Effect of Vacuum Profile on Breast Milk Expression Using an Electric Breast Pump

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Abstract

The authors compared milk expression using 5 experimental vacuum patterns and a commercially available vacuum pattern ranging in cycle times (20 to 78 cycles/min) and vacuum curve dynamics in 30 mothers using an experimental, software-controlled electric breast pump. The volume of milk removed over 5 minutes differed ($P = .0072$) between patterns (range = 62.8 ± 6.6 mL to 47.2 ± 5.1 mL). However, there was no difference in the percentage of available milk removed (range = 99.4% ± 15.1% to 70.6% ± 8.6%). The rate of milk removal differed between patterns at both the beginning (1 minute) and end (1.5 minutes) of the expression period ($P < .05$). Peak vacuum chosen differed between patterns ($P = .0085$) but was not related to either the volume or percentage of available milk expressed. Breastfeeding characteristics did not differ between poor and successful expressers. These results show that breast milk expression by an electric breast pump can be influenced by the vacuum pattern. *J Hum Lact*. 18(4): 353-360.

Keywords: breast milk, expression, electric breast pump

Infants have been shown to vary sucking frequencies and vacuums generated over the course of a breastfeed.[1-3] Woolridge[2] initially described 2 patterns of sucking, a nonnutritive pattern (sucking of a greater frequency that occurred when the infant was first put to the breast) and a nutritive pattern (sucking of a slower frequency that occurred once milk flow had started), and found not a distinction between them but, rather, a continuous grading between the two,[3] suggesting that the infant can change sucking characteristics during a feed to vary milk removal.

In contrast to these studies and others that have investigated the physical characteristics of sucking mechanics of breastfed infants,[1-3] none have applied the same approach to breast milk expression using an electric breast pump. Indeed, with regard to the mechanical expression of breast milk, only different expressing techniques (manual, electric, or hand) have been compared.[4,5] The effect of changing the physical characteristics of expression vacuum patterns (patterns) generated by a breast pump on the efficacy of breast milk expression has not been studied.

We have developed a method suitable for the objective determination of breast pump efficacy and have used this method to compare milk removal from the breast at a single 5-minute expression period using 6 different patterns in 30 women. Pattern efficiency was compared on the basis of the percentage of available milk removed and the rate of milk removal over the 5-minute expression period. The maximum vacuum applied and maternal responses to each pattern were also investigated.

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Methods

Subjects

Mothers (n = 30) of healthy term-delivered infants (1 to 6 months of age) were recruited through either the Australian Breastfeeding Association, Western Australia Branch, or private health care centers. All mothers supplied written informed consent to participate in the studies, which were approved by the Human Research Ethics Committee of The University of Western Australia. All infants were exclusively breastfed on demand. Details of mothers are provided elsewhere.[6] Mothers maintained normal breastfeeding patterns throughout study periods. All studies were conducted in the Breastfeeding Centre of Western Australia at the King Edward Memorial Hospital for Women.

Breastfeeding Characteristics

Determination of 24-Hour Milk Production

Milk yield was determined for each breast by test weighing the infant.[7] Test weighing was carried out over a 24-hour period using an electronic balance (BabyWeighScales, Medela AG, Switzerland) at each mother's home within approximately 1 week prior to undertaking the study. Mothers were instructed on the use of the balance, provided with written instructions, and were required to demonstrate the use of the balance to the visiting researcher.

Sample Collection

Milk samples (≤ 1 mL) were collected before (foremilk) and after (hindmilk) each feed from each breast over the same 24-hour period in which test weighing occurred by either hand expression or manual breast pump into polypropylene vials at the subject's home. Samples were initially stored in a household freezer for a maximum of 24 hours and then transported on ice to the laboratory where they were stored at –20°C until analysis.

