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Oral feeding in premature infants: advantage of a self-paced milk flow

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An earlier study demonstrated that oral feeding of premature infants (<30 wk gestation) was enhanced when milk was delivered through a self-paced flow system. The aims of this study were to identify the principle(s) by which this occurred and to develop a practical method to implement the self-paced system in neonatal nurseries. Feeding performance, measured by overall transfer, duration of oral feedings, efficiency, and percentage of successful feedings, was assessed at three time periods, when infants were taking 1–2, 3–5, and 6–8 oral feedings/day. At each time period, infants were fed, sequentially and in a random order, with a self-paced system, a standard bottle, and a test bottle, the shape of which allowed the elimination of the internal hydrostatic pressure. In a second study, infants were similarly fed with the self-paced system and a vacuum-free bottle which eliminated both hydrostatic pressure and vacuum within the bottle. The duration of oral feedings, efficiency, and percentage of successful feedings were improved with the self-paced system as compared to the standard and test bottles. The results were similar in the comparison between the self-paced system and the vacuum-free bottle.

Elimination of the vacuum build-up naturally occurring in bottles enhances the feeding performance of infants born <30 wk gestation as they are transitioned from tube to oral feeding. The vacuum-free bottle is a tool which caretakers can readily use in neonatal nurseries.

Key words: *Low birthweight infants, oral feeding performance, bottle feeding, oral motor*

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Premature infants do not feed as readily as their full-term counterparts. As the discharge of these newborns from the hospital is correlated with attainment of full oral feeding (1), there is a growing need for understanding the development of sucking in premature infants and for the development of interventions which enhance their oral feeding performance. With a broader knowledge in this area, appropriate clinical management of oral feeding would be reflected not only by earlier attainment of full oral feeding and hospital discharge, but also by a potential decrease in the occurrence of feeding disorders.

Advancement of oral feeding is based primarily on the competence of the infant to feed safely and successfully. Safety implies the proper coordination of suck, swallow, and respiration in order to minimize the risk of aspiration and to allow proper ventilation (2–10). Success is defined as the infant's ability to finish an entire feeding within an allotted time. The clinical practice of restricting the duration of oral feedings is to prevent excessive fatigue for the infants. In addition, it is speculated that by limiting their energy expenditure towards feeding, weight gain could be enhanced. To facilitate oral feeding performance, therapists routinely work with infants using a variety of interventions to enhance their oral-motor skills and/or facilitate their coordination of suck-swallow-breathe (2). For instance, the regulation of milk flow during bottle feeding is a method that is commonly used. Although studies have suggested that a faster flow increases milk intake (11–13), caretakers frequently comment on how a fast flow can lead to aspiration and choking, particularly in premature infants. To reduce flow, it is common practice to switch to a harder nipple or change the size of the nipple hole. A decrease in flow may enhance feeding performance by allowing more time for the formation of the bolus and decreasing swallow frequency and volume, thereby improving coordination of swallow-breathe (2, 6, 14).

In an earlier study (14), we showed that the feeding performance of infants born <30 wk gestation improved when milk flow was "self-paced" vs "unrestricted" as provided by the standard bottles routinely used in neonatal nurseries. The self-paced flow was obtained using a specially designed system that delivered milk to the nipple chamber from an open reservoir

