# Know the Flow

## *Milk Flow Rates From Bottle Nipples Used in the Hospital and After Discharge*

Britt Frisk Pados, PhD, RN, NNP-BC; Jinhee Park, PhD, RN; Pamela Dodrill, PhD, CCC-SLP

**ABSTRACT**
**Background:** Milk flow rate may play an important role in an infant's ability to safely and efficiently coordinate sucking, swallowing, and breathing during feeding.
**Purpose:** To test milk flow rates from bottle nipples used in the hospital and after discharge.
**Methods:** Bottle nipples used in hospitals (10 unique types) and available nationwide at major retailers (15 unique types) were identified. For each of the 25 nipple types, 15 nipples of that type were tested by measuring the amount of infant formula extracted in 1 minute by a breast pump. Mean milk flow rate (mL/min) and coefficient of variation (CV) were calculated for each nipple type. Comparisons between nipple types were made within brand and within category (eg, Slow, Standard). A cluster analysis was conducted to identify nipples of comparable flow.
**Results:** A total of 375 individual nipples were tested. Milk flow rates varied widely, from 0.86 to 37.61 mL/min. There was also a wide range of CVs, from 0.03 to 0.35. Packing information did not accurately reflect the flow rates of bottle nipples. The cluster analysis revealed 5 clusters of nipples, with flow rates from Extra Slow to Very Fast.
**Implications for Practice:** These data can be used to guide decisions regarding nipples to use for feeding infants with medical complexity in the hospital and after discharge.
**Implications for Research:** Research on infant feeding should consider the flow rate and variability of nipples used, as these factors may impact findings.
**Key Words:** bottle feeding, feeding behavior, feeding methods, infant, milk flow, newborn, premature



## BACKGROUND AND LITERATURE REVIEW

Infants with medical complexity, particularly those born premature[1-3] or with congenital heart disease,[4,5] frequently experience difficulty with oral feeding. Feeding difficulty may manifest as physiologic instability, such as apnea, bradycardia, and oxygen desaturations, or may manifest as signs of behavioral distress, such as stress cues, choking, gagging, and coughing.[3,4,6,7] Many factors contribute to an infant's ability to safely and efficiently feed by mouth, but one contributing factor is milk flow rate.[4,8]

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*The authors acknowledge all of the students who contributed their time to this study, including Audrey (Abby) Basler, Nina Hofmann, Elisa Kang, Lauren Mundy, Elaina Parrillo, and Mikaila Richards.*

*The authors report no conflict of interest.*

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*DOI: 10.1097/ANC.0000000000000538*

Milk flow is the rate at which milk (either human milk or formula) transfers from the bottle or breast to the infant's mouth. The shared anatomy of the respiratory and digestive system in the pharynx requires that the vocal folds close during swallowing to prevent aspiration of fluid into the airway.[9,10] During each swallow, respiration must cease. When milk flow rate is fast, the infant must swallow frequently to clear the bolus of fluid and thus respiratory interruption is high.[8,11] When the flow of milk is slowed, there is a longer time between swallows and therefore reduced respiratory interruption.[11] For the healthy, full-term, well-oxygenated infant, the interruption in respiration, even with a fast milk flow rate, is generally well-tolerated.[12] Healthy, full-term infants are able to alter their sucking rate and pressures to regulate flow rate[13,14] and are typically able to manage a relatively large volume per swallow safely.[15] While there is some evidence that suggests that infants born preterm may change their sucking patterns and pressures in response to milk flow,[16,17] it is unclear whether infants born preterm or with medical complexity are able to adapt their sucking patterns and pressures sufficiently in response to changes in milk flow to maintain appropriate oxygenation.[18] For infants with respiratory disease, poor oxygenation, or difficulty with swallowing, the interruption in respiration that occurs with oral feeding may lead to physiologic or behavioral distress. Residual fluid in the pharynx after the swallow may further place the infant at risk for aspiration.[19] A slower flow rate may allow the infant to breathe more, feed more efficiently,[20] maintain physiologic stability, reduce the risk of aspiration, and reduce the stress of feeding.[4]

The first tests of milk flow rates from bottle nipples were conducted in the 1980s and found that flow rates varied widely between nipple types.[21] In more recent work, Jackman[22] found a wide range in flow rates among nipples marketed as "slow flow" and considerable variability in flow rates between single-use nipples of the same type. The major limitation to her study was that she studied only 1 to 3 nipples of each nipple type. In our previous work, we built on the work by Mathew[21] and Jackman[22] by testing more nipple types, increasing the number of nipples tested per nipple type, and improving the testing method by measuring the weight of extracted fluid on a scale and videotaping the procedure to ensure accuracy.[23,24] Our previous studies of milk flow rates used for feeding hospitalized infants and infants after hospital discharge found that milk flow rate ranged from 1.68 to 85.34 mL/min and that there was considerable variability in flow rate between nipples of the same type.[23,24]

