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Evidence-based methods that promote human milk feeding of preterm infants: an expert review

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SYNOPSIS

Best practices that translate the evidence for high dose HM feeding for preterm infants during the NICU hospitalization have been described in multiple studies but their implementation has been compromised largely due to economic and ideologic concerns. Although the rates of "any" HM feeding have increased over the last decade, efforts to help mothers maintain human milk provision through to NICU discharge have remained problematic throughout the world. Special emphasis should be placed on prioritizing the early lactation period of coming to volume so that mothers have sufficient HM volume to achieve their personal HM feeding goals. Finally, donor HM does not provide the same risk reduction as own mothers' HM for multiple morbidities in preterm infants, providing needed evidence for channeling of limited resources into NICU programs that promote the use of mothers' own HM.

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Human milk (HM; milk from the infant's own mother) feedings during the neonatal intensive care unit (NICU) hospitalization represent a cost-effective strategy to reduce disease burden and associated costs in preterm infants.[1–7] However, this evidence must be translated into NICU best practices that target barriers to high-dose HM feedings if preterm infants and their mothers are to receive the benefits of this knowledge. Although multiple studies have revealed effective interventions for modifying barriers to maternal lactation and HM feeding in this population, economic and ideologic concerns have limited their wide-scale adaptation.[8] As a result, many mothers of preterm infants fail to achieve their HM feeding goals, and infants receive either donor human milk or formula, neither of which achieves similar reduction in disease burden and cost.[9] This chapter reviews data on the initiation and maintenance of lactation for mothers of preterm infants; summarizes best practices for protecting maternal HM volume during the NICU hospitalization; delineates predictable, preventable problems in the feeding of HM, and details quality indicators that measure the effectiveness of NICU HM feeding programs.

Methodology

The literature used to create this review spans multiple specialties, including preterm infants, nutrition, human milk science, lactation physiology, breast pump dependency, NICU lactation support and the economics of human milk feeding for very low birthweight (VLBW; <1500 grams birthweight) infants. These citations were accumulated over a number of years by the authors, who are primary researchers in this field. Thus, this expert review reflects current evidence, controversies and implications for research and practice.

Initiation and Maintenance of Lactation in Mothers of Preterm Infants

Initiation of Lactation

The past decade is characterized by an increasing proportion of mothers who initiate lactation (begin providing HM) for their preterm infants,[3,10,11] many because they change the decision from formula to HM due to information they received from NICU health care providers.[12–14] Studies have confirmed that NICU messaging about the superiority of HM does not make mothers feel guilty or coerced, but instead is interpreted as needed information to make the best feeding decision for their infants.[12,13] Although black and/or low-income mothers have been especially likely to change from formula to HM after speaking with their infant's care providers,[12–14] black preterm infants in the United States remain less likely than their Caucasian counterparts to receive any HM, especially if their mothers are low-income.[5,15–17] Specific talking points for sharing the science of HM with families of preterm infants have been published, and can standardize evidence-based messaging about providing HM within the NICU.[8,18,19]

Maintenance of Lactation

The maintenance of lactation, usually measured by whether the infant is still receiving partial or exclusive HM at the time of NICU discharge, (HM continuation through NICU discharge), remains a global problem with only a handful of best practices demonstrated to be effective.[20–27] In a prospective cohort study, Hoban et al reported that mothers of very low birthweight (VLBW; <1500 grams birthweight) infants changed their HM feeding goals over the course of the NICU hospitalization, and became increasingly unlikely to achieve their goals for exclusive or partial HM as the hospitalization progressed.[14] It has been proposed that the profound dislike and inconvenience of long-term HM expression, maternal stress and fatigue, insufficient encouragement and assistance from family and friends, and inconsistent advice in the NICU all play a role in mothers' discontinuation of HM provision prior to NICU discharge.[25–28] Furthermore, it is likely that some mothers, especially those whose initial pre-birth intent was to formula-feed, revert back to their pre-birth feeding goals, especially as the infant's condition improves and the mother perceives that "HM has done its job" of protecting from acquired morbidities.[8,14]

Maintenance of lactation is related to maternal HM volume—The failure to maintain HM provision through to NICU discharge is related to insufficient pumped HM to meet the infant's nutritional requirements. However, it is not clear whether insufficient HM volume precedes less intensive HM expression efforts or vice versa. For example, does the mother see that despite her best efforts, her pumped HM volume decreases, and she becomes discouraged and pumps less frequently, eventually discontinuing HM provision? Or, is the primary catalyst the dislike and inconvenience of pumping, such that the mother pumps less frequently, notes decreased HM volume and then decides that her growing preterm infant is doing well with partial supplements of formula or donor milk, ceasing HM provision altogether?[8,14,26] These distinctions are important because they require different interventions to prevent early cessation of HM provision.

