ORIGINAL ARTICLE

Gastric emptying of milk in infants and children up to 5 years of age: normative data and influencing factors

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Abstract

Background Gastric emptying scintigraphy is widely used in infants and children, but there is a lack of age-specific normative data.
Objective The objectives of this retrospective study were: 1) to establish a range of gastric emptying of milk or formula as a surrogate for normal gastric emptying in infants and young children ≤5 years of age, and 2) to investigate the effects of patient age, feeding volume, feeding route and gastroesophageal reflux on gastric emptying.
Materials and methods The reports of 5,136 gastric emptying studies of children ≤5 years of age performed at Children's National Medical Center from January 1990 to August 2012 were reviewed. Demographic data, 1-h and 3-h gastric emptying values and gastroesophageal reflux status of all patients were stored in a database. Using stringent inclusion and exclusion criteria, the studies of patients as similar to healthy children as possible were selected for this study.
Results The study group included 2,273 children (57% male) ages 0–59 months (median: 4.6 months). The median 1-h gastric emptying was 43% (interquartile range [IQR] 34–54%). The median 3-h gastric emptying was 91% (IQR 79–98%). Sixty-one percent of patients with 1-h gastric emptying value of <50% had 3-h gastric emptying ≥80%. Gastric emptying was significantly faster in children ≤6 months as compared with all older age groups. In each age group, the median gastric emptying decreased with increasing feeding volume. Gastric emptying was significantly faster in patients fed via combined nasogastric tube and oral routes as compared with those fed exclusively orally. There was no significant difference in gastric emptying of children with and without gastroesophageal reflux.
Conclusion Although there are statistically significant differences in gastric emptying based on age, volume and route of feeding, the data suggest that overall normal liquid gastric emptying in infants and children ≤5 years of age is ≥80% at 3 h. One-hour emptying measurements are not reliable for detecting delayed gastric emptying.

Keywords Children · Gastric emptying · Infants · Milk · Normative data · Nuclear medicine · Scintigraphy · Stomach

Introduction

Gastric emptying scintigraphy is a well-established examination in adults with normative values based on standardized protocols and consensus recommendations [1]. This scintigraphic test is also used in infants and children. However, the absence of age-specific norms limits its clinical value. Direct comparison of interinstitutional results is not possible

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because of the lack of standardization of the technique. Every center determines its own acceptable normal range with some guidance from the scarce pediatric literature or even adult data. Use of adult data in particular is problematic, especially in infants and younger children.

To the best of our knowledge, there are no studies reporting age-specific gastric emptying of milk or formula based on scintigraphy (milk scan) in healthy infants and children for obvious ethical reasons. There is a recent report of liquid gastric emptying in 133 healthy children >1 year of age using the C-acetate breath test [2]. There are a few small studies of solid gastric emptying in normal children [3–5]. All other reports of gastric emptying values in children are justifiably in the studies of patients evaluated mainly for gastroesophageal reflux [6–15]. In some of these reports, the study population included a small subset of healthy children over a wide range of ages [6, 7].

Scintigraphic gastroesophageal studies have been used routinely, employing a standardized technique, at Children's National Medical Center (CNMC) to evaluate gastroesophageal reflux and gastric emptying of milk or milk-based formula in infants and children for more than 40 years. The primary objective of this retrospective analysis of the data derived from a very large series of studies in infants and children was to establish age-specific ranges of gastric emptying of cow's milk or milk-based formula in infants and children ≤5 years of age. A secondary objective of the study was to investigate the effects of variables including patient age, feeding volume, feeding route and gastroesophageal reflux on gastric emptying.