Manufacturers change their products and new products enter the market frequently. For example, since our studies published in 2015 and 2016, several products from the brand nfant Labs have entered the market and are being marketed for use in the neonatal intensive care unit. Similarly, the brand Comotomo has become more widely used and Tommee Tippee has added a new product. Other products may be marketed under the same brand and name as in our previous work, but it is unclear whether manufacturing processes have changed, which may impact flow rates of those products. This study served to update the literature to reflect currently available products and test new products on the market. Given the variability found between nipples of the same type in our previous studies, this study was purposefully designed to increase the number of nipples tested per type in order to better account for this variability. The purpose of this study was to test the milk flow rates and variability in flow from bottle nipples used in the hospital and after hospital discharge. The following research questions were addressed: (1) What are the milk flow rates of bottle nipples used in the hospital and after discharge? (2) What is the variability in flow rates of bottle nipples used in the hospital and after discharge? (3) How do flow rates compare within brand and within category according to packaging information (eg, Slow vs Standard Flow)? and (4) Which nipples are comparable in flow rate to guide decision making regarding nipple choice for use after discharge?

### What This Study Adds

- Bottle nipples come in a wide range of flow rates, and there can be considerable variability in flow rates between nipples of the same type.
- Packaging and manufacturer's labeling information does not always provide accurate information on flow rates.
- Single-use nipples commonly used for feeding infants with medical complexity were found to be highly variable and/or faster flow than other products; the safety of these products for feeding infants with medical complexity needs to be reconsidered.

## METHODS

Institutional review board approval was not required because no human subjects were involved.

### Sample Selection

The target sample for this study was 2-fold. First, we aimed to test the most common bottle nipples used in hospitals for feeding fragile infants as well as a new product being marketed for in-hospital use. Second, we aimed to test the bottle nipples most commonly available for purchase after hospital discharge. The goal was to test bottle nipples that would be available to consumers either in stores or online across the United States. The Web sites of 6 large national retailers of baby bottles and nipples, specifically Babies R' Us, Buy Buy Baby, Diapers.com, Kmart, Target, and Walmart, were reviewed to identify the bottle nipples available at each site. To be included in this study, a nipple had to be sold at 3 or more of these major retailers and marketed for use with infants in the first 3 months of life.

### Sample Size Determination

Previous studies have examined 10 nipples of each type; however, these studies revealed significant variability in milk flow rates from certain types of nipples.[23,24] Using the data published in previous studies,[23,24] we conducted a series of power analyses to determine the sample size needed for 80% power at a significance level of .05 when pairwise comparisons were made between nipple types within each of the samples used in the previous studies (eg, hospital-based nipples were tested against other hospital-based nipples and community-based nipples were tested against other community-based nipples). It was determined that a minimum of 15 nipples per type would be sufficient to detect differences in milk flow rates for all comparisons to be made in the study with 80% power at a significance level of .05.

### Procedures

All nipples were tested using a rigorous methodological process that has been used in previous studies.[23,24] This method was designed to test nipples under standardized conditions so that nipple flow rates could be compared with each other but is not intended to mimic the suction pressures of infants during feeding. Infants vary their sucking pressure and sucking rate within and between feedings, and there are no established norms for these variables. The flow rates achieved using this standardized approach may or may not reflect the flow rate an infant would be exposed to when feeding with the nipple but can be used to evaluate the relative flow rates across nipple types.

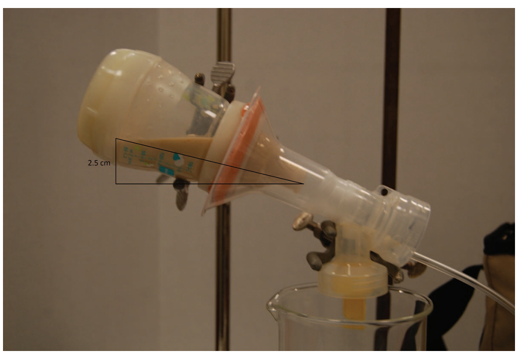
Each nipple was tested on the bottle with which it was sold. For bottles that include a venting system, testing occurred with the venting system in place. If a venting system was built into the nipple, care was taken not to block the venting system and to position the vent in the same location between tests of the same nipple type. Care was also taken to not tighten the collar and nipple on to the bottle too tightly to prevent disruption of venting. For single-use nipples, an Enfamil Grad-U-Feed nurser was used for the bottle. Enfamil 20 calorie/ounce (cal/oz) ready-to-feed formula was used for all tests. The amount of formula placed in the bottle for each bottle type was adjusted to ensure an approximately equal amount of hydrostatic pressure (ie, the amount of gravitational pressure pushing the fluid out of the nipple). The amount of formula placed in the bottle was adjusted to achieve a height of the liquid from the tip of the nipple to the level of fluid of 2.5 cm (Figure 1).

A Medela pump-in-style breast pump on the maximum suction pressure during the stimulation phase was used to create suction pressure. The bottle and the nipple were attached to the breastshield of the breast pump using a layer of parafilm and a silicone-based polymer to create a seal. The flange of the breastshield was adjusted between 24, 27, and 30 mm to best accommodate the nipple shape and the collar. The bottle and the nipple were positioned at an approximately 30° angle, and suction was applied for 1 minute at a suction rate of approximately 108 cycles per minute. Formula was expressed into a glass beaker on a scale accurate to 0.01 g. The full equipment setup for testing is shown in Figure 2. Nipples that were found to have considerably different flow rates (defined as >20%) than flow rates of others of the same type (ie, outliers) were washed gently with water, reattached to the breastshield, and retested to ensure accuracy of the finding. If the result of the retest was similar to the first, then the first test result was used. If the result of the retest was different from the first and more similar to the other nipples of the same type that had been tested, then the second test result was used.

