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Measures of Lactation Outcomes in Women Delivering Preterm Infants

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Abstract

Background: Mother's own milk (MOM) is well known to decrease prematurity-related morbidities, yet mothers delivering preterm infants often produce insufficient quantities of milk to provide these benefits. While a critical need exists for research to support lactation success in this vulnerable population, development and investigation of interventions to increase available MOM for infant consumption requires consistent, valid, and reliable measures of lactation outcomes.

Objectives: To compare and contrast methods of measuring lactation outcomes in mothers of preterm infants and evaluate their advantages and disadvantages.

Methods: Measure of lactation outcomes were reviewed and synthesized. Insights on best practices and future research directions are provided.

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Results: Volume of MOM produced, lactation duration, and time to onset of secretory activation are important measures of lactation success. The most valid and reliable measure of milk production is likely weighing each vial of expressed milk combined with test-weighing when infants breastfeed. Measures of lactation duration should include actual days mothers lactated rather than limiting to infant consumption of MOM as a proxy for duration and include not only whether mothers are lactating at infant discharge but whether they are also lactating at other health-relevant time points during hospitalization. Although time to onset of secretory activation is an important lactation outcome, information regarding valid and reliable indicators of onset in women delivering preterm infants is limited and investigation of such indicators is a research priority. Variables which may affect lactation outcomes including time to initiation of expression following delivery, duration of expression sessions, expression method, time spent in skin-to-skin care, maternal demographics and comorbidities, as well as maternal intent to lactate must be considered when researchers investigate lactation outcomes in mothers of very low birth weight infants.

Discussion: Consistent and valid measures of lactation outcomes are required to produce reliable results from which evidence-based practice recommendations can be developed in order to improve lactation success in this vulnerable population.

Keywords

human; ICU; lactation; methods; milk; neonatal

Mother's own milk (MOM) has been shown to improve neurodevelopmental outcomes and decrease prematurity-related morbidities such as feeding intolerance, late-onset sepsis, retinopathy of prematurity, chronic lung disease, and necrotizing enterocolitis in preterm very low birth weight (VLBW) infants (Cortez et al., 2018; J. Huang et al., 2019). However, mothers who deliver VLBW infants often produce an insufficient volume of MOM to provide these benefits; as such, research to support lactation success in this vulnerable population of women is essential (Fabiyi et al., 2015).

This decreased milk production may be related to limited exposure to lactation hormones, decreased mammary gland development, the need for a mother to mechanically express her breasts, and comorbidities known to negatively affect lactation (Y. Huang et al., 2019; Wilson et al., 2018). Mothers of VLBW infants are also at risk for delayed secretory activation—the transition from production of small amounts of colostrum to copious amounts of MOM—which can decrease milk production and result in shorter lactation durations (Murase et al., 2014; Nommsen-Rivers 2016). Delayed secretory activation limits the volume of MOM available for infant consumption during the first few days following delivery, which may result in infants receiving formula and/or donor human milk (DHM) or continue nil per os (NPO), which are all inferior to colostrum feedings (Battersby et al., 2017; Berkhout et al., 2018).

Given MOM's importance for infant health and its dose-dependent benefits, strategies to optimize the available amount of MOM for infant consumption are crucial. To develop evidence-based information with which to guide clinical practices, studies must utilize consistent, valid, and reliable measures of lactation outcomes. Therefore, the objective of

this review is to compare and contrast various methods of measuring lactation outcomes in mothers of preterm VLBW infants, evaluate these methods' advantages and disadvantages, discuss expression factors which may influence lactation outcomes, and offer insights on future research directions.

Lactation Outcome Measures

Volume of milk produced, lactation duration, and time to onset of secretory activation are common lactation outcomes included in research involving mothers of premature VLBW infants. The following section analyzes different methods of measuring each outcome and provides recommendations for use in future research. Table 1 provides an overview of each method including its strengths and weaknesses.

