Response of Breasts to Different Stimulation Patterns of an Electric Breast Pump

Jacqueline C. Kent, BSc, PhD, Donna T. Ramsay, DMU, PGDip, Dorota Doherty, PhD, Michael Larsson, MBA, Peter E. Hartmann, BRurSci, PhD

Abstract

To test the effect on milk ejection, an electric breast pump was programmed to provide pumping patterns with frequencies of 45 to 125 cycles/min and vacuums of –45 to –273 mm Hg. The time taken for milk ejection to occur (measured using ultrasound to detect a dilation of a lactiferous duct in the opposite breast) in response to the current Medela electric breast pump pattern (45 cycles/min) was 147 ± 13 s. For patterns that more closely resemble the sucking frequency of an infant when it first attaches to the breast, milk ejection occurred between 136 ± 12 and 104 ± 10 s, although this difference was not statistically significant. Milk ejection in response to breastfeeding occurred after 56 ± 4 s. The applied vacuum affected the amount of milk that was removed up to 50 to 70 s after milk ejection but not the time for milk ejection. *J Hum Lact*. 19(2):179-186.

Keywords: milk ejection, breast pump, ultrasound, lactiferous duct

Breast milk is the optimal nourishment for infants, and breastfeeding is the most convenient way of providing that nourishment. However, for mothers with premature infants and those returning to work outside the home, breastfeeding is not always either possible or practical. It is important that the expression of milk from the breast be as efficient and comfortable as possible so that these mothers can provide expressed breast milk for their infants.

Whether breast milk is removed by a breastfed infant or removed manually or by a mechanical or electric breast pump, little milk can be withdrawn unless a milk ejection has occurred.[1] During breastfeeding, milk ejection is triggered by neural impulses from infant sucking stimulating the release of oxytocin from the posterior pituitary gland. Oxytocin causes the contraction of the myoepithelial cells that surround the alveoli in the breasts and results in the expulsion of milk from the alveoli and an increase in intramammary pressure, facilitating the withdrawal of milk from the breast by the infant.[1] Milk ejection also can occur without the physical stimuli of the infant sucking the breast and can be inhibited by stress.[1]

An infant stimulates the milk ejection reflex at the beginning of a feed by sucking rapidly, between 72 and 120 sucks/min, before slowing to 60 sucks/min once milk starts to flow.[2,3] However, currently available electric breast pumps make no specific provision for the stimulation of the milk ejection reflex. Although the ISIS mechanical breast pump (Avent, Glemsford,

Received for review, May 6, 2002; revised manuscript accepted for publication, November 22, 2002.

Jacqueline C. Kent has been involved in breastfeeding research since 1986. She completed her PhD on calcium in milk in 1999. **Donna T. Ramsay** has 10 years of experience in clinical ultrasound. She completed her postgraduate diploma research on ultrasound studies of the milk ejection reflex and is currently undertaking her PhD studies on ultrasound of the lactating breast. **Dorota Doherty** has a PhD in medical statistics. She has worked as a biostatistician in medical research in the areas of physiotherapy, endocrinology, oncology, obstetrics, and gynecology. **Michael Larsson** has had a long involvement in the development of breastfeeding products and is currently responsible for breastfeeding research at Medela AG. **Peter E. Hartmann** began his research on the physiology and biochemistry of lactation in 1964. His human research dates from 1971, and he is the author of over 100 peer-reviewed research articles.

This research received support from Medela, the Lotteries Commission of Western Australia, and Acuson Pty Ltd. The authors thank the volunteer mothers, babies, and babysitters who participated in this study for generously providing their time, and the Australian Breastfeeding Association (Western Australia Branch) for recruiting volunteers. Dr Lyle Gurrin provided statistical advice, and Ching Tat Lai, Leon Mitoulas, and Shireen Pivac provided technical assistance. The support of Medela, the Lotteries Commission of Western Australia, and Acuson is gratefully acknowledged. Requests for reprints should be sent to Jacqueline C. Kent, Biochemistry and Molecular Biology, School of Biomedical and Chemical Sciences, The University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia.

J Hum Lact 19(2), 2003
DOI: 10.1177/0890334403252473

United Kingdom) is designed to provide pulsatile pressure around the areola to simulate an infant's compressive action on the areola during breastfeeding, the effect this has on milk ejection has not been quantitatively assessed.[4] We wished to assess the effectiveness of different stimulation patterns provided by an electric breast pump. Because milk ejection occurs simultaneously in both breasts and can be visualized using ultrasound,[5] we used this technique to measure the time taken for the patterns to elicit milk ejection. In addition, we compared the patterns with respect to the volume of milk removed in the short term, the changes in the lactiferous ducts of the breasts, and the mothers' perceptions of the patterns.

