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VIEWPOINT ARTICLE

Neonatal stomach volume and physiology suggest feeding at 1-h intervals

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ABSTRACT

There is insufficient evidence on optimal neonatal feeding intervals, with a wide range of practices. The stomach capacity could determine feeding frequency. A literature search was conducted for studies reporting volumes or dimensions of stomach capacity before or after birth. Six articles were found, suggesting a stomach capacity of 20 mL at birth.

Conclusion: A stomach capacity of 20 mL translates to a feeding interval of approximately 1 h for a term neonate. This corresponds to the gastric emptying time for human milk, as well as the normal neonatal sleep cycle. Larger feeding volumes at longer intervals may therefore be stressful and the cause of spitting up, reflux and hypoglycaemia. Outcomes for low birthweight infants could possibly be improved if stress from overfeeding was avoided while supporting the development of normal gastrointestinal physiology. Cycles between feeding and sleeping at 1-h intervals likely meet the evolutionary expectations of human neonates.

INTRODUCTION

Current practice in many health institutions worldwide is that full-term infants should feed every three to four hours. For example, Zangen et al. (1) state that the healthy newborn can at first swallow 20–40 mL per feeding, but 'after a few days ingests about 75 mL per feeding' (no reference provided). Edmond and Bahl (2) in a WHO technical report concur that this is 'standard practice' (p 78), but they note that there were no randomized controlled trials (RCTs) or observational studies identified which addressed feeding frequencies or feed intervals. Only case series and descriptive studies were found, and it was 'not possible to provide additional recommendations due to insufficient evidence'.

There is reasonable consensus on the amount of milk that human term newborn infants need per day, figures given vary from 150 to 160 mL/kg/day (1,2). For an average 3-kg neonate, feeding at 3-h intervals requires a feed volume of 60 mL and at 4-h intervals 80 mL per feed. The stomach stores this food, starts digestion and releases prepared contents in a controlled manner to the duodenum. As the feed requires processing in the stomach, the capacity or volume of the stomach to hold that feed could be regarded as the primary factor to derive a physiologically appropriate feed interval.

METHOD

A search was conducted for research articles covering prenatal or postnatal gastric capacity, volume or anatomical dimensions. The search was conducted in PubMed and CINAHL and through enquiries from the lactation consultant community. Articles that reported on gastric capacity with predetermined longer feeding intervals were excluded; the stomach may adapt to large volumes that distend it beyond healthy physiological limits.

RESULTS

Six studies on foetal and neonatal stomach capacity were identified and are summarized in Table 1.

Goldstein and colleagues measured foetal stomach size using ultrasound, reporting data with '± 2SD' (3). All measures across gestational ages showed linear growth of the foetal stomach. Similarly, Sase and colleagues evaluated foetal stomach size and the development of gastric emptying in human foetuses (4). They observed regular cycles during which the 'gastric area ratio' increased from 1% to 15% over 30–40 min, followed by 10- to 15-min periods of antropyloric peristalsis that emptied the stomach. This author suggests that the '+ 2SD' reported by Goldstein represents the upper range of 15% described by Sase, providing data for the size of the stomach when filled. A mathematical formula of stomach capacity (see Table 2), using Goldstein's data at near-term age, gives a stomach capacity of 12 mL.

Widstrom and colleagues aspirated stomach contents 'immediately after birth' and measured volumes, but also correlated these with amniotic fluid pH, gastrin and somatostatin (5). Based on calculations on the above, they concluded that just prior to term birth 'the fetus drinks about 10 mL portions of amniotic fluid'.

Zangen and colleagues measured gastric volumes and pressure by means of an inflatable balloon at the end of a nasogastric tube (1). They provide a figure of an intragastric pressure–volume plot from a single distention in a newborn. This study was included since it was a 'first feed', preceding a predetermined longer feed interval. Pressures are very low at volumes below 15 mL. When volume was increased, there was a linear relationship between volume and pressure; the pressure doubled at 20 mL. At 30 mL, the recording stops with a pressure of 26 mmHg, this being the pain threshold derived from studies in adults (1). Zangen interprets this as an immature response of the newborn, which 'improves' after 2 weeks of feeding at 4-h intervals. This author interprets this as meaning the stomach capacity is between 15 mL and 20 mL, as 30 mL causes distress.

Scammon and Doyle reported postmortem data, combining 25 cases reported by Alliot with 13 of their own cases (6). Their method entailed closing the cardia and the pylorus and filling the stomach with a measured volume of water to 'a pressure of 15 or 20 centimetres of water'. Almost regardless of the birthweight, the stomach volumes were 30–35 mL.

Naveed and colleagues studied stomach capacity in stillbirths and in early neonatal deaths (7). Their technique was to close both ends of the stomach and then to inflate it until 'obliteration of the gastric curvatures' and that volume was recorded. Stillbirths above 2500 g had an average capacity just under 20 mL, live born less than 18 mL.

Kernesiuk measured accurate *in situ* dimensions at postmortem; applying the above-mentioned stomach capacity formula (Table 2) to the dimensions reported results in a stomach capacity of 15 mL (8).