Measuring Volume of MOM Produced

Methods utilized in research determining MOM production have included maternal report (measured by visualization of volume gradations on vials) and measurement by researchers or clinicians (determined by either visualization or weighing each vial of expressed milk (Asztalos et al., 2019; Parker et al., 2020). At this time, maternal self-report using lactation diaries or mobile applications is likely the most common method of measuring milk production; however, this effort is often hampered by the well-known risk of error and the reduced validity of self-reported data (Asztalos et al., 2019; Wang et al., 2018).

Weighing each vial of expressed milk (each gram of milk equals 1 mL) by health care professions, including human milk technicians, is likely the most accurate method of measuring the volume of milk produced (Dowling et al., 2004). This method involves weighing each vial of milk brought to the newborn intensive care unit (NICU) and subtracting the weight of the vial, lid, and all labels to obtain the exact volume of milk produced. Not only is this an objective measurement of milk production, but it can also be used to validate maternal report of volume produced. Moreover, when mothers document the date and time of expression on each vial of milk, this method also provides information regarding expression frequency. Finally, to decrease the risk of bias in interventional studies, this method allows blinding of individuals measuring MOM production to any interventions they may have received.

Limitations of this method include the inability to determine expression method or duration —both of which may be important for promoting milk production (Lussier et al., 2015; Morton et al., 2009). In addition, mothers who produce large volumes of milk may store excess milk at home, those taking medications or drugs may discard expressed milk, and errors in maternal documentation of the date and time of expression are possible, which may misrepresent the precise amount of MOM produced. Therefore, frequent communication with mothers regarding the necessity of bringing in *all* expressed milk to the hospital and correctly labeling each vial is essential to avoid errors while measuring milk production.

As VLBW infants mature and begin to breastfeed, the total volume of milk produced and measured must include the volume consumed during each breastfeeding session. Test-weighing or weighing an infant prior to and immediately following breastfeeding clad in the

same clothing, diaper, and blanket has been shown in multiple studies to be an accurate method to measure MOM intake in preterm infants during breastfeeding with the difference between pre- and postfeeding weights indicating the volume of milk consumed by the infant (Rankin et al., 2016).

One challenge to test-weighing is determining how to define a "breastfeeding attempt" that is likely to result in milk transfer from mother to infant. In many NICUs, VLBW infants are encouraged to begin breastfeeding attempts earlier than 32 weeks postmenstrual age (Nyqvist et al., 2013). However, these attempts generally only consist of "nuzzling" at the breast with little to no actual milk consumption; even at more advanced postmenstrual ages, breastfeeding attempts in VLBW infants can often result in little to no milk consumption. Because test-weighing can be time-consuming and possibly stressful to premature infants, limiting this procedure to breastfeeding sessions that will likely result in an infant's consumption of MOM is important. Individuals, including research assistants, nurses, and mothers, who perform test-weighing must be properly trained and their measurement reliability must be regularly evaluated.

Both galactogogues and hormonal contraceptives may affect milk production and must be considered as influencing factors in any research that measures the volume of milk produced (Matias et al., 2012; Taylor et al., 2019). Because this information is often not available in a mother's antenatal or delivery records, and these substances may be taken at any time after delivery, mothers must be questioned frequently regarding their exposure. Furthermore, because the volume of milk expressed varies throughout the day, the measurement of milk produced should consist of a cumulative 24-hr total rather than the volume from a single expression (Acuña-Muga et al., 2014). Finally, the concept of "coming to volume" or whether a mother has reached a minimum volume of milk production of 500 mL or more per day within 14 days has been suggested as a measure of milk production and may predict future lactation success in mothers of VLBW infants (Hoban et al., 2018).

