

Milk Flow Rates Can Be Used to Identify and Investigate Milk Ejection in Women Expressing Breast Milk Using an Electric Breast Pump

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ABSTRACT

Currently there is no simple method available to assess milk ejection and breast milk flow in lactating women in both the clinical and research setting. The authors hypothesize that changes in milk flow rate are associated with milk ejection and therefore may provide a method suitable for the assessment of milk ejection and removal. Mothers ($n = 23$) expressed milk from one breast for a 15-minute period using both weak and strong vacuums on two to four separate occasions using an experimental electric breast pump (Medela AG, Baar, Switzerland). Breast milk flow rates were recorded at 5-second intervals by connecting a tube from the breast shield to a bottle placed on a balance that was connected to a computer. Milk ejection was determined by an acute increase in milk duct diameter in the contralateral breast using ultrasound (Acuson XP10, Siemens, Mountain View, CA), and the change in duct diameter was compared with milk flow rates. Milk flow rates ranged from 0 to 4.6 g per 5-second period. Increases in flow rates were positively associated with increases in duct diameter ($p < 0.05$). Furthermore, within each milk ejection, higher maximum duct diameters were positively related to greater volumes expressed per 5-second periods ($p < 0.001$). Time to the first milk ejection and number of milk ejections were the same when determined by ultrasound or flow rates. This direct relationship between increases in duct diameter and acute increases in milk flow rates suggests that changes in flow rates can be used to identify milk ejection in the absence of ultrasound data.

INTRODUCTION

MILK EJECTION—a critical component of human lactation—is either the stimulated or conditioned release of oxytocin from the posterior pituitary gland that causes the contraction of the myoepithelial cells surrounding the

alveoli in the mammary gland, forcing milk from the alveoli into the milk ducts. Studies in laboratory animals,^{1–3} sows,⁴ and women^{5,6} have shown that very little milk is removed from the mammary gland in the absence of milk ejection.

In spite of the acknowledged importance of

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milk ejection to the maintenance of lactation, and therefore the well-being of the mother–infant dyad, there are currently no reliable simple objective methods of assessing milk ejection in women that are suitable both for clinical and research use. Existing techniques include the measurement of oxytocin in serial samples of blood,^{7,8} the monitoring of changes in intramammary pressure by catheterizing a milk duct through its nipple orifice,^{9,10} and the monitoring of milk duct diameter using ultrasound.⁶ These techniques are either highly invasive or, in the case of ultrasound, require the services of a highly trained sonographer. Furthermore, all require expensive, specialized equipment. As such, these techniques are difficult to perform in both the clinical and research settings.

Previous work from this laboratory, using 30-second serial collection of milk taken from mothers expressing with an electric breast pump, has suggested that pulsatile increases in milk flow are associated with discrete milk ejection episodes visualized by ultrasound throughout the expression period.¹¹ However, analysis of milk ejection characteristics was limited by the length of the sampling period (30 seconds). The authors hypothesize that monitoring milk flow at shorter (5-second) time intervals will provide a more sensitive objective means of identifying and assessing milk ejection during the expression period. Therefore, the main aim of this study was to determine the association between the flow of milk as it is removed from the breast and the milk ejection episodes detected by ultrasound in mothers expressing their breast milk using an electric breast pump. In addition, this technique could be used to further investigate milk ejection physiology during pumping.

METHODS

Participants

Twenty-two (22) mothers of healthy, term infants (1 to 9 months of age) and one mother of a preterm infant were recruited through the Australian Breastfeeding Association, King Edward Memorial Hospital for Women or private health care centers. All infants were predomi-

nantly fed breast milk and mothers supplied written, informed consent to participate in the study, which was approved by the Human Research Ethics Committee of The University of Western Australia.

Determination of breastfeeding characteristics

Milk production was determined for each breast of 21 exclusively breastfeeding mothers by the test weighing of the infant.¹² Test weighing was carried out over a 24- to 28-h period using an electronic balance (Medela Baby-Weigh Scales, Medela AG, Baar, Switzerland) at each mother's home within approximately 1 week before undertaking the study. A corrected 24-hour production was then determined using these data. However, no correction for infant insensible water loss was made; therefore, milk production may be underestimated by $10\% \pm 12\%$ (mean $\pm$ SD).¹²

Two mothers were exclusively expressing their breast milk. In these instances, the milk expressed from each breast was weighed and recorded at each expression period over the 24- to 28-hour period and a corrected 24-hour production was determined as for the breastfeeding mothers.