Materials and methods

Patients

After obtaining approval from the CNMC Institutional Review Board, we used a radiology information system search engine (Montage Healthcare Solutions, Inc., Philadelphia, PA) to search for gastric emptying studies of infants and children up to 5 years of age, evaluated from January 1990 to August 2012. More than 5,000 studies were identified. Each patient's age, gender and prematurity status as well as the clinical indications for the study, type of feed (milk or formula), volume of feed, route of administration (orally, nasogastric tube, percutaneous gastrostomy tube), percent gastric emptying at 1 h and 3 h, and presence or absence of gastroesophageal reflux were recorded in a database. In an attempt to find cases representing otherwise healthy children, the following groups of patients were excluded: premature infants, patients on metoclopramide, patients with congenital or acquired chronic medical or surgical conditions including chromosomal disorders/syndromes, neurological disorders,

congenital heart diseases, chronic lung disease, congenital diaphragmatic hernia, chronic renal failure, malignancy, bowel pathologies and intra-abdominal/bowel surgeries. All repeat studies, those with missing 1-h or 3-h gastric emptying data, all cases with milk casein formation, those fed via gastrostomy tube and all patients who vomited during the examination were also excluded.

Imaging technique and processing

The following standardized technique was used in all patients for combined gastroesophageal reflux and liquid gastric emptying studies:

The patients fasted for 2 to 4 h depending on their age and the clinical circumstances. Cow's milk or milk-based formula labeled with Tc-99m sulfur colloid (5 μCi/ml with a maximum of 1 mCi) was administered orally or via a nasogastric tube in a volume equal to the customary feeding volume for the child. A large field of view gamma camera equipped with a high-resolution parallel-hole collimator was used for imaging. Initially, patients were positioned supine on the table and dynamic (5 s/frame) posterior images of the chest were obtained for 2.5 min during the oral administration of a few mL of labeled milk/formula, to evaluate for aspiration. The remainder of the labeled milk/formula was then administered orally or via the nasogastric tube. After completion of feeding, dynamic 10-s posterior images of the chest and abdomen were obtained for 60 min to evaluate for gastroesophageal reflux and gastric emptying. Immediately thereafter, an anterior image of the abdomen was obtained to calculate the percent of gastric emptying at 1 h. Two hours later, another anterior image of the abdomen was acquired to calculate the percent of gastric emptying at 3 h. Subsequently, a posterior image of the chest was obtained to evaluate any delayed aspiration of the labeled meal.

Calculating the percent of gastric emptying was simply based on the number of counts in the regions of interest drawn manually over the stomach and over the bowel (Fig. 1) as follows: Percent gastric emptying = counts in the bowel/ (counts in the bowel + counts in the stomach) * 100. No correction was made for any emptying during feeding because gastric emptying measurement at any point in time after completion of feeding should reflect a percentage of the total amount of ingested meal.

Gastroesophageal reflux was graded as mild, moderate or severe based on a combination of the number, level and clearance of all episodes of reflux observed on the dynamic 10-s images.

Statistical analysis

The percent of gastric emptying was recorded as a continuous variable and the distribution of values at 1 h and 3 h were

