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Ultrasound Imaging of Milk Ejection in the Breast of Lactating Women

Donna T. Ramsay, Dip*; Jacqueline C. Kent, PhD*; Robyn A. Owens, PhD‡; and Peter E. Hartmann, PhD*

ABSTRACT. *Objective.* **Currently, the methods for assessing milk ejection in women include serial sampling of plasma oxytocin and measurement of intraductal pressure, both of which are invasive and may induce stress. We hypothesized that milk ejection would cause an increase in milk-duct diameter that could be observed noninvasively with ultrasound, and this could be used to investigate the physiology of milk ejection in women.**

Methods. **One milk duct was scanned in the unsuckled breast in 2 groups of mothers: group BB ($n = 21$) for the beginning of a breastfeed and group EB ($n = 24$) for the entire breastfeed. A duct also was monitored for a 5-minute period on 2 separate days in the absence of factors that may induce milk ejection in group EB to provide a baseline duct diameter. Milk intake at a breastfeed was measured by test weighing.**

Results. **A significant increase in milk-duct diameter was observed when milk ejection was sensed and/or the infant changed its swallowing pattern in both groups. Multiple increases and decreases (mean: 2.5 per breastfeed; standard deviation: 1.5; $n = 62$) in duct diameter occurred in group EB. Duct diameter remained relatively stable between breastfeeds (coefficient of variation: 1.4%–8.3%). Infant milk intake was positively related to the number of milk ejections ($r^2 = .365$; $n = 57$).**

Conclusions. **Ultrasound is an objective, noninvasive technique for detecting milk ejection by observing an increase in milk-duct diameter. However, this technique requires an experienced ultrasonographer, adequate imaging time, and surroundings conducive to breastfeeding. Multiple milk ejections were common during breastfeeding, although they were not sensed by mothers. The number of milk ejections influenced the amount of milk the infant consumed.** ***Pediatrics*** **2004;113:361–367;** ***milk ejection, ultrasound, milk duct, breast.***

ABBREVIATIONS. BB, beginning of breastfeed; EB, entire breastfeed; CV, coefficient of variation; SD, standard deviation.

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Suckling stimulates the posterior pituitary gland to release oxytocin, which causes the contraction of the myoepithelial cells surrounding the alveoli, forcing milk from the alveoli into the milk ducts. This is termed the milk-ejection reflex. In species with mammary glands that contain milk cisterns (eg, cows, ewes, and goats), milk usually can be removed before milk ejection, whereas for those that do not have milk cisterns (eg, humans and sows), milk removal almost totally depends on the effective stimulation of the milk-ejection reflex.[1]

Women may sense milk ejection by a range of sensations in the breast such as pins and needles, pressure, and pain, as well as by milk leakage and thirst.[2] Also, in the immediate period after birth, uterine contractions may be felt as a consequence of the milk-ejection reflex. However, some women never sense milk ejection,[2] whereas in others the sensation either weakens or is lost as lactation advances. Milk ejection in women has been assessed objectively by either measuring oxytocin in serial samples of blood[3–5] or monitoring changes in intramammary (intraductal) pressure by catheterizing a milk duct through its nipple orifice.[6–9] These studies showed a pulsatile response in both plasma oxytocin and intraductal pressure during both breastfeeds and expression of milk with a breast pump. However, both serial sampling of blood and measurement of intraductal pressure are invasive procedures, and the associated stress may inhibit the milk-ejection reflex.[10,11]

Diagnostic ultrasound has been used extensively for the detection of breast abnormalities in nonlactating women.[12] Recent advances have enabled this noninvasive technology to image and measure small structures (1–2 mm in size) such as milk ducts in the breasts of nonlactating and lactating women.[13,14] In lactating women, both increased pressure in the milk ducts due to the expulsion of milk from the alveoli and the widening and shortening of the ducts due to the action of oxytocin at milk ejection[15] are likely to cause duct dilation. We hypothesize that milk ejection will result in changes in duct morphology that can be viewed by ultrasound imaging and that these changes can be used to investigate the physiology of milk ejection in women.

METHODS

Subjects

Forty-five mothers (Table 1) of healthy term infants were recruited from the Western Australian branch of the Australian Breastfeeding Association. Before each scan, the procedure was explained to the mother, and a written explanation was provided.