To ensure consistency across tests, the suction pressure of the pump was tested at least every 50 tests using a pressure gauge attached directly to the pump tubing. The approximate suction pressure applied was 230 mm Hg. The scale was calibrated prior to each day of testing using a 500-g weight. The formula used for testing was also changed regularly. The manufacturer's recommendation is to use formula within 60 minutes of preparation.[25] To be conservative, the formula was changed 10 tests or at least every 30 minutes. All tests were video-recorded to determine the exact weight of formula on the scale at the end of 1 minute. The weight of formula (grams expressed per minute) was then converted to volume (mL/min) using a conversion of 0.97 mL/g of Enfamil 20 cal/oz ready-to-feed formula (http://www.aquacalc.com/calculate/food-weight-to-volume).

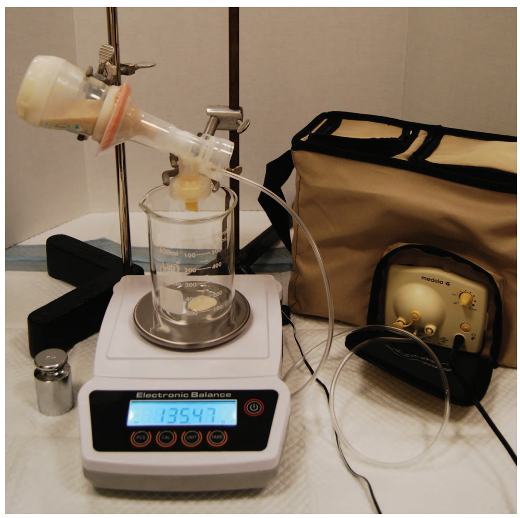
To evaluate the test–retest reliability of this method, we tested 1 nipple of each of the 25 different nipple types used in this study, gently washed, reassembled, and retested the same nipple again. Pearson's correlation coefficient between the

FIGURE 1




Hydrostatic pressure measurement. Photograph courtesy of Britt Pados. Copyright © 2018 Britt Pados.

FIGURE 2




Study testing equipment. Photograph courtesy of Britt Pados. Copyright © 2018 Britt Pados.

test–retest data was very high ($r = 0.99$; $P < .001$), suggesting this is a reliable method for testing flow rates of bottle nipples.

### Data Analysis

Descriptive statistics were calculated for the milk flow rate (mL/min) of each nipple type, specifically mean, standard deviation, minimum, maximum, and coefficient of variation (CV). The CV is calculated as the standard deviation divided by the mean and is a measure of variation relative to the mean. The CV was arbitrarily categorized into 3 levels: low (CV < 0.1), moderate (CV = 0.1-0.2), and high (CV > 0.2).

Comparisons were made in 3 ways. First, comparisons were made between nipple types of the same brand; this was done only if a brand had more than 1 nipple type included. Second, comparisons were made between nipple types that were marketed to be similar to each other (eg, all nipples marketed as being extra slow were tested against each other). Third, a cluster analysis was conducted to identify nipples of comparable flow rates to provide a guide for nipples available in the community that are of similar flow to nipples used in the hospital to guide families in choosing a nipple for use after discharge.

Comparisons within brands and groups were done using one-way analysis of variance with an α of .05 being considered significant. Duncan's multiple range test was used for post hoc comparisons, and a Bonferroni adjustment was made to the α statistic when more than 2 nipple types were compared (eg, if 3 nipples were compared, the $P$ value of .05 was divided by 3 and an α of less than .016 was considered statistically significant).

The cluster analysis was conducted using IBM SPSS Statistics version 24 using the K-means cluster function to explore distinct nipple flow rate clusters using the mean flow rate for each nipple type (n = 25). First, a cluster analysis was conducted with 7 clusters and then decreased by 1 until no more than 1 cluster had a single nipple type in the cluster.

## RESULTS

### Sample

A total of 375 individual nipples were tested in this study. This included 25 different nipple types. Within each nipple type, 15 of the same type of nipple were tested (ie, 25 nipple types × 15 nipples = 375). The bottle nipple types tested in this study are available in Table 1. In previous studies, we had tested the Enfamil crosscut but felt the negative pressure testing system was not an accurate reflection of the flow rate for this nipple because the nipple hole changes