Measuring Lactation Duration

While the American Academy of Pediatrics (AAP) recommends all infants be fed MOM for at the least the first 6 months of life, those born preterm and VLBW are much less likely to receive MOM for an extended time period through direct breastfeeding, bottle feeding, or a gastric tube than term infants (AAP, 2012). Still, research on lactation duration in mothers of VLBW infants remains limited, and the studies that are available typically measure lactation duration by whether infants receive MOM upon discharge from the NICU or at different points during their hospitalization (Fleurant et al., 2017; Romaine et al., 2018). Because infants may receive previously frozen milk from mothers who are no longer lactating, consumption of MOM does not necessarily indicate continued maternal lactation. Furthermore, an infant's consumption upon discharge from the NICU depends on their length of stay; thus, the most preterm and critically ill infants who have extended stays in the NICU are less likely to receive MOM upon discharge even if their mothers lactated for a significant length of time.

Although consumption of MOM upon discharge remains a neonatal care quality indicator, the timing of an infant's consumption and the dose received may be more important in

providing health-related benefits. For example, colostrum produced in the first few days following delivery is well-known to enhance protection against pathogens, promote development of the immune system, and support growth and maturation of the gastrointestinal system (Tlaskalová-Hogenová et al., 2020). Remaining NPO or providing pasteurized DHM or formula deprives vulnerable infants of these protective elements. Furthermore, the first 2 weeks following delivery is a critical window in which MOM significantly protects infants against prematurity-related complications. Therefore, limiting determination of lactation duration to only infant's consumption upon NICU discharge fails to provide critical information regarding lactation success in this population. In addition, accurate measurement of volume of MOM consumed by infants can provide information regarding daily percentage of feedings consisting of MOM versus DHM and/or formula and can easily be obtained from the infant's medical records.

Maternal intent to provide MOM to her infant may also affect lactation duration. Maternal intent has been shown to predict whether a VLBW infant consumes MOM upon discharge (Fleurant et al., 2017) but little is known regarding its influence on actual lactation duration. Furthermore, because women who previously intended to formula feed often decide to provide their infants MOM when faced with the delivery of a VLBW infant and their intentions frequently change throughout their infants' hospitalization, limiting maternal intent to a single antenatal point in time is insufficient (Sisk et al., 2006). Assessments of intent at various intervals throughout an infant's hospitalization better elucidates the role that this factor plays in lactation duration.

Finally, demographic characteristics also play a role in determining lactation duration. More specifically, researchers have found that mothers who are African American (Fleurant et al., 2017; Romaine et al., 2018), of lower socioeconomic status, have lower levels of education, (Fleurant et al., 2017; Romaine et al., 2018) or are unemployed (Mirkovic et al., 2014) are more likely to cease lactation earlier. Therefore, specific consideration of these demographic characteristics is essential in research regarding lactation duration.

Determining the Onset of Secretory Activation

Secretory activation, the change from production of small quantities of colostrum to copious amounts of MOM, is often delayed in mothers of VLBW infants. This delay is likely related to their shortened pregnancy and high incidence of comorbidities known to delay secretory activation including cesarean section, diabetes, obesity, and pregnancy-induced hypertension (Cordero et al., 2012; Nommsen-Rivers, 2016; Zanardo et al., 2013). Past studies that examined breastfeeding mothers of healthy-term infants have used several different indicators of secretory activation such as maternal self-report of a sudden feeling of breast fullness and biomarkers contained in MOM including sodium, lactose, protein, and citrate (Chapman & Pérez-Escamilla, 2000; Neville, 2009). Valid and consistent indicators are key to administering interventions that promote the early onset of secretory activation. However, little information exists regarding indicators of secretory activation in mothers delivering preterm.

While maternal report of breast fullness is considered a valid indicator of secretory activation in mothers of term healthy breastfeeding infants, it has not been validated in

mothers delivering prematurely (Chapman & Pérez-Escamilla, 2000). Information regarding when a mother perceives breast fullness can be collected through interviews and maternal reports in a lactation journal. Because recall error increases with time and is common amongst individuals under stress, mothers should be questioned daily, beginning the day following delivery, regarding when they first experienced a feeding of breast fullness.