Materials and Methods

Participants

The study was approved by the Human Research Ethics Committee, The University of Western Australia. Mothers of healthy, term infants aged between 1 and 6 months who were members of the Australian Breastfeeding Association (formerly the Nursing Mothers' Association of Australia) or acquaintances of the researchers volunteered to participate and provided written informed consent. All infants were exclusively breastfed on demand.

Ultrasound

An Acuson XP10 ultrasound machine (Acuson Pty Ltd, North Ryde, Australia) with a linear array transducer (5-10 MHz) was used for this study, with average setting values of 7 dB for gain, 57 dB for dynamic range, and single focus. The use of this machine allowed real-time visualization of the dilation of a lactiferous duct at milk ejection.[5] Duct diameter was continuously monitored in all sessions and recorded to video for subsequent quantitation. Measurements of duct diameter were made at intervals of < 10 s. From the increase in diameter, the increase in cross-sectional area of a duct was calculated, assuming the cross-section of the duct to be circular.

Breast Pump

An experimental electric breast pump (B2000, Medela AG, Baar, Switzerland) equipped with standard breast shield and bottle was used. The pump was computer driven and was able to produce 7 stimulation patterns (A-G) with frequencies of 45 to 125 cycles/min and adjustable vacuums (0%-100%) ranging from –45 to –273 mm Hg (Table 1). Pattern A was similar to the pattern used by the Medela Classic electric breast pump and had a frequency slightly lower than the frequency infants use during breastfeeding after milk ejection while milk is flowing.[2] Pattern B was similar to the initial sucking frequency observed by Drewett and Woolridge,[2] whereas patterns D to F were similar to the initial nonnutritive suckling frequencies observed by Woolridge.[3] In addition, Luther et al[6] observed breastfeeding sucking frequencies of 53 to 122 sucks/min. Pattern G was the same as pattern C, except it paused at 0 mm Hg for 1 second after each 3 s of pumping to mimic the pauses of some infants. The duration of pumping and the vacuums used at each session were recorded.

Table 1. Characteristics of the Stimulation Patterns*

	A	*B*	*C*	*D*	*E*	*F*	*G*
Frequency (cycles/min)	45	76	105	110	125	125	105
Vacuum setting (mm Hg)							
0%	–136	–87	–85	–57	–45	–80	–85
24%	–174	–128	–112	–84	–67	–104	–112
50%	–204	–152	–132	–99	–80	–120	–132
100%	–273	–239	–188	–166	–138	–166	–188

*The vacuums were recorded at the nadir of each cycle using a closed system.

Protocol

Prestudy Protocol

Before the first study day, mothers were asked to measure milk production from each breast for a period of 24 hours plus 1 breastfeed by test-weighing their infants before and after each breastfeed from each breast[7] on a Medela electronic BabyWeigh™ Scale. In addition, milk samples (≤ 1 mL) were collected from each breast by hand expression into 5-mL polypropylene plastic vials (Disposable Products, Adelaide, Australia) immediately before and after each breastfeed from each breast. Samples were frozen as soon as possible and kept at –15°C for analysis.

Milk samples were warmed to 37°C and gently mixed, and subsamples were taken up into microhematocrit tubes (Chase Scientific Glass, Inc, Rockwood, Tenn, USA) and centrifuged at 15,700 g for 6 min (Mikro 12-24, Hettich centrifuge, HD Scientific, Blacktown, Australia). The creamatocrit was calculated as the length of the column of cream in the tube divided by the total length of the column of milk.[8] The measured creamatocrit provided an estimate of the fat content of each sample.[8] Daly et al[9] described the equation relating the fat content of the milk to the degree of emptying of the breast. The degree of fullness is calculated as 1 – Degree of Emptying. Thus, the creamatocrit was used to determine the degree of fullness of the breast at the particular time the sample was collected.[9,10] From these data, it was determined when the breast was full and when it was most drained of milk over the course of the day. The storage capacity (the amount of milk available to the infant when the breast is full) was determined using a regression line relating change in the degree of fullness at each feed to the amount of milk removed from the breast at that feed. Assuming that a change in the degree of fullness of zero corresponded to a feed amount of zero, the regression line was forced to pass through the origin. Storage capacity could then be calculated as the amount of milk corresponding to a change in the degree of fullness of 1.