Determination of Milk Fat Content

The percentage of fat in the milk was determined using the creamatocrit technique[8,9] and standardized to content (g/L) by way of comparison with the esterified fat assay[10] as modified by Atwood and Hartmann[11] and described by Cox et al.[12] Briefly, small amounts of milk (50 to 100 μL) were collected into microhematocrit tubes and then centrifuged at 12,000 g for 10 minutes in a microhematocrit centrifuge. The length of the cream layer was then measured, using vernier calipers, to the nearest 0.05 mm and was expressed as a percentage of the total length of milk in the tube (also measured with vernier calipers to the nearest 0.05 mm). Creamatocrit percentage was converted into g/L by comparison to the esterified fat assay[10] using the following equation: fat (g/L) = (5.37 × creamatocrit %) + 5.28.[6]

Determination of Degree of Fullness

The degree of fullness of the breast[12] is a measure of how much milk is stored in the breast at any one point in time and was determined using the relationship between the fat content of the milk and the degree of emptying of the breast.[13] Briefly, milk samples collected during the 24-hour sampling period containing the maximum and minimum content of fat were designated as having degrees of emptying of 1 and 0, respectively. The remaining samples collected during the 24-hour sampling period were then used to determine the relationship between fat content and degree of emptying within the limits set by the samples containing the maximum and minimum contents of fat for that mother by fitting the curve described by Daly et al.[13] The fat content of any subsequent milk sample was then able to be used to determine the degree of emptying of the breast at the time the sample was collected for that mother. This was then converted to the degree of fullness of the breast by subtracting the value determined for the degree of emptying from 1.[12]

Breast Pump and Expression Characteristics

Study Design

Milk was expressed from only one breast, and each mother used each of the 6 patterns on the same breast, over 3 separate days (2 per day, 1 day per week over 3 weeks), in an order determined by computer-generated random sequence. The degree of fullness of the breast at the first pumping session was used as a guide, and subsequent pumping sessions were required to start at a similar degree of fullness. In this regard, the timing of the sessions either between or within mothers was not important, as the sessions were accounted for by maintaining a similar starting degree of fullness, and therefore each session started with a similar amount of milk in the breast.

Determination of Available Milk

The amount of milk in the breast prior to each expression period that was available to be expressed was determined using the degree of breast fullness[12] and the maximum feed volume from the 24-hour sampling period. In this regard, the maximum volume of milk removed by the infant at 1 feed over the course of the 24-hour sampling procedure (maximum feed volume) correlated well with the calculated storage capacity of the breast ($y = 1.15x + 39.65$, $r = 0.72$, $P < .001$, where y is the storage capacity and x is the maximum feed volume) and was used as an objective measure of the amount of milk able to be stored in the breast. The fat content of the milk prior to each expression period was used to determine the degree of fullness of the breast. By multiplying the degree of fullness of the breast by the maximum feed volume, the amount of milk in the breast available to be removed was estimated.

For example, if the fat content of a small sample of milk (≤ 1 mL) expressed from the breast prior to the experimental session was 3.5 g/L, and using the relationship between milk fat content and degree of fullness of the breast, we found that the breast had a degree of fullness of 0.8 (ie, 80% full). Then, by using the maximum amount of milk removed by the infant in the 24-hour sampling period, for example 120 mL, as an indicator of the amount of milk able to be stored in the breast, it can be calculated that the breast has 96 mL (0.8×120 mL) available to be expressed. Therefore, we would assume that the breast has a maximum amount of 96 mL available to be removed by the breast pump at that point in time. If only 48 mL of milk was expressed by the breast pump, we would conclude that 50% of the available milk was expressed.

Breast Pump

An experimental, software-controlled electric breast pump (B2000, Medela AG, Switzerland) connected to a standard, commercially available breast shield and collection bottle (Medela AG, Switzerland) was used to express milk from the breast. The pump was able to provide continuous vacuum over the range of 0 to –250 mm Hg, with cycling times over the range of 20 to 120 cycles per minute. Mothers were able to adjust the vacuum, to comfort, at all times throughout the pumping session.

In all cases, a stimulation pattern preceded each expression pattern for each mother. The stimulation pattern was used over the vacuum range of 0 to –250 mm Hg and had a constant rate (105 cycles/min). This pattern was used to stimulate the milk ejection reflex in all mothers, a condition for continuing to the expression pattern. Once the mother sensed that milk ejection had occurred, the vacuum pattern was changed to a predetermined expression pattern and the breast expressed for a further 5 minutes. In the case of a mother unable to sense milk ejection, the pattern was changed when there was an increase in milk flow. All expression volumes referred to are those volumes of milk removed by the expression pattern subsequent to the milk ejection reflex.