The degree of fullness and storage capacity of the breast were determined using breastfeeding and expression data for each mother with the method described by Kent et al.⁵ The volume of milk available to be removed during the expression period was determined by multiplying the degree of fullness before the expression by the storage capacity of the breast.

Ultrasound equipment

The breasts of mothers were scanned using an Acuson XP10 (Siemens, Mountain View, CA) with a linear array transducer (5 to 10 MHz). The superficial organ preset was used and adjustments were made to the gain, dynamic range, and time gain compensation to optimize the image. Average setting values for the Acuson XP10 were 7db gain, 57db dynamic range, and single focus for milk ducts. The performance of the ultrasound system was verified using a multipurpose phantom (model 539, 1992, ATS Laboratories, Inc., CT). All ultrasound scans were videotaped for later anal-

ysis. Parker Ultrasonic Gel (Fairfield, NJ) was used for the scans.

Ultrasound imaging of milk ducts in the nonexpressed breast

Ultrasound monitoring of milk ducts was performed on the breast that was not expressed. The ultrasound transducer was positioned on the areola next to the nipple on the lateral portion of the nonexpressed breast. The transducer then was oriented to display one duct in sagittal section. Color Doppler flow imaging¹³ was used to discriminate between milk ducts and blood vessels when necessary. The same duct was monitored for each expression period for each mother. The milk ducts were identified for repeated measurements by their position in the breast and branching patterns. Details of the duct scanned were recorded diagrammatically in a workbook and before the second and subsequent scans of the duct the videotape of the first scan was reassessed to ensure that the same milk duct was monitored. The scan began simultaneously with the expression period; that is, when the breast pump was turned on. After each expression period, the videotape of the scan was analyzed to measure duct diameter every 8 to 12 seconds, when the image had stabilized from movement of either the mother or the positioning of the transducer.⁶

Breast pump equipment

Breast milk expression studies were conducted at the Breastfeeding Centre of Western Australia, King Edward Memorial Hospital for Women. An experimental, software-controlled, electric breast pump (Medela AG) was used to express milk from the breast. The pump was able to provide vacuum over the range of 0 to -270 mmHg with frequencies over the range of 48 to 120 cycles per minute. For the current study, vacuum curve dynamics were set to be the same as those generated by the commercially available Symphony Breast Pump (Medela AG). This is a two-phase pumping pattern, consisting of an initial stimulation phase (125 cycles/min) and an expression phase (range 54 to 78 cycles/min).

Expressed breast milk was collected directly

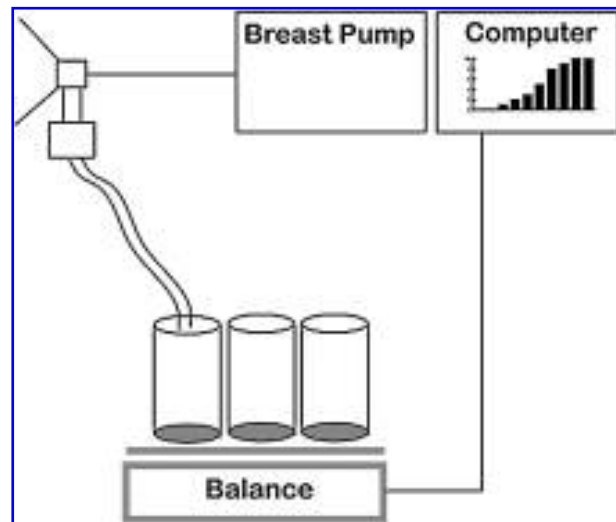


FIG. 1. Schematic diagram showing the breast pump and milk collection equipment. A breast shield was connected to an experimental electric breast pump. A thin tube delivered the expressed milk from the breast shield to tared containers placed on a balance. The balance was connected to a computer and the weight was recorded and plotted every 5 seconds.

into a series of tared containers placed on a balance using a modified collection kit (Fig. 1). Briefly, as milk was expressed from the breast it was conveyed by a thin tube from the modified breast shield to a container positioned on a balance (Scout Pro SP401; OHAUS Corp., Pine Brook, NJ). The balance had an upper measurement limit of 400 g and was accurate to 0.1 g. The balance was connected to a computer and the weight reading from the balance was recorded every 5 seconds over the entire 15-minute expression period. This system was able to record the cumulative increase in milk expressed (i.e., milk flow) in 5-second increments. Milk flow rate (mL/s) was calculated as the derivative of weight change with time (Fig. 2).