The mothers attended the Breast Feeding Centre at King Edward Memorial Hospital for Women on 3 occasions commencing between 9 AM and 1 PM. During the first visit, the lactiferous ducts were located using ultrasound, and 1 duct close to the nipple on the lateral part of the right breast was chosen to be monitored during all subsequent sessions. At the beginning of each session, the transducer was positioned similarly on the breast and the duct relocated by its unique topography. Measurements were made perpendicular to the long axis of the duct. This duct was monitored (1) during a 5-minute period to establish variations in duct diameter while the breasts were not being stimulated, (2) while the infant was breastfeeding from the left breast, and (3) while the left breast was being pumped using pattern A. In addition, if the infant was fed from the right breast, a duct on the left breast was monitored. This visit also allowed the mothers to become familiar with the investigators, the experimental room, and the research pump.

Study Protocol

During the second and third visits to the Breast Feeding Centre, the 7 different stimulation patterns of the breast pump were tested in a predetermined random order such that each pattern was tested in each position an equal number of times. During each session, there were no other psychological stimuli for milk ejection (eg, baby pictures) in the room, the mothers' infants were cared for in another room, the sound of the ultrasound machine provided white noise, the mothers were instructed to concentrate on the sensations within their breasts during pumping, and apart from adjusting the vacuum to the comfort of the mother, the investigators remained silent.

Small milk samples (≤ 1 mL) were collected by manual expression into 5-mL polypropylene tubes from each breast on arrival at the center, the creamatocrit was measured, and the degree of fullness of the breasts was calculated. We aimed to commence the first stimulation when both breasts had a degree of fullness of at least 0.3. The mother applied the breast shield to the left breast, the ultrasound transducer was positioned over the lactiferous duct previously selected in the right breast, and pumping commenced. The vacuum was initially set to 24% of maximum and adjusted as soon as possible to the mother's comfort. Pumping continued until 60 s after milk ejection was visually detected by ultrasound, or for 240 s if milk ejection did not occur. The amount of milk removed was measured by reweighing the tared collection bottle and a subsample collected for the measurement of creamatocrit and the calculation of the average degree of fullness of the left breast during that expression. The time of milk ejection was defined as the time at which the duct dilated beyond 3 standard deviations (determined from the 5-minute period without stimulation) of the mean baseline diameter. Because the quantitation of the duct diameter was done retrospectively from videotape recordings, there was occasionally a discrepancy between the visual and quantitative detection of the time of milk ejection. Quantitative data were used for all analyses. If milk ejection did not occur, a time of 240 s was recorded. The data for the amount of milk removed during pumping were used only when the actual collection period was between 50 and 70 s after milk ejection (determined quantitatively).

The mother also gave a qualitative evaluation of each pattern by rating the frequency and strength on a scale of 1 (slow, soft) to 10 (fast, strong) and rating on a scale of 1 (dislike) to 5 (like) her approval of the frequency and strength of each pattern. She was also asked to comment on how the pattern compared to her infant when it first latched on to the breast and on the milk ejection (if any) that she experienced. The mother was then allowed to rest for 20 min before the testing of the next stimulation pattern. We aimed to test 4 patterns on the first day and 3 on the second. The selected duct was monitored for a 5-min period between 2 stimulations on each day and during a breastfeed after the last stimulation if possible. A small milk sample (≤ 1 mL) was collected by manual expression into a 5-mL polypropylene tube from the right breast after each test, the creamatocrit was measured, and the degree of fullness of the breast was calculated.

Statistical Analysis

The primary goal of the analysis was to examine the effects of different breast pump stimulation patterns on the milk ejection reflex. Several performance measures were considered, with the primary performance indicator measured being time for milk ejection. Other evaluations of stimulation patterns included (1) analysis of the absence or presence of milk ejection, (2) the total amount of milk removed over 50 to 70 s after milk ejection, (3) the mother's perception of the strengths and speeds of stimulation patterns compared to the actual strengths and speeds, and (4) comparisons of strength and speed with the infant's sucking. Supplementary analyses were also performed to assess factors influencing increases in the duct's cross-sectional area during the milk ejection. A number of potential covariates were considered in all analyses, including estimated breast storage capacity, degree of fullness of the breast, feeding an infant immediately before the test, time since the last stimulation, and mean vacuum chosen by the mother for each stimulation pattern.

