery of feedings to high-risk newborns is a complex process, with many potential errors due to their individualized feeding needs. Successful implementation of individualized feeding plans thus requires multidisciplinary effort from nutritional assessment and prescription to preparation and administration of feedings. Problems associated with traditional bedside preparation and delivery of feedings include order entry errors, incorrect labeling, improper storage, refrigeration and thawing, incorrect mixing, pathogenic contamination of feedings, and misidentification during milk delivery. During this process flow, expressed mother's milk is typically labeled by either the parent or the nurse and then transferred to a refrigerator or a freezer for storage. If no fresh human milk is

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available, frozen human milk or donor milk must be thawed prior to feeding time. Feeding additives or formula is obtained and milk is then mixed. Finally, the nurse must complete a "double check" by having 2 people verify that the correct milk or formula reaches the patient.[3,6,7] Nurses may be pulled from important clinical responsibilities to complete this step, causing increased stress and error risk.[6,8,9] Feeding preparation is not a patient care activity exclusive to the nursing scope of practice; furthermore, it may qualify as an appropriate activity for nurses to delegate to assistive personnel. Importantly, freeing nurse time from the labor demands of mixing milk at bedside may allow for registered nurses (RNs) to spend more time providing specialized care.[6-8,10-13]

CONSEQUENCES OF FEEDING-RELATED ERRORS

Contamination of human milk and commercial infant feeding products during modification and preparation may increase infection risk for immunocompromised neonates.[3,5,6,10,14,15] Because of the inability to commercially sterilize powdered human milk additives or formulas, the Food and Drug Administration and the Food and Agriculture Organization/World Health Organization advise against use of these products in the neonatal intensive care unit (NICU) setting unless it is the last viable option.[16-18] The Infant Formula Act of 1980 permits a manufacturer's bacterial counts up to 10,000 colony-forming units per gram of powder, despite suggestions from other sources for restriction to 100 colony-forming units per gram or less before initiating feeds.[16,18]

Receipt of the incorrect formula may lead to inappropriate nutrient provision for one's clinical condition; this error may also increase patient risk for allergic reactions.[18] Likewise, neonates who receive an incorrect human milk preparation are at increased risk for infectious disease.[3,12,13,19,20] Receipt of the wrong human milk is considered fluid exposure and provides an opportunity for spread of pathogens.[7,14,21] Since healthcare organizations are required to develop policies and procedures in regard to safe handling of bodily fluids, it is important that these be adopted as part of human milk handling practices due to infection risk.[22]

REGULATORY GUIDELINES APPLICABLE TO FEEDING PROCESSES IN THE NICU

Strategies to minimize feeding-related errors in the NICU include use of centralized preparation, trained technicians dedicated to feeding preparation, inclusion of a registered dietitian (RD), and use of feeding-related software. Some of these strategies have been adopted by regulatory agencies as recommended standards of care. As referenced in Table 1, The Joint Commission has guidelines that can be applied to feeding practices and specifically recommends the use of Hazard Analysis and Critical Control Point guidelines with infant feeds.[4,8,23,24] Other organizations, such as the Food and Drug Administration, the American Hospital Association, the American Academy of Pediatrics, the American Nurses Association, and the Infant Formula Council, have collaborated with the Academy of Nutrition and Dietetics to publish standardized and evidence-based guidelines for the preparation and administration of infant feedings in healthcare facilities.[18]

These guidelines, which are referenced in an addendum to the Infant Formula Act of 1980, designate a separate, centralized room for expressed human milk intake, storage, and preparation as the criterion standard.[18] The American Society for Parenteral and Enteral Nutrition also recommends implementation of diligent protocols, procedures, and compliance monitoring for the handling and administration of enteral nutrition requiring an open system, such as infant feedings.[25] The importance of infant feeding safety is further emphasized by the US News Best Hospitals' criteria, which promote centralized milk preparation and allocate points to NICUs with RD to patient ratios of less than 20:1 as well as for dedicated centralized area for milk and formula preparation.[26] Therefore, the purpose of this review is to evaluate the effect(s) of centralized milk preparation, use of trained technicians, use of feeding-related software, and collaboration efforts between RDs and nurses on feeding safety in the NICU.