TABLE 1. Details of Mother and Infant Characteristics: mean (range)

Group	Breastfeeding Status	Number of Subjects	Age of Subjects (y)	Parity	Number of Children Previously Breastfed	Stage of Lactation (Days)	Number of Ultrasound Scans	
							First Breast	Second Breast
BB	1–6 mos exclusively breastfeeding	10	36.4 (26–37)	1.9 (1–3)	0–2 (0.8)	96 (31–186)	18	14
BB	1–6 mos partly breastfeeding	5	30.8 (25–37)	1.4 (1–2)	0–1 (0.2)	142 (86–178)	10	9
BB	7–22 mos partly breastfeeding	6	31.7 (24–39)	2.2 (2–3)	1.2 (1–2)	333 (199–634)	11	8
EB	1–6 mos exclusively breastfeeding	24	30.2 (22–38)	1.79 (1–4)	0.79 (0–3)	124 (42–182)	62	NA

NA indicates not applicable.

The Human Research Ethics Committee of the University of Western Australia approved the study, and each mother supplied written consent. The mothers were divided into 2 groups. The first group of mothers (1–21) were scanned for the first 2 to 5 minutes of a breastfeed (group BB). These mothers were either exclusively (n = 10) or partly (n = 5) breastfeeding 1- to 6-month-old infants or partly (n = 6) breastfeeding 6- to 21-month-old infants. The second group of mothers (22–45) were participants in a study on the stimulation of milk ejection using an electric breast pump.[16] These mothers reported that they were exclusively breastfeeding 1- to 6-month-old infants on demand (providing no nutrition other than breast milk) and were scanned for an entire breastfeed (group EB). At each visit, mothers were asked to confirm exclusivity of breastfeeding.

Ultrasound Equipment

Group BB was scanned in 1997 at Perth Imaging, Mount Hospital, Perth, Australia, who kindly gave out-of-hours access to their equipment. These mothers had their breasts scanned using a Toshiba Power Vision 370 (Tokyo, Japan) with a linear array transducer (6–10 MHz). The mothers in group EB were scanned in 2000 and 2001 at the Breast Feeding Centre of Western Australia using a dedicated ultrasound machine (Acuson XP10, Siemens, Mountain View, CA) with a linear array transducer (5–10 MHz). For both ultrasound machines 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 Toshiba Power Vision 370 were: gain = 80 dB; dynamic range = 50 dB; and single focus for imaging of milk ducts. Average setting values for the Acuson XP10 were: gain = 15 dB; dynamic range = 57 dB; and single focus for milk ducts. The performance of the ultrasound systems was verified by using a multipurpose phantom (model 539, ATS Laboratories, Inc, Bridgeport, CT). All ultrasound scans were videotaped for later analysis. Parker Ultrasonic Gel (Fairfield, NJ) was used for the scans.

To visualize milk ducts in the lactating breast, it is necessary to use a mid- to high-range ultrasound machine. Video recording and playback facilities are essential to analyze changes in milk-duct diameter. An experienced ultrasonographer familiar with breast imaging with practice will be able to provide good images and interpretation.

Measurement of Milk Intake

For the purposes of this study, a breastfeed was defined as an uninterrupted sucking session at 1 breast. The amount of milk consumed by the infant during a breastfeed was determined by test weighing the infant.[17] This involved weighing the infants (Medela Electronic Infant-Weigh Scales, Medela AG, Baar, Switzerland) before and after breastfeeding, and milk intake was calculated by subtracting the initial weight of the infant from the final weight of the infant. For group BB, milk intake was measured for 35 of the 41 scans performed. For group EB, milk production over 24 hours was determined for each breast by test weighing the infant before and after each breastfeed over a 24- to 28-hour period.[17] The mean amount of milk removed per milk ejection was calculated by dividing the amount of milk consumed by the infant by the number of milk ejections observed at that breastfeed.

Ultrasound Imaging of Breast Milk

The echogenicity of breast milk was determined by placing 3 samples of breast milk in Ansell nonlubricated condoms (Ansell Medical Ltd, Richmond, Australia) and scanning before and after the milk fat (cream) had separated under the influence of gravity. After separation, the cream layer was measured in the condom by using both vernier and ultrasound calipers. In addition, 3 condoms containing olive oil and water were scanned as described above.