Repeated-measures analyses of the time for milk ejection and the amount of milk removed for the stimulation patterns and modeling of the duct diameter were implemented using PROC MIXED.[11] Repeated-measures analysis of variance (ANOVA) of vacuum setting and mean vacuum was carried out using SuperANOVA.[12] Evaluations of mothers' ratings and perceptions of the stimulation patterns as well as the comparisons of the stimulation patterns with the infants' sucking action were conducted using Friedman's ANOVA.[13]

Two-sided *P* values are quoted, and a *P* value < .05 is regarded as statistically significant. Multiple contrasts in the repeated-measures analyses were performed at the overall significance level of .05.

Results

Maternal Breastfeeding Characteristics

Twenty-eight mothers (22 to 38 years old, parity 1 to 4) participated. Three of the mothers had no previous experience of breast pumps, whereas some expressed regularly. The pumps used by the mothers before the study were AmedaEgnell Purely Yours, Avent ISIS, Boots, Cannon Babysafe, Kaneson, Medela (electric, minielectric, or manual), Pigeon, and Tommee Tippee. Some mothers were not able to express significant volumes of milk with these pumps, whereas others could express up to 200 mL per breast per expression.

The total 24-hour milk production of the mothers ranged from 372 to 1101 g, and the 24-hour milk production of the left breast ranged from 196 to 566 g. The storage capacities of the left and right breasts were 169 mL (SD = 50) and 173 mL (SD = 54), respectively. Tests were commenced between 16 and 225 min after the last stimulation of either breast by breast pump or breastfeed. The mean degree of fullness before each test for the left breast was 0.51 (SD = 0.22; range, 0.04-1.00) and for the right breast 0.46 (SD = 0.23; range, 0.01-0.98).

Milk Ejection

When the infants were put to the breast, milk ejection occurred with the exception of 1 occasion. During pumping, milk ejection occurred in response to all patterns for 14 mothers. For the remaining mothers, milk ejection occurred in response to between 1 and 6 patterns (Table 2). Neither parity nor previous experience with breast pumps affected the occurrence or timing of milk ejection. Three mothers never sensed milk ejection, and overall, 21% of milk ejections detected by ultrasound were not sensed by the mothers. When mothers did sense milk ejection, the generalized sensation coincided with the dilation of the duct monitored by ultrasound.

The time taken for each pattern to elicit milk ejection as detected by ultrasound, the vacuum settings chosen, and the resulting vacuums are presented in Table 2. The time for milk ejection to occur in response to breastfeeding was faster than for all stimulation patterns of the pump (all *P* < .0001). Further comparisons were made only between the different stimulation patterns. The time for milk ejection was affected by the time since last stimulation of either breast (*P* < .001), with a longer time since last stimulation being associated with a shorter time for milk ejection. The degree of fullness of the left breast also had a significant effect (*P* = .002), whereas the degree of fullness of the right breast had only a marginal effect (*P* = .059). After adjusting for the time since last stimulation and degree of fullness of the left breast, the time for milk ejection was not related to the stimulation pattern used (*P* = .630) or the applied vacuum (*P* = .795). Although statistical significance was not reached, after adjusting for the time since last stimulation and degree of fullness, patterns C, G, and D

Table 2. Time for Milk Ejection, Vacuums Chosen, and Amount of Milk Removed for Each Stimulation Pattern*

	A	*B*	*C*	*D*	*E*	*F*	*G*	*BF***
Time for milk ejection† (s)	149 ± 12[a]	129 ± 12[a]	120 ± 13[a]	123 ± 9[a]	125 ± 10[a]	129 ± 9[a]	121 ± 11[a]	56 ± 4[b]
Number of mothers‡	21	22	23	25	25	23	23	58
Vacuum setting (%)	25.8 ± 4.6[a]	35.3 ± 3.8[b]	42.6 ± 4.6[b,d]	56.1 ± 4.0[c]	56.8 ± 4.2[c]	54.4 ± 4.4[c]	46.9 ± 3.5[c,d]	
Vacuum (mm Hg)								
Initial	–148	–96	–83	–56	–41	–76	–83	
Mean	–139 ± 8[a]	–113 ± 6[b]	–99 ± 6[c]	–87 ± 4[d]	–70 ± 6[e]	–99 ± 4[c]	–105 ± 4[b,c]	
Milk removed (g)	24.0 ± 4.7[a]	15.3 ± 2.3[a]	14.6 ± 3.0[a]	13.8 ± 2.8[a]	9.9 ± 1.8[a]	15.2 ± 2.2[a]	8.7 ± 1.4[a]	

*Values are presented as $\bar{x}$ ± SEM. Values in the same row with the same superscripts are not significantly different (univariate analysis).
**BF = breastfeed.
†Adjusted for time since last stimulation and degree of fullness of the left breast.
‡Number of mothers who experienced milk ejection within 240 s for the stimulation patterns, or the number of breastfeeds.

had the shortest times for milk ejection, with estimated means of 120, 121, and 123 s, respectively. Similar results were obtained considering only the data when milk ejection occurred within 240 s.