Fig. 1 Gastric emptying at 1 h (**a**) and 3 h (**b**) after completion of feeding in a 79-day-old girl. The percent of gastric emptying is calculated by the number of counts in the small bowel divided by the total counts in the small bowel and the stomach
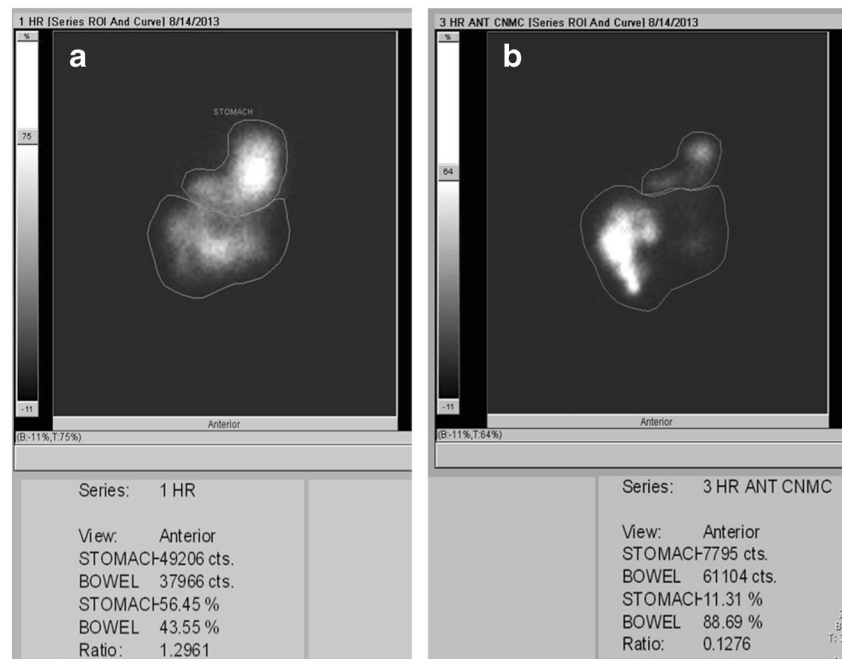
tested for normality. The data were summarized using means (and standard deviation), medians (and interquartile ranges [IQR]) and/or ranges. Because the 3-h values were highly skewed, nonparametric tests were used for all statistical analyses and some of the tables only present the medians and interquartile ranges [16]. The 3-h gastric emptying values were further classified as being ≥80% or <80% based on the guidelines used at CNMC.

Age on the day of exam was calculated in days since birth and used to group children into five age categories: A) 0–3 months (0 to 90 days), B) >3–6 months (91 to 180 days), C) >6–12 months (181 to 365 days), D) >12–24 months (366 to 730 days) and E) >24–60 months (731 to 1,783 days). Feeding volume was recorded to the nearest mL and used to assign children to one of eight feeding volume categories (0–60 mL, 61–90 mL, 91–120 mL, 121–150 mL, 151–180 mL, 181–210 mL, 211–240 mL, >240 mL). Route of feeding was derived from the electronic medical records and children were classified as either being orally fed or fed using a combination of routes (oral + nasogastric tube). The presence/absence and grade of reflux were based on the dynamic images obtained during the gastric emptying study and children were classified as having mild, moderate, severe or no reflux.

The Mann-Whitney test was used to compare gastric emptying values (at 1 h and 3 h, separately) for males and females and by route of feeding (oral versus oral + nasogastric tube). The Kruskal-Wallis test was used to compare gastric emptying values (at 1 h and 3 h, separately) across the five age, eight feeding volume and four reflux status categories.

Because the primary group of interest was children who were orally fed (~90% of the study cohort), children who were

fed using a combination method (oral + nasogastric tube) were excluded from some of the remaining analyses.

Dunn's test (with a Bonferroni adjustment for multiple comparisons) was used to examine gastric emptying values (at each time point) between all 10 possible pairs of age groups of orally fed children. A nonparametric test for trend was used to examine whether gastric emptying values (at each time point) systematically declined across feeding volume categories within each age group of orally fed children.

Receiver operator characteristic (ROC) curve analyses were used to examine the ability of 1-h gastric emptying values to correctly classify patients with "normal" (≥80%) versus "slower than normal" gastric emptying at 3 h in an attempt to identify a cutoff value for 1-h gastric emptying that might obviate the need for delayed imaging.

In order to visualize the effect of feeding volume and age on children who were orally fed (90% of the study cohort), the gastric emptying values were summarized and then plotted for each unique age-feeding subgroup of orally fed children. The 15th, 25th, 50th (median), 75th and 85th percentile values were shown to illustrate how the middle 50% and 70% of observed values were distributed.

Stata 14.1/IC (College Station, TX) was used to conduct all analyses. All statistical tests were two-sided and a *P*-value of less than 0.05 was considered statistically significant.