Ultrasound Monitoring of Resting Milk Ducts

Resting milk ducts were defined as ducts monitored in the absence of factors that may have induced the milk-ejection reflex. For group EB mothers (n = 24), ducts were identified for repeated measurements by their position in the breast and branching patterns, and, when necessary, color Doppler flow imaging[12] was used to discriminate between milk ducts and blood vessels. Measurements of duct diameter were made repeatedly in a portion of the duct that was perpendicular to the ultrasound beam (Fig 1b). To determine the reproducibility of measurements of resting milk ducts, the ultrasound transducer was initially positioned on the areola next to the nipple on the lateral portion of the right breast and orientated to display a duct in sagittal section. This duct was scanned continuously for a 5-minute period on 2 separate days, at least 7 days apart. On 7 occasions, due to either the mother's commitments or an unsettled infant, it was not possible to obtain a second 5-minute observation period. Measurements of resting-duct diameter were made at 3- to 20-second intervals, that is, at times when the breast had stabilized from movement of either the mother or the positioning of the transducer. The resting mean, standard deviation (SD), and coefficients of variation (CVs) of the duct diameter were calculated for both monitoring periods for each mother.

Ultrasound Imaging of Milk Ducts at the Beginning of a Breastfeed

To determine whether ultrasound could be used to detect changes in the diameter of the milk duct at the beginning of a breastfeed, a duct in the unsuckled breast was visualized as described previously, and the scan began when the infant attached to the mothers breast (group BB; n = 21). Mothers were asked to indicate either when they sensed milk ejection or, if they did not sense milk ejection, when the infant changed its sucking pattern. The scan was terminated 30 to 90 seconds after milk ejection occurred. The amount of milk the infant consumed was measured when the infant finished feeding at the breast. If the infant fed from both breasts, the contralateral breast was scanned at each breastfeed. For the first breast, 2 mothers were monitored for 3 breastfeeds, 16 mothers for 2 breastfeeds, and 3 mothers for 1 breastfeed. For the second breast, 1 mother was monitored for 3 breastfeeds, 14 mothers for 2 breastfeeds, and 3 mothers for 1 breastfeed.

After each breastfeeding session, the videotape of the scan was analyzed by measuring the changes in duct diameter every 3 to 20 seconds, that is, at times when the breast had stabilized from movement of either the mother or infant or the positioning of the transducer.

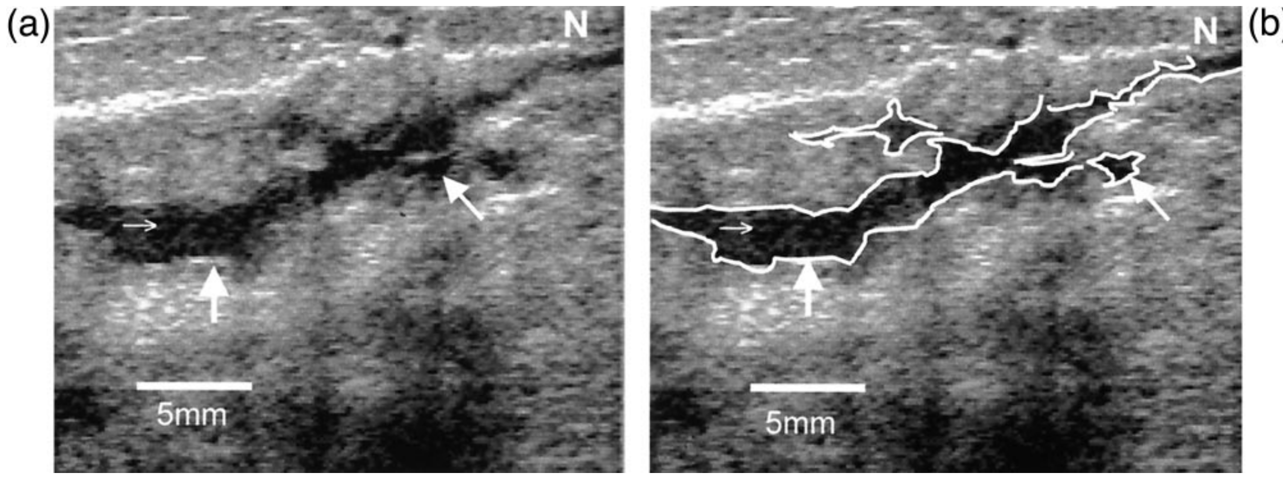

Fig 1. a, Ultrasound image of milk duct in the lactating breast. The duct is traced from deep in the breast to the nipple (N). The walls are echogenic (↑) and the lumen is hypoechoic (→). Note the echogenic flecks within the duct that are consistent with fat globules in the breast milk. A small branch is noted (↖). b, The milk duct is outlined.

Ultrasound Imaging During the Entire Breastfeed

Group EB mothers ($n = 24$) were scanned in the same manner as group BB but for the duration of a breastfeed (1 mother was monitored for 6 breastfeeds, 4 mothers for 4 breastfeeds, 5 mothers for 3 breastfeeds, 11 mothers for 2 breastfeeds, and 3 mothers for 1 breastfeed), and the amount of milk the infant consumed was measured. After each breastfeeding session, the videotape of the scan was analyzed as described for the beginning of a breastfeed.