TABLE 1. Nipples Tested

| Brand | Nipple Type | Manufacturer's Label Information |
|---|---|---|
| Comotomo | Natural Feel Bottle | Slow Flow (0-3 mos) |
| Dr. Brown's | Standard-Neck<br>Standard-Neck<br>Standard-Neck | UltraPreemie<br>Preemie<br>Level 1 |
| Enfamil | Single-use<br>Single-use | Standard Flow (Royal Blue Collar)<br>Slow Flow (Turquoise Collar) |
| Evenflo | Classic | Slow Flow 0m+ |
| Gerber | First Essentials | 0m+ (Slow) |
| MAM | Anti-colic | 0m+ |
| Medela | Calma Breast Milk Feeding Nipple<br>Wide-Base | All Stage Nipple<br>Slow Flow |
| nfant Labs | | Extra Slow Flow (Gold)<br>Slow Flow (Purple)<br>Standard Flow (White) |
| Philips Avent | Natural<br>Natural<br>Anti-colic | 0mos+<br>First Flow<br>0mos+ |
| Playtex Baby | Naturalatch<br>Ventaire<br>Ventaire | 0-3 m<br>Full Sized<br>Breastlike |
| Similac | Single-use<br>Single-use<br>Single-use | Standard Flow (Clear Collar)<br>Slow Flow (Yellow Collar)<br>Premature (Red Nipple) |
| Tommee Tippee | Anti-colic<br>Closer to Nature | 0m+<br>0m+ |

significantly with positive pressure applied, so this nipple was not tested. The Enfamil Preemie nipple is no longer sold on the Mead-Johnson Nutrition Web site, so it was not tested.

The review of available bottle nipples from the 6 major national retailers revealed 215 unique nipple options from 52 different brands. There were 15 nipple types identified that met inclusion criteria. It should be noted that the following nipple types were identified for inclusion but did not work with our testing system: Born Free Breeze, due to the blockage of the venting system by the breastshield; Kiinde Active Latch Natural, due to the collapsible bottle; and the Munchkin Latch, due to the long length between the nipple tip and the collar.

## Results

Mean milk flow rates for the 25 nipple types tested varied widely between nipples, ranging from 0.86 mL/min for the Philips Avent Natural First Flow nipple to 37.61 mL/min for the Medela Calma nipple (Figure 3). There was also a wide range of variability, ranging from a CV of 0.03 for the Medela Calma nipple to 0.35 for the Philips Avent Natural First Flow nipple (Figure 4). Eight of the 25 nipple types tested had a CV of less than 0.1 (ie, low variability), 14 had a CV of 0.1 to 0.2 (ie, moderate variability), and 3 had a CV of more than 0.2 (ie, high variability).

## Comparisons Within Brand

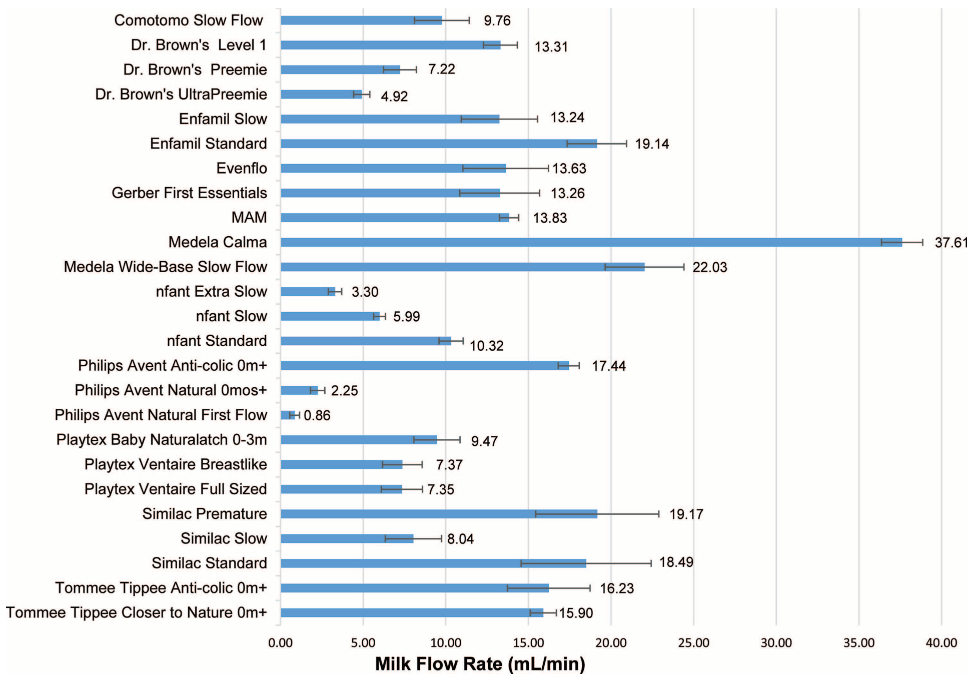
**Dr. Brown's.** Within the Dr. Brown's brand, there were significant differences in milk flow rate between nipple types ($F_{2,42}$= 371.05, $P < .01$). Post hoc comparisons revealed all 3 Dr. Brown's products were significantly different from one another, with Dr. Brown's UltraPreemie being slowest ($M$ = 4.92 mL/min), followed by Dr. Brown's Preemie ($M$ = 7.22 mL/min) and then Dr. Brown's Level 1 ($M$ = 13.31 mL/min).