Results

Of the 5,136 total patients, 2,273 met our inclusion and exclusion criteria and formed the study group. There were 1,292

(57%) males and 981 (43%) females. Age range was 0–59 months with a mean of 9.0 months and median of 4.6 months (IQR 2.1–10.8 months). The median feeding volume was 120 ml (IQR 90–180 ml). Two thousand twenty-seven (89%) patients were fed orally and 246 (11%) patients were fed via a combination of nasogastric tube and oral routes. All except 225 (10%) patients had gastroesophageal reflux.

Distribution of percent gastric emptying at 1 h and 3 h for all patients is shown in Fig. 2. The median and IQR percent gastric emptying values for the entire group, males, females, different age groups, different feeding volumes, oral versus nasogastric route of administration, as well as for patients with and without gastroesophageal reflux are summarized in Table 1. The mean, median and IQR percents of gastric emptying at 1 h and 3 h among all orally fed children, by age and feeding volume, are summarized in Table 2.

The median percent gastric emptying at 1 h and 3 h for the 205 patients who were fed orally and who did not demonstrate gastroesophageal reflux (group closest to normal healthy children) was 43% (IQR 34–52%) and 91% (IQR 81–98%), respectively.

There was no significant difference in gastric emptying between male and female subjects at 1 (P=0.36) or 3 h (P=0.56). There were also no significant differences in gastric emptying in patients with mild, moderate, severe or no gastroesophageal reflux at 1 (P=0.07) or 3 h (P=0.58). Overall median percent gastric emptying at 1 and 3 h was significantly higher for children ≤3 month of age when compared with all other age groups (P<0.01) (Table 3). Children >3–6 months of age also had a significantly higher median percent gastric emptying when compared to all older age groups of children (P<0.05) (Table 3).

Gastric emptying values (at 1 and 3 h) declined across feeding volume categories in each one of the five age groups (Table 2 and Fig. 3). In all instances, these declines were

statistically significant (nonparametric test for trend with P<0.01), except for 1-h gastric emptying values in children >24–60 months old (P=0.12).

In patients who had received part of their feed via nasogastric tube, the median gastric emptying at 1 h and 3 h were significantly higher than in those fed exclusively by mouth (P=0.00) (Table 1).

The relationship between percent gastric emptying at 1 and 3 h for all study patients is shown in Fig. 4 and Table 4. The sensitivities and specificities of different gastric emptying cut-offs to correctly identify patients with normal gastric emptying (≥80%) at 3 h are listed in Table 4.

Discussion

As previously discussed, healthy asymptomatic children cannot be prospectively studied by scintigraphic techniques to establish age-specific gastric emptying ranges. The data presented here are obtained from a retrospective analysis of gastric emptying studies in more than 2,200 children who were derived from a larger pool of more than 5,000 children using very stringent inclusion and exclusion criteria to have a subject population as similar to healthy children as possible. Even though the majority of children did have varying grades of gastroesophageal reflux, the authors believe that the data presented here are a reasonable surrogate for normal gastric emptying ranges of cow's milk or milk-based formula in infants and children ≤5 years of age.

Age

An interesting finding in our study was a significantly higher median percent gastric emptying at 1 and 3 h for children ≤3 months of age when compared with all other age groups and in children >3–6 months of age when compared to all