For the current study, 6 different patterns were tested. Pattern 1 (Figure 1A) curve dynamics were the same as those generated by the non-software-controlled, commercially available Classic breast pump (Medela AG, Switzerland), with a vacuum range of 0 to –250 mm Hg and a cycle time of 47 cycles/min. Pattern 2 (Figure 1B) differed from pattern 1 in that it had a faster frequency and the vacuum did not return to 0 mm Hg immediately but fell back to a lesser holding vacuum prior to returning to 0 mm Hg to finish the cycle. In addition, the rate and vacuum were related to maintain vacuum curve shape and characteristics over a range of vacuums. Therefore, as the peak vacuum decreased (tended toward 0 mm Hg), the frequency increased (became quicker) toward a maximum of 78 cycles/min compared to 54 cycles/min at –250 mm Hg. Patterns 3, 4, and 5 (Figures 1C, 1D, and 1E, respectively) were variations of pattern 2. These patterns had the slower, constant rate of 20 cycles/min (not related to vacuum), but the fall-back vacuum after the point of inflection was different for each pattern, with pattern 5 falling back and holding at the lowest vacuum prior to returning to 0 mm Hg. Pattern 6 (Figure 1F) also had the slower, constant rate of 20 cycles/min (not related to vacuum), but it achieved this with a slow application of pressure as opposed to the slow release of pressure evident in patterns 3, 4, and 5.

Sampling

Expressed milk was collected in a preweighed empty bottle that was replaced every 30 seconds during a 5-minute expression period. A subsample (≤ 2 mL) of milk from each 30-second period was collected and the remaining milk pooled in another bottle and later offered to the mother to be either fed immediately to the infant or taken home. Samples collected were analyzed immediately.

Measurement of Breast and Nipple Temperature

Infrared images of the breast and nipple were taken using the ThermaCAM™ SC1000 camera (FLIR Systems, Australia) as previously described[6] to observe any

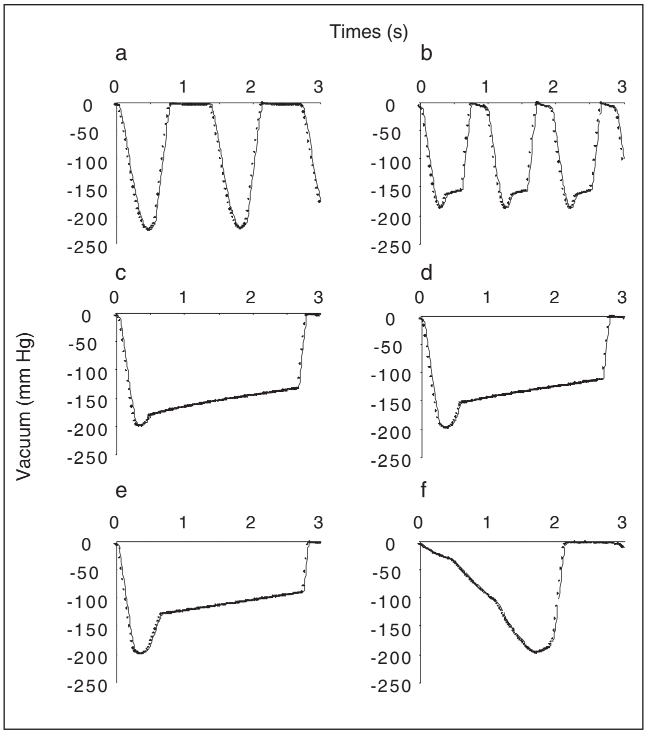

Figure 1. Profiles of the 6 different expression vacuum patterns tested. (a) Pattern 1, (b) Pattern 2, (c) Pattern 3, (d) Pattern 4, (e) Pattern 5, (f) Pattern 6.

changes in the temperature of the breast and nipple during the pumping period. Briefly, the room in which the studies were conducted was maintained at 25°C. Infrared images of the breast and nipple were obtained at 1-minute intervals from 5 minutes prior to the beginning of each session and at 10-second intervals for the first minute immediately after the end of each session and then at 1-minute intervals for the subsequent 4 minutes. These images were then analyzed using ThermaGRAM 95 pro (version 1.30, FLIR Systems, Australia) to determine changes in breast and nipple temperature before and after each pumping period.

Maternal Evaluation of Vacuum Patterns

An evaluation form, completed immediately after each pumping period, was used to obtain information with regard to mothers' experiences during each session. Mothers used numeric rating scales to indicate the frequency, vacuum, and overall dislike or like of each pattern. Open-ended questions were also used to obtain any additional comments mothers chose to make.