TABLE 1. Pertinent Joint Commission Regulatory Guidelines[a]

The hospital assigns responsibility for the safe and accurate provision of food and nutrition products.
The hospital prepares food and nutrition products using proper sanitation, temperature, light, moisture, ventilation, and security.
All hospital components and functions are integrated into infection prevention and control activities.
Use at least 2 patient identifiers when providing treatments or procedures. The patient's room number or physical location is not used as an identifier.

[a]*Adapted from The Joint Commission.*[23]

METHODS

Data Sources

This systematic review was guided by the PRISMA[27] guidelines to address the question, "What common safety measures are associated with error reduction and feeding safety in NICU patients?" PubMed and CINAHL searches were conducted through January 2018. The following key terms were used to identify relevant studies using medical subject headings (MeSH) when possible: (quality improvement [MeSH Terms]) AND milk [MeSH Terms]), (food handling [MeSH Terms]) AND infants, newborn [MeSH Terms]), (milk, human [MeSH Terms]) AND food labeling [MeSH Terms]), (milk) AND technician (process improvement) AND milk, human), and (milk, human [MeSH Terms]) AND food labeling [MeSH Terms].

Study Selection and Analysis

Studies were included in the review if they addressed feeding-related errors in relation to the presence of the following: centralized preparation, trained technicians, feeding-related software (ie, bar code scanning), or inclusion of an RD. The target population was the NICU setting. Studies were not eligible for inclusion if results included general pediatric units that inhibited isolation of NICU-related data. There were no restrictions regarding the length of intervention. All study designs were eligible for inclusion. Studies included were limited to human studies written in the English language.

The level of evidence for each article was independently evaluated by 2 reviewers using a modified Downs and Black checklist. A third reviewer settled any discrepancies. The well-established Downs and Black scoring tool[28] was reported to have high internal consistency (KR-20: 0.89), with little difference found in its performance between nonrandomized and randomized studies. A limitation of the tool was that it had relatively poor external validity (KR-20: 0.54). The 25-item modified Downs and Black tool addressed criteria such as clarity of description, providing estimates of random variability in the data, reporting of adverse events and patients lost to follow-up, reporting of actual probability values, data that represented the entire population, proper blinding and controls, reporting of bias, appropriate statistical analyses, and reporting of confounding factors. Each item in the tool was given a value of 1 point. Quality Index ratings obtained from the numerical scores were set by the reviewers. A score of 17 and above was rated as "high"; a score of 14 to 16 was rated as "moderate"; and a score of 13 and below was rated as "low."

RESULTS

Data Synthesis

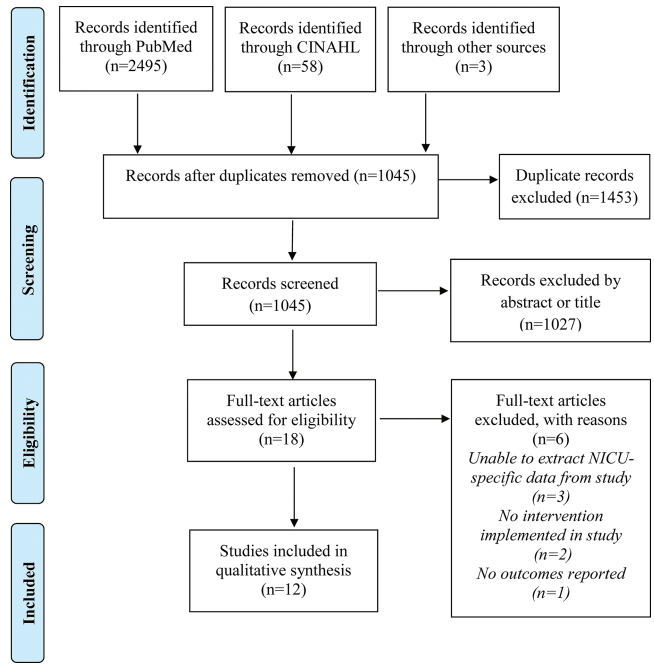
Database searches generated 2495 articles. A hand search was also performed to identify studies that may have been missed. After abstract review and removal of duplicates, 18 full-text articles were identified for further review. Six[6,7,11,12,28,29] of these articles did not meet inclusion criteria (Figure 1). The 12 remaining articles[1,3-5,8,13,14,24,30-32] met criteria and were identified for use in this systematic review. Quality scoring among the studies ranged from 11 to 18 out of 25 possible points and studies were rated "low," "moderate," or "high" (Table 2). All were included during data synthesis.

