

Importance of Vacuum for Breastmilk Expression

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ABSTRACT

Objective: To determine the effect of the strength of applied vacuum on the flow rate and yield of breastmilk using an electric breast pump.

Study Design: Twenty-one breastfeeding mothers and two expressing mothers expressed their breastmilk for 15 minutes using an electric breast pump set at their own maximum comfortable vacuum, and at one to three softer vacuums. Milk yield and flow rate were measured.

Results: At the maximum comfortable vacuum (-190.7 ± 8.8 mm Hg) 4.3 ± 0.4 milk ejections occurred during 15 minutes of expression and yielded 118.5 ± 11.4 mL of milk ($65.5 \pm 4.1\%$ of the available milk). Softer vacuums yielded less milk volume ($p < 0.05$) and less of the available milk ($p < 0.01$). Milk flow rate was greater during the first milk ejection than the third or subsequent milk ejections ($p < 0.001$). Cream content of the milk was highest after expressing for 15 minutes using the mother's maximum comfortable vacuum.

Conclusions: Use of the mother's maximum comfortable vacuum enhances milk flow rate and milk yield. The cream content of the milk at the end of the expression period was an indicator of how effectively the breast had been drained.

INTRODUCTION

BREASTMILK IS THE OPTIMAL NUTRITION for babies. However, because of prematurity, illness, attachment difficulties, or separation, babies are not always able to breastfeed. UNICEF states that the best food for a baby who cannot breastfeed is milk expressed from the mother's breast.¹ Therefore, it is important for many mothers to express their breastmilk. In Western Australia the proportion of mothers of full-term infants who express breastmilk has doubled in the past decade.² Breastmilk expression

can be done by hand, or with manual or electric breast pumps, but the proportion of mothers using electric pumps has increased three-fold to nearly 20% in the past decade.² Therefore, mothers and health professionals require evidence-based advice to optimize the use of electric breast pumps. Simultaneous expression of both breasts can save time and has been shown to yield more milk than sequential expression, although the percentage of available milk expressed was not assessed.³ Recent research on electric breast pumps has focused on evaluating vacuum patterns to stimulate

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milk ejection, and the efficacy of expression patterns,^{4,5} but the strength of the applied vacuum was not controlled during these studies. There is evidence in cows that the strength of vacuum has an effect on milk flow rate and the time spent milking.⁶ However, the optimal vacuum for milk expression for lactating women has not been investigated.

The aim of this study was to determine the effect of the strength of vacuum on the total yield and rate of flow of milk from the breast, and provide evidence for health professionals advising mothers who are expressing breastmilk for their babies.

MATERIALS AND METHODS

Twenty-three lactating mothers provided written informed consent to participate in the study, which was approved by the Human Research Ethics Committee at The University of Western Australia and the Human Ethics Committee of King Edward Memorial Hospital for Women (Subiaco, WA, Australia). Nineteen of the mothers were exclusively breastfeeding babies less than 6 months old, and two were partially breastfeeding babies aged 7 and 8 months. Two mothers were expressing breastmilk to satisfy all the needs of their babies. One of these mothers was expressing for her 20-week-old full-term baby, and the other mother was expressing for her 6-week-old baby who was born at 24 weeks of gestation. The studies were carried out in the mothers' homes and at the Breast Feeding Centre at King Edward Memorial Hospital for Women.

The 21 breastfeeding mothers measured their 24-hour milk production in their own homes by test-weighing their babies on a Medela Electronic Baby Weigh Scale (Medela AG, Baar, Switzerland) before and after each breastfeeding from each breast for a period of 24 hours plus one breastfeeding. The two mothers who were expressing all their breastmilk for their babies weighed the collection bottle on a balance before and after every expression from each breast for a period of 24 hours plus one expression. The corrected 24-hour milk production was calculated by the method of Arthur et al.⁷; however, no correction for in-