Based on the collective evidence from the studies reviewed (Table 1), the newborn stomach capacity at term is approximately 20 mL.

Table 1 Summary of evidence on stomach capacity for human neonates

Author	Number	Method	Capacity	Comments
Goldstein et al. (1987)	152	Ultrasound	12 mL*	Foetal studies, gastric dimensions for 37- to 39-week gestation.
Sase et al. (2000)	80	Ultrasound	*	Foetal studies, gastric filling and emptying (only areas provided)
Widstrom et al. (1988)	25	Aspirates	10 mL	Term neonates, sampled immediately after birth
Zangen et al. (2001)	17	Balloon	20 mL	Term neonates, pressure study, this author's inference on data reported
Scammon & Doyle (1920)	38	Autopsy	30–35 mL	Term neonates, 20 cm water pressure.
Naveed et al. (1992)	100	Autopsy	18–20 mL	Stillbirths at term (63) and neonatal deaths (37), water pressure.
Kernesiuk et al. (1997)	11	Autopsy	15 mL*	Neonatal deaths at term, undisturbed *in situ* dimensions
Bergman			20 mL	This author's conclusion from available data

*Mathematical calculation (see Table 2) based on dimensions provided.

DISCUSSION

Given a stomach size of about 20 mL at birth and the assumption that stomach size should correspond to feeding volume, for a total daily feeding volume of 160 mL/kg, the viewpoint proposed is that the feeding interval should be approximately one hour for an average-term neonate.

Stomach capacity and feed interval should be regarded in the broader context of the newborn. Two primary occupations of all neonates are sleeping and feeding (9). A 20 mL breast milk feed empties from the stomach in approximately 1 h (10). Sleep cycling is fundamental for brain development (11); in neonates, the normal sleep cycle is also approximately 1 h (12). Both state organization and ingestive behaviours are regulated by the same autonomic nervous system (13). The synactive model for developmental care described by Als includes observations on these behaviours (14). The autonomic control of the stomach includes a cephalic phase that prepares the stomach for food, followed by a gastric phase (15). The cues for these

Table 2 Formula used for calculation of stomach capacity (Charles Bradshaw)

Derivation	Details
Assumptions	The stomach can be approximated by dividing into three sections, namely an ellipsoidal hemisphere, an ellipsoidal cylinder and a skewed ellipsoidal cone.
Variables:	a = anteroposterior radius, t = transverse radius, l = length stomach
Relations:	The height of the cone and the hemisphere are both the same as ‘a’
Ellipsoid	$= 4/3 \times \pi \times r1 \times r2 \times r3 = 4/3 \times \pi \times a \times a \times t$; therefore volume of hemisphere $= 2/3 \times \pi \times a \times a \times t$
Cylinder	$=$ Area of base $\times$ height $= (\pi \times a \times t) \times (l-2a)$
Skewed cone	$= 1/3 \times$ base $\times$ height $= 1/3 \times \pi \times a \times t \times a$
	$= (2/3 \times \pi \times a \times a \times t) + (\pi \times a \times t \times (l-2a)) + (1/3 \times \pi \times a \times t \times a) = (\pi \times a \times t \times l - \pi \times a \times a \times t)$
Total volume	$= \pi \times a \times t \times (l-a)$

phases are primarily olfactory (16), but also linked to state organization (15). Therefore, the proposed hourly feeding of the term neonate should be matched to the neonate’s own sleep cycle, rather than the clock.

Insel and Young identify feeding, sleeping and locomotion as the most basic needs for survival, but add the need for ‘social attachment’ (17). Oxytocin is the hormone enabling secure attachment, from early bonding and ongoing breastfeeding that fosters prolonged maternal–infant interaction (17). A single milk ejection reflex following oxytocin release produces a remarkably constant 20–30 mL volume of milk (18), which matches the stomach capacity. Eliciting subsequent ejections during the same feed takes longer and requires more work than the first (18). Anthropological studies in most tropical hunter–gatherer societies report frequent feeds during the day (19), the extreme being perhaps the !Kung who feed several times an hour (20). Winberg reviews the role of frequent breastfeeding and survival needs in the first hours of life, in an evolutionary context (21). Over and above the early social bonding, the maternal body and interaction with it provide the neonate with an energy-efficient environment and metabolism (21). Single milk ejection volumes are elicited within two minutes (18) and are thus energy and time efficient for both mothers and infants, consistent with the needs of the hunter–gatherer of our evolutionary biology (21).

Implications for full-term neonates

This viewpoint has some practical implications. While *spitting up* is usually regarded as normal, the physiologically indistinguishable *reflux* can become a severe problem (22). Given the described small stomach capacity and large volume of feeds routinely given, spitting up shows that the food ingested does not fit into the stomach. One definition of colic is ‘distention of any hollow viscera’ (American Heritage Dictionary), which is consistent with the discomfort shown by neonates who have been fed typical volumes of 60 or 80 mL. This discomfort should not be confused with ‘infantile colic’ seen in older infants, although other mechanisms related to excessive volumes may be involved.