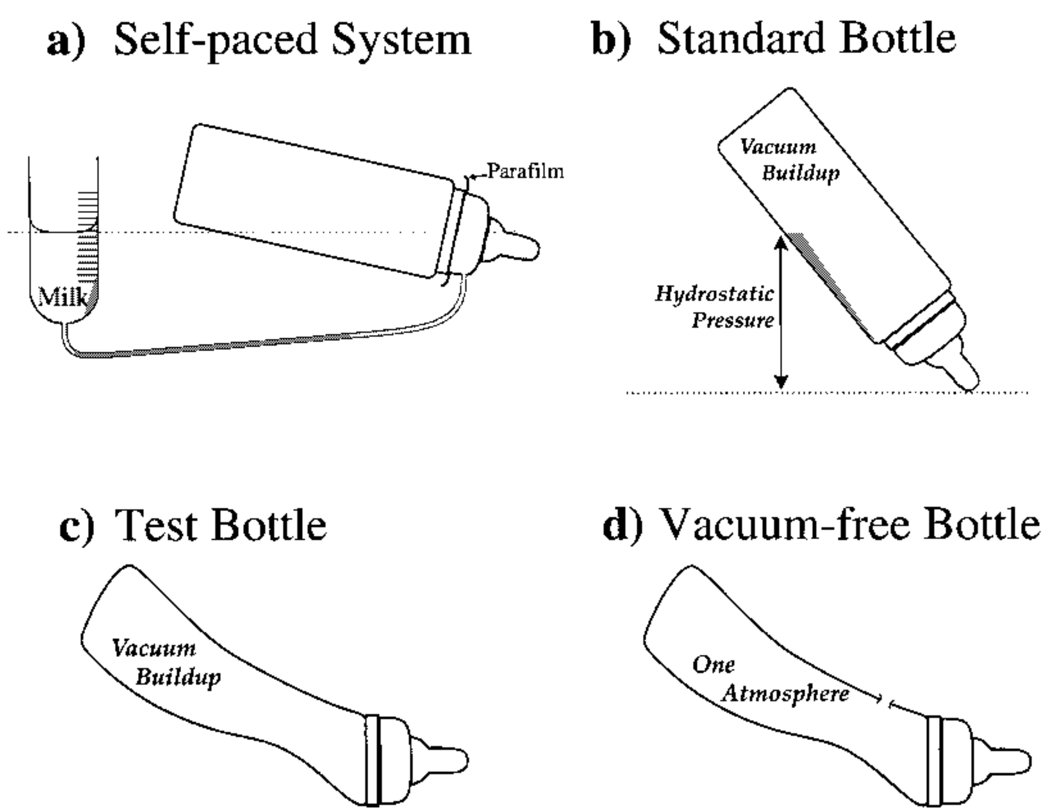

Fig. 1. Schematics of (a) the self-paced system; (b) the standard bottle; (c) the test bottle; and (d) the vacuum-free bottle.

which could be adjusted such that the level of milk was maintained at all times to that of the infant's mouth (Fig. 1a). For this system, a standard nipple, as routinely used by the nurseries, was adapted onto a standard bottle (Fig. 1b), the opening of which was tightly covered with parafilm. At the base of the nipple, a catheter was inserted into the nipple chamber and connected to a graduated reservoir containing the milk. The level of the milk in the reservoir was continuously adjusted to the level of the infant's mouth/nipple hole so as to eliminate any net hydrostatic pressure. With such a system, milk only flowed when the infant was sucking. In contrast, standard bottles inherently possess two factors which may hamper the feeding performance of the infant: (i) a net hydrostatic pressure generated by the presence of the milk, which tends to increase flow rate (11, 15), and (ii) a gradual build-up in negative pressure or vacuum inside the bottle, which tends to retain milk within, as the infant is sucking while maintaining a seal around the nipple (Fig. 1b). Based on the results obtained from our earlier study (14), it is hypothesized that the beneficial effect of the self-paced flow resulted from the elimination of the net hydrostatic pressure and/or of the vacuum build-up normally occurring in a standard bottle. Thus, the aims of the present study are to identify the mechanism(s) by which the self-paced flow facilitates oral feeding in the premature infant, and to develop a practical technique to introduce the benefits of the self-paced flow system in neonatal nurseries.