Statistical Analysis and Determination of Changes in Milk-Duct Diameter

Results are presented as mean ± SD unless otherwise stated. The variation of repeated measurements is expressed as the CV. For both groups of mothers, $T = 0$ was taken as the time when the infant first attached to the breast. For group BB mothers, the change in duct diameter observed at milk ejection by ultrasound was expressed as the percentage change from the initial duct diameter, and its significance was determined by using Student's paired t test (baseline milk-duct diameters were not obtained for this group). For group EB mothers, a significant increase in duct diameter was determined to have occurred during a breastfeed when the duct diameter increased by >3 SDs (determined for each mother by the 5-minute monitoring of a resting milk duct) over the initial duct diameter, calculated as a progressive mean. The duration of increased duct diameter was the time during which the duct diameter was >3 SDs from the mean initial duct diameter. In a proportion of scans (58%), duct diameter did not return to the initial value. On these occasions, a mean from the lower duct diameters was calculated to provide a new initial duct diameter.

Student's paired t tests were used to determine differences between breastfeeds. Two-way analysis of variance was performed to determine differences between groups of mothers at different stages of lactation. Correlation and partial correlation coefficients[18] were calculated by using the statistical software package SPSS for Windows (student version, release 6.1.3, and standard version, release 10.0.1; SPSS Inc, Chicago, IL). Regression relationships were calculated by using Microsoft Excel (Microsoft Corporation, Seattle, WA). For trends over time, SuperANOVA (Abacus Concepts Inc, Berkeley, CA) was used for repeated-measures analysis. P values of <0.05 were taken to be significant.

RESULTS

Ultrasound Echogenicity of Breast Milk

When mixed breast milk was scanned, evenly dispersed echoes (bright flecks) were observed throughout the milk. After the milk had separated, the cream layer appeared as a hyperechoic (highly reflected sound waves giving a bright image) band. The skim milk appeared hypoechoic (darker image). The thicknesses of the top hyperechoic layer of 3 milk samples measured by ultrasound were 1.70, 3.00, and 1.00 mm. These values were in close agreement with the cream layer measured by using vernier calipers: 1.75, 2.73, and 1.03 mm, respectively. Scans were also performed on a mixture of oil and water. After separation of the oil layer, similar ultrasound appearances to breast milk were observed. Measurements of the thickness of the oil layer with ultrasound were 6.00, 4.30, and 13.40 mm and were in close agreement with the measurements made by using vernier calipers: 6.04, 4.09, and 12.78 mm, respectively.

Ultrasound Monitoring of Resting Milk Ducts

Milk ducts were identified as tubular structures with hyperechoic walls and a hypoechoic lumen (Fig 1) similar to that of the nonlactating breast.[12–14] However, echoes were observed within the ducts, similar to the echoes observed in mixed milk and the cream layer of separated breast milk, and were attributed to the milk fat globules. The ducts readily collapsed under slight pressure similar to that required to compress a superficial vein on the back of the hand, and therefore accurate images of the ducts could only be obtained when minimal pressure was applied to the ultrasound transducer. Ducts with diameters >0.5 mm were readily identified.

The diameter of resting milk ducts for group EB mothers was 2.82 ± 0.09 mm (range: 1.09–5.85 mm; $n = 51$). The variation in the duct diameter during the 5-minute observation period was small, with CVs for individual mothers ranging from 1.4% to 8.3%. No significant difference was found between the mean duct diameter on the first and second days. The duct diameters for the 2 days were in close agreement regardless of either the duct size or the time since the last breastfeed (Fig 2).

Ultrasound Imaging of Milk Ducts at the Beginning of a Breastfeed

The milk-duct diameter increased significantly ($P < .001$) during a breastfeed in the unsuckled