Expression conditions

Mothers were asked to express milk from their left breast on up to four separate occasions, each time using a different vacuum level. Vacuums used included A (100% of maximum comfort, the uppermost comfortable vacuum for that mother), B (75 % of vacuum A), and two fixed vacuums C (-125 mmHg) and D (75 mmHg). No extra sessions were conducted in cases in which the 100% or 75% tolerance levels were within 10 mmHg from either the -125

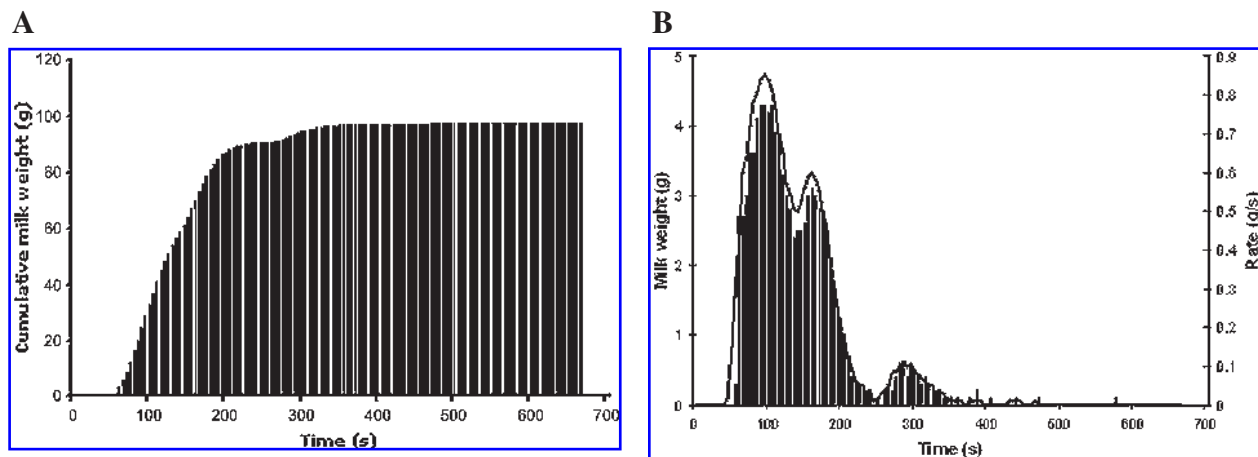


FIG. 2. (A) The cumulative milk weight of the milk expressed during a 15-minute period of one mother. (B) The milk weight plotted as 5-second volumes (*bars*) and derivative of rate of change (*line*). Three milk ejections are identified as an increase and decrease in milk flow. Note the rate of milk flow and the volume of milk expressed during the first milk ejection is greater than that for the subsequent milk ejections.

or -75 mmHg. The application of vacuums A and B was randomized.

In all sessions the stimulation phase vacuum was chosen by the mother. The stimulation of milk ejection by this pattern, as determined by ultrasound, was a requirement of continuing to the expression phase. Volumes of milk removed before milk ejection are referred to as stimulation volumes. Once milk ejection had occurred the vacuum pattern was changed to the expression pattern and the breast expressed for a further 15 minutes at the test vacuum. Volumes of milk removed after milk ejection are referred to as expression volumes.

Statistical analysis

Milk ejections detected by ultrasound imaging were identified according to the method described by Ramsay et al.⁶ To determine the relationship between milk duct diameter and milk flow, milk volumes were paired with milk duct diameter measurements, where for each available time of the milk volume measurement, the last duct diameter immediately before the milk volume measurement was allocated. Stimulation and expression periods were analyzed separately.