Methods

Subjects

Infants born between 26 and 29 wk gestation and appropriate for gestational age, as determined by maternal dates and antenatal ultrasonography, were recruited from the neonatal nurseries at Texas Children's Hospital. Infants with any of the following conditions were excluded from the study: grades III and IV intraventricular hemorrhage (16), necrotizing enterocolitis, hydrocephalus, bronchopulmonary dysplasia, or major congenital abnormalities. Infants were treated prophylactically with caffeine citrate until they demonstrated mature control of breathing, usually around 35 wk postmenstrual age. Once full tube-feeding was achieved, oral feeding was initiated and advanced upon the sole recommendation of the attending physician. Initiation of oral feeding occurred around 33–34 wk postmenstrual age (Table 1). If enteral feeding was provided through an orogastric tube, the latter was removed prior to the assessments of oral feeding.

Table 1. Subject characteristics.

	Study 1	Study 2
No. of subjects	10	8
Gestational weeks	27 ± 2*	28 ± 1
Gender (male/female)	4/6	6/2
Birthweight (g)	820 ± 211	1070 ± 276
Age at first oral feeding (d)	46 ± 13	41 ± 14
Postmenstrual age at first oral feeding (wk)	33.4 ± 1.8	34.1 ± 1.5
Age at attainment of full oral feeding (d)	60 ± 15	56 ± 17
Postmenstrual age at full oral feeding (wk)	35.4 ± 1.8	36.3 ± 2.1
Age at hospital discharge (d)	68 ± 17	69 ± 21

* Mean ± SD.

Informed consent was obtained from parents. The study was approved by the Baylor College of Medicine Institutional Review Board for Human Research.

Study design

To follow oral feeding performance over time, the infants were monitored when receiving 1–2, 3–5, and 6–8 oral feedings/day. This was instituted because oral feedings were advanced at the discretion of the attending physicians, and the longitudinal monitoring of infants at regular time intervals did not allow for the assessment of the infant's oral feeding performance at the start, middle, and end of their oral feeding progression. The infants were held by the caretaker on the lap during each feeding, as routinely done in the nursery, and did not receive any encouragement during these sessions. The infants were offered their designated type of milk for all assessments. Care was taken to ensure that the subjects were not disturbed for at least 30 min before each test. The incidence of apnea (cessation of respiration > 20 sec), bradycardia (heart rate < 100) and oxygen desaturation (<90%) were noted before, during, and after all the assessments.

Study 1. Effect of hydrostatic pressure. Ten infants (27 ± 2 wk gestational age) were enrolled in study 1 (Table 1). At each assessment period, i.e., 1–2, 3–5, and 6–8 oral feedings/day, the infants were monitored during three consecutive feedings. In a random order, they were offered the self-paced flow (Fig. 1a), the standard bottle (Fig. 1b), and a test bottle (Fig. 1c), the shape of which allowed for easy adjustment of the level of milk to that of infant's mouth, so as to eliminate the hydrostatic pressure normally present in standard bottles.

Study 2. Effect of vacuum build-up within bottle. (a) To verify that a vacuum build-up occurs within a bottle when an infant maintains a good seal around the nipple while sucking, the following assessment was conducted. A Mikro-Tip sensor transducer (Model SPR-524, Millar Instr., Houston, TX) was placed inside the test bottle, such that the sensor was situated at the bottom of the inverted bottle. The internal pressure was monitored during the feeding of an infant (28 wk gestation, at 52 postnatal days) who was taking all his feedings orally.

(b) Eight infants (28 ± 1 wk gestational age) were recruited (Table 1). Within the same three assessment periods, they were offered in two consecutive feeding sessions, in a random order, the self-paced flow (Fig. 1a) and a vacuum-free bottle (Fig. 1d). This was made from the test bottle described in study 1, to which a hole was placed so as to maintain equilibrium with atmospheric pressure.

The number of subjects in both studies was based on data collected from our earlier study (14). The efficiencies of infants between 26 and 29 wk of gestation who were offered a self-paced or unrestricted flow were 3.1 ± 0.8 ml/min and 1.6 ± 1.1 ml/min, respectively. Thus, in order to detect a difference of 1.5 ml/min, we estimated that 8–10 infants would be sufficient.