Centralized Milk Preparation Areas

Seven studies[3,8,13,14,24,32] evaluated the use of centralized milk preparation areas to reduce feeding errors. All studies indicated a reduction, ranging 83% to 100% in error improvements. Two of the studies[3,13] applied six-sigma methodology to identify risks for error. Root cause analysis was completed to determine contributors to feeding error incidences, such as inconsistency in the process, inconsistency in educating parents regarding the process, staff errors, limited preparation space, lack of accountability, and lack of communication. Both studies implemented a centralized milk preparation area and again measured the rate of milk misappropriation, which decreased by 100%[3] and 83%,[13] respectively. Similarly, another study[8] used the healthcare failure mode and effect analysis model to assess feeding error risks in the NICU. An investigative team was developed to identify potential failure modes and document the rate of occurrences with the current workflow. The team proposed that a centralized milk preparation area would resolve 84% of the potential failure modes identified. One study did not implement a centralized preparation area. The researchers concluded that a designated area for infant-feeding storage and preparation was one of the most important factors impacting safety, among other contributing factors indicated in Table 2.[8]

An additional study[14] similarly evaluated the efficacy of centralized infant-feeding preparation and a feeding error protocol on improving patient safety as part of a quality improvement initiative. After implementation of a centralized milk preparation area, a quality assurance (QA) team was created to identify errors and initiate a feeding error protocol. The feeding error protocol consisted of a decision-making flow chart to handle the ethical and legal issues of a feeding mistake. If the QA team identified errors, the feeding error protocol was initiated. The authors determined that the feeding error protocol improved

FIGURE 1



PRISMA flow diagram of search strategy.

standards of care through the use of centralized preparation, feeding technicians, and electronic labels. Use of this standardized preparation improved detection and correction of feeding errors.[14] Similarly, centralized preparation and a QA audit were found to eliminate misadministration errors after implementation in a 60-bed NICU compared with 3 reported misadministration errors in other hospital units utilizing manual checks and bedside milk handling during the same 36-month time frame.[32]

Another study[24] looked at patient safety specifically related to infant-feeding contamination. During the first part of the study, nurses prepared formula at bedside in alignment with the current process in the NICU, and formula samples were assessed for contamination. The researchers then created a centralized milk preparation area staffed by trained technicians and again measured formula milk samples for contamination. Formulas prepared at bedside were 24 times more likely to show contamination than formula mixed in the centralized preparation area.[24]

Trained Technicians

Ten studies[4,5,8,10,13,14,30-32] were identified evaluating the use of a trained technician and its effect on feeding-related patient safety events. All 10 studies indicated improvements in patient safety outcomes (Table 2). One study[5] developed a human milk management center team that reviewed feeding practices and identified areas for improvement. Baseline data were collected regarding mislabeled and expired milk. Next, technicians were trained over 26 classroom hours through the Columbus State Pharmacy Technician program. The trained technicians exclusively performed milk handling and feeding error rates dropped sharply.[5] A human milk management center team was also developed at another NICU facility.[4] The team met weekly in rounds to review each feeding plan of those patients who received human milk with additives. The goal was for proactive error reduction, and it was hypothesized that reviewing orders as a team would reduce feeding errors and improve consistency. The trained technicians held a critical role on this team as they performed all milk preparation, storage, and delivery. The trained technicians provided information on feeding volume, feeding frequency, fortifier type, calorie level, and type of milk used. An 8.6% prevention of error was noted.[4] Furthermore, adequacy of staffing numbers for trained technicians appears to be important in reducing feeding errors.

Another institution[30] reported a 58% reduction in scans of expired bottles during working hours of the trained technician and a 40% reduction in scans of expired bottles during nonworking hours. In a follow-up study performed 6 years later in the same institution,[31] regression analysis identified an association between the addition of dedicated milk technicians and decreases in scanned errors for expired milk and milk preparation.