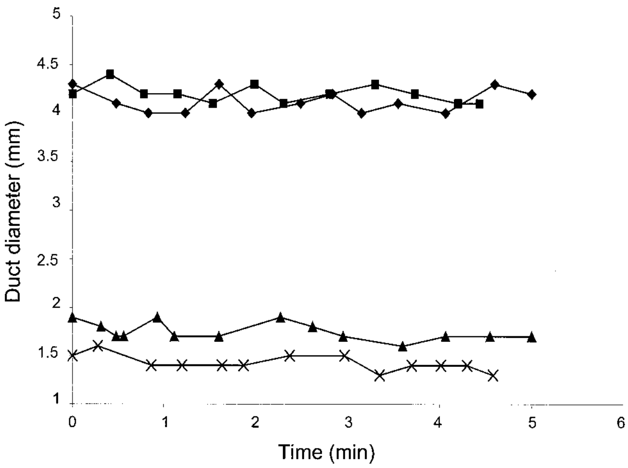

Fig 2. Monitoring of milk ducts for 5 minutes. A relatively large (4.2-mm) duct (■ and ♦) and small (1.9-mm) duct (▲ and X) monitored for 5 minutes at least 7 days apart are shown. The range of resting milk ducts was 1.09 to 5.85 mm (n = 51), and the variation in milk-duct diameter was 1.4% to 8.3% (CV) within the 5-minute period, with no difference in mean duct diameter between days.

breast of group BB mothers (Fig 3). When the first breast was offered, duct diameter in the unsuckled breast increased from 1.63 ± 0.11 to 2.75 ± 0.17 mm (n = 41). The increase in duct diameter coincided with the sensation of milk ejection and a change in the sucking pattern of the infant. In those mothers who could not sense milk ejection, the increase in duct diameter occurred when the sucking pattern of the infant changed. The increase in duct diameter was usually associated with a flow of small hyperechoic flecks toward the nipple. When the second breast was offered, duct diameter increased from 1.56 ± 0.11 to 2.09 ± 0.15 mm (n = 32) in the other breast (that is, the breast that the infant had suckled recently). The percentage increase in duct diameter in the unsuckled breast was significantly greater (P = .001) when the first breast was offered (76 ± 7%; n = 41) than when the second breast was offered (40 ± 6%; n = 32). More milk was consumed when the first breast was offered compared with the second breast (P = .002; first breast: 65 ± 8 g, n = 35; second breast: 39 ± 5 g, n = 30).

The mean time to the first increase in duct diameter in the unsuckled breast was not significantly different when either the first (56 ± 33 seconds; n = 41) or second (47 ± 38 seconds; n = 32) breast was offered. Neither the mode of breastfeeding (exclusively or partly) nor the age of the infant (1–6 or 7–21 months) affected the time to the first increase in duct diameter. Furthermore, the time since the last breastfeed (105–435 minutes) did not influence the time to the first increase in duct diameter. The increase in duct diameter in the unsuckled breast was not related to milk intake, time to duct-diameter increase, time since the last breastfeed, or stage of lactation for either the first or second breastfeeds.

Ultrasound Imaging of the Entire Breastfeed

The mean length of a breastfeed (group EB) was 6 minutes, 40 seconds ± 3 minutes, 29 seconds, and the amount of milk consumed by the infant was 75 ± 40 g. The amount of milk consumed at the monitored breastfeed was not significantly different from the mean amount of milk consumed at each breastfeed during a 24-hour period (left breast: 73 ± 26 g; right breast: 76 ± 29 g). The total 24-hour milk production for the mothers was 779 ± 181 g.

Initial milk-duct diameter in the unsuckled breast was 2.49 ± 0.84 mm, and an increase in duct diameter of 58 ± 41% was detected within 56 ± 30 seconds of the start of the breastfeed on the other breast. One mother did not show a significant increase in duct diameter during 1 breastfeed lasting 3 minutes and 37 seconds, and the infant received 5 g of milk. For all breastfeeds that showed an initial increase in duct diameter, a significant decrease in duct diameter followed.

Multiple increases in milk-duct diameter (duct dilations; Fig 4) were detected in 74% of breastfeeds, whereas only 1 duct dilation was observed in 26% of breastfeeds. There was an average of 2.5 duct dilations per breastfeed (SD: 1.5; range: 0–9; n = 62). Of the 24 mothers, 21 reported sensing milk ejection at