fant-insensible water loss was made, and therefore milk production may be underestimated by $10 \pm 12\%$ (mean $\pm$ SD). During this period, the mothers hand-expressed small milk samples (<1 mL) into 5-mL polypropylene plastic vials (Disposable Products, Adelaide, SA, Australia), immediately before and after each breastfeeding or expression from each breast. Samples were frozen as soon as possible and kept at -15°C until analyzed. The cream content of all these samples was measured by the creamatocrit method.⁸ Because there is a relationship between the cream content of the milk and the degree of fullness of the breast,⁹ measuring the cream content of the samples allows the calculation of the change in degree of fullness of the breast from before to after each breastfeeding. These changes, combined with the volumes of the breastfeedings, are used to calculate the breastfeeding storage capacity of the breast for milk.⁴ For example, if a change in degree of fullness of 0.5 occurred when 50 mL of milk was removed from the breast, the breastfeeding storage capacity would be calculated to be 100 mL. In addition, small milk samples were similarly collected before and after each experimental expression session at the Breast Feeding Centre. The cream contents of these milk samples and the volumes of the expressions, in combination with the data used to calculate the breastfeeding storage capacity, were used to calculate the potential storage capacity of the breasts of each mother¹⁰ (Fig. 1). The initial degree of fullness of the breast for each expression was calculated from the cream content of the milk collected before the expression,¹¹ and the volume of available milk in the breast was calculated as the initial degree of fullness of the breast multiplied by the potential storage capacity of the breast.

During the first visit to the Breast Feeding Centre, the maximum comfortable vacuum was determined for the left breast of each mother. An experimental electric breast pump (B2000, Medela AG) equipped with standard breastshield and bottle was used. The pump was computer-driven, and the stimulation pattern (125 cycles per minute) and the expression pattern (54–78 cycles per minute) were similar to those used by the Medela Symphony breast pump. The vacuums were adjustable (0–100%),

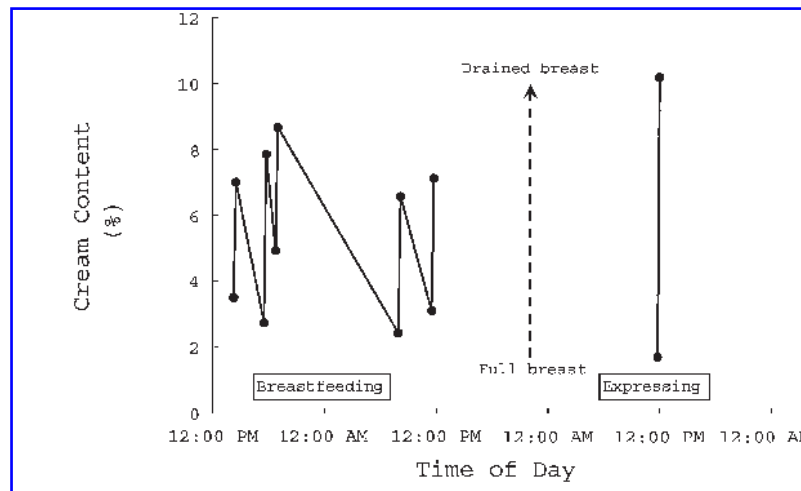


FIG. 1. Example of data used to calculate breastfeeding and potential storage capacity of the breast. Small milk samples were collected before and after each breastfeeding during a 24-hour period of breastfeeding, and before and after one expression session after a prolonged interval without removal of milk from the breast. These breastfeeding data and volumes of breastfeedings were used for calculation of breastfeeding storage capacity. Calculation of potential storage capacity included cream and volume data for both breastfeeding and expressing.

and the vacuum measured at the breast when the pump was set at 100% was -270 mm Hg. The breastshield was applied to the left breast, the pump was turned on using the stimulation pattern, and the vacuum was adjusted to the comfort of the mother. A milk duct in the right breast was monitored using ultrasound with a linear array transducer (5–10 MHz) (Acuson XP10; Siemens, Mountain View, CA) until milk ejection was detected as described by Ramsay et al.¹² All ultrasound scans were videotaped for later analysis. Parker (Fairfield, NJ) Ultrasonic Gel was used for the scans.

After milk ejection was detected, the pump pattern was changed to the expression pattern, and the vacuum rapidly decreased to 24% of maximum vacuum. The vacuum was then increased over the following 30 seconds until the mother started to feel uncomfortable. The vacuum was then decreased by 10 mm Hg, and this vacuum recorded as the maximum comfortable vacuum for that mother. For subsequent visits, this vacuum was used as the 100% vacuum for the individual mother (vacuum A). Expression at 75% of this vacuum was also tested (vacuum B), and the order of testing vacuums A and B was randomized. When vacuum A was stronger than -173 mm Hg (i.e., vacuum B was stronger than -130 mm Hg), expression at -125 mm Hg (vacuum C) and at -75 mm Hg (vacuum D) was also tested. When vacuum A was softer than -173 mm Hg but stronger than -125 mm Hg, testing at vacuum C was omitted. When vacuum A was softer than -125 mm Hg, testing at vacuums C and D were omitted.