Statistical Analysis

All quantitative data were analyzed using repeated-measures 2-way analysis of variance to account for the experimental design, where observations were cross-classified by mothers and patterns. In the case of analyzing summary or univariate measures across either patterns or mothers, 1-way analysis of variance was used. When it was necessary to include additional covariate information in the analysis, linear regression models were developed. Inflated type I error rates associated with multiple significance testing resulting from pairwise comparisons of subject or treatment means were alleviated using Duncan's multiple-range test. Statistical analyses were performed using SAS (version 6.12, SAS Institute, Cary, NC, USA) and SuperANOVA version 1.1 (Abacus Concepts Inc, Berkeley, CA, USA). All values are expressed as means ± SE unless otherwise stated.

Results

The mean age of all mothers was 32.1 ± 4.5 years (range = 25 to 42), and the mean age of the infants was 12.6 ± 5.8 weeks (range = 4 to 24). Mean 24-hour milk production from the left breast was 380.7 ± 127.0 mL (range = 169.7 to 601.1 mL) and from the right breast was 369.9 ± 121.8 (range = 81.3 to 585.9 mL). Ninety percent (n = 27) of mothers were able to sense the milk ejection reflex. Of these, 52% (n = 14) were able to sense multiple milk ejections during a single feeding episode. All mothers completed all 6 expression patterns. There was no difference in the mean degree of fullness of the breast at the start of each pumping session (pattern 1, 0.60 ± 0.24; pattern 2, 0.61 ± 0.23; pattern 3, 0.57 ± 0.24; pattern 4, 0.57 ± 0.27; pattern 5, 0.62 ± 0.23; pattern 6, 0.59 ± 0.21). The mean time to milk ejection for all mothers across all patterns was 89.2 ± 62.6 seconds (range = 0 to 420 seconds).

The volume of milk removed from the breast varied greatly between both women and patterns ($P = .0072$), with patterns 1 (60.6 ± 7.1 mL) and 2 (62.8 ± 6.6 mL) removing more milk over the 5-minute expression period than patterns 3 (50.6 ± 5.7 mL), 4 (51.2 ± 5.2 mL), 5 (50.2 ± 6.2 mL), and 6 (47.2 ± 5.1 mL) (Table 1). However, when the volume was reclassified as a percentage of available milk removed, the relationships between patterns changed (Table 1). Pattern 1 (99.4% ± 15.1%) removed the greatest percentage of available milk, followed by patterns 3 (92.8% ± 12.8%), 2 (85.7% ± 10.2%), 6 (84.2% ± 11.5%), 4 (79.1% ± 9.0%), and 5 (70.6% ± 8.6%). However, there was no significant difference in the percentage of available milk removed

Table 1. Differences in Expression Parameters Between Expression Patterns*

	Pattern					
Expression Parameter	*1*	*2*	*3*	*4*	*5*	*6*
Volume (mL)	60.6 ± 7.1^{ab}	62.8 ± 6.6^{a}	50.6 ± 5.7^{c}	51.2 ± 5.2^{bc}	50.2 ± 6.2^{c}	47.2 ± 5.1^{c}
% removed 2 min	48.2 ± 6.5^{a}	43.3 ± 5.0^{a}	61.2 ± 8.1^{b}	50.9 ± 6.8^{ab}	48.1 ± 6.8^{a}	46.7 ± 8.0^{a}
% removed 5 min	99.4 ± 15.1^{a}	85.7 ± 10.2^{ab}	92.8 ± 12.8^{ab}	79.1 ± 9.0^{ab}	70.6 ± 8.6^{b}	84.2 ± 11.5^{ab}
Vacuum (mm Hg)	-191.3 ± 6.5^{a}	-175.9 ± 8.9^{bc}	-167.2 ± 6.0^{c}	-174.4 ± 6.2^{bc}	-182.2 ± 7.4^{ab}	-174.1 ± 7.7^{bc}

*Same-letter superscripts are not significantly different, $P > .05$, repeated-measures ANOVA.