One study[8] evaluated root causes for feeding error in a NICU. It was determined through healthcare

TABLE 2. Summary of Studies Exploring Feeding Process Factor(s) and Their Effect on Safety in the NICU

Author	Design	Sample	Quality Rating	Elements Studied	Results
Dumm et al (2010)[5]	Pre-post	Feeds provided to infants over 48 mo in a 120-bed level II/III NICU.	L	Trained technicians	Use of trained technicians decreased feeding errors from 0.9% of total incidences to 0% of total incidences, a 100% reduction.
Paul (2015)[4]	Pre-post	Feeds provided to 558 infants over 12 mo in a 95-bed level IV NICU.	L	Trained technicians	Use of trained technicians proactively increased safety through an 8% error prevention rate by clarifying 15 orders, 26 backup orders, and 41 total "near miss" catches.
Brock et al (2016)[10]	Pre-post non-experimental design	309 infants over 12 mo in a 24-bed level III NICU. Control group: infants admitted 6 mo before using trained technicians. Experimental group: infants admitted 6 mo after using trained technicians.	M	Trained technicians	Use of trained technicians decreased average length of time to reach full feeds from 10.1 d to 7.9 d postimplementation, although this change was not considered significant ($P = 0.10$). Results divided on the basis of gestational age indicated use of trained technicians' decreased average length of time to reach full feeds from 32 d to 19 d postimplementation ($P = .704$).
Dougherty and Nash (2009)[20]	Pre-post	Feeds provided to infants over 29 mo in a 42-bed level III NICU. Average (range) number of infant feedings prepared monthly: 8686 (7797-9884), depending on census.	M	Feeding software	Use of software decreased feeding errors from 3% to 0.4%, an 86.6% reduction.
Dreckpohl et al (2006)[3]	Pre-post using six-sigma methodology.	Feeds provided to infants over 39 mo in a 35-bed level III NICU. Average number of infant feedings prepared monthly: 71,904	L	Centralized milk preparation	Use of a centralized milk preparation ensured 0 feeding errors after implementation, a 100% reduction, and prevented "near misses."
Steele and Short (2008)[24]	Randomized controlled trial	526 formula samples over a nonconsecutive 13-mo period in a NICU. Control group: formula samples prepared by nurse at bedside. Experimental group: formula samples prepared by trained technician in centralized preparation room.	H	Centralized milk preparation Trained technicians	Formulas prepared at bedside were more likely to be contaminated 24-fold than formula prepared in centralized milk preparation room ($P < .001$). Powdered formulas were more likely to be contaminated 12-fold than RTF formulas ($P < .001$).

(*continues*)

TABLE 2. Summary of Studies Exploring Feeding Process Factor(s) and Their Effect on Safety in the NICU (*Continued*)

Author	Design	Sample	Quality Rating	Elements Studied	Results
Wolford et al (2013)[30]	Retrospective	Feeds provided to infants over 24 mo in a 99-bed level III NICU, split into 3 separate units.	M	Trained technicians Feeding software	On the unit using the trained technician, there was a 58% reduction in scans of expired bottles during her working hours and a 40% reduction in scans of expired bottles during her nonworking hours. Use of software decreased feeding errors from 5.64% to 1.79%, a 68.2% reduction. During the first year, 2757 "near misses" were prevented.
Oza-Frank et al (2017)[32]	Retrospective	Feeds provided to infants over 6 years among 114 beds in a level IIIC NICU, split into 3 separate units.	M	Trained technicians Feeding software	Scanned errors declined by 86.3% over the 6-year study period. Decreases in scanned errors for expired milk and milk preparation were associated with the addition of dedicated milk technicians. Decrease in scanned errors for wrong milk was associated with the addition of bedside scanning equipment and software.
Dougherty and Giles (2000)[14]	Pre-post	Feeds provided to infants over 24 mo in a 42-bed level III NICU	L	Centralized milk preparation Trained technicians Feeding software	This qualitative study found that a feeding error protocol improved standards of care and ability to identify feeding errors through use of centralized preparation, feeding technicians, and software to produce electronic labels.
Gabrielski and Lessen (2011)[31]	Pre-post	Feeds provided to infants over 36 mo in a 60-bed level III NICU	M	Centralized milk preparation Trained technicians Feeding software	No errors (0 errors/219,554 feeds) occurred in the 36 mo following implementation of centralized milk preparation, trained technicians, and bar code-scanning software in the NICU compared with a 0.2% misadministration rate on all non-NICU units using manual processing (3 errors/137,921 feeds) during the same time frame.
Zhang et al (2014)[8]	Pre-post using HFMEA	Feeds provided to infants in a 30-bed level IV NICU	H	Centralized milk preparation Trained technicians Feeding software	Using centralized milk preparation, trained technicians, and bar code-scanning software, the study estimated an approximately 84.4% reduction in risk through HFMEA.
Luton et al (2015)[13]	Pre-post using six-sigma methodology	Feeds provided to infants over 12 mo in 173-bed single Newborn Center, split into 3 separate NICUs: a 55-bed level II, a 76-bed level IV, and a 42-bed single-room level II/III	M	Centralized milk preparation Trained technicians-Feeding software	Use of centralized milk preparation and trained technicians decreased feeding errors by 83% from the baseline 12-mo period. The study did not publish direct data regarding feeding error reduction with software use but concluded from six-sigma that bar code-scanning software would be part of an ideal process.