Descriptive summaries of continuous data used means and standard deviations (mean $\pm$ SD) and medians and interquartile ranges (Q1 to Q3) as appropriate. Analyses of expression sessions were weighted according to the num-

ber of expressions recorded per mother. Multivariate analysis was based on analysis of variance with repeated measures performed using PROC MIXED (SAS version 8.02, SAS Institute Inc., Cary, NC) and goodness of fit was assessed via analysis of residuals. Two-sided *p*-values are quoted, and a *p*-value < 0.05 was regarded as statistically significant.

RESULTS

Breastfeeding characteristics

The mean age of the mothers was 33.1 ± 3.5 years (range, 28 to 40) and the mean age of the infants was 16.4 ± 7.2 weeks (range, 5 to 37). Of the 23 infants, 14 were male and 9 female. Mean 24-hour milk production was marginally different between breasts ($p = 0.050$) with the left breast producing 391 ± 157 g (range, 213 to 925 g) and the right breast producing 473 ± 146 g (range, 178 to 769 g). For the 24-hour period during which milk production was measured, the storage capacity of the left breast was 179 ± 61 g and the right breast was 184 ± 65 g. On the study days, some mothers did not feed their babies or express from the left breast for an extended interval (up to 17 hours), and the fat content of the foremilk was lower than the lowest measurement on the day 24-hour milk production was measured. In addition, the fat content of the milk at the end of some of the

expression periods was higher than the highest measurement on the day 24-hour milk production was measured. For these mothers, the storage capacity of the left breast was recalculated including the fat content of the expression volumes and was 243 ± 88 g, which was significantly larger than the calculation based on the 24-hour study period ($p = 0.002$). The mean amount of milk taken at a breast feed was 74.9 ± 30 g from the left breast and 80.6 ± 27 g from the right breast.

Milk expression characteristics

Seventy-five (75) expression sessions were conducted. Twenty-three (23) expressions used the maximum comfortable vacuum (-191 ± 56 mmHg); 23 used 75% of the maximum comfortable vacuum (-143 ± 42 mmHg); 11 used -125 mmHg; and 18 used -75 mmHg. The mean starting degree of fullness of the expressed breast for all expression periods was $65\% \pm 9\%$; this corresponded to a mean total available milk volume of 188 ± 81 g.

During the stimulation phase, the mothers chose a vacuum of -85 ± 28 mmHg. Milk was removed in the stimulation phase in 11 expression sessions (14%) (mean, 4.0 ± 1.7 g).

Relationship between duct diameter and milk flow rates. Initial duct diameter (0.5 to 6.6 mm) and peak duct diameter (in response to milk ejection; 0.7 to 7.5 mm) varied considerably between women. The number of milk ejections detected by ultrasound ranged from 1 to 12, and were unrelated to the applied vacuum ($p = 0.954$). Milk flow rates during the expression period ranged from 0 to 4.6 g per 5-second interval for all vacuums. Increases in milk flow rates were readily apparent when either individual 5-second volumes or the derivative of the changes in cumulative volume were plotted (Fig. 3). For all vacuums increases in flow rates were positively associated with increases in duct diameter (Fig. 4), as determined by ultrasound ($p < 0.001$). Furthermore, within each milk ejection, duct diameters were positively related to volumes expressed for each 5-second period ($p < 0.001$).

Determination of milk ejection using duct diameter and milk flow rates. Although the time to the

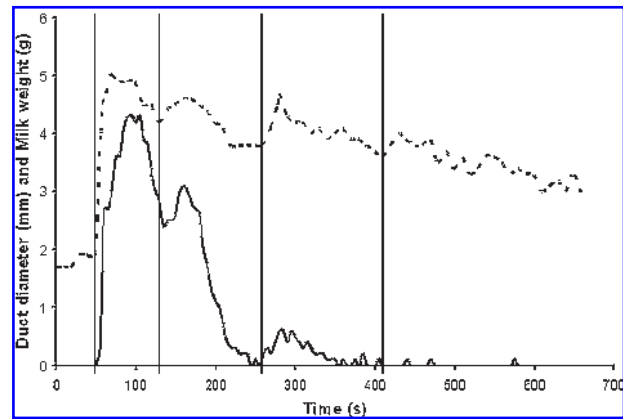


FIG. 3. The milk flow rate plotted as 5-second volumes (—) and milk duct diameter (-----) in the nonexpressed breast is plotted for the expression period shown in Figure 2.