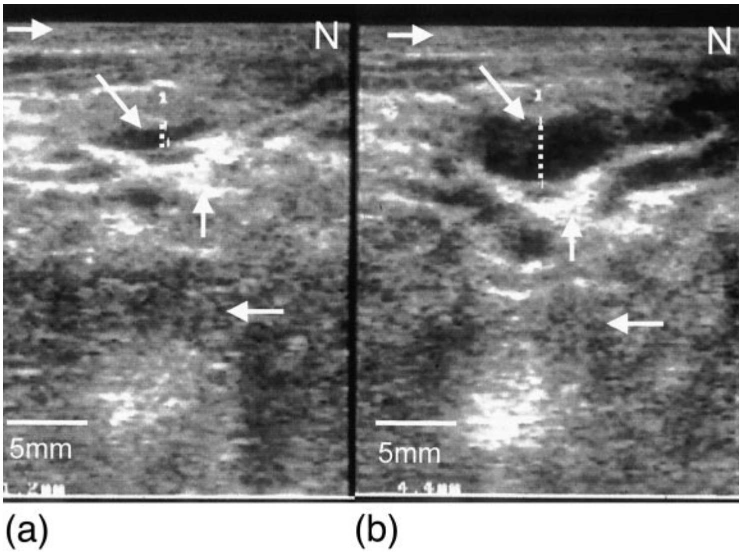

Fig 3. Milk ejection imaged on ultrasound. The skin (→), glandular/secretory tissue (↑), adipose tissue (←), and nipple (N) are visualized. a, A milk duct before milk ejection (↘) measures 1.2 mm (dotted line). b, At milk ejection, the same duct (↘) measures 4.4 mm (dotted line). Milk ducts dilated an average of 58 ± 41% at milk ejection.

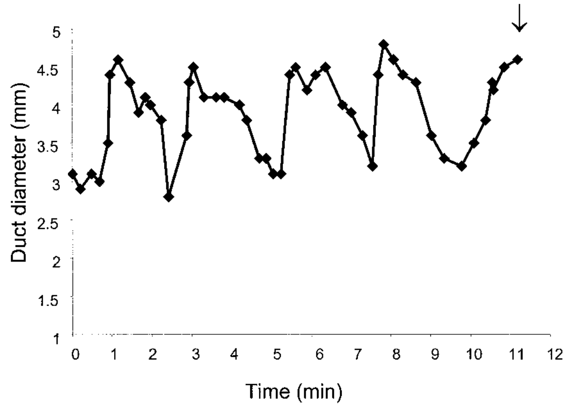

Fig 4. Multiple milk ejections. Four milk ejections are detected in this mother during an 11.5-minute breastfeed. The maximum diameter for each milk ejection was consistent. The duration of each duct dilation was between 90 and 120 seconds. The infant finished feeding as the duct diameter reached a maximum (↓).

the time of the initial increase in duct diameter; however, none of them reported sensing milk ejection for the remainder of the breastfeed. The maximum diameter of the duct for each significant increase during a breastfeed was consistent (mean CV: 4.5%). The mean increase in duct diameter was 1.15 ± 0.22 mm, in cross-sectional area of the duct 4.66 ± 3.69 mm^2, and percentage increase of the duct diameter 49 ± 12% (n = 61). The initial increase in duct diameter to a maximum occurred in 34 ± 22 seconds (range: 4–88 seconds) and then returned to either the initial diameter or greater in all but 1 breastfeed. Of the mothers who had multiple duct dilations, 39% of infants finished feeding at the time of an increase in duct diameter (Fig 4).

Partial correlation analysis demonstrated a significant correlation between the number of milk-duct dilations that occurred during a breastfeed and the amount of milk the infant consumed when controlling for the length of the breastfeed (r^2 = .365; P < .01; n = 57; Fig 5). Importantly, there was no relationship between milk intake and length of the breastfeed when controlling for the number of duct dilations. However, there was a positive relationship between the number of duct dilations and the length of the breastfeed when controlling for the effect of milk intake (r^2 = .353; P < .01; n = 52).

The duration of the initial milk-duct dilation was not significantly different than subsequent duct dilations (Fig 4), and the duration of duct dilations was not significantly different either between breastfeeds or between mothers. The mean time the duct was dilated was 86 ± 51 seconds (n = 146), and the time between the beginning of each milk-duct dilation was 122 ± 56 seconds (range: 45–356 seconds). Some women displayed extreme responses during the breastfeed; for example, 1 mother had 1 duct dilation that lasted 231 seconds and the infant consumed 140 g of milk (Fig 6), whereas another mother had 3 duct dilations in 270 seconds and the infant consumed 100 g of milk (Fig 6). The total milk consumed divided by the number of duct dilations during a breastfeed gave a mean milk intake per duct dilation of 35 ± 22 g. Milk intake was not related to either the degree of duct dilation or the maximum duct diameter.