**Enfamil.** The Enfamil Slow nipple ($M$ = 13.24 mL/min) was found to be significantly slower than the Enfamil Standard nipple ($M$ = 19.14 mL/min) ($F_{1,28}$= 61.03, $P < .01$).

**Medela.** The Medela Wide-Base Slow ($M$ = 22.03 mL/min) and Medela Calma ($M$ = 37.61 mL/min) nipples had significantly different flow rates ($F_{1,28}$= 503.18, $P < .01$).

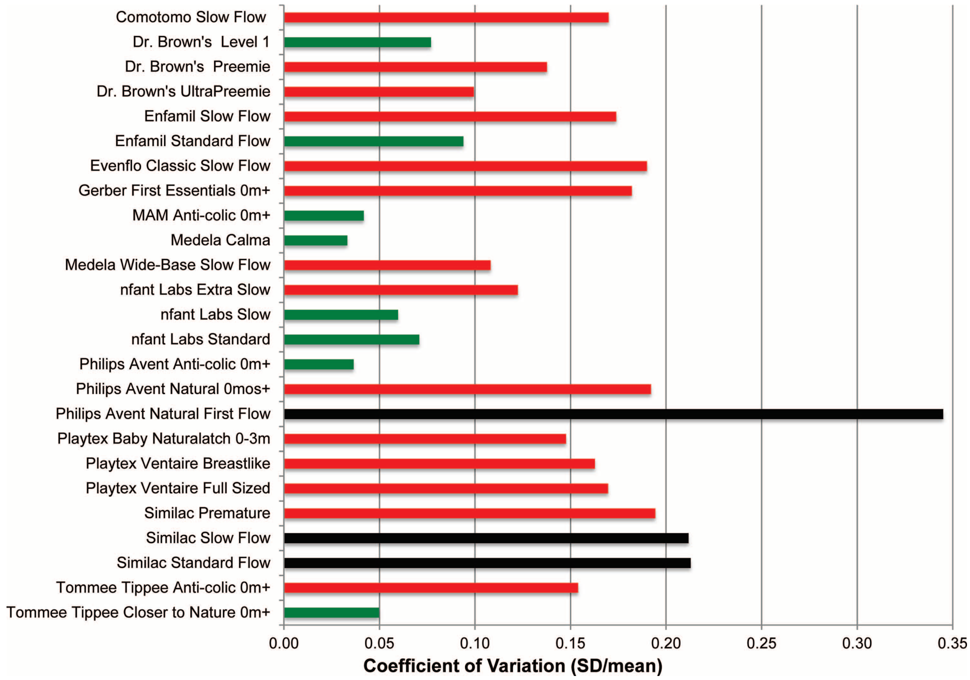
**nfant Labs.** Within the nfant Labs brand, significant differences were found in milk flow rates between nipple types ($F_{2,42}$= 683.70, $P < .01$). Post hoc comparisons revealed the 3 nipple types within the nfant Labs brand were all significantly different from one another. The Extra Slow nipple was slowest ($M$ = 3.30 mL/min), followed by the Slow nipple ($M$ = 5.99 mL/min) and then the Standard nipple ($M$ = 10.32 mL/min).

FIGURE 3




Milk flow rate (mL/min) of all 25 nipple types tested. Mean milk flow rate is indicated by solid bar, and the value is noted at the end of the bar. Error bars indicate ± 1 standard deviation.

FIGURE 4




Coefficient of variation of all 25 nipple types tested, calculated as the standard deviation/mean. Green indicates CV < 0.1 (low variability), red indicates CV = 0.1-0.2 (moderate variability), and black indicates CV > 0.2 (high variability).

**Philips Avent.** Within the Philips Avent brand, there were significant differences between flow rates of nipple types ($F_{2,42}$= 5600.02, $P < .01$). Post hoc comparisons revealed all 3 nipple types from the Philips Avent brand had significantly different flow rates, with the Natural First Flow nipple ($M$ = 0.86 mL/min) being the slowest, followed by the Natural 0mos+ nipple ($M$ = 2.25 mL/min) and then the Anti-colic 0mos+ nipple ($M$ = 17.44 mL/min).

**Playtex.** Within the Playtex brand, there were significant differences found between nipple types ($F_{2,42}$= 13.47, $P < .01$). The post hoc comparisons revealed that the Playtex Ventaire Full Sized ($M$ = 7.35 mL/min) and Ventaire Breastlike ($M$ = 7.37 mL/min) nipples were comparable in flow, but the Playtex Baby Naturalatch 0-3m nipple ($M$ = 9.47 mL/min) was significantly faster.

**Similac.** There were significant differences in flow rates found between the Similac nipple types tested ($F_{2,42}$= 54.25, $P < .01$). The Similac Standard ($M$ = 18.49 mL/min) and Similac Premature ($M$ = 19.17 mL/min) nipples were not significantly different; the Similac Slow nipple ($M$ = 8.04 mL/min) had significantly slower flow than either of the other 2 Similac products.

**Tommee Tippee.** The Tommee Tippee nipple types had comparable flow rates ($F_{1,28}$= 0.24, $P$ = .63): Anti-colic 0m+ ($M$ = 16.23 mL/min) and Closer to Nature 0m+ (15.90 mL/min).