Outcome measures

The following feeding performance outcomes were used: overall milk transfer (the percent volume transferred during an entire feeding/total volume ordered for that feeding), duration of an oral feeding, and efficiency (the volume transferred per unit time during an entire feeding, ml/min). A maximum of 20 min was allowed for each feeding session. If, at any feeding, the overall transfer was <100%, the remaining volume was given by naso- or orogastric tube.

In study 1, the data were analyzed by one-way repeated measure analysis of variance between the various oral feeding devices and post-hoc *t*-test, when appropriate. In study 2, paired *t*-test was used.

Results

Study 1

Fig. 2 shows the feeding performance outcomes of infants using the self-paced system, the standard bottle, and the test bottle. There was no difference observed in overall transfer between groups within the same time periods (Fig. 2a). Fig. 2b shows the duration of all the feedings monitored. There was a significant difference between feeding devices at 1–2 and 3–5 oral feedings/day, with the use of the self-paced flow leading to significantly shorter feeding duration times. No difference was observed between the use of the standard and test bottle. As the infants progressed from 1–2 to 6–8 oral feedings/day, there was no significant change in duration of oral feedings with each feeding device. The percentage of infants with successful feedings, i.e., overall milk transfer of 100%, is given in Table 2. As they progressed from 1 to 8 oral feedings/day, there were significantly more infants successful with the self-paced bottle than with the standard or test bottle. In addition, the duration of these successful feedings was

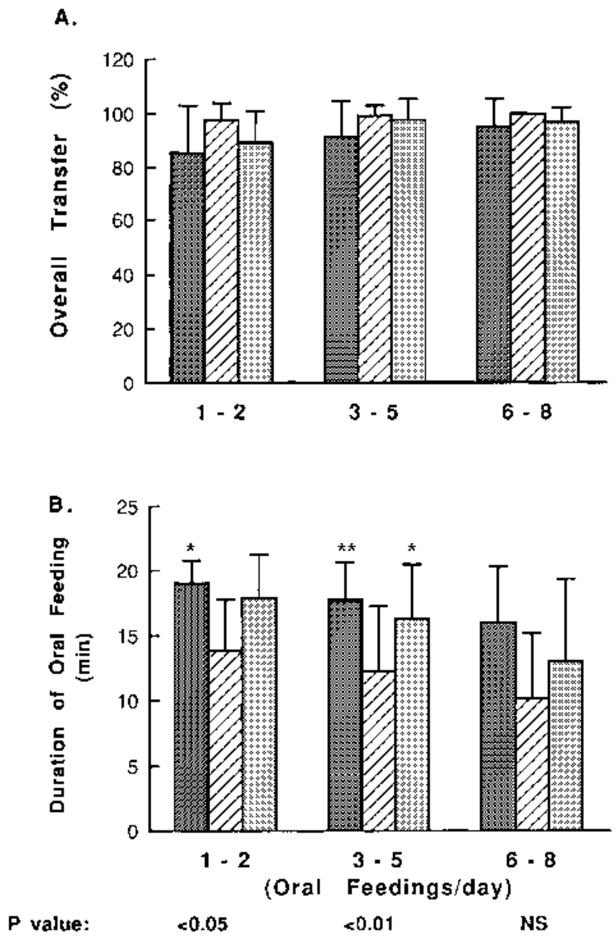

Fig. 2. A. Percent overall transfer. B. duration of oral feeding (min) when milk is delivered through a standard bottle (▩), a self-paced system (▨), and a test bottle (▦) (mean ± SD). *Post-hoc *t*-test vs self-paced: $p < 0.05$; **post-hoc *t*-test vs self-paced: $p < 0.01$.

achieved in a significantly shorter time period with the self-paced than with the other two devices (Table 2).

Efficiency (ml/min) was significantly enhanced at 3–5 oral feedings/day with the self-paced mode (Fig. 3), compared with the standard or test bottles. Although at 1–2 and 6–8 oral feedings/day, there was no statistical difference between the three devices, efficiency always tended to be greater when the self-paced mode was offered.