Successful initiatives to improve the maintenance of lactation—A handful of multi-institutional quality initiatives have demonstrated higher rates of HM provision at NICU discharge by adopting multidisciplinary infant nutrition and lactation teams that incorporate clear protocols for premature infants.[24] Other initiatives have focused on developing a NICU nursing lactation team, increasing availability of hospital grade breast pumps, and implementing lactation rounds.[23] Larger state-wide initiatives that report increased rates of HM feedings at NICU discharge have included multidisciplinary teams to provide education and advocacy for HM provision, to support establishing and maintaining HM supply, and to provide a consistent and comprehensive nutritional monitoring program.[22] Many of the evidence-based interventions to maintain lactation in this population such as timely access to effective and efficient breast pumps, freezer storage space and proactive NICU-specific lactation care, have not been adopted due to the upstart economic investments that would be required. (Table 1). In many instances it is easier to acquire institutional approval for donor human milk infrastructure than for programs that facilitate mothers' providing their own HM, despite the fact that own mothers' HM is more economical to provide and acquire and provides greater protection from acquired morbidities.[9,29,30]

Research Priorities to Improve the Initiation and Maintenance of Lactation in Mothers of Preterm Infants

Most previous studies addressing barriers to the initiation and maintenance of lactation in mothers of preterm infants have focused primarily on motivational and behavioral interventions such as skin-to-skin care, patterns of breast pump use and models of support.[23–25,27,31–34] However, many breast pump-dependent mothers of preterm infants have chronic health problems or pregnancy and birth complications that impact lactation outcomes and that may be unresponsive to current behavioral and motivational interventions.[8,18,35] These complications, which include pre-pregnancy body-mass-index (BMI) >25, preterm birth, Cesarean delivery and preeclampsia, as well as prolonged bedrest and medications to treat these complications, impact the hormonal processes that regulate secretory differentiation and early lactation.[36–42] However, because preterm infants require so little HM volume in the early post-birth period, these maternal HM volume problems can easily go unrecognized for days or weeks, making the problems more difficult to diagnose and manage. Thus, a research priority is understanding the role of maternal health complications that impact lactation outcomes for breast pump dependent mothers of preterm infants, who are often ill themselves.

Another research priority is addressing the mothers' consistent reports about the dislike and inconvenience of breast pump use. Mothers of preterm infants are completely breast pump dependent, meaning that the breast pump regulates the lactation processes of HM removal and mammary gland stimulation, which are critical to continued HM production.[35] Despite the reality that breast pump-dependency will continue for weeks or months, surprisingly few rigorous studies have examined features of breast pumps, breast pump suction patterns, breast shield-sizing and other product-related considerations such as the ability to warm breast shields.[35,43,44] Whereas it is well-known that breast pump evaluations in this population should include objective outcomes that include effectiveness, efficiency, comfort and convenience of the breast pump, the primary outcome measures in most studies continues to be pumped HM volume and maternal "preferences," both of which lack rigor and are affected by multiple extraneous variables. [35] Thus, a critical research priority for the maintenance of lactation in mothers of preterm infants is the improvement in the design of breast pumps and breast pump supplies so that they optimize efficiency and convenience, consistent with mothers' concerns.[35,45] Unfortunately, ideological barriers to breast pump research affect the study and dissemination of findings from industry-funded trials as well as the selection of breast pumps for clinical NICU use based on data versus compliance with WHO code marketing interpretation and other ideologic initiatives.[45,46]

Protecting Maternal HM Volume in Breast Pump Dependent Mothers of Preterm Infants

Breast pump-dependent mothers of preterm infants have specific, predictable barriers to the initiation and maintenance of lactation, which do not affect mothers of healthy term infants. These lactation processes and barriers have been delineated in two recent review papers,[8,35] and are summarized in Table 2 according to the stage of lactation: initiation, coming to volume and the maintenance of established lactation. Of particular concern are initiation and coming to volume because the first two weeks post-birth is a critical period for transition of the mammary gland from secretory differentiation to secretory activation, and little is known about these processes in breast pump-dependent mothers of preterm infants.[38,41,43,47] Furthermore, several studies indicate that daily pumped HM volume at either week 1 or week 2 post-birth in this population predicts HM continuation at NICU discharge.[35,48–50] In one recently completed study, mothers of VLBW infants who successfully experienced coming to volume, e.g., achieving HM volume ≥ 500 mL/day by day 14 post-birth, were over 3 times more likely to provide HM at NICU discharge than mothers who did not achieve this threshold.[50]

Early Lactation: Initiation and Coming to Volume

The early post-birth lactation stages of initiation and coming to volume warrant further detail because they pose predictable problems for breast pump-dependent mothers of preterm infants and should be monitored and addressed proactively.[35] The initiation of lactation coincides with the closure of tight junctions in the mammary epithelium,[38,47] a process that is disrupted and/or delayed by preterm and/or complicated birth,[41] lack of exposure to human infant-specific sucking patterns,[43] delayed breast pump use,[51,52] early hormonal contraception,[53] and prolonged hand expression in the absence of breast pump use.[54]