Table 2. Percentage of Available Milk Removed in Each 30-second Period of a 5-minute Expression Period*

	Pattern					
Time (min)	*1*	*2*	*3*	*4*	*5*	*6*
0.5**	10.63^{b}	13.67^{b}	22.65^{a}	18.87^{a}	16.68^{a}	15.13^{a}
1.0†	14.53^{a}	13.16^{b}	22.59^{a}	18.74^{a}	15.96^{a}	13.33^{b}
1.5	15.16^{a}	14.64^{a}	22.10^{a}	15.58^{a}	18.52^{a}	14.47^{a}
2.0	22.76^{a}	16.65^{a}	22.50^{a}	16.89^{a}	18.40^{a}	14.93^{a}
2.5	23.23^{a}	19.15^{a}	19.06^{a}	16.83^{a}	15.47^{a}	17.42^{a}
3.0	19.73^{a}	21.17^{a}	13.84^{a}	13.56^{a}	12.34^{a}	15.84^{a}
3.5	18.21^{a}	18.80^{a}	12.80^{a}	12.81^{a}	11.80^{a}	16.96^{a}
4.0††	21.43^{a}	20.92^{a}	12.25^{b}	13.81^{a}	10.66^{b}	16.19^{a}
4.5†	18.81^{a}	18.44^{a}	14.46^{a}	13.10^{a}	10.78^{b}	20.65^{a}
5.0†	21.06^{a}	22.34^{a}	13.45^{a}	11.61^{b}	13.13^{a}	14.39^{a}

* Same-letter superscripts across patterns within a time point are not significantly different, $P > .05$ unless otherwise noted, repeated-measures ANOVA.
** $P < .01$.
† $P < .05$.
†† $P = .01$.

between patterns 1, 2, 3, 4, and 6, with these patterns all greater than pattern 5.

The rate of milk removal, expressed as the percentage of milk removed in each 30-second period over the 5-minute expression period, differed between patterns during the first and last 1.5 minutes of the pumping period (Table 2). Patterns fell into 2 categories, those removing an increasing percentage of available milk as time progressed (patterns 1, 2, and 6) and those removing a decreasing percentage of available milk as time progressed (patterns 3, 4, and 5). Therefore, when focusing on the first 2 minutes of expression, pattern 3 removed the greatest percentage of available milk (61.2% ± 8.1%) when compared to pattern 4 (50.9% ± 6.8%), pattern 1 (48.3% ± 6.5%), pattern 5 (48.1% ± 6.8%), pattern 6 (46.7% ± 8.0%), and pattern 2 (43.3% ± 5.0%) (Table 1).

The peak vacuum chosen by each mother differed between patterns ($P = .0085$) (Table 1). Pattern 1 was used at the highest peak vacuum (–191.3 ± 6.5 mm Hg), followed by pattern 5 (–182.2 ± 7.4 mm Hg) and patterns 2 (–175.9 ± 8.9 mm Hg), 4 (–174.4 ± 6.2 mm Hg), 6 (–174.1 ± 7.7 mm Hg), and 3 (–167.2 ± 6.0 mm Hg). Mothers tended not to adjust the vacuum during each expression period, as no statistically significant change in peak vacuum over the 5-minute period was found. The peak vacuum chosen by the mother was not related to either the volume of milk expressed or the percentage of available milk removed.

Nipple temperature changed with time for all patterns ($P = .0001$). For all patterns, preexpression nipple temperature decreased during the 5 minutes leading up to the pumping period ($P < .005$). Postexpression nipple temperature (30 seconds) was higher than preexpression nipple temperature for each pattern ($P < .005$). However, postexpression nipple temperature decreased to preexpression temperatures by 120 seconds after the expression period. Breast temperature also differed with time ($P = .0001$). For all patterns, preexpression breast temperature decreased during the 5 minutes leading up to the pumping period ($P < .003$). Postexpression breast temperature was lower than preexpression breast temperature for patterns 1, 3, 4, and 5, and no difference in pre- and postexpression breast temperature was found for patterns 2 and 6. However, breast temperature remained constant for the 6 minutes postexpression.