Abbreviations: H, high; HFMEA, healthcare failure mode and effect analysis; L, low; M, moderate; NICU, neonatal intensive care unit; RTF, ready to feed.

failure mode and effect analysis that implementing a staffing model to support milk technicians, among other contributing factors, would improve patient safety (Table 2).[8] In another study,[13] the investigators mapped out the feeding process in detail to evaluate for potential error points. The authors concluded that insufficient technician staffing leads to increased multitasking, thus increasing error incidence. This justification for an increased staffing need subsequently resulted in improved safety.

An additional study[14] developed a QA plan after the facility established a centralized preparation area with trained technicians responsible for milk preparation. Trained technicians and nurses collaborated to validate error prevention processes; specifically, a protocol was initiated upon identification of an error. Creation of the protocol was found to improve standards of care, and technicians completed "checks" to improve detection and correction of feeding errors.[14] Interestingly, another study[10] demonstrated that use of trained technicians could significantly decrease ($P = .026$) the time that infants less than 32 weeks of gestation reach prescribed enteral feeding volumes. Six enlisted military service members were chosen and trained to work as trained technicians. The baseline group included infants admitted 6 months before implementing trained technicians, whereas the experimental group comprised infants admitted up to 6 months after implementing trained technicians. Researchers monitored the length of time required until full enteral feeding volume was reached.

Observational data indicated that the trained technicians performed safe preparation of enteral feedings. Average length to reach goal feeds decreased from 32 days to 19 days when isolating very preterm and extremely preterm data. Other comparison groups demonstrated change from 10.1 days to 7.9 days. While the decrease in time to full feeds in this infant population was not statistically significant, these finds may represent a clinically important patient outcome, as the authors noted that infants who achieve full feeds sooner are likely to be discharged sooner. Researchers concluded that the use of trained technicians improved consistency, safety, and accuracy in enteral nutrition preparation.[10] Patient safety was improved through a reduction in errors with more consistent feeding preparation. However, generalization of these findings is limited by small subgroup analysis sample size. Large, adequately powered studies assessing the impact of milk technicians and centralized feeding preparation on time to full feedings in extremely preterm and very preterm infants are needed to further validate these findings.

Specialized Software

Four studies[13,14,20,30] assessed the impact of software use in the NICU and its effect on reducing feeding errors. One institution[14] implemented a feeding-related software program to accurately identify patients; create printable labels; scan expressed milk into inventory; monitor volume, location, and expiration of milk; and calculate volumes and additives. Investigators at the same institution found an 82% reduction in feeding errors in a follow-up study[20] after implementing bar code-scanning software; however, the accuracy of baseline data was dependent on employees noticing and reporting mistakes.

Researchers at another institution[30] retrospectively collected data on previously unreported errors following the implementation of bar code scanning. This system prevented a total of 2757 feeding-related errors during the first year of implementation compared with the 8 feeding-related error reported by employees during the previous year. The system tracked 3 types of errors, including attempts to feed the wrong milk, expired milk, and fortification errors. After modifying this system to account for employee work-arounds, there was a 40% reduction in expired milk errors and a 22% error reduction regarding wrong milk administration attempts in the second year of bar coding compared with the first year.

Another study[13] described a NICU's quality improvement project that initially mapped the feeding process and evaluated error points. The researchers indicated that software technology would reduce feeding errors. However, the expense of initiating the software made this change a long-term goal of the process improvement initiative and could not be analyzed in the results of the study.[13] Although this study[13] did not publish direct data regarding feeding error reduction with software use, the authors concluded that bar code-scanning software would be part of an ideal process.