Coming to volume refers to the lactation stage between the onset of lactogenesis II and the establishment of a threshold HM volume, typically ≥500 mL/day.[35] This transition heralds the autocrine control of lactation[55] via the suckling-induced prolactin surge[56] and feedback inhibition of lactation.[57] Coming to volume in a breast pump-dependent mother with a NICU infant is impaired by easily-overlooked conditions that lead to HM stasis, thereby triggering feedback inhibition of lactation. These conditions include using an ineffective breast pump that does not empty the breasts thoroughly, improperly fitted breast shields that obstruct the outflow of HM from the ducts, inappropriate breast pump suction pressures, short pumping sessions and long intervals between breast pump use.[35] Furthermore, several lines of evidence suggests that the early post-birth stages of initiation and coming to volume are critical periods for the programming of lactation structures and functions, making it difficult or impossible for mothers with low HM volume to ‘catch up’ after these critical periods have passed.[35,43,54]

Clinical Tools to Monitor Coming to Volume and Maternal HM Feeding Goals

All available evidence indicates that the NICU staff should prioritize the first 14 days post-birth using proactive interventions to achieve maternal HM volume measures that are ≥500 mL/day.[18,35] A NICU toolkit for managing these early lactation phases has been described and includes a user-friendly pumping diary (My Mom Pumps for Me!), the Coming to Volume Assessment Tool and a weekly maternal feeding goals interview tool (My Plans for Feeding my Baby at NICU discharge) that assures mothers’ individual HM feeding goals are monitored and supported.[18] Whereas the costs for these interventions are often assumed to be unaffordable, in reality they are quite economical (Table 1), especially considering that the cost savings afforded to each additional fed mL of HM during the first 14 days post-birth is valued at $534 toward reduction in NICU costs of care, exclusive of costs specifically attributed to necrotizing enterocolitis.[2]

Improving the Use of HM for Preterm Infants

Considerable global variation exists in the storage, handling, fortification and feeding of HM in the NICU, as detailed in two recent review papers.[3,8] Barriers to the integration of evidence-based practices to improve the use of HM for preterm infants include lack of HM/ lactation specialists with NICU expertise, cost of investment in resources and ideologic objections to the use of technology that makes breastfeeding “unnatural”.

Safe Handling of Pumped HM in the NICU

When HM is pumped, transferred among containers, stored, warmed, fortified and fed via gavage infusion, there are multiple avenues for compromising the nutritional and bioactive components that actually reach the infant.[3,8] Furthermore, HM is easily contaminated during these processes and can serve as an excellent medium for bacterial growth, especially if HM has been previously frozen. These concerns are the most comprehensively addressed by feeding freshly pumped HM that has not been either refrigerated or frozen (e.g., directly from mother to infant), and this strategy should be prioritized to the greatest possible extent.[3,8] Table 3 summarizes best practices for safe handling of pumped HM in the NICU.

New data about changes in the integrity of HM with storage have significant clinical implications for conserving pumped HM.[58–60] Slutzah et al reported that freshly pumped, unfortified HM is safely fed after refrigeration for 96 hours.[58] Separate studies suggest that pumped HM can be thawed and refrozen at least one time[61] (allowing aliquoting of HM from large containers into smaller ones for smaller volume feeds), and that HM from serial pumpings can be safely added to previously pumped HM over a 24-hour period.[62]

There is no evidence to inform whether HM storage and preparation should be centralized within a milk bank area or prepared at the bedside by the NICU nurse. A centralized service is potentially safer with respect to misallocation of HM (e.g., infant receiving another mother’s HM), although this assumption has not been tested. Centralized preparation may also be more efficient and convenient, especially if donor HM is used to supplement mothers’ own HM. In contrast, HM preparation at the bedside by a NICU nurse enables more individualization of the feeding that potentially impacts infant outcome. For example, the NICU nurse can prioritize fresh versus frozen HM, colostrum versus mature HM and other strategies that are impossible when a centralized service has already prepared 12 or 24 hours of HM feedings in advance. The pros and cons of each practice have been reviewed recently.[8] One single-center study has demonstrated a reduction in the rate of HM misallocation in the NICU with the adoption of an electronic HM tracking/scanning system, while others have implemented non-electronic measures to reduce errors.[63,64]

Within- and Between- Mother Variability in Pumped HM and Impact on Infant Growth

The within- and between- mother variability in pumped HM fed in the NICU has been documented for decades.[3,8] Of all HM components, lipid which contributes 50–60% of HM calories, is the most variable with one study of pumped HM specimens provided by NICU mothers revealing minimum and maximum values for caloric density of 604 kCal/L and 1098 kCal/L respectively.[65] Multiple modifiable factors contribute to lipid variability, which can be quickly identified and managed using the creamatocrit or other more costly HM analysis technologies.[3,65] Table 4 summarizes common NICU scenarios that result in low-lipid, high lactose HM being fed with resultant slow infant weight gain and potential feed intolerance. Recent review papers on this topic provide extensive clinical examples of the impact of low-lipid HM on infant growth and feed intolerance.[3,8] Although the adequacy of protein impacts infant growth, HM protein varies little after the first month of lactation, during which time protective and growth proteins (e.g., secretory IgA, lactoferrin, epidermal growth factor) are more concentrated that nutritive protein.[66,67]