Secretory activation is associated with a significant increase in milk volume and attainment of 20 mL in two consecutive expression sessions has been utilized as an indicator of the onset of secretory activation in mothers of preterm infants (Meier et al., 2012). Because mothers of VLBW infants bring their expressed milk to the NICU where the volume can be reliably measured, it is possible that volume attainment may be a simple and reliable indicator of secretory activation in this population of women. However, when utilizing this method, it is important to note that the volume of milk expressed may not always be a direct indicator of secretory activation since it also reflects the mother's ability to effectively remove milk from her breasts.

Finally, changes in the levels of sodium, lactose, citrate, and protein present in MOM have been used as biomarkers to signify the onset of secretory activation. A decrease in sodium and protein and an increase in citrate signify closing of tight junctions between mammary epithelial cells, while lactose increases due to upregulation of gene expression for production of lactose (Lemay et al., 2013; Neville, 2009). Secretory activation has been defined as occurring when biomarker levels are within three standard deviations from mean levels occurring in mothers of term breastfeeding infants at 5 days of life (Arthur et al., 1989; Cregan et al., 2002). However, limited information exists regarding biomarkers of secretory activation in mothers of preterm VLBW infants and discrepancies regarding normalcy of these biomarkers at 5 days following delivery have been reported (Cregan et al., 2002; Hoban et al., 2018). Because delayed secretory activation is associated with compromised lactation success, including a shorter duration and decreased milk production, interventions promoting an earlier onset are necessary and require valid and reliable indicators of secretory activation (Huang et al., 2020).

Influence of Expression Practice on Lactation Success Measures

Expression practices, including the timing of initiation following delivery, expression frequency, and expression method as well as skin-to-skin care, may significantly affect milk production and must be considered in research regarding lactation success in mothers of VLBW infants.

Time to Expression Initiation Following Delivery

To optimize lactation success, mothers of healthy-term infants are recommended to begin breastfeeding 30 min to 60 min following delivery (Bass et al., 2019), Previous research has suggested that initiation of milk expression within 6 hours following delivery may increase milk production and prolong lactation duration in mothers of VLBW infants (Furman et al., 2002; Parker et al., 2020). Collecting accurate data on when expression is initiated following delivery may be challenging. Due to the stress, physiologic instability, and effects of

anesthesia surrounding delivery, maternal report can be unreliable and thus nursing documentation in the medical records is likely the most reliable sources of information.

Expression Frequency

Consistent with recommendations for breastfeeding mothers of healthy-term infants, mothers of VLBW infants are recommended to express eight to 12 times per 24-hr period or, at the very minimum, six times per 24-hr period to establish and maintain milk production (Bass et al., 2019). Unfortunately, mothers of VLBW infants often express far less frequently than recommended even after they receive these recommendations, which may negatively affect milk production (Parker et al., 2020). Determining daily expression frequency can be challenging. While maternal documentation in a lactation diary is a simple and often utilized method of determining expression frequency, limitations in subject recall may decrease validity of this measurement; thus, verification of expression frequency by health care providers or human milk technicians through assessment of the time and date written on each vial of expressed milk is likely more accurate. Because the volume of milk expressed prior to secretory activation is often minimal, mothers may not bring this limited volume to the NICU necessitating verification of expression frequency through daily maternal questioning.

Expression Method

While it is recommended that mothers of VLBW infants use hospital-grade breast pumps capable of simultaneous, rather than sequential, breast expression—due to lack of access and delays in obtaining an appropriate pump—mothers often use less-effective devices such as manual or battery-operated breast pumps (Nyqvist et al., 2013). Furthermore, hand expression—which involves breast massage and compression and may be more effective in removing viscous colostrum than a mechanical breast pump—may be used in the first few hours and days following delivery (Morton et al., 2009), Information regarding type of breast pump used and the expression method utilized can be collected via maternal reports and lactation diaries.

Skin-to-Skin Care

Skin-to-skin or holding an infant directly on the mother’s chest clad only in a diaper is recommended for mothers and their term-healthy infants by the Baby-Friendly Hospital Initiative (Bass et al., 2019). Skin-to-skin care between mother and infant has been shown to increase maternal oxytocin levels and is associated with a higher milk production in mothers of VLBW infants (Cong et al., 2015; Fewtrell et al., 2016). Information regarding minutes mothers spend skin-to-skin with their infants can be collected from maternal diaries or from medical records if this information is documented as part of the nurses’ daily charting.