## Comparisons Within Marketed Flow

For the purposes of this study, the following groupings were used to make comparisons within marketed flow: Extra Slow, which were chosen on the basis of marketing to extremely fragile infants having difficulty with feeding; Slow, which were chosen on the basis of marketing to fragile or hospitalized infants; Standard—Hospital, which were selected as the standard-flow nipples used in hospitalized infants; and Standard—Community, which were chosen on the basis of marketing to typical newborns in the community after hospital discharge. Nipples marketed to newborns in the community often had packaging stating "Slow Flow" but, for the purposes of this study, were included in the Standard—Community group. Dr. Brown's Level 1 is often used in hospitals and thus was included in both the Standard—Hospital and Standard—Community groups.

**Extra Slow.** The nfant Labs Extra Slow nipple ($M$ = 3.3 mL/min) was significantly slower than the Dr. Brown's UltraPreemie nipple ($M$ = 4.92 mL/min) ($F_{1,28}$= 97.97, $P < .01$).

**Slow.** There were significant differences in flow rates between nipple types ($F_{4,70}$ = 96.52, $P < .01$)

in this category. The post hoc comparisons revealed the nfant Labs Slow ($M = 5.99$ mL/min), Dr. Brown's Preemie ($M = 7.22$ mL/min), and Similac single-use slow ($M = 8.04$ mL/min) nipples were comparable to one another. The Enfamil Slow nipple ($M = 13.24$ mL/min) was significantly faster than the group of 3. The Similac Premature nipple ($M = 19.17$ mL/min) was significantly faster than all of the other nipple types in this category.

**Standard—Hospital.** Within this category, there were significant differences found between nipple types ($F_{3,56} = 52.89$, $P < .01$). In the post hoc analysis, the Similac Standard ($M = 18.49$ mL/min) and Enfamil Standard ($M = 19.14$ mL/min) nipples were not significantly different from one another. Dr. Brown's Level 1 was significantly slower than these other 2 ($M = 13.31$ mL/min). The nfant Labs Standard nipple (M = 10.32 mL/min) was significantly slower than all others.

**Standard—Community.** Within this category, there were significant differences in milk flow rates between the 15 different nipple types ($F_{14,210} = 474.39$, $P < .01$). Post hoc comparisons revealed 7 groupings of nipple types with significantly different flow rates (Table 2).

TABLE 2. Comparisons Among 15 Standard Flow Community-Based Nipple Types[a]

| Group | Nipple Type | Flow Rate, mL |
|---|---|---|
| 1 | Philips Avent Natural First Flow | 0.86 |
| 1 | Philips Avent Natural 0mos+ | 2.25 |
| 2 | Playtex Ventaire Full Sized | 7.35 |
| 2 | Playtex Ventaire Breastlike | 7.37 |
| 3 | Playtex Baby Naturalatch 0-3m | 9.47 |
| 3 | Comotomo Slow Flow (0-3 mos) | 9.76 |
| 4 | Gerber First Essentials | 13.26 |
| 4 | Dr. Brown's Level 1 | 13.31 |
| 4 | Evenflo Classic Slow Flow | 13.63 |
| 4 | MAM Anti-colic 0mos+ | 13.83 |
| 5 | Tommee Tippee Closer to Nature 0m+ | 15.9 |
| 5 | Tommee Tippee Anti-colic 0m+ | 16.23 |
| 5 | Philips Avent Anti-colic 0m+ | 17.44 |
| 6 | Medela Wide-Base Slow Flow | 22.03 |
| 7 | Medela Calma | 37.61 |

[a]*Nipple types in the same group have comparable flow rates and were statistically different from other groupings in post hoc comparisons ($P < .003$).*

### Cluster Analysis

The cluster analysis revealed 5 distinct clusters of nipple types based on mean flow rates; convergence was achieved in 6 iterations. The clusters were named on the basis of the flow rates: Extra Slow ($n = 4$), Slow ($n = 8$), Medium ($n = 7$), Fast ($n = 5$), and Very Fast ($n = 1$). The nipple types within each cluster are presented in Table 3.

## DISCUSSION

### Implications for Practice

The results of this study provide nurses and other healthcare providers with important information to guide decision making around products to use, particularly for feeding infants with medical complexity, both in the hospital and after discharge. The results of this study suggest that the choice of bottle nipple significantly alters the flow rates to which the infant is exposed. This may play a significant role in how safely and successfully an infant is able to feed.[4] In this study, mean milk flow rate ranged from less than 1 mL/min to more than 35 mL/min. The choice of nipple type is important for medically complex infants, but the packaging of these products does not provide accurate information to guide nipple choices. For example, the Medela Wide-Base Slow Flow nipple is marketed as slow-flow, as is the Philips Avent Natural products, but there is a difference of more than 15 mL/min between these products.