Neonatal hypoglycaemia is a common concern in neonatal nurseries, where neonates are separated from mothers and experience long feed intervals. Maternal–infant separation activates neonatal stress responses that may use up calories faster than they can be replaced (21). Small frequent feeds allows the neonate a constant supply of lactose, without the stress of sympathetic nervous system activation of glycogenolysis (23). In non-Western cultures, close maternal–infant skin-to-skin contact and small frequent feeds are the norm. With skin-to-skin contact, blood glucose levels are higher than when neonates and their mothers are separated (24).

Application to preterm and low birthweight infants

While the stomach volume and the one-hourly feed interval derived from it apply to full-term neonates (first four weeks of life), this viewpoint has particular application for preterm and low birthweight infant care. No studies of stomach capacity on preterm infants were found. Likewise, Edmond and Bahl found no studies on feed intervals for low birthweight infants (2). They concluded that no policy implications could be drawn from the available data to apply to infants of various gestational ages and weights at birth. They nevertheless provide recommendations based on ‘standard practice’ and available consensus (p 78):

> ‘These studies indicated that feeding regimens such as 4-hourly feeds for infants >2000 g, 3-hourly for infants 1500–2000 g, 2-hourly for infants 1000–1500 g, and hourly in infants <1000 g were well tolerated, promoted biochemical stability, and produced minimal gastric aspirates’.

The rates of growth of the foetal stomach dimensions reported by Goldstein are remarkably linear (3). The period of this foetal linearity matches the neonatal period of the preterm and allows for a simple calculation for stomach capacity of any preterm, as well as a term neonate in the first month of life: namely 7 mL per kilogram of body weight.

One of the most vexing areas in the clinical management of preterm infants is their nutrition. Preterm infants have less resilience than those born at term and are more dependent on care that minimizes stress. Translating this to practice would require small and frequent feeds, with the exact feeding frequency determined by intact sleep cycles as experienced by the newborn brain, as can be identified by developmental care observers (14).

A common practice is to provide continuous gavage feeding to very small preterm infants. Dsilna et al. showed that continuous feeding gave better results than 3-hourly feeds (25); in contrast, a similar study by Silvestre showed no difference (26). International surveys show marked variability in feeding practices (27). A Cochrane review comparing continuous and intermittent bolus feeds (28) noted that the latter are typically every 2 or 3 h and concluded that benefits and risks cannot be discerned from current data. To this author's knowledge, there are no studies of one-hourly feeds, nor feeds adjusted to sleep–wake cycles.

The arguments of prolonged intervals increasing risk of hypoglycaemia, as well as too large volumes increasing risk of reflux, could be used to predict better outcomes from continuous feeds, as shown by Dsilna (25). Continuous gavage feeds may however have some disadvantages compared with one-hourly feeds. The normal sensory priming of the cephalic phase is absent, and the physiological stomach filling and emptying are disturbed.

'Feed intolerance' is a commonly diagnosed problem in preterm infants, confirmed by an increased gastric residual volume. Kairamkonda and colleagues showed that this was correlated to high levels of amylin, a satiety hormone, which is a potent inhibitor of gastric emptying (29). Amylin is secreted with insulin from the pancreas and works in a short feedback loop to the stomach, achieving 'control of nutrient entry to the duodenum' (30). 'Feed intolerance' could therefore be a misnomer, it may be 'volume intolerance'. Biologically it would be surprising if maternal milk is not tolerated. It may be well accepted if it was given in volumes that matched preterm stomach size, preceded by sensory cues (smell) that trigger the stomach's cephalic phase.

Specific predictions are that hourly interval feeds would reduce the incidence of reflux and hypoglycaemia or even abolish these altogether for preterms in continuous skin-to-skin contact (the expected milieu of their evolutionary biology). In contrast to skin-to-skin contact, maternal–infant separation increases somatostatin that may cause some reflux even with hourly feeds (5). Further, weight gain per day of preterm infants would increase and length of hospital stay decrease. Necrotizing enterocolitis is as common in bolus and continuous feeding (28), it is plausible this could be reduced with the appropriate hourly feed volumes proposed.

CONCLUSION

It is surprising that for such a 'primary occupation' as neonatal feeding (9), there should be so little basic data or evidence-based research. The six articles providing stomach capacity data presented here are the only ones found. Notwithstanding being 'old', they provide internally consistent support for a stomach capacity of around 20 mL at term birth. This capacity is very much smaller than the current feeding volumes, with longer intervals, given to neonates. The one-hourly feeding frequency proposed here matches other primary occupations of the neonate, specifically gastric emptying time and sleep cycling. Larger feeding volumes at longer intervals may therefore be stressful to neonates, disturb state organization and cause spitting up, reflux and hypoglycaemia. Outcomes for low birthweight infants specifically could possibly be improved if such stress was avoided while supporting the maturation of normal gastrointestinal physiology. The stomach capacity of approximately 20 mL suggests that cycles between feeding and sleeping at 1-h intervals likely meet the evolutionary expectations of human neonates.

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CONFLICT OF INTEREST

Author has no conflict of interest to declare.

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