Timing of Enrollment in Studies

Because milk production in the first days following delivery correlates with long-term production, inventions aimed to improve lactation success should begin soon after delivery (Murase et al., 2014). However, consenting mothers for research studies immediately following delivery may be difficult due to maternal clinical instability and emotional

distress. Therefore, antenatal consent may be the most effective method of ensuring that research-based interventions are initiated in a timely manner. Because women delivering preterm infants are often hospitalized for days to weeks prior to delivery, consent during this time is often feasible. Because mothers hospitalized for potential preterm delivery may not always deliver prematurity, and prenatal fetal weight estimations are associated with some inaccuracy, mothers who provide antenatal consent may no longer meet inclusion criteria following delivery (Parker et al., 2020).

Conclusion

Mothers of VLBW infants face considerable challenges in providing MOM to their vulnerable infants and research focused on improving lactation success in this population is needed to overcome these barriers. To be effective, research surrounding lactation in mothers of VLBW infants requires valid and reliable measures of lactation outcomes, many of which were presented in this review. This information can be used to investigate personalized interventions that begin antenatally and continue throughout a VLBW infant's hospitalization and even after discharge. Focusing on these measures and indicators of lactation success may improve lactation outcomes and aid mothers in achieving their lactation goals, including providing sufficient volumes of MOM to their vulnerable infants.

References

Acuña-Muga J, Ureta-Velasco N, de la Cruz-Bértolo J, Ballesteros-López R, Sánchez-Martinez R, Miranda-Casabona E, Miguel-Trigoso A, Garcia-San José L, & Pallás-Alonso C (2014). Volume of milk obtained in relation to location and circumstances of expression in mothers of very low birth weight infants. Journal of Human Lactation, 30, 41–46. 10.1177/0890334413509140 [PubMed: 24212300]

Arthur PG, Smith M, & Hartmann PE (1989). Milk lactose, citrate, and glucose as markers of lactogenesis in normal and diabetic women. Joural Pediatric Gastroenterology and Nutrition, 9, 488–496. 10.1097/00005176-198911000-00016

Asztalos EV, Kiss A, daSilva OP, Campbell-Yeo M, Ito S, & Knoppert D (2019). Role of days postdelivery on breast milk production: A secondary analysis from the EMPOWER trial. International Breastfeeding Journal, 14, 21. 10.1186/s13006-019-0215-z [PubMed: 31171928]

Bass JL, Gartley T, & Kleinman R (2019). World Health Organization baby-friendly hospital initiative guideline and 2018 implementation guidance. JAMA Pediatrics, 173, 93–94. 10.1001/jamapediatrics.2018.3808 [PubMed: 30476942]

Battersby C, Longford N, Mandalia S, Costeloe K, & Modi N (2017). Incidence and enteral feed antecedents of severe neonatal necrotising enterocolitis across neonatal networks in England, 2012–2013: A whole-population surveillance study. Lancet Gastroenterology and Hepatology, 2, 43–51. 10.1016/s2468-1253(16)30117-0 [PubMed: 28404014]

Berkhout DJC, Klaassen P, Niemarkt HJ, de Boode WP, Cossey V, van Goudoever JB, Hulzebos CV, Andriessen P, van Kaam AH, Kramer BW, van Lingen RA, Vijlbrief DC, van Weissenbruch MM, Benninga M, de Boer NKH, & de Meij TGJ (2018). Risk factors for necrotizing enterocolitis: A prospective multicenter case-control study. Neonatology, 114, 277–284. 10.1159/000489677 [PubMed: 29996136]

Chapman DJ, & Pérez-Escamilla R (2000). Maternal perception of the onset of lactation is a valid, public health indicator of lactogenesis stage II. Journal of Nutrition, 130, 2972–2980. 10.1093/jn/130.12.2972