Even within brands, packaging information does not always consistently reflect flow rates. For example, the Philips Avent Natural 0mos+ and the Philips Avent Anti-colic 0mos+ are both marketed as "0mos+," but the Natural nipple had a flow rate of 2.25 mL/min and the Anti-colic nipple had a flow rate of 17.44 mL/min. This is particularly problematic for the parent trying to purchase a very slow-flow product, because it would be easy to confuse these 2 products and accidently purchase a relatively fast flowing nipple. Conversely, within the Similac products, the Standard and Premature nipples were found to have comparable flow rates. The naming of the nipple "Premature" suggests that it will be a slow-flow nipple, but in this case, that was not true.

The variability between nipples of the same type is another important finding from this study. Typically, variability in an infant's feeding from one feeding to another is attributed to infant factors, such as fatigue, stress related to procedures, or immaturity. The results of this study, and previous studies, suggest that the nipple may play a role in the variability seen from feeding to feeding. If a nipple type with high variability is used, the infant may be exposed to very different flow conditions from one feeding to another. Theoretically, when the conditions change

TABLE 3. Results of Cluster Analysis

| Flow Category | Nipple Brand and Type | Mean Flow Rate (Range) |
|---|---|---|
| Extra Slow | Philips Avent Natural First Flow | 0.86 (0.15-1.19) |
| | Philips Avent Natural 0mos+ | 2.25 (1.49-2.74) |
| | nfant Labs Extra Slow | 3.30 (2.6-3.77) |
| | Dr. Brown's UltraPreemie | 4.92 (4.09-5.73) |
| Slow | nfant Labs Slow | 5.99 (5.10-6.62) |
| | Dr. Brown's Preemie | 7.22 (4.35-8.37) |
| | Playtex Ventaire Full Sized | 7.35 (5.65-10.29) |
| | Playtex Ventaire Breastlike | 7.37 (6.10-9.86) |
| | Similac single-use Slow Flow | 8.04 (6.59-13.28) |
| | Playtex Baby Naturalatch 0-3m | 9.47 (7.66-12.88) |
| | Comotomo Slow Flow (0-3 mos) | 9.76 (6.05-12.49) |
| | nfant Labs Standard | 10.32 (9.12-11.79) |
| Medium | Enfamil single-use Slow Flow | 13.24 (9.93-17.39) |
| | Gerber First Essentials | 13.26 (9.85-20.17) |
| | Dr. Brown's Level 1 | 13.31 (11.51-14.59) |
| | Evenflo Classic Slow Flow 0m+ | 13.63 (10.66-20.64) |
| | MAM Anti-colic 0mos+ | 13.83 (13.04-15.68) |
| | Tommee Tippee Closer to Nature 0m+ | 15.90 (14.05-17.08) |
| | Tommee Tippee Anti-colic 0m+ | 16.23 (11.28-20.30) |
| Fast | Philips Avent Anti-colic 0mos+ | 17.44 (16.31-18.5) |
| | Similac single-use Standard Flow | 18.49 (10.55-26.61) |
| | Enfamil single-use Standard Flow | 19.14 (14.09-21.78) |
| | Similac single-use Premature | 19.17 (13.53-26.82) |
| | Medela Wide-Base Slow Flow | 22.03 (17.97-25.61) |
| Very Fast | Medela Calma | 37.61 (35.54-39.96) |

with each feeding experience, infants have to learn to alter their sucking pressure, pattern, and rate to accommodate this change and may revert to a more primitive pattern (eg, separating swallowing and breathing) that is safer, but less efficient, than a more complex pattern that is more efficient (eg, integrating breathing and swallowing).[26]

The Similac Slow flow nipple, for example, was found to be relatively slow with a mean flow rate of 8.04 mL/min but was highly variable (CV = 0.21) and had a maximum flow rate of 13.28 mL/min. Interestingly, 2 of the 3 products that were found to have high variability were the single-use Similac brand nipples, which are frequently used in hospitals. The other brand of products that are frequently used in hospitals is the Enfamil brand. A total of 5 nipple types were tested from these 2 brands. In the cluster analysis, 3 of these products were in the "Fast" category (Enfamil Standard, Similac Standard, and Similac Premature), 1 was in the "Medium" category (Enfamil Slow), and only 1 type was in the "Slow" category (Similac Slow). These products may be appropriate for healthy, full-term infants, for whom the effect of flow and/or variability is negligible, but the data indicate that it may be time to reconsider the nipples that are used for feeding vulnerable infants. Providing consistent and safe flow rates that support positive feeding experiences in infants with medical complexity should be a priority.

### *Incidental Findings With Implications for Practice*

Aside from the data presented here, there were several incidental findings across our 3 studies of milk flow rate that are relevant to clinical practice. There were some cases, particularly of single-use nipples, where a nipple did not have a hole. In these cases, we attempted to extract formula from the nipple unsuccessfully and upon further examination found no hole. Along the same lines, some nipples had a hole/slit, but the silicone had stuck to itself, causing flow to be blocked. If an infant appears to be sucking well, but is not extracting fluid as expected, it is necessary to check the nipple hole.

Two other factors that potentially affect milk flow are how tightly the collar is screwed on to the bottle and the amount of fluid in the bottle. Most nipples have a venting method built into the nipple. This is often done as ridging or other alterations in the silicone of the nipple along the edge between the collar and the bottle. Overtightening the collar may interfere with the venting system and cause negative pressure to build within the bottle. As this negative pressure builds, it becomes harder for the infant to suck fluid from the bottle. This can result in the nipple collapsing, which is often misinterpreted as the nipple being too slow and/or the infant's suck being too strong for the flow of the nipple. To prevent this, the collar should be tightened just a little bit more than is required to prevent leaking but no more.