Feeding at Breast in the NICU

Feeding at breast for preterm infants can be conceptualized as a series of steps, including: breast pump use at the infant's bedside; skin-to-skin holding; tasting HM (suckling after breast pump use to remove all or some of the HM); and finally consuming full feedings at the breast.[18,68–71] There are no data to indicate that infants must attain a threshold weight or gestational age to begin tasting HM, and several studies reveal that preterm infants remain more physiologically stable during breast than bottle feeding.[8] However, a myriad of international studies suggest that preterm infants are prone to underconsumption of HM during exclusive at-breast feeding until they reach approximately term, corrected age despite the fact that the mother has more than enough HM and can remove it effectively with a breast pump.[3,8]

HM Transfer during Breastfeeding Requires Mature Infant Suction Pressures

This ineffective and inefficient HM removal by preterm infants is due to weak intraoral suction pressures that are critical to breastfeeding but not bottle feeding. Suction pressures strengthen as the infant matures, as does the ability to stay awake and alert during the feeding and not slip off the breast repeatedly.[8] Figure 1 depicts HM intake by breast and bottle during the first 4 weeks post-discharge in VLBW infants whose mothers had adequate HM for their requirements.[72] As demonstrated in Figure 1, mothers have adequate volumes of HM and can remove it with a breast pump, but the infant cannot remove the available HM during exclusive breastfeeding. Figure 1 can be used to help families understand that NICU discharge does not mean that breastfeeding will magically "work" because the mother and infant are no longer separated. In fact, the breast continues to synthesize HM only because additional breast pump use removes HM effectively and efficiently. Early discontinuation of breast pump use during this transition to exclusive at-breast feedings predisposes to low HM volume and inadequate infant intake.[8]

Use of Evidence-Based Lactation Technologies to Facilitate Breastfeeding

The first month post-discharge can be extremely difficult for breastfeeding mothers with preterm infants in part because lactation technologies that can guide this transition are not commonly employed. First, test-weights performed during the last week or two in the NICU using accurate scales can help individualize breastfeeding strategies for use in the home.[8] For example, if serial test-weights reveal that the infant consumes only 5–10 mLs at breast, more bottle supplement of HM is required than if the infant consumes 80% of the prescribed volume. Multiple studies of test-weights to measure HM intake during breastfeeding reveal that they are accurate, acceptable by mothers, and cannot be replaced by clinical indices such as counting swallows or checking for milk in the infant's mouth.[45,73,74] One randomized study revealed that mothers of preterm infants can use of test-weights in the home after NICU discharge to manage supplements and complements of their pumped HM until infants can consume exclusive breastfeeds.[75]

A second lactation aid that can be useful during this transition is the ultra-thin silicone nipple shield, which partially compensates for weak suction pressures by creating and maintaining a nipple shape for the infant to latch onto.[8,72,76] Although not originally designed as a milk transfer device, evidence indicates that use of the nipple shield increases HM transfer during breastfeeding in preterm infants for whom maintaining sufficient suction pressure to extract HM is suboptimal or impossible.[8] Multiple ideological objections to nipple shield use in this population abound, including that it decreases HM transfer, decreases maternal HM volume, looks like a bottle nipple, and is addictive. In contrast, data indicate that the nipple shield can serve as a short-term lactation aid in this population until suction pressures mature sufficiently to allow effective and efficient transfer of HM during exclusive breastfeeding.[8,72,76]

Evidence-Based Quality Indicators that Target High-Dose HM Feedings

Given the link between high-dose HM feedings and improved short- and long-term health and cost outcomes, many NICUs and have established quality improvement initiatives for the use of HM. The most commonly used metrics are the proportion of preterm infants who ever receive HM and the proportion who are still receiving any or exclusive HM at the time of NICU discharge. However, Bigger et al., using data from a prospective cohort study, revealed that significant proportions of VLBW infants who were discharged as "no HM" had received very high-dose HM feedings through the first 14 and 28 days of life.[77] These data, which emphasize collecting measures of "dose" (in mL/kg/d or as a proportion of total enteral feeding), in addition to the "ever received" and "still receiving" HM quality indicators, are consistent with findings that link early high-dose HM to the reduction in the risk of necrotizing enterocolitis and sepsis and associated increased costs.[77]