Cong X, Ludington-Hoe SM, Hussain N, Cusson RM, Walsh S, Vazquez V, Briere C-E, & Vittner D (2015). Parental oxytocin responses during skin-to-skin contact in pre-term infants. Early Human Development, 91, 401–406. 10.1016/j.earlhumdev.2015.04.012 [PubMed: 25988992]

Cordero L, Valentine CJ, Samuels P, Giannone PJ, & Nankervis CA (2012). Breastfeeding in women with severe preeclampsia. Breastfeeding Medicine, 7, 457–463. 10.1089/bfm.2012.0019 [PubMed: 22871169]

Cortez J, Makker K, Kraemer DF, Neu J, Sharma R, & Hudak ML (2018). Maternal milk feedings reduce sepsis, necrotizing enterocolitis and improve outcomes of premature infants. Journal of Perinatology, 38, 71–74. 10.1038/jp.2017.149 [PubMed: 29048409]

Cregan MD, De Mello TR, Kershaw D, McDougall K, & Hartmann PE (2002). Initiation of lactation in women after preterm delivery. Acta Obstetricia et Gynecologica Scandinavica, 81, 870–877. [PubMed: 12225305]

Dowling DA, Madigan E, & Siripul P (2004). The effect of fluid density and volume on the accuracy of test weighing in a simulated oral feeding situation. Advances in Neonatal Care, 4, 158–165. 10.1016/j.adnc.2004.04.002 [PubMed: 15273946]

Fabiyi C, Rankin K, Norr K, Yoder JC, Vasa R, & White-Traut R (2015). The association of low social support with breast milk expression in low-income mother–preterm infant dyads. Journal of Human Lactation, 31, 490–497. 10.1177/0890334415586199 [PubMed: 25975943]

Fewtrell MS, Kennedy K, Ahluwalia JS, Nicholl R, Lucas A, & Burton P (2016). Predictors of expressed breast milk volume in mothers expressing milk for their preterm infant. Archives of Disease in Childhood—Fetal and Neonatal Edition, 101, F502–F506. 10.1136/archdischild-2015-308321 [PubMed: 26936878]

Fleurant E, Schoeny M, Hoban R, Asiodu IV, Riley B, Meier PP, Bigger H & Patel AL (2017). Barriers to human milk feeding at discharge of very-low-birth-weight infants: Maternal goal setting as a key social factor. Breastfeeding Medicine, 12, 20–27. 10.1089/bfm.2016.0105 [PubMed: 27906557]

Furman L, Minich N, & Hack M (2002). Correlates of lactation in mothers of very low birth weight infants. Pediatrics, 109, e57. 10.1542/peds.109.4.e57 [PubMed: 11927730]

Hoban R, Patel AL, Medina Poeliniz C, Lai CT, Janes J, Geddes D, & Meier PP (2018). Human milk biomarkers of secretory activation in breast pump-dependent mothers of premature infants. Breastfeeding Medicine, 13, 352–360. 10.1089/bfm.2017.0183 [PubMed: 29708764]

Huang J, Zhang L, Tang J, Shi J, Qu Y, Xiong T, & Mu D (2019). Human milk as a protective factor for bronchopulmonary dysplasia: A systematic review and meta-analysis. Archives of Diseases in Childhood—Fetal and Neonatal Edition, 104, F128–F136. 10.1136/archdischild-2017-314205 [PubMed: 29907614]

Huang L, Xu S, Chen X, Li Q, Lin L, Zhang Y, Gao D, Wang H, Hong M, Yang X, & Hao L (2020). Delayed lactogenesis is associated with suboptimal breastfeeding practices: A prospective cohort study. Journal of Nutrition, 150, 894–900. 10.1093/jn/nxz311

Huang Y, Ouyang Y-Q, & Redding SR (2019). Maternal prepregnancy body mass index, gestational weight gain, and cessation of breastfeeding: A systematic review and meta-analysis. Breastfeeding Medicine, 14, 366–374. 10.1089/bfm.2018.0138 [PubMed: 31081684]