Milk Removal

Because milk ejection was one of the responses on which this study was focused, we did not want to disturb the mothers by changing collection bottles during the application of the stimulation patterns. Therefore, we only have estimates of the amount of milk removed before milk ejection occurred. This ranged from 0 to 37.5 g, with a mean of 2.7 g, and is comparable to the quantitative data of Mitoulas et al[14] (6.5 g), who used a stimulation pattern similar to C.

The amount of milk that was removed from the breast by the pump up to 50 to 70 s after milk ejection (detected by ultrasound) ranged from 0.1 to 69.5 g and is shown in Table 2. The total time of milk collection ranged from 96 to 249 s and was not significantly different between the patterns. Univariate analysis indicated that there was no significant difference between the patterns in the amount of milk removed (P = .118). However, the mean vacuum chosen by the mother significantly influenced the amount of milk removed over 50 to 70 s (P < .001), with a stronger vacuum chosen associated with a higher volume of milk removed. After adjustment for the mean vacuum chosen, there was a significant association between stimulation patterns and the amount of milk removed over 50 to 70 s (P = .016), with significant differences between patterns E and G (P = .004) and D and G (P = .009). The estimated mean differences were 8.35 mL (95% confidence interval [CI], 4.13-12.57) and 7.12 mL (95% CI, 1.95-12.30) for differences between patterns D and G and between patterns E and G, respectively. There was no relationship between either the initial duct diameter or the increase in cross-sectional area of the duct measured and the amount of milk removed.

Changes in Lactiferous Ducts

The mean diameter of the lactiferous ducts before each stimulation test was 2.83 mm (SD = 0.99; range, 1.1-5.9 mm). During the 5-minute periods without stimulation, there was little variation in duct diameter ($\bar{x}$ ± SD of coefficient of variation was 3.74 ± 1.73%). In response to stimulation by the pump, the increase in cross-sectional area of the duct when milk ejection occurred was 6.15 ± 0.52 mm^2 ($\bar{x}$ ± SEM; n = 163; range, 0.9-50.6 mm^2). There was no difference between the 7 different patterns (P = .158). The increase in cross-sectional area of the duct in response to breastfeeding was 6.45 ± 0.98 mm^2 ($\bar{x}$ ± SEM) for 58 breastfeeds, which was not different from the response to stimulation by the pump (P = .945). No significant predictors of change in the cross-sectional area were found.

Mothers' Perceptions

The mothers' perceptions of the frequencies and strengths of the patterns are presented in Figure 1. There were highly significant differences between the stimulation patterns (P < .001) in the mothers' ratings of the frequencies and strengths of the patterns. Pairwise comparisons of frequency ratings indicated that pattern A was judged to be different from all other patterns (all P < .001), pattern E was judged to be faster than patterns B (P < 0.001) and G (P < .001), and pattern F was different from pattern G (P < .001). Pairwise comparisons of strength ratings indicated that pattern A was judged to be stronger than pattern E (P < .001), and there was a significant difference between patterns A and G (P < .003) (Figure 1).