Another concern in developing quality improvement initiatives for the use of HM is the increasing tendency to combine own mother's HM and donor HM into the same metric, which is often called *human milk-fed* or *breast milk-fed*.[9] The distinction between own mother's HM and donor HM is critical when measuring quality outcomes because donor HM does not provide similar risk reduction from sepsis, BPD and neurodevelopmental problems when compared to mother's own HM.[9,78] Many of the bioactive components in HM are mother-specific such as probiotic bacteria (HM microbiome) and accompanying prebiotic oligosaccharides,[79,80] and multiple other HM components are reduced or eradicated due to longitudinal changes in lactation (e.g., early HM versus later HM), preterm versus term HM, storage, freeze-thaw cycle and pasteurization, all of which impact donor HM.[9] Furthermore, the processes involved in achieving high rates of mothers' own HM feedings in the NICU are completely different from acquiring DHM, and scarce funds are often invested into establishing a donor HM infrastructure rather than in acquiring HM from the infants' own mothers.[9]

Summary

Although the evidence for high dose HM feeding for preterm infants during the NICU hospitalization is widely accepted, best practices that translate and implement this evidence into daily clinical NICU care have been slow to follow. These best practices have been delineated and model programs for improving the use of HM during the NICU hospitalization have been described. However, increasing the rates of high-dose HM feedings for this population requires an economic investment in personnel, equipment and supplies as well as a commitment to select best practices based on evidence rather than ideology. Special emphasis should be placed on prioritizing the early lactation period of coming to volume so that mothers have sufficient HM volume to achieve their personal HM feeding goals. Finally, it is important to recognize that donor HM does not provide the same risk reduction as own mothers' HM for multiple morbidities in preterm infants, providing evidence for the channeling of limited resources into NICU programs that promote the use of mothers' own HM.

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KEY POINTS

1. The evidence for the use of human milk feedings during the NICU hospitalization for preterm infants has been slowly adopted into clinical best practices.
2. In multiple instances, these best practices have been identified and tested, but are not adopted due to economical and ideological constraints.
3. The early post-birth periods of maternal secretory activation and coming to volume appear to comprise a critical window for the protection of maternal human milk provision through to NICU discharge.
4. Lactation technologies that improve the use of human milk during the NICU hospitalization have been detailed in the scientific literature, but not widely implemented.
5. Donor HM feeding infrastructure costs can compete with costs for the acquisition of mothers' own HM in the NICU, with implications for the cost-effective prioritization of limited resources.

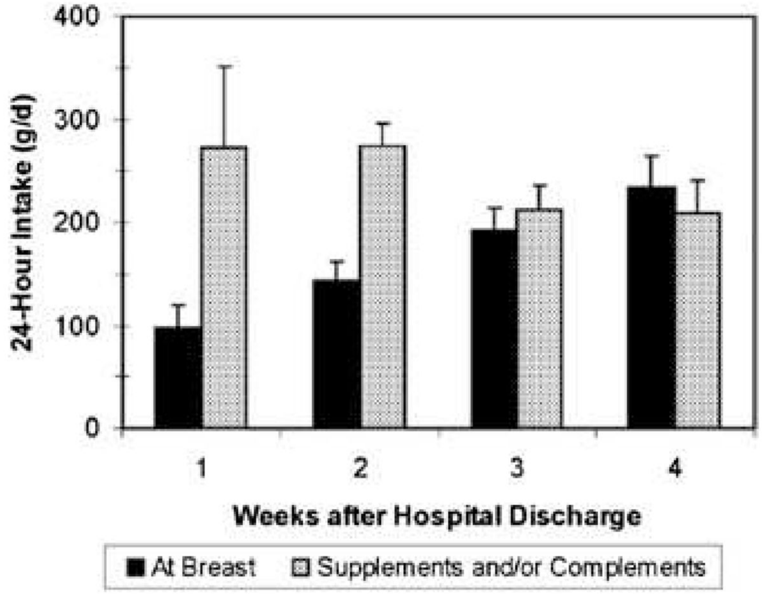

Figure 1.

Volume of milk consumed at the breast and as extra milk (supplements and complements of pumped mothers' milk) during the first 4 weeks at home in premature infants discharged from the neonatal intensive care unit. (Courtesy of N. Hurst, PhD, Houston, TX; P. Meier, PhD, Chicago, IL; and J. Engstrom, PhD, Chicago, IL.)