As we mentioned in the "Methods" section, hydrostatic pressure is the gravitational pressure pushing milk out of the nipple and plays a role in the rate of milk flow. Although variation in hydrostatic pressure is unlikely to be significant enough to affect the healthy infant during feeding, this change in flow may affect the extremely fragile infant who is struggling to coordinate sucking, swallowing, and breathing. To reduce the effect of hydrostatic pressure for extremely fragile infants, the minimum amount of fluid should be placed in the bottle. In other words, if a ready-to-feed formula is being used and there is 60 mL in the bottle, but the infant is only being offered 20 mL, pouring off the excess fluid may reduce flow rate. Hydrostatic pressure and the effect on flow may also be part of the explanation as to why side-lying positioning has been found to be supportive of extremely fragile infants during feeding.[6,27] When the bottle is held horizontal, the height from the tip of the nipple to the level of fluid is reduced, so there is little hydrostatic pressure contributing to milk flow.

### *Comparison of Flow Rates Between Drip Test and Suction Test*

The method of testing flow rate that is commonly used at the bedside by neonatal nurses is the drip test, where the bottle is inverted and the rate at which milk escapes the nipple is estimated. In an effort to determine whether this was an accurate test of flow rate, we compared the suction method used in the study presented in this article with a drip method where the amount of milk that dripped from an inverted nipple was measured at 1 minute and 2 minutes, respectively. We tested 35 nipples from each of 7 nipple types (n = 245). The findings suggested that the drip test works only with a vented bottle. When the bottle is not vented, milk will stop dripping when the negative pressure inside the bottle overcomes hydrostatic pressure; this may make the nipple appear slower than it is. When single-use nipples were placed on a vented bottle system to make the method of testing consistent across nipple types, there was dripping around the nipple and the collar. Given these limitations, the drip test should not be considered an accurate test of flow rate and the suction method remains the best available method for testing flow rate at this time.

## Implications for Research

These data have direct implications for infant feeding research. In a recent study on the effect of flow rate on feeding in preterm infants, McGrattan et al[18] reported that minute ventilation decreased from baseline for both Enfamil Slow and Enfamil Standard flow nipples and that the change from baseline was not significantly different between the two. However, our data indicate that the Enfamil Slow flow nipples are moderately variable and significantly faster than many other slow-flow nipples, both of which likely contributed to the lack of statistical significance found in that study. Investigators examining the effect of milk flow should chose nipples with low variability and with tested flow rates that reflect the flow they intend to achieve.

## Limitations

The primary limitation of this study is that the testing system applies only negative pressure. During typical infant feeding, positive compression pressure

| Summary of Recommendations for Practice and Research | |
|---|---|
| **What we know:** | • Milk flow rate from the bottle nipple may impact how safely and efficiently an infant feeds.<br>• Currently available products provide a wide range of milk flow rate, and within certain nipple types, there is considerable variation in flow rate between nipples of the same type.<br>• The choice of nipple is an important decision, particularly for infants with medical complexity, and these data can be used to guide decision making. |
| **What needs to be studied:** | • Periodic updates to this study will need to be conducted to provide data on currently available products.<br>• The effect of flow rate on swallowing function in infants with medical complexity needs to be studied.<br>• Exploration of the effect of flow rate and other mechanical properties of bottle nipples, such as compressibility and elasticity, on the sucking patterns and pressures of infants with medical complexity needs to be conducted. |
| **What we can do today:** | • These data can be used to guide decisions about products used in hospitals for feeding infants with medical complexity, with regard to both flow and variability.<br>• Healthcare providers can use these data to guide parents in choosing a nipple for use after hospital discharge that will continue to support the infant's safety and learning experience.<br>• Be mindful not to overtighten the collar on to the bottle and consider hydrostatic pressure as contributing to flow rate in very fragile infants. |

is also applied. Further development of the testing system to include positive compression pressure and testing of flow under specified suction pressures would allow for continued improvement in the ability to test flow rates of new products and crosscut nipples. Also, it should be noted that the flow rates from this study should not be compared directly with the flow rates published in our previous studies because a different pump and suction pressure were used. Finally, the products tested were limited to the United States. Future studies should test bottle nipples available in other countries.

### Future Directions

As manufacturer's change products or release new products, periodic testing of flow rates will need to be conducted in order for clinicians and researchers to make decisions about nipple choices based on data that reflect the most recent products. Future directions for this work include exploring the effect of milk flow rates on the sucking pressures and patterns, swallowing function, and physiologic and behavioral responses to feeding in infants with medical complexity. There is also a need for better understanding of the other properties of nipples, including nipple shape, compressibility, and elasticity, and how these factors play a role into the feeding experience of the infant. A comprehensive understanding of these factors may allow for the personalized selection of bottle nipples to best support the infant with medical complexity during oral feeding.

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