initial milk ejection as determined by ultrasound (90.9 ± 34.6 seconds) was not significantly different to the time to milk ejection determined by an increase in milk flow rate (97.5 ± 29.9 seconds), the trend was for the milk flow rate technique to take longer to identify the initial milk ejection. The initial milk ejection was first detected by ultrasound and then by the milk flow technique for 64% of the expression periods. The mean delay times between milk ejection detected by ultrasound and increase in milk flow were 21, 38, 52, and 68 seconds for vacuums A, B, C, and D, respectively, increased with softer vacuum.

For all expression periods ($n = 75$), the mean number of milk ejections determined by an increase in duct diameter was 4.4 ± 1.2 and was not different from the number of milk ejections determined by an increase in milk flow rate, 4.4 ± 2.2 .

First milk ejection. The amount by which duct diameter increased and decreased ($p = 0.048$) at the first milk ejection and peak duct diameter ($p = 0.040$) was significantly greater for the first milk ejection when compared with subsequent milk ejections. For the first milk ejection, the time taken for the duct diameter to reach a maximum was not related to the initial degree of fullness of either breast.

The first milk ejection produced 45%, 29%, 27%, and 42% of the total volume expressed for the vacuums A, B, C, and D, respectively, which was significantly higher than subse-

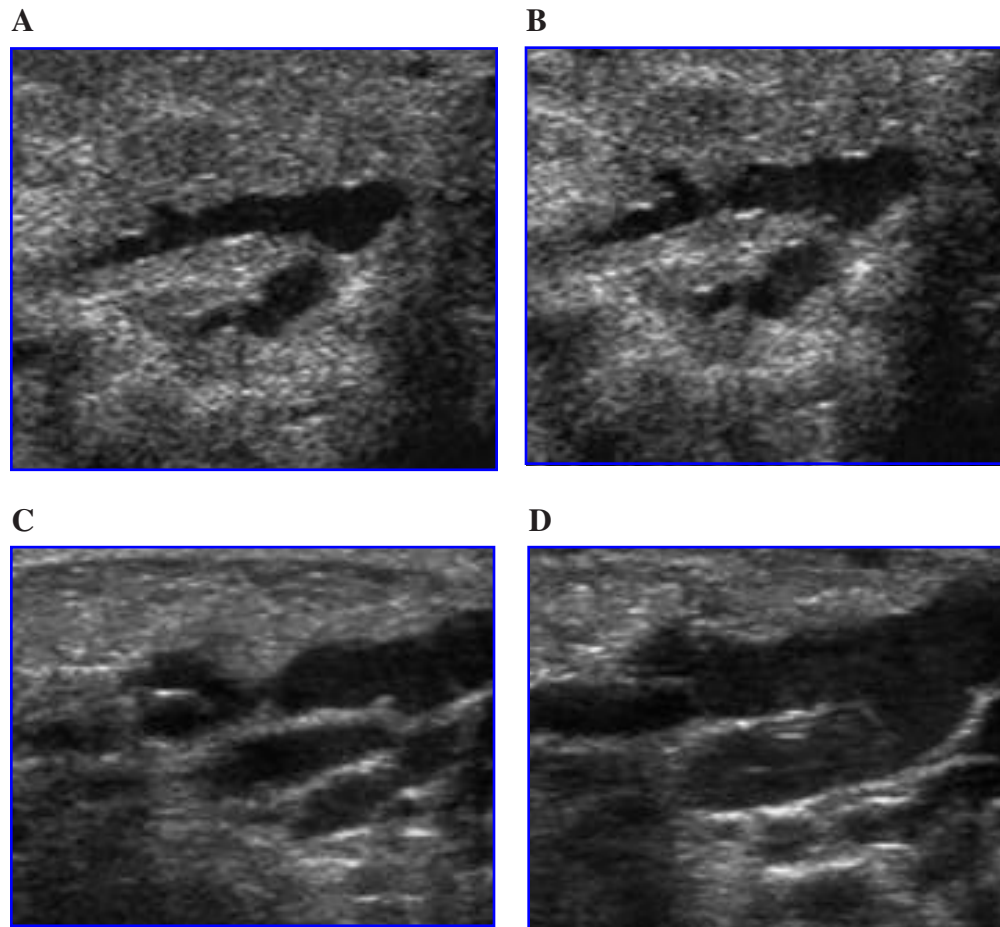


FIG. 4. (A) A milk duct before milk ejection in mother A. (B) The milk duct in (A) shows a small duct dilation at milk ejection in mother A. (C) A milk duct before milk ejection in mother B. (D) The milk duct of mother B (C) shows a larger duct dilation at milk ejection than that in mother A (A,B).

quent milk ejections ($p = 0.008$). Both the volume of milk and percentage of available milk expressed was positively related to the strength of vacuum ($p < 0.001$) (Table 1). In addition, both the volume of milk and percentage of available milk expressed during the first milk ejection were positively related to the duration of the milk ejection ($p < 0.001$). The rate at which milk flowed during milk ejection was positively related to both strength of vacuum and initial degree of fullness of the breast ($p = 0.020$).