Infants tolerated the assessments well. Of 84 sessions evaluated in the 10 subjects, one infant exhibited two episodes of oxygen desaturation, once with the standard bottle and once with the test bottle. Three other infants each had one episode of bradycardia when feeding with the self-paced system. All events were self-corrected and did not require additional support.

Study 2

Fig. 4 shows the continuous change in pressure inside the bottle of an infant who was actively sucking while maintaining a seal around the nipple. During a 39-sec period, the infant demonstrated a 16-sec sucking burst followed by a 13-sec pause and a second 10-sec sucking burst. During the first sucking burst, a negative pressure builds up inside the bottle, reaching −22 mmHg by the time the infant pauses. As the infant did not release the nipple, this negative pressure was maintained, such that after a second sucking burst of 10-sec duration, the internal pressure further decreased to −32 mmHg. The end of the tracing shows the return to atmospheric pressure when the bottle was taken out of the infant's mouth and the internal pressure was allowed to re-equilibrate with outside pressure.

Table 3 shows that the outcome measures were similar when the self-paced system and the vacuum-free bottle were used. Out of a total of 42 sessions evaluated in 8 subjects, there was 1 occurrence of oxygen desaturation in 1 subject when the self-paced flow was used. This event also was self-corrected.

Discussion

It is well acknowledged that premature infants have difficulty weaning from tube-feeding, but there is little understanding on the cause(s) for such occurrence. Although the presence of a mature sucking pattern with the rhythmic alternation of suction and expression has been presumed to be necessary for oral feeding, our earlier study has shown that low birthweight infants, with an immature sucking pattern, can bottle-feed

Table 2. Comparison of successful oral feedings (i.e., 100% overall transfer) between the standard, self-paced, and test bottles (mean ± SD) as the infants progressed from 1 to 8 oral feedings/day.

	Standard	Self-Paced	Test	p*
Percent of successful feedings (100% transfer) to total number of feedings evaluated	$64 \pm 28^{\#}$	90 ± 21	$64 \pm 18^{\#\#}$	0.025
Duration of successful feedings (min)	$15.9 \pm 3.6^{\#\#\#}$	10.3 ± 3.7	$13.3 \pm 5.0^{\#}$	<0.001

* One way repeated measure ANOVA.
# Post-hoc *t*-test: $p < 0.05$ vs self-paced.
Post-hoc *t*-test: $p < 0.01$ vs. self-paced.
Post-hoc *t*-test: $p < 0.001$ vs. self-paced.

Table 3. Comparison of feeding outcome measures (mean ± SD) between the self-paced system and vacuum-free bottle (paired t-test).

	Flow type	1–2 oral feedings/day	3–5 oral feedings/day	6–8 oral feedings/day
Overall transfer	Self-paced	100	100	100
	Vacuum-free	90 ± 17	100	100
Duration of oral feeding (min)	Self-paced	13.2 ± 5.4	10.0 ± 3.6	8.4 ± 4.5
	Vacuum-free	15.2 ± 6.1	9.5 ± 4.8	9.1 ± 2.9
Efficiency (ml/min)	Self-paced	3.22 ± 1.57	4.23 ± 1.58	5.50 ± 1.75
	Vacuum-free	2.85 ± 2.14	4.87 ± 2.02	4.66 ± 1.71

No statistical differences were observed.

successfully and safely (14). It is unclear when the coordination of suck-swallow-breathe, which is essential for safe oral feeding, appears, and there is no reliable clinical indicators to help identify the appropriate times for initiation and advancement of oral feeding. However, the lack of understanding in the maturational process of sucking behavior should not hinder studies in the development of interventions to facilitate oral feeding in premature infants.