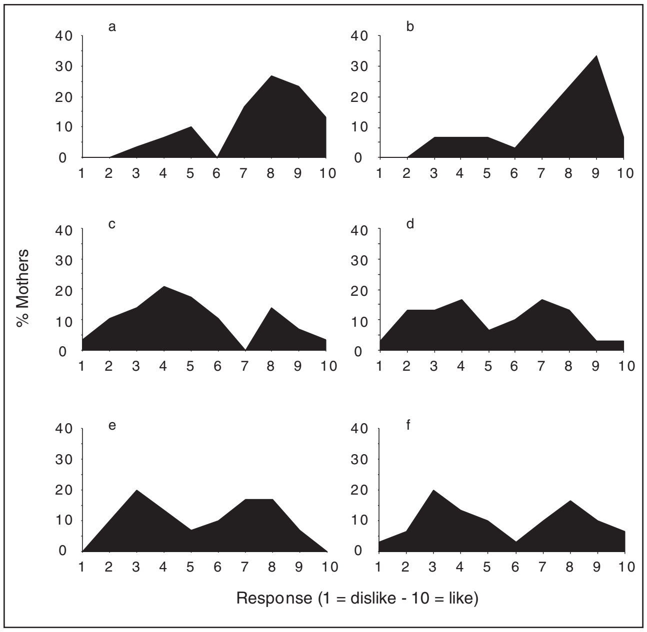

Figure 2. Summary of mothers' scores for each vacuum expression pattern, (a) Pattern 1, (b) Pattern 2, (c) Pattern 3, (d) Pattern 4, (e) Pattern 5, (f) Pattern 6.

Maternal responses to each pattern (Figure 2) showed that patterns 1 (80%) and 2 (80%) received the greatest number of positive responses (≥ 6) followed by patterns 5 (50%), 4 (46.67%), 6 (46.67%), and 3 (34.5%). Responses were not related to either the volume of milk or the percentage of available milk removed. However, the mother's preference score for each pattern (1 = dislike, 10 = like) was directly related to the vacuum score (0 = weak, 5 = strong) as chosen by each mother ($y = 0.21x + 2.52$, $r = 0.52$, $P < .001$, where y is the vacuum score and x is the pattern score).

Mothers were classified into 3 groups based on ratio of expressed breast milk to mean breastfeed (BF) volume. The low-ratio group consisted of 5 mothers whose ratio of expressed breast milk to mean BF volume was less than 0.50 for at least 5 of the patterns. The high-ratio group consisted of 10 mothers whose ratio of expressed breast milk to mean BF volume was greater than 1 for at least 3 of the patterns. The remaining 15 mothers were considered to be the middle-ratio group.

Mothers in the low-ratio group had equivalent or higher values for breastfeeding characteristics (mean BF volume, 24-hour production, maximum feed volume, and feeding frequency) than mothers in the middle- or the high-ratio group, with the lowest means recorded by the middle-ratio group. Mothers in the low- and middle-ratio groups do, however, have lower expression characteristics (expression volume, time to milk ejection, and vacuum) than mothers in the high-ratio group (Table 3). However, there were no differences between the groups in the preference score assigned to each pattern.

Table 3. Summary of Breastfeeding and Expression Characteristics for Low-, Middle-, and High-Ratio Expression Groups

Characteristic	*Low Ratio (n = 5)*	*Middle Ratio (n = 15)*	*High Ratio (n = 10)*
Breastfeeding ($\bar{x} \pm$ SD)			
Breastfeed volume, mL	82 ± 27	68 ± 28	72 ± 22
Maximum breastfeed volume, mL	131 ± 33	106 ± 35	120 ± 35
Feeding frequency, feeds per 24 h	5.6 ± 1.1	6.1 ± 2.0	6.3 ± 0.9
24-h milk production per breast, mL	403 ± 118	362 ± 124	431 ± 121
Expression ($\bar{x} \pm$ SE)			
Stimulation vacuum, mm Hg	–100 ± 9	–114 ± 5	–119 ± 6
Time to milk ejection, s	124 ± 13	83 ± 7	81 ± 9
Expression volume, mL	25.0 ± 7.6	44.0 ± 4.6	82.0 ± 5.6
Expression vacuum, mm Hg	–160 ± 13	–178 ± 8	–185 ± 9

Discussion

Previous studies investigating milk removal from the breast have focused on differences between the available modes of expression (hand, manual, or electric) rather than attempting to optimize the characteristics of expression. In this study, we used 6 different patterns generated by an experimental, software-controlled electric breast pump (Figure 1) to determine whether any one pattern is more efficient at removing milk from the breast. The patterns were designed to vary both the rates of application of vacuum to the breast and time that effective vacuum was applied to the breast during the cycle. This approach used the objective determination of the amount of milk removed as a percentage of the milk available in the breast at the start of the pumping session, a method previously developed in this laboratory.[6]

The volume of milk removed by each pattern differed between both mothers and patterns (Table 1). However, in this instance the subjective value of "volume of milk removed" can be converted to the more objective value of "percentage of available milk removed."[6] Using this approach, relationships between patterns were altered (Table 1); however, there were no significant differences between patterns 1, 3, 2, 6, and 4, with these patterns all greater than pattern 5. The high placing of pattern 1 when using either criterion is of considerable importance, as this pattern has remained largely unchanged from the time of its initial development and is the one generated when a mother uses the currently available Medela Classic electric breast pump.