Multiple milk ejections. During the expression period there were 4.4 ± 1.2 milk ejections, with a duration of 228.4 ± 182.5 (range 100 to 800 seconds) and an increase of duct diameter from 2.4 ± 0.7 to 2.8 ± 0.7 (average, 0.46 ± 0.19), and they were unaffected by vacuum. However, there was an inverse correlation between the

number of milk ejections and the time to the first milk ejection ($p = 0.049$).

Larger maximum duct diameters at milk ejection (see Fig. 4) were associated with both higher volumes of milk ($p = 0.008$) and percentage of available milk expressed ($p = 0.001$). In addition, the first half of the milk ejection (the time taken for the duct to dilate to maximum diameter) produced both significantly higher milk volumes and percentage milk expressed compared with the second half of the milk ejection ($p < 0.001$).

The time that milk was available for removal ("active time") was defined as the time that the duct was dilated above baseline duct diameter. There was significantly more milk flow during each 5-second interval of active time compared with inactive time ($p < 0.001$). Furthermore, milk flow during the active time was positively

TABLE 1. CHARACTERISTICS OF THE FIRST MILK EJECTION (MEDIAN AND INTERQUARTILE RANGES Q1 TO Q3) OF A 15-MINUTE EXPRESSION WITH AN ELECTRIC BREAST PUMP

<i>Vacuum (mmHG)</i>	<i>Duration (s)</i>	<i>Volume (g)</i>	<i>Percentage available milk (%)</i>	<i>Initial duct diameter (mm)</i>	<i>Maximum duct diameter (mm)</i>
A	115 (85,300)	36.8 (10.1,80.1)*	21.4 (5.3,54.6)*	1.9 (1.4,3.1)	2.3 (1.9,3.7)
B	110 (70,170)	25.4 (6.5,41.6)	15.5 (8.1,30.1)	2.0 (1.2,3.3)	2.3 (1.5,4.0)
C	125 (90,180)	14.6 (8.0,26.3)	7.2 (5.6,15.6)	1.9 (1.3,2.7)	2.5 (1.8,3.8)
D	178 (90,405)	14.6 (4.0,55.9)	8.4 (2.0,22.9)	2.3 (1.5,2.7)	2.6 (2.0,3.7)

*Significance of $p < 0.001$.

related to strength of vacuum ($p < 0.001$) and initial degree of fullness of the expressed breast ($p < 0.001$).

Strength of vacuum had no effect on the duration of each milk ejection ($p = 0.127$). However, higher initial degrees of fullness of the breast ($p = 0.049$) and smaller monitored duct diameters ($p = 0.004$) were related to shorter duration of duct dilation.

In eight expression periods (five mothers) milk was not removed when an increase in duct diameter was detected (milk ejection). For five of these expressions the vacuum applied was low (four at -75 mmHg and one at -125 mmHg) and for seven of the eight expression periods a very small total volume of milk ranging from 4.8 g to 26.5 g (3% to 66% available milk) was removed.