Lemay DG, Ballard OA, Hughes MA, Morrow AL, Horseman ND, & Nommsen-Rivers LA (2013). RNA sequencing of the human milk fat layer transcriptome reveals distinct gene expression profiles at three stages of lactation. PLoS ONE, 8, e67531. 10.1371/journal.pone.0067531 [PubMed: 23861770]

Lussier MM, Brownell EA, Proulx TA, Bielecki DM, Marinelli KA, Bellini SL, & Hagadorn JI (2015). Daily breastmilk volume in mothers of very low birth weight neonates: A repeated-measures randomized trial of hand expression versus electric breast pump expression. Breastfeeding Medicine, 10, 312–317. 10.1089/bfm.2015.0014 [PubMed: 26204125]

Matias SL, Nommsen-Rivers LA, & Dewey KG (2012). Determinants of exclusive breastfeeding in a cohort of primiparous periurban Peruvian mothers. Journal of Human Lactation, 28, 45–54. 10.1177/0890334411422703 [PubMed: 22058120]

Meier PP, Engstrom JL, Janes JE, Jegier BJ, & Loera F (2012). Breast pump suction patterns that mimic the human infant during breastfeeding: Greater milk output in less time spent pumping for breast pump-dependent mothers with premature infants. Journal of Perinatology, 32, 103–110. 10.1038/jp.2011.64 [PubMed: 21818062]

Mirkovic KR, Perrine CG, Scanlon KS, & Grummer-Strawn LM (2014). Maternity leave duration and full-time/part-time work status are associated with US mothers' ability to meet breastfeeding intentions. Journal of Human Lactation, 30, 416–419. 10.1177/0890334414543522 [PubMed: 25034868]

Morton J, Hall JY, Wong RJ, Thairu L, Benitz WE, & Rhine WD (2009). Combining hand techniques with electric pumping increases milk production in mothers of preterm infants. Journal of Perinatology, 29, 757–764. 10.1038/jp.2009.87 [PubMed: 19571815]

Murase M, Nommsen-Rivers L, Morrow AL, Hatsuno M, Mizuno K, Taki M, Miyazawa T, Nakano Y, Aizawa M, & Itabashi K (2014). Predictors of low milk volume among mothers who delivered preterm. Journal of Human Lactation, 30, 425–435. 10.1177/0890334414543951 [PubMed: 25063573]

Neville MC (2009). Introduction: Tight junctions and secretory activation in the mammary gland. Journal of Mammary Gland Biology and Neoplasia, 14, 269–270. 10.1007/s10911-009-9150-8 [PubMed: 19649773]

Nommsen-Rivers LA (2016). Does insulin explain the relationship between maternal obesity and poor lactation outcomes? An overview of the literature. Advances in Nutrition, 7, 407–414. 10.3945/an.115.011007 [PubMed: 26980825]

Nyqvist KH, Häggkvist A-P, Hansen MN, Kylberg E, Frandsen AL, Maastrup R, Ezeonodo A, Hannula L, & Haiek LN (2013). Expansion of the baby-friendly hospital initiative ten steps to successful breastfeeding into neonatal intensive care: Expert group recommendations. Journal of Human Lactation, 29, 300–309. 10.1177/0890334413489775 [PubMed: 23727630]

Parker LA, Sullivan S, Kruger C, & Mueller M (2020). Timing of milk expression following delivery in mothers delivering preterm very low birth weight infants: A randomized trial. Journal of Perinatology, 40, 1236–1245. 10.1038/s41372-020-0688-z [PubMed: 32461626]

Rankin MW, Jimenez EY, Caraco M, Collinson M, Lostetter L, & DuPont TL (2016). Validation of test weighing protocol to estimate enteral feeding volumes in preterm infants. Journal of Pediatrics, 178, 108–112. 10.1016/j.jpeds.2016.08.011

Romaine A, Clark RH, Davis BR, Hendershot K, Kite V, Laughon M, Updike I, Miranda ML, Meier PP, Patel AL, Smith PB, Cotten CM, Benjamin DK Jr., & Greenberg RG (2018). Predictors of prolonged breast milk provision to very low birth weight infants. Journal of Pediatrics, 202, 23–30. 10.1016/j.jpeds.2018.07.001