Table 1

Economic Barriers to the Initiation and Maintenance of Lactation: Estimated Average Cost of Required Services per Infant

Barrier	Cost per Infant	Low	High	Assumptions
1 Provision of professionally-produced, evidence-based materials targeting the importance of HM for preterm infants + monitoring of HM volume and goals for HM feeding	Brochure + education sheets = $10; Mother's Milk Volumes (MMV) record = $5.50; Maternal Goals record = $0.10;	$15.60	$15.60	1 set of materials per infant
2 Hospital grade electric breast pump rental for 3 months (through term, corrected age)	$40 to $70 per month	$120.00	$210.00	3 month rental; low estimate assumes $40 per month, wholesale cost; high estimate assumes $70/month retail cost
3 Provision of pump kit	$32.91 cost per kit	$32.91	$32.91	1 kit per infant
4 Access to custom-fitted breast shields for effective, efficient and comfortable HM removal	$7 retail cost	$7.00	$7.00	1 set per infant
5 Provision of sufficient numbers of hospital-grade HM storage containers for pumped HM	$0.21 cost per container (Jegier 2013)	$89.46	$134.19	Low estimate assumes 6 containers per day (350 mL/120 * 1.2 rounded to next multiple of 3); high estimate assumes 9 containers/day (700 mL/120 *1.2 rounded to next multiple of 3); for 71-day NICU stay
6 Access to NICU-specific lactation support from NICU-based certified breastfeeding peer counselors (BPC) during *coming to volume,* weekly group forums and on an individual basis, as needed	$18/hour + 26% fringe benefits	$417.11	$539.79	71-day NICU stay; $18/hour + 26% fringe benefits; low estimate assumes 2 BPC for 44 infants per day; high estimate assumes 2 BPC for 33 infants per day (75%)
7 Availability of NICU freezers for safe storage of all pumped HM (e.g., not telling mothers to store HM in the home and bring it in as needed)	$8,000 cost per freezer	$6.92	$10.37	Storage for 15 infants per freezer; low estimate assumes 15 year life; high estimate assumes 10 year life; for 71 day length of NICU stay
8 Use of HM waterless warmers to avoid HM contamination with waterborne pathogens	$773 cost per warmer	$30.07	$50.12	1 warmer per infant for 71-day NICU stay; low estimate assumes 5 year life; high estimate assumes 3 year life
9 Use of liners for waterless warmer	$3.25 cost per liner	$230.75	$230.75	1 liner per day for 71-day NICU stay
10 Basic creamatocrit and/or other HM analysis technology to individualize HM feedings and HM collection strategies	$1,500 per creamatocrit	$0.38	$0.63	1 creamatocrit per NICU; assumes 800 NICU admissions per year; low estimate assumes 5 year life; high estimate assumes 3 year life
11 Availability of infant scales for measuring HM intake during breastfeeding	$1,500 per scale	$3.89	$6.48	1 scale per 15 infants for NICU stay; low estimate assumes 5 year life; high estimate assumes 3 year life
Total		**$954.08**	**$1,237.84**	

Costs reported in 2015 US dollars.

Based on Average length of NICU stay for VLBW infants of 71 days from RUMC data

Table 2

Critical Periods for Protecting Maternal Milk Volume in Breast Pump Dependent Mothers of Preterm Infants

Critical Period	Problem	Impact	Best Practice(s)	References
Initiation	• Lack of understanding about the mechanisms that trigger secretory differentiation and regulate lactation • Multiple risk factors for delayed or impaired initiation of lactation • Use of ideology versus evidence about method and timing of milk removal/ mammary gland stimulation • Early administration of hormonal contraceptives • Economic barriers for access to equipment and NICU-specific lactation care	• Interference with rapid post-birth decline in progesterone • Lack of timely mammary gland stimulation to complete secretory differentiation (lactogenesis II) • Impaired or delayed secretory differentiation segues into permanent low milk volume	• Assure that mothers are taught about the potential impact of hormonal contraception during the maternity hospitalization on the initiation of lactation so they can make an informed decision about its timing • Screen mothers for risk factors for delayed or impaired onset of lactation (e.g. hypertension, obesity, Cesarean delivery) and share this information (and a plan for monitoring) with them • Do not use exclusive hand expression in the absence of breast pump stimulation. • Initiate pumping within the first hour post-birth • Use a breast pump suction pattern that mimics the human infant during the initiation of lactation and has been shown to increase HM volume compared to standard breast pump suction patterns • Assure mothers have access to NICU lactation care providers with expertise in breast pump dependency	35,41–43, 45,51–54,81–86
Coming to Volume	• Lack of understanding about change from endocrine to autocrine regulation of lactation • Unclear messaging for mothers about necessity of frequent and complete HM removal to effect this transition. • Lack of proactive lactation care strategies that prevent and or detect early problems with HM volume	• Mothers who fail to come to volume by 14 days post-birth are statistically unlikely to provide sufficient HM through to NICU discharge. • Overlooking common pitfalls during coming to volume can translate into long-term HM volume problems	• Educate mothers about the critical nature of *coming to volume*, emphasizing that most HM volume problems present during this time, and must be managed quickly and correctly. • Share HM targets ($\geq$ 500 mL/day) for post-birth day 14 or before. • Explain and use Coming to Volume Assessment tool to detect and manage modifiable HM volume problems • Explain and use My Mom Pumps for Me! maternal HM volume log • Assess pumping technique by watching mothers use the pump daily during *coming to volume*. – Check for correct breast shield sizing, pumping pressures and thorough breast emptying	18,35,81
Maintenance of Established Lactation	• Lack of proactive strategies to monitor changes in mothers' personal goals for providing HM through to NICU discharge • Inadequate proactive counseling/teaching about common problems/scenarios that reduce HM volume during the later NICU hospitalization • Lack of support for long-term pumping	• As the duration of the NICU hospitalization increases, mothers do not achieve their personal HM feeding goals. • Infants do not receive the highest possible NICU dose of HM, reducing protection from potentially preventable morbidities	• Meet with each mother weekly to review and update personal HM feeding goals (Use "My Feeding Plans" tool) • Proactively review common scenarios that reduce HM volume during the late NICU hospitalization. – Substituting a feeding at breast for breast pump use (Need to pump after breastfeeding) – Returning to employment and reducing total daily pumping time or using less effective (portable) breast pump	14,26,27,33, 77,81,87