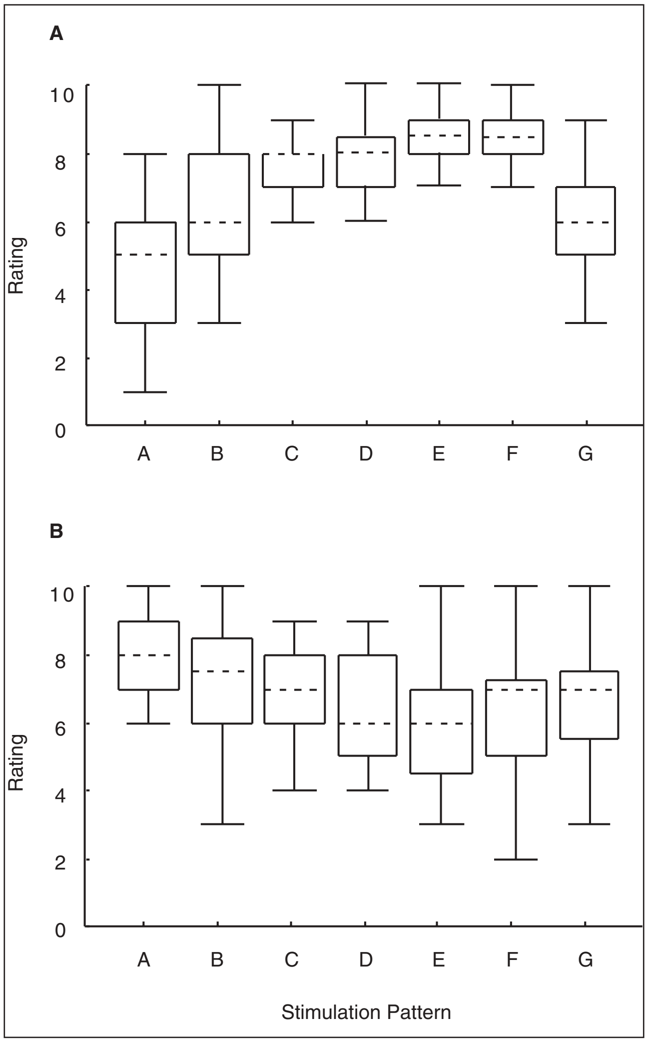

Figure 1. Mothers' ratings of the frequencies (A) and strengths (B) of the stimulation patterns on a scale of 1 (slow, soft) to 10 (fast, strong). Bars indicate the range of responses, boxes indicate the first and third quartiles, and the dashed line indicates the median.

There were differences between the perceptions of the frequencies and strengths of the stimulation patterns compared to the mothers' own infants (Table 3) (Friedman's ANOVA, $P < .001$, $P < .001$, respectively). Pattern C was most often judged to be similar in frequency and strength to an infant, whereas pattern A was most often judged to be slower and stronger.

There was no significant difference in the approval ratings of the stimulation patterns according to their frequencies ($P = .544$) or strengths ($P = .289$), with all patterns having a median approval rating of 4 out of 5 for both frequency and strength.

The mothers' descriptions of the strength of the sensation of milk ejection compared to that elicited by breastfeeding ranged from weak (1) to very strong (5). However, there was no relationship between the perceived strength of the milk ejection and the stimulation pattern or the vacuum used. Nor was there any relationship between the perceived strength of milk ejection and the degree of fullness of either breast, the dilation of the lactiferous ducts, or the amount of milk removed.

Table 3. Comparison of the Perceived Frequency and Strength of Each Pattern With the Infant's Frequency and Strength (% of responses)

	Frequency			*Strength*		
Pattern	*Slower*	*Similar*	*Faster*	*Softer*	*Similar*	*Stronger*
A	92	8	0	15	40	45
B	43	48	9	17	57	26
C	24	56	20	32	64	4
D	8	46	46	39	52	9
E	7	37	56	50	41	9
F	12	50	38	38	50	12
G	52	43	4	29	59	12

Discussion

Maternal Breastfeeding Characteristics

All the mothers were fully breastfeeding their infants when they commenced their participation in the study, although some mothers had experienced difficulties at the start of their lactation. The mother who had the lowest milk production (372 g/d) was taking a full-strength oral contraceptive pill, which has been associated with reduced milk production.[15] The infant of the mother with the next lowest milk production (398 g/d) was under the care of a pediatrician for low weight gain. The milk production of the remaining mothers ranged from 535 to 1101 g/d, consistent with normal milk production, as discussed by Kent et al.[16]

Response to Stimulation Patterns

We have shown that the stimulation patterns applied by the electric breast pump in this study elicited an increase in the cross-sectional area of the lactiferous ducts that was similar to the response during breastfeeding. Other workers have also found that the response of the breast is independent of the mechanism of stimulation. Zinaman et al[17] demonstrated a physiologic response in oxytocin concentration to stimulation by an electric, battery-operated, or manually operated breast pump. Moreover, Sandholm[18] observed a physiologic increase in intramammary pressure both in response to artificial stimulation of the nipple and after intranasal administration of oxytocin.

Although some of the stimulation patterns mimicked the physical characteristics (frequency and strength of sucking) of an infant when it first latches on to the breast, the faster time taken for milk ejection to occur when breastfeeding compared to pumping is consistent with the fact that milk ejection is, at least in part, a conditioned response.[1] This conditioning could also reduce the time taken for milk ejection to occur in response to a breast pump when the mother expresses her breasts routinely. The only stimulation pattern to which the mothers would have had the opportunity to become conditioned was A, because those mothers who had previously used electric pumps would have experienced patterns similar to A, and all mothers experienced pumping with A on their first visit to the Breast Feeding Centre. Therefore, the testing of the other stimulation patterns is rigorous because there was no opportunity for the mothers to become accustomed to these patterns.