Registered Dietitian-Registered Nurse Collaboration

Collaboration between nursing staff members and an RD is likely to improve feeding-related safety. Whether milk preparation takes place at the bedside or in a centralized preparation area, nurses are still responsible for administering feeds as well as coordinating the neonate's plan of care. This is clearly demonstrated in the studies included in this review, as 11 out of the 12 studies[3-5,7,8,10,13,14,20,31,32] include nurses within process improvement teams or with data collection. While the importance of the RN in NICU feeding processes has been well established, use of an RD is less documented. Registered dietitian involvement in feeding protocols and performance improvement efforts was cited in 8 of the 12 studies[4,5,7,13,14,20] without any reference regarding the singular effect of an RD in error prevention. However, no studies individually looked at the effect an RD has on reducing feeding errors or promoting safety. In several studies,[4,5,7,13,14,20] an RD was involved in the training of technicians, improving interactions

between nurses and trained technicians, communicating feeding orders, and interfacing with families. It is possible that collaborative efforts between RDs and nurses made a difference in feeding safety in these studies; however, this outcome was not a controlled variable for evaluation.

DISCUSSION

A centralized preparation area reduces errors associated with contamination, improper mixing, delivery errors, improper storage, and expiration. Therefore, a state-of-the-art NICU facility should implement a centralized preparation area.[6,8,10,11] To ensure additional safety controls related to decreasing contamination, improper mixing, delivery errors, improper storage, and expiration, trained technicians should staff centralized preparation areas.[4,5,7,8,10,11,13,24] Implementing bar code-scanning technology improves feeding safety through proper labeling, use of patient identifiers, standardize volumes, and monitoring of expiration.[6-8,11,13,20,24]

Centralized preparation areas should invest in bar code-scanning methods to reduce errors in mixing, storage, and delivery. Like nurses, RDs are interested in providing safe feedings to neonates. Therefore, use of an RD may improve coordination of individualized feeding plans in the NICU. Research is limited, but it is reasonable, based on the scope of practice, that use of an RD can improve safety, communication, and feeding plan management through collaboration with the RN.[4,11,33,34] Ideally, improving feeding processes in the NICU would allow for more time for nurses to spend on nursing-specific specialized care.[6]

Gaps in Research

Overall, there is limited research available looking at the specific strategies necessary to provide an ideal feeding model for patient safety. Ethical concern for participant safety can impact studies completed on preterm infants, limiting data available for the practitioner. The Office for Human Research Protections[35] has ethical regulations in place to ensure that studies conducted on preterm infants minimize risk for the population. Therefore, there are limited randomized control trials, which would better support conclusions. While the research makes an argument for reduction in feeding errors, decrease in contamination, and overall patient safety, it does leave some gaps to consider. It would be beneficial to NICU stakeholders to have more unbiased data on the specific impact of each component independently reviewed. Per study results,[7] combining centralized preparation, trained technicians, and use of bar code technology in a children's hospital made an impact on quality improvement as a grouping, but the study was not designed to detect individual impacts. This study could not be considered in data synthesis of this systematic review, as the population did not meet inclusion criteria. However, these findings support the need to evaluate relationships between variables.

Moreover, it would be valuable to further evaluate the cost-benefit of suggested associations between the reduction in feeding errors and impact on length of stay considering the financial burden associated with prolonged length of stays. Considering an average stay in the NICU costs upward of $3500 daily, the significant reduction demonstrated by a study's research with very preterm and extremely preterm infants could have large financial benefits, and it is possible that even the less significant decrease found in other comparison groups would equate to annual savings.[10] This could provide additional motivation to facilities to invest in the equipment, space, and staffing to ensure an ideal feeding process. Another study[6] looked at the potential cost-benefits of using bar code-scanning software and trained technicians to save nursing time. The researchers concluded that bar code scanning decreased labor demands of trained technicians. Therefore, by staffing 2 trained technicians during peak hours and 1 during non-peak hours, the hospital was able to eliminate the cost of 1 part-time trained technician salary and benefits, resulting in yearly savings. Researchers also determined that time saved-eliminating formula "double checks" resulted in cost savings for the organization. Despite the cost of the software and trained technician salary, the benefit was seen as profitable.[6] However, additional cost-benefit analyses would be useful in determining potential saving benefits when looking at factors such as cost of equipment, changes in nursing labor demands, and trained technical salaries versus benefits of reduced length of stay and projected saved labor time. The need for an ideal model sheds light on another gap in research, that is, what is an ideal feeding process? Because of the variation and inconsistencies between studies, a standardized approach in future research on this topic may strengthen the interpretation and generalizability of data.