DISCUSSION

In 133 successful breastfeeds, changes detected by ultrasound (increased duct diameter [Fig 3] and movement of fat globules) coincided with the mother sensing milk ejection and/or a change in sucking pattern of the infant. Furthermore, the time to milk ejection (group BB: 56 ± 33 seconds; group EB: 56 ± 30 seconds) when the first breast was offered was similar to previous clinical observations,[2,19] the increase in the concentration of oxytocin in the blood,[3,4] and intramammary pressure in the unsuckled breast.[6–8] Therefore, it was concluded that the changes in duct morphology associated with breastfeeding were a consequence of milk ejection. This ultrasound technique is therefore a valuable nonin-

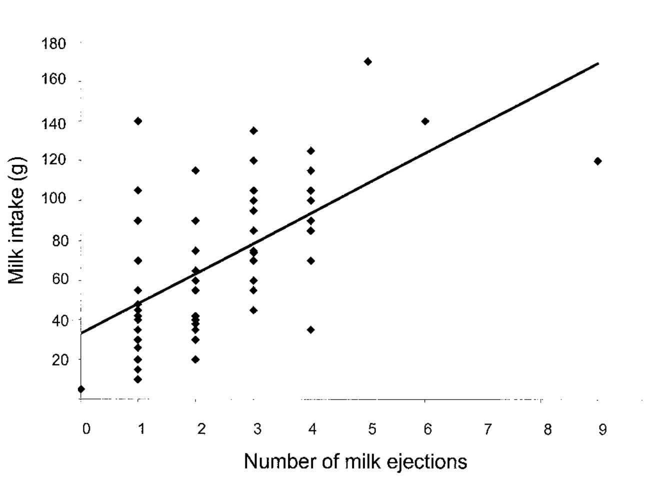

Fig 5. Milk intake of the infant in relation to the number of milk ejections detected during a breastfeed for group EB. There was a significant correlation between the number of milk ejections during a breastfeed and the amount of milk the infant consumed when controlling for the length of the breastfeed (r^2 = .365; P < .01; n = 57).

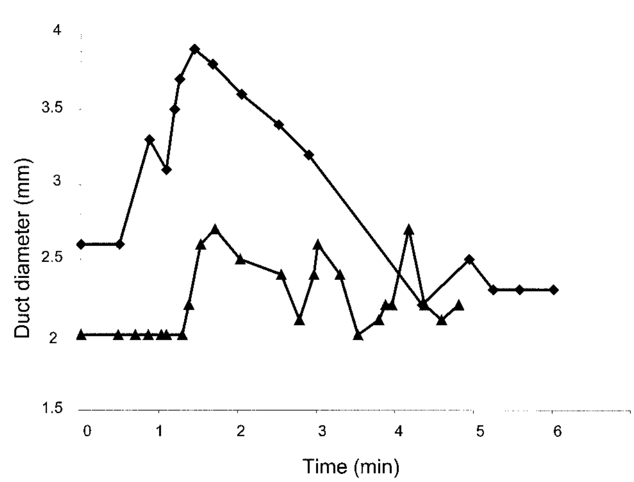

Fig 6. Variation of the duration of milk-duct dilation. ◆ indicates a single milk ejection. One duct dilation lasted 231 seconds during this mothers' breastfeed, and her infant consumed 140 g of milk. ▲ indicates multiple milk ejections. Three duct dilations of 45, 64, and 89 seconds were observed during this mothers' breastfeed of 4 minutes and 49 seconds, and her infant consumed 100 g of milk.

vasive method of objectively assessing milk ejection in women who are either breastfeeding or expressing breast milk.

During our study, 1 mother showed no duct changes during a breastfeed (3.5 minutes), and the infant consumed only 5 g of milk. This mother had a normal 24-hour milk production (674 g), and we had previously monitored 3 breastfeeds in which the infant consumed 60, 65, and 115 g of milk and increases in milk-duct diameter were detected. Thus, ultrasound suggests the absence of milk ejection as an explanation for the low milk intake by the infant. Ultrasound monitoring of multiple breastfeeds could therefore be used to assess milk ejection in infants that appear to be latching well to the breast but consume little milk.

Although spontaneous milk ejections have been reported between breastfeeds,[20] we did not observe these during monitoring periods (Fig 2). If a spontaneous milk ejection had occurred, it seemed to have no persistent effect on resting duct diameter. The very small variations in duct diameter (SD: 0.09 mm) were attributed to either movement of the mother or ultrasound transducer and measurement error. Accurate monitoring of a milk duct with ultrasound was ensured by applying only enough pressure to make contact with the breast and produce an ultrasound image. This was assisted by the application of extra ultrasound gel.

The increase in milk-duct diameter at milk ejection in the unsuckled breast is likely to be caused by a combination of shortening and widening of the duct[15] and increased pressure within the duct due to the expulsion of milk from the alveoli. A recent study of lactating human breasts[21] suggests that oxytocin receptors are more prevalent in the ductal and glandular epithelium than the myoepithelial cells. However, the increase in duct diameter was less when the second breast was suckled compared with first. This suggests that the response of the ducts may be affected by the degree of fullness of the monitored breast. Contraction of the myoepithelial cells surrounding alveoli that have been partially emptied may result in lower intraductal pressure and subsequently cause smaller duct dilation.