An adapter with an 80-cm-long polyvinyl chloride tube was connected to the breastshield. The tube conveyed the milk to sample collection tubes placed on a balance (Scout Pro SP401, OHAUS Corp., Pinebrook, NJ) connected to a computer that recorded the cumulative weight of the milk collected every 5 seconds. During the entire expression period a milk duct in the right breast of the mother was monitored continuously using ultrasound to detect milk ejections.^{10,12}

The stimulation pattern was applied by the pump at a vacuum chosen by the mother until milk ejection was detected. The pump was then changed to the expression pattern, and the vacuum was adjusted to the vacuum being tested. Expression continued for 15 minutes after the first milk ejection was detected. The milk removed during application of the stimulation pattern was collected into the first collection tube. After milk ejection, the milk expressed was collected during 30-second intervals. The cream content of each fraction collected was measured.

Continuous data were summarized using means and their standard errors (SEM) or medians and interquartile ranges, as appropriate. Comparisons between the outcomes achieved for each vacuum were carried out using regression modeling with generalized estimating equations methods suitable for analysis of repeated measures (PROC MIXED), where vacuums were modeled as fixed factors and individuals were modeled as random factors. Transformations to achieve normality were used when required, and model assessments

were performed via analysis of regression residuals. SAS statistical software (SAS Institute Inc., Cary, NC) was used for data analysis. Values of $p < 0.05$ were considered statistically significant, and pairwise contrast testing was conducted at an overall significance level of 0.05.

RESULTS

The mothers (previously described¹⁰) were 33.1 ± 3.5 years old, feeding babies 16.4 ± 7.2 weeks old. During their normal breastfeeding or expressing the mothers were producing between 213 and 925 mL of milk per day from the left breast, and the mean amount of milk taken at a breastfeeding from the left breast was 75 ± 30 mL.

The longest interval between breastfeedings or expressions during the day the 24-hour milk production was measured was 8 hours 52 minutes $\pm$ 40 minutes for the left breast (range 3 hours 40 minutes to 15 hours 30 minutes). Before all test sessions, the mothers were asked to refrain from feeding from the left breast long enough for the breast to be more than half full. In some mothers who did not breastfeed or express from the left breast for an extended interval (up to 17 hours), the breast felt very full, and the fat content of the foremilk was lower than the lowest measurement on the day the 24-hour milk production was measured. Since there is an association between the fat content of the milk and the degree of fullness of the breast, this is an indication that the breast was filled to a greater degree compared to before any one breastfeeding on the day the 24-hour production was measured. In addition, at the end of some of the expression periods the breast was more drained than after breastfeeding, and the fat content of the milk was higher than the highest measurement on the day the 24-hour production was measured (Fig. 1). This is an indication that the breast was drained to a greater degree when compared to after any one breastfeeding on the day the 24-hour production was measured. Therefore, for those mothers who had an unusually low cream content of the breastmilk before expression and/or for whom breast expression left minimal re-

sidual milk with an unusually high cream content, an estimation could be made of the potential storage capacity of the breast. The potential storage capacity calculated for the left breast (243 ± 21 mL) was greater than the breastfeeding storage capacity (179 ± 13 mL) ($p < 0.001$). Just as the vital capacity of the lungs is the largest amount of air that can be exhaled after taking a deep breath, so the potential storage capacity of the breast is the amount of milk in a distended breast that is available for removal.

The maximum comfortable vacuum measured during expression was -190.7 ± 8.0 mm Hg (range -98 to -270 mm Hg). Therefore vacuum B was -143.0 ± 8.8 mm Hg (range -75 to -203 mm Hg). Eleven mothers tested vacuums A, B, C, and D, seven mothers tested vacuums A, B, and D, and five mothers tested only vacuums A and B.

No milk was expressed during the stimulation phase for 64 of the study sessions. For the other 11 study sessions the median amount of milk expressed before milk ejection was 2.7 mL (interquartile range 1.3–6.8; range 0.4–10.3 mL). There was no relationship between the volume expressed during stimulation and the stimulation vacuum applied ($p = 0.559$). The data for the expression sessions are shown in Table 1.