The frequency of pattern A was least similar to that of nonnutritive sucking at the beginning of a breastfeed[3] and was perceived as such by the mothers. Although all mothers had experienced pattern A at least once before, 7 of the mothers had no milk ejection after 240 s of pumping with A, and the time for the milk ejection reflex in response to A was longest. The frequencies of patterns C, D, E, and F were within the range reported for nonnutritive sucking at the beginning of a breastfeed.[3] Mothers were more sensitive to the differences in frequency of the patterns than the significant differences in strength (Figure 1 and "Results"). The higher frequency, lower strength patterns were as good as, if not better than, pattern A in facilitating milk ejection. Although some infants pause at variable intervals in their stimulation of the breast, the response to pattern G indicates that a regular pause in the pump pattern gave no added advantage. Moreover, the perception of some mothers that an increase in the applied vacuum would "get the milk ejection reflex going" was not supported by the data (Table 2).

Because the mothers were able to have the vacuum adjusted to their comfort, it is interesting that there were significant differences between the patterns both in the vacuum chosen (Table 2) and in the perception of the strength of the applied vacuum. The lower the initial vacuum of the pattern, the higher the final setting (percentage of maximum) chosen, but the same vacuum was not achieved. The perception of the strength of vacuum may be related to the frequency of the pattern because the stronger vacuums were used with the slower patterns A and B.

Milk Removal

Because the lactiferous ducts remain dilated for 86 s (SD = 51) after the commencement of duct dilation during milk ejections that occur during breastfeeding (D. Ramsay, personal communication, 2002), the breast pump should be able to remove milk from the breast without restriction for up to at least 70 s. Pumping with pattern A resulted in the highest amount of milk (24.0 g, SD = 17.5) removed from the breast up to 50 to 70 s after milk ejection. This is comparable with the breastfeeding data of Ramsay et al,[5] who found that the average milk yield for each milk ejection was 35 g, resulting in a calculated flow rate of 24.4 g/min.

The amount of milk removed from the breast could depend on the degree of dilation of the ducts and/or the vacuum applied to the breast. However, there was no relationship between the initial diameter or the degree of dilation of the ducts measured and the amount of milk removed. This is similar to the findings of Ramsay et al (personal communication), who found that during breastfeeding, there was no relationship between the increase in cross-sectional area of the ducts and the amount of milk taken by the infant from the other breast. Assuming that the duct that was monitored is representative of the ducts in the breast being milked, this suggests that the dilation of the ducts plays a permissive rather than a controlling role in the rate of milk transfer.

The current findings of a relationship between the applied vacuum and the milk yield are apparently in contrast with those of Mitoulas et al,[14] who found no relationship between applied vacuum and total milk yield up to 5 min after milk ejection in a study on different expression patterns of a Medela electric breast pump. In addition, Prieto et al[19] measured peak intraoral pressures in different infants of –60 to –170 mm Hg, but there was no obvious relationship between the degree of suction applied by the infant and the total amount of milk the infant received during the breastfeed. However, further analysis of the data of Mitoulas et al[14] reveals a relationship between the applied vacuum and the amount of milk removed by a pattern similar to C before milk ejection (R^2 = 0.137, P = .0001, N = 174). These data suggest that in the short term, strength of suction is a more important variable than magnitude of duct dilation in the determination of milk flow. In addition, the lower milk yield of pattern G demonstrates that the pause at zero vacuum results in milk not being removed while it is available. Ramsay et al[5] found that milk intake during a breastfeed was related to the number of milk ejections experienced by the mother rather than the time spent at the breast. Combined with the current findings, we suggest that each milk ejection makes a certain amount of milk available, and the applied vacuum affects how fast this amount is removed.

Conclusions

Although all of the stimulation patterns of the breast pump took longer than an infant to elicit a milk ejection, a frequency of 105 to 125 cycles/min was at least as effective as one of 45 cycles/min. The strength of the applied vacuum had no effect on the time taken to elicit milk ejection, but a stronger vacuum resulted in a higher yield of milk during the first minute after milk ejection. Using ultrasound, we have demonstrated that lactiferous ducts of the breast respond similarly to stimulation patterns applied by an electric breast pump as to the stimulation when an infant first latches on to the breast. Monitoring the ducts in the breast that is being milked will be required to confirm if the degree of dilation of the lactiferous ducts plays a permissive rather than a controlling role in the initial yield of milk.