Sisk PM, Lovelady CA, Dillard RG, & Gruber KJ (2006). Lactation counseling for mothers of very low birth weight infants: Effect on maternal anxiety and infant intake of human milk. Pediatrics, 117, e67–e75. 10.1542/peds.2005-0267 [PubMed: 16396850]

Taylor A, Logan G, Twells L, & Newhook LA (2019). Human milk expression after domperidone treatment in postpartum women: A systematic review and meta-analysis of randomized controlled trials. Journal of Human Lactation, 35, 501–509. 10.1177/0890334418812069 [PubMed: 30481478]

Tlaskalová-Hogenová H, Kverka M, & Hrdý J (2020). Immunomodulatory components of human colostrum and milk. In Milk, Mucosal Immunity, and the Microbiome: Impact on the Neonate (Vol. 94, pp. 38–47), Nestle Nutrition Institute Workshop Series. Karger Publishers. 10.1159/000505068

Wang C-J, Chaovalit P, & Pongnumkul S (2018). A breastfeed-promoting mobile app intervention: Usability and usefulness study. JMIR Mhealth Uhealth, 6, e27. 10.2196/mhealth.8337 [PubMed: 29374000]

Wilson E, Edstedt Bonamy A-K, Bonet M, Toome L, Rodrigues C, Howell EA, Cuttini M, & Zeitlin J (2018). Room for improvement in breast milk feeding after very preterm birth in Europe: Results from the EPICE cohort. Maternal & Child Nutrition, 14, e12485. 10.1111/mcn.12485

Zanardo V, Pigozzo A, Wainer G, Marchesoni D, Gasparoni A, Di Fabio S, Cavallin F, Giustardi A, & Trevisanuto D (2013). Early lactation failure and formula adoption after elective caesarean delivery: Cohort study. Archives of Diseases in Childhood—Fetal Neonatal Edition, 98, F37–F41. 10.1136/archdischild-2011-301218 [PubMed: 22516475]

Table 1:

Measures of Lactation Outcomes

Measures	Method	Strengths	Limitations
Milk Volume	Maternal self-report	Easy to learn Requires only a journal or diary	High risk for error Requires maternal compliance Recall bias
	Weighing vials of expressed milk	Likely most accurate technique Requires an accurate and precise scale Can be used to validate maternal report of volume and pumping frequency Potential to blind individuals weighing milk	Training required for accuracy Time consuming Relies on mothers bringing all vials of expressed milk to the NICU
	Visualizing milk vial graduations	Easy to learn Requires no equipment	Relies on nurse documentation or maternal report Relies on precision of volume graduations on vials Potential high error rate
	Test-weighing	Validated method to measure milk volume during breastfeeding	Time consuming Requires a precise infant scale Training required
Lactation Duration	Infant consumption at discharge	Easily collected from medical records	Does not include post-discharge data Infants may be receiving MOM when mothers are no longer lactating Varies depending on length of hospital stay Excludes other health relevant time-points during hospitalization as well as dose of MOM received
	Infant consumption at different time-points during hospitalization	Data easily collected from medical records Considers timing of consumption	Infants may receive MOM when mothers are no longer lactating
Onset of Secretory Activation	Production of ≥20mL of milk in two consecutive expression sessions	Easy to measure	May reflect a mother's ability to effectively remove milk from her breasts Relies on accurate measurement of milk volume
	Maternal report of sudden breast fullness	Validated in mothers of term infants No equipment or training required	Unknown validity in mothers of preterm infants Mothers should be questioned daily to reduce recall bias
	Biomarkers contained in MOM	Validated in mothers of term Infants Likely most accurate indicator Reflects changes at the physiological level	Validity not established for mothers of preterm infants Cut-off levels not established for mothers of preterm infants

Note. NICU = neonatal intensive care unit; MOM = Mother's own milk