After 15 minutes of expression, within mothers there were differences between the vacuums in the total yield of milk, the time taken to express 50% and 80% of that volume, and the proportion of the available milk expressed (Table 1). The initial degree of fullness of the breast affected the total yield of milk ($p = 0.05$), but not the time taken to reach 50% or 80% of the total yield of milk or the proportion of available milk expressed. There were no significant differences between the four vacuums in the initial degree of fullness of the breasts, the stimulation vacuum chosen by the mothers, the time taken until the first milk ejection occurred, or the number of milk ejections that occurred during the 15-minute expression period.

When the vacuums tested were reclassified according to absolute vacuum applied (less than or equal to -200 mm Hg, -151 to -200 mm Hg, -101 to -150 mm Hg, greater than or equal to -100 mm Hg) there was a difference between the total yield of milk using the

TABLE 1. EXPRESSION OF MILK FROM THE LEFT BREAST

	<i>Vacuum (mm Hg)</i>			
	<i>A (190.7 ± 8.0)</i>	<i>B (143.0 ± 8.8)</i>	<i>C (-125)</i>	<i>D (-75)</i>
<i>n</i>	23	23	11	18
Initial cream content (%)	1.98 ± 0.27	2.71 ± 0.46	1.59 ± 0.31	2.05 ± 0.29
Initial degree of fullness	0.78 ± 0.04	0.72 ± 0.04	0.86 ± 0.03	0.81 ± 0.04
Potential storage capacity (mL)	249 ± 21	249 ± 21	242 ± 29	258 ± 25
Stimulation vacuum (mm Hg)	-80.9 ± 4.8	-84.3 ± 2.2	-89.3 ± 11.2	-88.5 ± 7.4
Time to first milk ejection (seconds)	91.6 ± 12.9	90.0 ± 14.0	86.7 ± 21.5	73.9 ± 9.9
Number of milk ejections	4.3 ± 0.4	4.8 ± 0.6	4.5 ± 0.5	4.4 ± 0.5
Total milk volume (mL)	118.5 ± 11.4	90.7 ± 9.4*	81.2 ± 11.2*	73.2 ± 11.0**
Time to 50% total (minutes)	3.6 ± 0.4	4.1 ± 0.5	4.9 ± 0.8**	11.0 ± 0.6**
Time to 80% total (minutes)	6.7 ± 0.6	7.6 ± 0.8	8.3 ± 1.1*	12.9 ± 0.6**
% available milk expressed	65.5 ± 4.1	55.3 ± 5.3	42.5 ± 5.7**	36.4 ± 4.1**

Data are mean ± SEM values.

Significantly different from vacuum A: * $p < 0.05$, ** $p < 0.01$.

strongest vacuum (less than or equal to -200 mm Hg) and all the other vacuums ($p = 0.03$, $p = 0.04$, and $p < 0.0001$, respectively). Using this classification, the initial degree of fullness also affected the total yield of milk ($p = 0.029$).

For the breastfeeding mothers, the ratio of the volume of breastmilk expressed during the study sessions to the average breastfeeding of the baby was calculated. When this ratio was <0.5, 0.5–1, or >1 the mothers have been classified as low-ratio, medium-ratio, or high-ratio mothers, respectively.⁵ When the 21 mothers who were breastfeeding expressed using vacuum A, one was a low-ratio, four were medium-ratio, and 16 were high-ratio mothers. Five of the high-ratio mothers changed to medium-ratio when they expressed using vacuum B.

The number of milk ejections that occurred during the 15-minute expression period, detected by ultrasound, was variable (range one to 12) with a mean of 4.3 and was independent of the vacuum applied. The duration of each milk ejection was 228 ± 10 seconds (range 100–8,005 seconds) and was independent of milk ejection number and vacuum. The amount of milk expressed from the first to the seventh milk ejection in the 15-minute expression period is shown in Table 2. The amount of milk expressed during each milk ejection related to applied vacuum ($p < 0.001$) was directly proportional to the degree of fullness ($p < 0.001$) and to the duration of milk ejection ($p < 0.001$) and was inversely proportional to the number

of milk ejections that had already occurred during the expression ($p < 0.001$). Pairwise comparisons of the amount of milk expressed during the consecutive milk ejections showed no difference between the volumes expressed during the first and second milk ejection ($p = 0.101$). Compared to the volume expressed during the first milk ejection, significantly lower volumes were expressed for successive milk ejections from the third milk ejection onwards (all $p < 0.001$) (Table 2).