General Strengths and Weaknesses

This review incorporated similar study designs, making comparison between studies achievable (Table 2). Importantly, while there were low-, medium-, and high-quality studies, all studies in this review showed safety and/or error reduction benefits through implementation of interventions, despite quality-ranking differences. Studies were conducted in a similar environment, the NICU, which helps compare trends among facilities. In addition, studies self-reported limitations. This helped assess for bias and adjust the quality rating for each study.

Limitations of this review include the sparsity of available data on this topic. Study models were simplistic, such as before and after study design or case-control through process improvement models. Some

Summary of Recommendations for Practice and Research	
What we know:	• Modified human milk or commercial products pose safety dangers for the immunocompromised NICU population due to increased risk for contamination. • Milk mixed at the bedside is at increased risk for contamination. • Milk mixed at the bedside pulls the registered nurse away from important clinical tasks. • Benchmarking indicates that top-ranked NICU facilities use centralized milk preparation areas, trained technicians, and bar code-scanning software to improve feeding safety.
What still needs to be studied:	• Centralized milk preparation, trained technicians, and bar code-scanning software's independent impact on feeding safety outcomes. • Benefits to feeding safety through RD-RN collaboration. • More advanced studies, such as randomized controlled trials, to evaluate feeding error reduction. • Evaluation of the cost-benefit(s) of implementing discussed practices, the reduction in feeding errors, and impact on length of stay costs.
What can we do today:	• Use ready-to-feed products to reduce contamination. • Evaluate current feeding procedures and identify areas of weakness. • Explore quality improvement initiatives to reduce feeding errors. • Communicate effectively between all stakeholders involved in feeding the neonate.

studies implemented multiple changes at the same time, such as developing centralized milk preparation as well as trained technician use, so it is difficult to analyze which component had the greatest impact on the outcomes. Furthermore, some data were dependent on nurses noticing and reporting errors, which could reduce the accuracy of the reported information. The studies demonstrated selection bias through populations of convenience, as studies used their own facility's NICU to complete the research.

Recommendations for the Future

This literature review highlights what is needed to reduce feeding-related errors in the NICU, which further improves quality of patient care. First, more robust data collection is required through randomized, controlled, and multicenter studies to eliminate reporting bias and develop evidence-based recommendations. Second, further exploration of the RD role in NICU collaborative performance and quality improvement teams is warranted. Since an RD was involved in many of the studies, it is likely that this role provides a benefit in feeding-related patient safety. Third, increased facility adherence to The Joint Commission and the Centers for Medicare & Medicaid Services regulations, as applicable to NICU feeding practices, is in the best interest of health care systems. Fourth, there are current economic and financial concerns associated with feeding errors in the NICU.[7,13] According to accreditation standards, adverse safety incidences from feeding errors should be reported and may have associated fines. In addition, if incorrect human milk is delivered, facilities may be financially responsible for blood work costs of both parties to confirm that spreading of pathogens did not occur. Hospitals would also be responsible to cover treatment expenses if adverse health effects arise after a feeding error. Likewise, it would be beneficial for future studies to analyze the impact of each individual component discussed. As process change is often expensive, it would be helpful to stakeholders to understand what variables are most important to implement first, especially to the financially conscientious organizations.

CONCLUSION

Feeding-related errors in the NICU are important to eliminate, as errors can lead to adverse health effects in premature infants. Currently, the ideal procedure for feeding preparation and delivery is unclear; therefore, there is great variability in NICU practices. Neonatal intensive care units are challenged by accreditation boards to aim for the goal of no negative feeding-related incidences. Research indicates that quality improvement initiatives, including the use of centralized milk preparation, trained technicians, bar code-scanning technology, and RD-RN collaboration reduce feeding errors and promote safety. Each factor appears to make a positive impact on reducing risk, but the best combination of strategies is unknown.[7] Centralized milk preparation standardizes storage, preparation, and administration of milk.[6,8,10,11] Use of trained technicians and bar code-scanning technology decreases nursing demand, improves control, and prevents "near misses."[6-8,11,13,20,24] It is reasonable for NICU stakeholders to adopt a model employing a combination of these strategies to promote best practice.

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