In an earlier study (14), we observed that a self-paced milk flow delivery system enhanced the feeding performance of premature infants. The present study was initiated to identify the principle(s) by which this occurred and to develop a practical method to implement the benefits offered by the self-paced system. We assessed the feeding performance of premature infants as a function of clinically relevant feeding outcomes such as overall transfer, duration of oral feeding, and efficiency. Results from our first study show that, although overall transfer was similar between the standard, self-paced, and test bottle, the duration of oral feedings, and efficiency were significantly enhanced with the self-paced compared with the other two devices at 1–2, 3–5, and 3–5 oral feedings/day, respectively. Inasmuch as 20 min is the maximum time allowed for oral feeding, overall transfer, in fact, is the

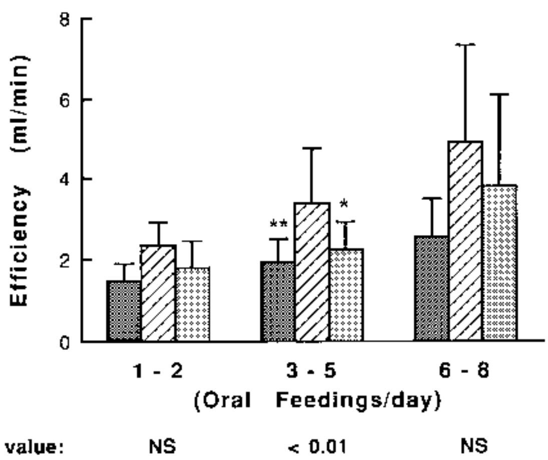

Fig. 3. Efficiency (ml/min) when milk is delivered through a standard bottle (▩), a self-paced system (▨), and a test bottle (▦) (mean ± SD). *Post-hoc t-test vs self-paced: $p < 0.05$; **post-hoc t-test vs. self-paced: $p < 0.01$.

"minimal" requirement that infants must meet in order for their caretakers to define an oral feeding as successful. As such, it does not provide information on whether one feeding device is more advantageous than another. This, however, can be obtained by comparing the duration of oral feeding, efficiency as well as the percent and duration of successful feedings, i.e., 100% overall transfer, between the different delivery systems. Such comparisons showed that the self-paced system allowed infants to feed faster as well as increased their occurrence of successful feedings. Inasmuch as there was no difference between the vacuum-free bottle and the self-paced system, it is advanced that these two devices provide the same advantages.

The use of the test bottle demonstrated that the sole elimination of the positive hydrostatic pressure normally present in standard bottles was not sufficient to enhance the feeding performance of the subjects. However, the combined effect of the elimination of the hydrostatic pressure and the prevention of the vacuum build-up within the bottle, as obtained with the self-paced and vacuum-free system, did.

The build-up of the negative pressure within a bottle, recorded from one particular infant, demonstrates the principle by which vacuum can readily be generated. It is evident that the magnitude of that internal pressure depends upon the amplitude of suction, duration of the sucking burst(s), and how long a seal is maintained. It is of interest to note that the negative pressure of −32 mmHg generated within 30 sec by this infant is similar to the suction amplitude that premature infants can generate at about the time they begin to show the mature rhythmic suction/expression pattern (17; in prep.). It is easily understandable that the accumulated negative pressure inside the bottle can reach an equilibrium with the opposing suction amplitude exerted by the infant, such that milk flow out of the bottle is halted. If sucking is maintained under such conditions, fatigue and poor efficiency would ensue. This is supported by our observation that the durations of oral feeding at the earlier two time periods, i.e., 1–2 and 3–5 oral feedings/day, are significantly briefer when the self-paced flow is used as compared to that of the standard and test bottles. From this observation we speculate that a longer feeding time leads to fatigue and a greater energy expenditure, which, in turn, may be one