Critical Period	Problem	Impact	Best Practice(s)	References
			• Incorporate NICU-based breastfeeding peer counselors and mother-to-mother support for long-term pumping	

Table 3

Safe Handling of Pumped HM for Preterm Infant Feeding in the NICU

Data from Meier PP, Patel AL, Bigger HR, et al. Human milk feedings in the neonatal intensive care unit. In: Rajendram R, Preedy VR, Patel VB, eds. *Diet and nutrition in critical care.* New York: Springer-Verlag; 2015:807–822 and Meier PP, Rossman B, Patel AL, Johnson TJ, Engstrom JL, Hoban R, Patra K, Bigger HR. Human milk in the neonatal intensive care unit. In: *A state-of-the-art view about human milk and lactation.* Stuttgart: Thieme; in press.

Objective	Best Practices
A. Maximize nutritive and bioactive components	• Feed freshly pumped, never frozen, HM to greatest possible extent – Freshly pumped, unfortified HM can be refrigerated for up to 96 hours • Do not pasteurize mothers' own HM • Implement mechanism for identifying pumped colostrum and transitional HM so it can be fed in the order it is pumped during advancement of enteral feedings – Alternate colostrum and transitional HM with freshly pumped HM after 72 hours post-feed initiation if colostrum and transitional HM collections have been previously frozen • Minimize number of temperature changes (e.g., serial refrigeration + warming)
B. Optimize nutrient delivery and utilization	• Feed freshly pumped, never frozen, HM to greatest possible extent • Use strategies to minimize the impact of exogenous additives on the delivery and utilization of HM components • Feed HM by intermittent rather than continuous gavage infusion to prevent lipid entrapment in infusion tubing and resultant loss of nutritional lipid and energy • Invert syringe (bevel upward) if intermittent feedings are placed on an infusion pump to ensure HM lipid is delivered to infant • Flush HM remaining in infusion tubing after feeding with 1–2ml air so that infant receives as much of trapped lipid as possible
C. Minimize bacterial contaminants and bacterial growth	• Feed freshly pumped, never frozen, HM to greatest possible extent • Standardize protocols for collection, storage and transport of HM that are user-friendly and easily understood by NICU families • Ensure all HM specimens are collected and stored in sterile receptacles • Store all pumped HM in industrial NICU refrigerators and freezers that are tamper-proof and routinely monitored for appropriate temperature maintenance • Do not implement a routine culturing surveillance program for pumped HM as this approach has been shown ineffective in minimizing bacteria • Use waterless warming and thawing techniques to prevent HM contamination • Feed previously frozen HM within 24 hours of thawing
D. Eliminate errors in HM fed to the wrong infant	• Implement a HM management system that minimizes the risk of HM being fed to the wrong infant • Engage parents in the importance of accurate labeling of HM receptacles and other activities (such as checking that all pumped HM is moved from one NICU room to another with the infant) per individual NICU protocol

Table 4

Factors Influencing the HM Lipid Received by the Preterm Infant

Data from Meier PP, Patel AL, Bigger HR, et al. Human milk feedings in the neonatal intensive care unit. In: Rajendram R, Preedy VR, Patel VB, eds. *Diet and nutrition in critical care*. New York: Springer-Verlag; 2015:807–822 and Meier PP, Rossman B, Patel AL, Johnson TJ, Engstrom JL, Hoban R, Patra K, Bigger HR. Human milk in the neonatal intensive care unit. In: *A state-of-the-art view about human milk and lactation*. Stuttgart: Thieme; in press.