The increase in milk-duct diameter during a breastfeed was not related to milk intake, time to milk ejection, time since last breastfeed, or stage of lactation. The increase in duct diameter and time to milk ejection were not related to either 24-hour milk production or milk intake, suggesting that the milk-ejection reflex operates independently of the synthetic activity of the breast and/or the appetite of the infant.[22]

The subsequent decrease in duct diameter after milk ejection (Fig 4) suggests that milk is not stored in the larger ducts close to the nipple but flows back into the smaller collecting ducts and ductules, a phenomenon we have observed as a reversal in flow of the echogenic fat globules within the duct. Reversal of milk flow has been demonstrated previously in vitro in the rat, mouse, guinea pig, and rabbit[15] and is likely to occur in the sow.[23] Also both women and the above-mentioned species do not have milk cisterns,[24] and therefore little milk would be expected to be available before milk ejection. This is consistent with the observation of the mother who did not display a milk ejection and yielded only 5 g of breast milk.

In this study, 88% of the mothers were able to sense the initial milk ejection; however, none sensed subsequent milk ejections. During 74% of breastfeeds (group EB), multiple milk ejections were demonstrated by further peaks in duct diameter as the feed progressed (Fig 4). This is comparable with the pulsatile release of oxytocin,[3–5] as well as increases in intraductal pressure during breastfeeding[6–8] and breast expression.[9] The number of milk ejections detected during a breastfeed was the only factor related to the amount of milk the infant consumed for that breastfeed regardless of the length of the breastfeed (Fig 5). However, in 39% of the mothers that had multiple milk ejections (Fig 4), the infant terminated the breastfeed during a milk ejection, consistent with the infant's appetite regulating milk intake.[22]

Maximum milk-duct diameters were similar during a breastfeed (Fig 4), inferring consistent ductal responses to multiple releases of oxytocin. Peak concentrations of oxytocin in the blood are inconsistent during breastfeeding,[25] and the first increase in intraductal pressure during a breastfeed and breast expression usually displays a higher maximum than subsequent increases.[8,9,20] Our observations suggest that there is a maximum duct expansion within a breastfeed regardless of pressure or oxytocin release.

Duct dilation at milk ejection lasted ~1.5 minutes as measured by ultrasound (Fig 4) and is similar to the duration of oxytocin pulses in the blood[3,26] and increases in intraductal pressure.[9,20] Duration of duct dilation was similar for all milk ejections, breastfeeds, and mothers. However, extreme responses did occur; for example, in 1 mother a single duct dilation lasted 231 seconds (Fig 6), suggesting a sustained response to oxytocin. Sustained increases of oxytocin in the blood have been shown during a breastfeed[3] and hand breast expression.[5] Also, we found a minimum latency period of 45 seconds between milk ejections, which is similar to the time between pulses of oxytocin during a breastfeed (<1 minute).[26] Thus, it is apparent that a large number of milk ejections can occur in a short period of time. Indeed we have observed 3 duct dilations in 3 minutes (Fig 6), corresponding with similar reports of oxytocin release.[26] It therefore is conceivable that infants who consume a large amount of milk in a short time are stimulating frequent milk ejections.

The results of this study support the use of ultrasound imaging as a noninvasive, familiar, nonthreatening procedure for assessing milk ejection, because the sensation of milk ejection is not a reliable indicator of the physiologic response of the breast to oxytocin during a breastfeed. The relationship of number of milk ejections to milk consumed by the infant suggests that ultrasound monitoring would be useful in infants with consistently low milk intakes.

CONCLUSION

Ultrasound is an objective, reliable, noninvasive technique that can be used to assess milk ejection by detecting an increase in milk-duct diameter in the unsuckled breast during a breastfeed. After duct dilation the subsequent decrease in duct diameter suggests reverse flow of breast milk within the duct if it is not removed, and this was confirmed on ultrasound as backward flow of fat globules. This suggests that there is increased availability of milk when the duct is dilated. Multiple milk ejections are common during breastfeeding, although most mothers are unable to sense them, and the number of milk ejections was the only factor found to influence the amount of milk the infant consumed. Currently, little diagnostic support exists for lactating women experiencing difficulties.

We believe that ultrasound is a valuable tool for both researchers and clinicians investigating both the milk-ejection reflex and ductal anomalies in breastfeeding and expressing women.

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Rimer S. *New York Times*. October 29, 2003

Noted by JFL, MD