DISCUSSION

The direct relationship between increases in duct diameter in the nonexpressed breast, an objective means of determining milk ejection,⁶ and increases in milk flow in women expressing breast milk using an electric breast pump (see Fig. 3) suggests that milk ejection can be identified in women by monitoring changes in milk flow rates during an expression period.

Milk flow rates have been used previously to identify milk ejection, albeit in an indirect manner. During breastfeeding, observations of changes in the pattern of infant sucking have been assumed to be caused by an increase in milk flow associated with milk ejection.^{14,15} Similarly, in one woman a change in the drips

of milk collected during a breastfeed from the warmed breast that was not fed from was thought to result from milk ejection.¹⁶ During expression Alekseev et al.¹⁰ measured milk flow using a calibrated bottle in conjunction with intraductal pressure measurements. However, this technique of milk flow measurement relies on intermittent observations of the bottle, which makes it unsuitable for low expression volumes and short-interval measurements. Apart from the present study, none has independently, directly verified milk ejection, nor has milk flow been quantitated. The current study is the first to associate actual changes in milk flow rates with milk ejection using ultrasound as a means of objectively, directly determining milk ejection.

The rate of milk flow from the breast during the expression period was extremely variable and ranged from 0 to 4.6 g per 5 seconds. In addition, duct diameters also have been shown to be extremely variable.⁶ This study has shown that as the milk duct expanded at milk ejection in the nonexpressed breast the rate at which the milk flowed from the breast increased concomitantly. Because milk ejection and therefore duct dilation is likely to occur in both breasts at the same time¹⁷ (as a result of oxytocin being released from the posterior pituitary into the blood), it is possible to associate milk flow in one breast with milk ejection in the other.

The time taken to stimulate the first milk ejection as detected by ultrasound was approximately 90 seconds. This is comparable to the time taken by the infant to induce a milk ejection during a breastfeed^{6,9,18,19} (approximately 60 seconds) and pumping studies using

a pre-milk ejection vacuum of more than 100 cycles/min.^{5,11}

Although there was no significant difference between the ultrasound and milk flow techniques, there was a trend for the milk flow technique to detect milk ejection later. This delay was most likely caused by a combination of the time the breast pump took to extract the newly ejected milk from the breast and the distance the milk had to travel from the breast shield to the containers on the balance. To decrease the lag time it is recommended that the tube conveying the milk is kept as short as possible and the breast shield is tilted downward to prevent pooling of milk in either the tubing or breast shield.

Duct diameter increased to a maximum and then decreased within a milk ejection episode (see Fig. 3). This is consistent with previous reports in breastfeeding⁶ and expressing¹¹ mothers. These increases in duct diameter were associated with increases in milk flow rates and conversely decreases in duct diameter were associated with decreases in milk flow. Increases in milk flow are likely to result from the combined effect of increasing positive pressure within the duct and the negative pressure of the breast pump. Interestingly, as duct diameter decreased, which is reflective of decreasing positive pressure in the breast, a corresponding decrease in milk flow was observed regardless of the consistent negative pressure applied by the breast pump.

The relationship between milk flow rates and duct diameter was apparent when expressing with both strong and weak vacuums, although flow rates during milk ejection were greater with stronger vacuums. It is important to note that milk ejection is a discrete event.^{6,9,10} Thus, any increase in flow rate during the expression period is suggestive of milk ejection. The authors frequently observed small increases in milk flow rate, typically from the later stages of an expression period (see Figs. 2B and 3). These are most likely milk ejection episodes; however, point peak flow rates are not as great because less milk is available to be removed at this time. This conclusion is further supported by the increases in duct diameter in the contralateral breast in the latter stages of the expression period being of a similar magnitude

to those at the start (see Fig. 3; 250 to 400 seconds).

The number of milk ejections detected during the expression period was statistically the same for both techniques. However, in practice it is possible to underestimate the number of milk ejections if there are very low volumes of milk available in the breast and the vacuum used is very weak. Conversely, overestimation of milk ejections may occur if there is a buildup of milk at any point in the collection tubing. Should this occur, an artificial surge of milk will result that on analysis may resemble the increase in flow expected at milk ejection.