The percentage of the total yield of milk during each milk ejection using different vacuums is shown in Figure 2. Using vacuum A, 45% of the total milk yield was expressed during the first milk ejection, with a further 31% during the second milk ejection, i.e., 76% of the milk that was expressed was removed during the first two milk ejections.

The cream content of the milk was initially $2.33 \pm 0.22\%$ and increased during expression. When expressing using vacuums A and B, the cream content of the milk had increased when 50% of the total yield had been expressed ($p = 0.002$ and $p = 0.001$, respectively); however, when expressing using vacuums C and D the cream content of the milk did not increase until 80% of the total yield had been expressed ($p = 0.001$ and $p = 0.010$, respectively). When expressing using vacuums A, B, and C, the cream content of the milk increased further from when 50% to when 80% of the total yield had been expressed ($p \leq 0.001$, $p = 0.004$, and $p = 0.050$, respectively). Only when using vac-

TABLE 2. MILK EXPRESSED DURING MILK EJECTIONS

	Milk expressed (mL) at milk ejection number						
	1	2	3	4	5	6	7
Vacuum A	53.5 ± 10.5 (23)	37.1 ± 6.1 (23)	15.8 ± 2.8 (19)*	13.4 ± 3.1 (14)*	6.9 ± 2.6 (11)*	6.8 ± 3.2 (7)*	2.4 ± 0.8 (4)*
Vacuum B	26.1 ± 4.1 (23)	30.0 ± 4.2 (23)	15.5 ± 3.0 (21)*	13.3 ± 2.4 (16)*	10.3 ± 2.9 (10)*	7.3 ± 2.5 (6)*	2.4 ± 0.6 (5)*
Vacuum C	22.1 ± 7.2 (11)	16.2 ± 2.7 (11)	10.8 ± 1.9 (10)*	20.1 ± 7.4 (9)*	17.5 ± 6.5 (6)*	4.4 ± 2.5 (2)	7.7 (1)
Vacuum D	31.3 ± 8.0 (18)	23.6 ± 8.4 (18)	9.7 ± 2.6 (11)*	8.2 ± 2.8 (11)*	7.4 ± 1.8 (11)*	6.5 ± 1.9 (5)*	5.6 ± 3.4 (3)*

Data are mean ± SEM values (numbers of observations).

*Significantly different from milk ejection 1, $p < 0.001$.

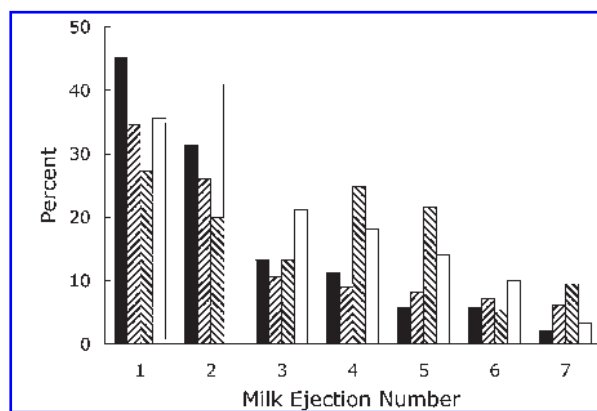


FIG. 2. Percentage of total milk yield expressed during each milk ejection using vacuum A (maximum comfortable vacuum, ■), vacuum B (75% of vacuum A, ▨), vacuum C (−125 mm Hg, ▩), or vacuum D (−75 mm Hg, □).

uum A was there a further change in the cream content from when 80% of the total yield had been expressed to the end of the expression period ($p = 0.005$). The cream at the end of the expression period using vacuum A was $9.48 \pm 0.74\%$, which was higher than at the end of the expression period using vacuums C ($6.64 \pm 1.38\%$) and D ($5.50 \pm 0.87\%$) ($p = 0.012$ and $p < 0.001$, respectively). The maximum cream contents of the hindmilk for individual mothers were 18%, 18%, 17%, and 12% for vacuums A, B, C, and D, respectively.