Factor	Impact	Best Practices
	Pumping	
• Long intervals between pumpings yield a low-lipid, high lactose HM	• Longer intervals between pumpings (such as during sleep or return to employment) result in low-lipid HM in the first pumping after the longer interval, whereas • Shorter intervals (such as every two hourly pumpings during a visit to the NICU) result in a high-lipid HM in the first pumping after the interval	• If sufficient HM volume, freeze low-lipid HM for use after NICU discharge, and • Feed HM collected after shorter inter-pump intervals • HM can be pooled over a 24 hour period in the same storage container to decrease this within-mother variability
• Not emptying breasts thoroughly yields a low-lipid, high lactose HM	• HM that flows from the first few minutes of a pumping is low-lipid (foremilk), whereas • Following milk ejection and through to thorough breast emptying, the HM lipid increases significantly	• Do not teach mothers to use a standard time to complete pumping such as 10 or 15 minutes. • Emphasize that time to complete breast emptying is individual • Teach mothers the concept of foremilk and hindmilk so that they understand the importance of complete breast emptying
• Inadvertently separating foremilk and hindmilk with small pumping/storage receptacles	• Container filled from the earlier part of the pumping will be low-lipid HM, whereas • Container filled from the later part of the pumping will be high-lipid HM and • These differences may translate into calories that are 3 times higher in the last versus first pumped receptacle	• Avoid the use of these products for mothers whose pumped HM volume exceeds the capacity of the receptacle. • Teach all mothers the importance of not separating HM during pumping (unless used as a strategy to concentrate hindmilk lipid)
	Storage	
• HM is not homogenized so lipid separates and rises to the top of the storage container • Freezing disrupts the HM fat globule membrane	• Mothers may think there is something wrong with the pumped HM if not informed about separation of lipid • Lipid becomes difficult to thoroughly mix	• Teach mothers that lipid rises to the top of the storage container and that it is a different color from the rest of the HM • Develop and implement protocols that assure the HM is thoroughly mixed • Recognize that this process takes extra time for the bedside RN

Factor	Impact	Best Practices
Handling		
• Lipid adheres to crevices of storage containers, lids and is not transferred to feeding receptacles	• Lipid is not delivered to the infant • This is a commonly overlooked contribution to slow weight gain	• Assure that HM feeding protocols include guidelines for transferring as much HM lipid as possible by thorough checking and mixing • Do not use HM storage bags in the NICU because lipid is very difficult to remove from corner crevices
Feeding		
• Lipid is poorly delivered with slow-infusion gavage feedings	• Lipid is trapped in infusion tubings • The slowest infusion rates yield the greatest lipid trapping (loss)	• Avoid continuous infusions of HM • Use intermittent, gravity gavage feedings when possible • If intermittent gavage feedings are administered by infusion pump, use the most rapid rate that is safe • Use creamatocrit or HM analysis to diagnose/manage the degree of lipid trapping if continuous infusions must be used
• Lipid rises to the top of HM infusion instruments and is poorly delivered in a horizontal position	• Significant lipid loss can occur over a 24-hour period • Infant receives equivalent of defatted HM with a greater proportion of calories from lactose • This problem is a significant source of caloric loss	• Place the infusion syringe so that the bevel is pointing up so as much lipid as possible is moved from the syringe into the infusion tubing
• Lipid is trapped in infusion tubing if not flushed post-feed with air	• Even when intermittent gavage feedings are administered by infusion pump, lipid is trapped in the infusion tubing • This is worsened when the nurse adds "extra" HM to the prescribed feed volume, knowing that a final 2 mLs will remain in the tubing at the end of the feeding (which is discarded) • The infant does not receive the trapped lipid	• Do not add extra HM to compensate for the volume remaining in the tubing at the end of the infusion. Instead, • Flush the remaining HM from the infusion tubing using a slow air purge
• During breastfeeds the preterm infant may not consume sufficient volume to remove lipid- rich hindmilk	• Mothers often have more HM in the breast than the preterm infant can consume • Infants can consume sufficient HM volume (as measured by test weights) and still gain weight slowly if the intake reflects low-lipid foremilk that flows at the beginning of the feeding • Failure to remove hindmilk at the end of the feeding also impacts the feedback inhibitor of lactation with resultant downregulation of HM volume	• Until the preterm infant is able to effectively and efficiently consume all of the HM from a single breast, bottle supplements of pumped HM can consist of fractionated hindmilk, as needed • Recognize that slow weight gain when consuming an adequate volume of HM from the breast does not mean that the infant needs extra fortification or formula products. • This scenario is easily diagnosed and managed using a combination of creamatocrits with pumped HM and test-weights

Factor	Impact	Best Practices
• Frequent switching the infant between breasts potentiates low-lipid foremilk intake	• Due to weak suction pressures the preterm infant may not consume an adequate HM volume at breast • Consuming an adequate HM volume is facilitated when maternal HM flow is rapid, such as with post-milk ejection. • The common strategy of switching breasts after 5 minutes of sucking is meant to facilitate intake at breast, but • It potentiates low-lipid, high volume feedings • In extreme circumstances infant may demonstrate symptoms of lactose intolerance, including explosive stools and slow weight gain	• Do not recommend this approach with recently discharged preterm infants • It is preferable to provide some pumped HM (as hindmilk as necessary) to provide sufficient HM intake until the infant is capable of exclusive at-breast feeding