During expression both milk duct diameter in the nonexpressed breast and milk flow rate increased at milk ejection. After reaching peak duct diameter, both duct diameter and milk flow rate decreased before the next milk ejection. Because peak duct diameter was independent of the amount of milk within the breast, it is plausible that there is a maximum possible dilation of the duct regardless of the magnitude of increase in intraductal pressure at milk ejection. Furthermore, when maximum duct diameter was reached, milk has been observed either to flow backward or leak or spray from the breast, depending on nipple integrity. It is interesting that peak duct diameter was higher for the first compared with subsequent milk ejections. This variation in peak duct diameter among milk ejections may be caused in part by the redistribution of milk through the ductal system, resulting in differing pressure losses with milk flow.

The first milk ejection of the expression period released significantly more milk (volume and percentage of milk available) than subsequent milk ejections regardless of vacuum. The maximum comfortable vacuum (A) removed almost half of the total volume of milk expressed at this vacuum, whereas weaker vacuums removed between one-third and one-fourth of the total volume of milk expressed. This effect also was reflected by the percentage of available milk expressed; the maximum comfortable vacuum removed one-third of the available milk and weaker vacuums removed 10% to 25% of the available milk at the first milk ejection. The rate of milk flow during the first milk ejection increased with both increasing

vacuum and the amount of milk in the breast. In practice it would be beneficial to switch from the stimulation pattern to the expression pattern at the maximum comfortable vacuum as soon as milk ejection occurs to take advantage of the increased milk availability.

The number of milk ejections during the expression period was independent of the strength of the vacuum applied, implying that strength of breast stimulation is not critical in the continued stimulation of the milk ejection reflex. However, it was found that the mother tended to have more milk ejections during the pumping if the first milk ejection occurred quickly. Several factors may contribute to this phenomenon, such as conditioning of the milk ejection reflex, heightened response to continuous stimulation of the breast, and milk ejection duration.

For this study the assessment of milk ejection was made by ultrasound measurements of ductal physiology in the nonexpressed breast, as were measurements of intraductal pressure changes at milk ejection in previous studies.^{9,18,19} However, the correlation between increasing duct diameter in the nonexpressed breast and increased milk flow from the expressed breast suggests that measurement of milk ejection in the nonexpressed breast is representative of milk ejection in the expressed breast. However, a detailed analysis of milk ejection characteristics with regard to milk flow rate requires a short measurement interval, such as the 5-second interval the authors used compared with the 30-second interval used previously in this laboratory.¹¹ Consequently, the authors showed that more milk was expressed (volume and percentage of available milk) during the first half of the milk ejection, as the duct dilated, than during the second half, as the duct contracted. This is consistent with both ultrasound observations of forward flow toward the nipple at the beginning of milk ejection and reverse flow after peak duct diameter was reached in the nonexpressed breast,⁶ as well as the increase and decrease in intraductal pressure in response to breastfeeding, expression, and intravenous injections of oxytocin.^{9,10}

This study is the first to highlight the possibility of ductal anatomy and physiology im-

pacting on milk removal from breast. Women with higher peak duct diameters (see Fig. 4D) and longer milk ejections express more milk (volume and percentage of available milk). There also was a relationship between the duration of milk ejection and duct diameter; smaller duct diameters (see Fig. 4A) are associated with shorter milk ejections and consequently less milk expressed. Interestingly, when the breast contained more milk the duration of milk ejection was shorter. With regard to the whole expression period, during active time (the time that the duct was dilated) significantly higher rates of milk flow were recorded compared with inactive time (time that the duct was at baseline diameter). Furthermore, rate of flow increased with both increasing vacuum and amount of milk in the breast. This indicates that milk ejection is essential for the effective removal of milk and that the characteristics of milk ejection influence the rate at which milk is removed.

CONCLUSION

In conclusion, this study has shown that acute increases in milk flow rate in mothers expressing their milk using an electric breast pump are indicative of milk ejection episodes. This relationship and the described methodology have the potential to provide the researcher and clinician alike with a tool for the assessment of milk flow and milk ejection in the breastfeeding mother. Clinically, this tool could be useful to assess mothers who are unable to breastfeed and are expressing all of their milk for the infant when devising pumping times and intervals. For researchers it may assist in determining the effects of the administration of pharmaceuticals on the mother's lactation. In addition, the effect of ductal anatomy and physiology in relation to the removal of milk requires further investigation.

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