Previous studies on breast pump efficiency have paid little attention to the determination of an optimal duration for each expression episode. In this regard, a recent article noting the increasing number of women in the workforce suggested that one quarter of employed women with a child younger than 1 year old will be concurrently breastfeeding and working for at least 1 month.[14] Thus, for the woman expressing while at work, the issue of time spent at the breast pump is of particular importance. Our data show that patterns 1, 2, and 6 increased in efficiency as the expression period progressed whereas patterns 3, 4, and 5 decreased (Table 2). Indeed, pattern 3 was the most efficient during the first 2 minutes (Table 1).

Therefore, it may be that certain characteristics of each pattern determine into which group the pattern will fall. The specific vacuum curve dynamics of patterns 3, 4, and 5 may provide an increased opportunity to take advantage of milk availability in the seconds immediately after the milk ejection reflex. This is in contrast to patterns 1, 2, and 6, which seem more suited to the removal of milk as the expression period continues. These data suggest that an efficient means of removing milk from the breast may not be achieved by the use of 1 vacuum pattern throughout the expression period. Indeed, just as the infant has been shown to change sucking frequency during a feed,[1-3] this strategy might also be useful for the expressing mother. However, maternal responses for each pattern show preference for faster (> cycles/min) rather than slower patterns (Figure 2). This does not preclude the combination of any of the 6 patterns, as in all cases mothers' responses were made after a 5-minute expression period and it is unlikely that these responses would remain the same if the exposure time was reduced.

The experimental, software-controlled breast pump used in the current study provided mothers with the ability to vary the maximum vacuum applied within the boundaries of 0 to –250 mm Hg for each pattern. Mothers used pattern 1 at the strongest maximum vacuum, followed by patterns 5, 2, 4, 6, and 3 (Table 1). It is interesting to note that mothers were asked to set the vacuum to a level that they found comfortable, not at the level that they thought would remove the most milk. In this regard, it can be seen that different patterns produced different "comfort" vacuums. The vacuum ultimately chosen by the mother was not related to either the volume or the percentage of available milk removed, thus not supporting the anecdotal notion of "increased vacuum results in more milk" that is often heard among expressing mothers. These data suggest that the vacuum used is not important from an efficacy point of view but rather from the more subjective viewpoint of consumer preference. Indeed, when asked to rate each pattern on a response scale of 1 (dislike) to 10 (like), mothers' responses were related to how they felt about the maximum vacuum chosen rather than the volume of milk removed.

The changes in the temperature of the nipple and breast prior to each expression period cannot be related to the pattern applied. The prepumping time period allowed the nipple and breast to equilibrate with the room temperature. Nipple temperature tended to increase after the expression period, which may be due to the warming effect of expressed breast milk on the nipple and breast shield. More important, the fact that temperature increased as opposed to decreased indicates that the application, release, and resting phase of each pattern was adequate to maintain blood flow to the breast and to not cause constriction in the nipple. Postexpression breast temperature was lower than preexpression breast temperature for patterns 1, 3, 4, and 5, whereas there was no change for patterns 2 and 6. This was not unexpected, as recent evidence from our laboratory has shown a decrease in breast temperature after a breastfeed in demand-feeding women (P. E. Hartmann, unpublished observations), indicating the similar response of the breast to both expressing and breastfeeding.

The classification of mothers based on the relative success of each pattern to the mothers' own breastfeeding characteristics resulted in the mothers forming 3 groups (Table 3). In contrast to expression characteristics, breastfeeding characteristics did not differ between mothers from each group. These data highlight the fact that women deficient at expressing do not suffer any deficiencies in breastfeeding their infants. Furthermore, the consistency of the results across patterns for the low-ratio mothers suggests that these women will not successfully express under any conditions. Whether the reasons for these poor expressing outcomes lies at the level of the milk ejection reflex or is due to the interaction of the negative pressure generated by the breast pump with the ductal structure within the mammary gland, or both, is unclear and requires further investigation.