DISCUSSION

The milk production characteristics of the participating mothers were variable, but the milk production of all mothers of babies who were exclusively breastmilk-fed was within the normal range,¹³ and the mothers of the partially breastfed babies were producing more than 580 mL per day. The maximum comfortable vacuum chosen by the mothers was also variable. Half of the mothers were comfortable using a vacuum stronger than −200 mm Hg, but one mother could not tolerate a vacuum stronger than −98 mm Hg. Therefore, clinicians should advise mothers not to expect to use the maximum vacuum able to be applied by the breast pump and encourage them to determine their own maxima.

Expressing breastmilk for 15 minutes using

the mother's maximum comfortable vacuum yielded more milk, and more of the available milk, than using softer vacuums. In addition, the time taken to express 50% and 80% of the total milk yield was shorter using maximum comfortable vacuum than using vacuums of −125 mm Hg or −75 mm Hg. This is a consequence of high milk flow rates resulting in a high volume of milk being expressed (76% of the total) during the first two milk ejections. These occur on average within the first 8 minutes after the beginning of the initial milk ejection when the pump was changed from the stimulation pattern to the expression pattern.¹⁰

In this study use of the stimulation pattern resulted in a milk ejection after approximately 90 seconds, and little or no milk was expressed during the stimulation phase. Therefore, health professionals can advise mothers that they can maximize their milk yield and minimize their expression time by using the maximum comfortable vacuum of the expression pattern as soon as the milk ejection is detected, by either the mother's sensation or the observation of jets of milk from the openings of the ducts in the nipple. Mothers should also be aware that the initial degree of fullness of the breasts will affect the total yield of milk that will be expressed, but will have no effect on the time taken to express 50% or 80% of that volume.

After the first two milk ejections, as many as 10 more milk ejections were detected, but these subsequent milk ejections made only a minor contribution to the total yield of milk. If a mother is expressing to leave breastmilk with a temporary carer, expression using maximum comfortable vacuum for 8 minutes may be sufficient.

Comparing expressing using maximum comfortable vacuum to breastfeeding, 76% of the breastfeeding mothers were high-ratio, indicating that these mothers were able to effectively express milk from the breast. The reason for some mothers remaining in the medium-ratio or low-ratio categories is not clear. A positive association between milk flow rate and duct diameter in women has been previously demonstrated.¹⁰ Furthermore, comparative analysis with the dairy industry shows that the milk flow rate in cows is associated with both the teat canal length and vacuum.¹⁴ Therefore,

it is possible that the ductal characteristics of the breast contribute to the effectiveness of breast expression. This is an area that requires further investigation.

The cream content of the foremilk collected in this study was lower than that measured by Meier et al.¹⁵ in the milk of preterm mothers (mean 8.1%, SD 1.8%), perhaps reflecting a different composition of milk of preterm mothers, or suggesting a higher starting degree of fullness of the breasts in the current study. Significant increases in the cream content of the milk when 50% of the total yield of milk had been expressed using vacuums A and B reflect the higher yields of milk using these vacuums leading to larger changes in the degree of fullness of the breasts. The maximum cream contents of the hindmilk of individual mothers in the current study were similar to the 17.5% measured by Meier et al.¹⁵ However, the mean cream content of the milk collected at the end of the expression period in this study was lower than that measured by Meier et al.¹⁵ (mean 12.4%, SD 2.7%), but similar to the cream content of the hindmilk collected after breastfeedings of term infants (mean 9.3%, SD 2.4% [J.C.K., unpublished data]). Since the cream content of the milk is related to the degree of fullness of the breast, these results are consistent with breastfeeding babies taking 67.3% of the available milk during a breastfeeding¹³ and breast expression using the mother's maximum comfortable vacuum removing 65.5% of the available milk. The lower cream contents of the milk collected at the end of the expression period using vacuums C and D are consistent with less of the available milk being expressed using these vacuums. Therefore the cream content of the milk at the end of expression can be used as a gauge of the effectiveness of the breast pump in draining the breast.

CONCLUSION

When mothers are expressing breastmilk using an electric breast pump the yield of milk and the milk flow rate are maximized if they use their own maximum comfortable vacuum. Since most of the milk is removed during the first two milk ejections mothers should use their maxi-

mum comfortable vacuum of the expression pattern and as soon as milk ejection occurs take advantage of the high milk flow rate. A high cream content of milk at the end of expression indicates effective drainage of the breast.

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