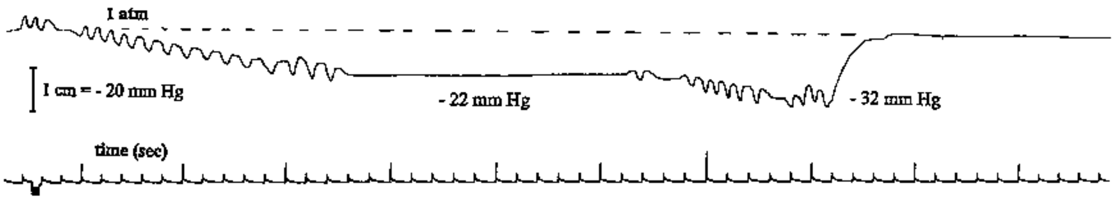

Fig. 4. Actual tracing of the vacuum build-up occurring within a test bottle recorded from an infant (28 wk gestation, 52 d of age) who was taking 8 oral feedings per day.

of the causes for poor weight gain noted in premature infants during the advancement of oral feedings.

Therapists working with infants who have difficulty coordinating suck-swallow-breathe routinely use an intervention called “external pacing”. Pacing, by removing the bottle at regular intervals, allows the infant time to catch-up with breathing. This parallels the “catch-up” breathing frequently practiced by premature infants (2) and term newborn (10; personal observations) soon after birth. Indeed, on their own, these infants often will alternate between active sucking with no breathing and pauses with rapid breathing by blocking the nipple hole with their tongue to occlude milk flow in order to breathe (4). From the present observations, we are proposing that feeding therapists should take into account the additional benefit that external pacing also allows re-equilibration of the internal pressure with atmospheric pressure. As such, this intervention may be used, not only for infants who have a limited ability to regulate their ventilation, but also for those whose endurance and/or sucking ability cannot counteract the progressive build-up of vacuum which arises within the bottle as they are feeding. By the time the infants achieved 6–8 oral feedings per day, the advantage offered by the self-paced or vacuum-free bottle disappeared. The attainment of a more mature sucking pattern (14), along with a decrease in fatigue and an improved coordination of suck-swallow-breathe, are likely candidates for the infants not needing the advantage offered by the self-paced flow.

The concern over safe oral feeding has led to a large number of studies focusing on understanding suck, swallow, and respiration (18). It is important to remember that in the study of premature infants, interpretations of earlier studies need to take into account the age of the subjects under study. The degree of prematurity is a significant determinant of these infants’ physiological and behavioral aptitudes. Observations made from full-term or older premature infants may not be applicable to younger premature infants. For instance, although we have shown in our earlier study (14) that infants, born <30 wk gestation, benefited from a self-paced milk delivery system, this was not so for premature infants born between 31 and 33 wk gestation (19). The latter performed equally well with the self-paced and the standard bottle. This would suggest that infants born at ≥ 31 wk may have reached a level of maturation that allows them to bottle-feed more readily than their younger counterparts. A number of studies have observed that faster milk flow increases swallowing frequency (3, 11, 12), bolus size (11), and consumption rate (11–13). However, it is important to note that these studies were conducted on full-term (3, 11, 12) and premature infants born ≥ 30 wk gestation (12, 13). Increased milk intake is often associated with decreased ventilation; this likely being the result of increased swallowing frequency (9, 11). Although, immediately after birth, full-term infants may show a transient swallow-breathe incoordination (10, personal observations), this occurrence is far more common in premature infants with its incidence increasing with increased prematurity (6–8, 20–22). Thus, increasing flow in order to increase intake may not be appropriate for all infants. In light of these studies as well as our own (14, 19), great care should be taken before any generalized statements can be made in regard to premature infants.

In summary, the self-paced flow not only offers the advantage of allowing the infant to regulate milk flow, i.e., milk flowing only during active sucking, but also of facilitating milk flow by eliminating the vacuum generated within the container during sucking. The vacuum-free bottle developed for this study may be a new tool which can be used to facilitate oral feeding of infants who demonstrate sucking difficulty, not only from prematurity, but also from poor endurance and/or uncoordinated suck-swallow-breathe.

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