In summary, this study has shown that milk removal from the breast by an electric breast pump can be investigated, provided that patterns are compared using an objective means of determining relative success rather than relying solely on volume of milk removed. Our results show that newly developed patterns can be as effective as a currently available pattern in removing milk from the breast. However, these data suggest that certain characteristics of each pattern make the patterns more likely to be successful at different stages of the expression period. Therefore, it is suggested that an optimal pattern may include up to 2 different patterns in succession: the first, to take advantage of the milk released by the milk ejection reflex, and the second, to remove milk remaining in the ductal system of the breast and perhaps also to provide stimulus for subsequent milk ejection reflexes.

References

1. Weber F, Woolridge MW, Baum JD. An ultrasonographic study of the organisation of sucking and swallowing by newborn infants. *Dev Med Child Neurol*. 1986;28:19-24.
2. Woolridge MW. The "anatomy" of infant sucking. *Midwifery.* 1986; 2:164-171.
3. Woolridge MW, Drewett DF. Sucking rates of human babies on the breast: a study using direct observation and intraoral pressure measurements. *J Reprod Infant Psychol*. 1986;4:69-75.
4. Boutte CA, Garza C, Fraley JK, Stuff JE, Smith EO. Comparison of hand- and electric-operated breast pumps. *Hum Nutr Appl Nutr.* 1985;39:426-430.
5. Zinaman MJ, Hughes V, Queenan JT, Labbok MH, Albertson B. Acute prolactin and oxytocin responses and milk yield to infant suckling and artificial methods of expression in lactating women. *Pediatrics*. 1992;89:437-440.
6. Mitoulas LR, Lai CT, Gurrin LC, Larsson M, Hartmann PE. Efficacy of breast milk expression using an electric breast pump. *J Hum Lact*. 2002;18:342-350.
7. Arthur PG, Hartmann PE, Smith M. Measurement of the milk intake of breast-fed infants. *J Pediatr Gastroenterol Nutr.* 1987;6:758-763.
8. Fleet IR, Linzell JL. A rapid method of estimating fat in very small quantities of milk. *J Physiol*. 1964;175:15-17.
9. Lucas A, Gibbs JAH, Lyster JLJ, Baum JD. Creamatocrit: simple clinical technique for estimating fat concentration and energy value of human milk. *Br Med J*. 1978;14:111-114.
10. Stern I, Shapiro B. A rapid and simple method for the determination of esterified fatty acids and for total fatty acids in blood. *J Clin Pathol*. 1953;6:158.
11. Atwood CS, Hartmann PE. Collection of fore and hind milk from the sow and the changes in milk composition during suckling. *J Dairy Res*. 1992;59:287-298.
12. Cox DB, Owens RA, Hartmann PE. Blood and milk prolactin and the rate of milk synthesis in women. *Exp Physiol*. 1996;81:1007-1020.
13. Daly SEJ, Di Rosso A, Owens RA, Hartmann PE. Degree of breast emptying explains changes in the fat content, but not fatty acid composition, of human milk. *Exp Physiol*. 1993;78:741-755.
14. Zinn B. Supporting the employed breastfeeding mother. *J Midwifery Women's Health*. 2000;45:216-226.

Resumen

Efecto del patrón de vacío en la expresión de leche utilizando extractoras eléctricas. Comparamos la expresión de leche materna utilizando cinco patrones experimentales al vacío y un patrón al vacío disponible comercialmente con ciclos en un rango de 20-78 ciclos/minuto y la dinámica en curva del vacío en 30 madres utilizando un programa de extractora eléctrica experimental computarizada. El volumen de leche extraído durante cinco minutos era diferente ($P = .0072$) entre los patrones (rango 62 ± 6.6 mL a 47.2 ± 5.1 mL). Aun así, se vieron diferencias en el porcentaje de leche extraída (rango 99.4 ± 15.1% a 70.6 ± 8.6%). El índice de leche removida difería entre los patrones en los dos tanto al principio (1 minuto) como al final (1.5 minutos) del período de expresión ($P < .05$). El vacío mayor difería entre los patrones ($P = .0085$) pero no estaba relacionado ni con el volumen ni con el porcentaje de leche extraída. Las características de la lactancia no cambiaron entre la expresión exitosa y pobre. Estos resultados muestran que la expresión de leche materna con extractoras eléctricas son influenciadas por el patrón del vacío.