References

1. Hartmann PE. The breast and breastfeeding. In: Philipp E, Setchell M, Ginsburg JG, eds. *Scientific Foundations of Obstetrics and Gynaecology.* 4th ed. London, UK: Heinemann; 1991;378-390.
2. Drewett RF, Woolridge M. Sucking patterns of human babies on the breast. *Early Hum Dev.* 1979;3:315-320.
3. Woolridge MW. The “anatomy” of infant sucking. *Midwifery.* 1986;2:164-171.
4. Fewtrell MS, Lucas PSC, Singhal A, Ahluwalia JS, Lucas A. Randomized trial comparing the efficacy of a novel manual breast pump with a standard electric breast pump in mothers who delivered preterm infants. *Pediatrics*. 2001;107:1291-1297.
5. Ramsay DT, Kent JC, Owens RA, Hartmann PE. Ultrasound imaging of milk ejection in the human lactating breast. *Society for Reproductive Biology, Proceedings of the Thirty Second Annual Conference, Gold Coast, QLD, September 2001*, abstract 30.
6. Luther EC, Arballo JC, Sala NL, Cordero Funes JC. Suckling pressure in humans: relationship to oxytocin-reproducing reflex milk ejection. *J Appl Physiol*. 1974;36:350-353.
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. Lucas A, Gibbs JH, Lyster RLJ, Baum JD. Creamatocrit: a simple technique for estimating fat concentration and energy value in human milk. *Br Med J*. 1978;1:1018-1019.
9. 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.
10. Cox DB, Owens RA, Hartmann PE. Blood and milk prolactin and the rate of milk synthesis in women. *Exp Physiol*. 1996;81:1007-1020.
11. *SAS/STAT User's Guide*. Version 8. Cary, NC: SAS Institute Inc; 2000.
12. SuperANOVA. Berkeley, Calif: Abacus Concepts, Inc; 1987.
13. Siegel S, Castellan NJ Jr. *Nonparametric Statistics for Behavioural Sciences*. 2nd ed. New York, NY: McGraw-Hill; 1988.
14. Mitoulas LR, Lai CT, Gurrin L, Larsson M, Hartmann PE. Effect of vacuum profile on breastmilk expression using an electric breastpump. *J Hum Lact*. 2002;18:353-360.
15. Tankeyoon M, Dusitsin N, Chalapati S, et al. Effects of hormonal contraceptives on milk volume and infant growth. WHO Special Programme of Research, Development and Research Training in Human Reproduction Task Force on Oral Contraceptives. *Contraception*. 1984;30:505-522.
16. Kent JC, Mitoulas LR, Cox DB, Owens RA, Hartmann PE. Breast volume and milk production during extended lactation in women. *Exp Physiol*. 1999;84:435-447.
17. Zinaman MJ, Hughes V, Queenan JT, Labbock M, 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.
18. Sandholm L-E. The value of the electric breast pump in studies of the milk ejection reflex. *J Obstet Gynaec Br Commonwealth*. 1967;74:929-932.
19. Prieto CR, Cardenas H, Salvatierra AM, Boza C, Montes CG, Croxatto HB. Sucking pressure and its relationship to milk transfer during breastfeeding in humans. *J Reprod Fertil*. 1996;108:69-74.

Resumen

La respuesta de los pechos a diferentes patrones de estimulación de una extractora eléctrica

Se evaluó el efecto de la eyección de la leche programando una extractora eléctrica con patrones de succión con frecuencias entre 45 a 125 ciclos por minuto y vacío de –45 a –273 mm Hg. El tiempo que tomo para la eyección ocurrió (medido por ultrasonido para detectar la dilatación de los conductos lactíferos en el pecho opuesto) como respuesta a la extractora eléctrica Medela (45 ciclos por minuto) que fue 147 ± 13 segundos. Los patrones que se asemejan a la frecuencia de succión del niño cuando se agarra al pecho, la eyección ocurre entre 136 ± 12 segundos y 104 ± 10 segundos, aun así la diferencia no fue estadísticamente significativa. La eyección de leche en respuesta al amamantamiento ocurre después de 56 ± 4 segundos. El vacío afectó la cantidad de leche que se removió hasta los 50 a 70 segundos después de la eyección de leche, pero no el tiempo de la eyección de leche.