Fig. 2 Distribution of percent of gastric emptying values at 1 h (a) and 3 h (b) for all children in the study (n=2,273)
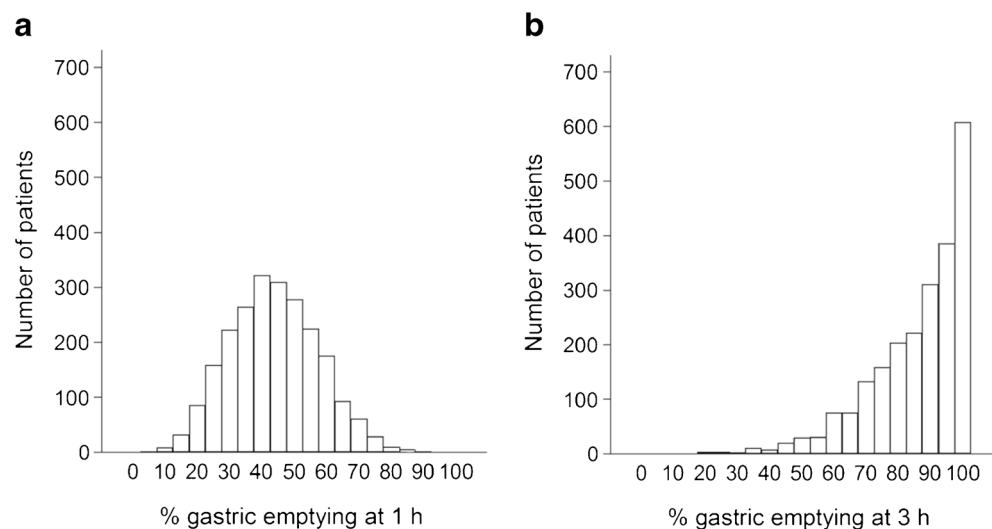
Table 1 Percent gastric emptying at 1 h and 3 h among all study patients

	n	% gastric emptying at 1 h			% gastric emptying at 3 h		
		Median	IQR	P^a	Median	IQR	P^a
Total	2,273	43	34-53	NA	90	78–98	NA
Gender				0.36			0.56
Male	1,292	43	33–53		90	78–98	
Female	981	44	34–53		91	78–98	
Age group				0.00			0.00
0–3 months	828	46	37–56		94	83–99	
>3–6 months	508	42	32–51		91	79–98	
>6–12 months	424	42	31–53		90	76–97	
>12–24 months	300	40	31–50		86	72–95	
>24–60 months	213	42	35–49		86	75–93	
Feeding volume				0.00			0.00
≤60 mL	240	51	40–59		96	86–99	
61–90 mL	441	50	41–58		95	88–99	
91–120 mL	522	44	37–53		92	82–99	
121–150 mL	267	43	33–51		91	79–97	
151–180 mL	305	38	30–47		85	72–95	
181–210 mL	151	37	30–46		83	73–92	
211–240 mL	264	35	28–46		81	67–90	
>240 mL	83	41	31–46		77	68–91	
Route of feeding				0.00			0.00
Oral	2,027	42	33–52		90	77–98	
Oral + NG	246	48	39–57		93	86–99	
Reflux status				0.07			0.58
Absent	225	43	34–52		91	81–98	
Mild	1,105	43	33–53		90	78–98	
Moderate	535	43	34–52		91	77–98	
Severe	408	44	35–55		91	78–98	

IQR interquartile range, *NA* not applicable, *NG* nasogastric tube

[a] The Mann-Whitney test was used for two-group comparisons (gender and route of feeding). The Kruskal-Wallis test was used to compare age, feeding volume and reflux status categories. *P*-values <0.05 were considered statistically significant

older age groups of children (Table 2). This may be due to the fact that all infants ≤6 months of age were fed baby formula while older infants and children were fed cow's milk. This finding contradicts previously published reports. Seibert et al. [9], using Tc-99m sulfur colloid-labeled milk, reported 1-h gastric emptying of 48% (±16% standard deviation [SD], range: 32–64%) in 41 patients 1–23 months of age and 51% (±7% SD, range: 44–58%) in 8 children ≥2 years. Rosen and Treves [10] used dextrose and water labeled with Tc-99m sulfur colloid in 126 pediatric patients and reported 1-h gastric emptying of 19–73% in 76 children ≤2 years of age and 53–89% in 50 children >2 years. Di Lorenzo et al. [11] evaluated gastric emptying in 477 infants and children, using milk in infants younger than 1 year old and pudding in those ≥1 year

old. Their data show faster gastric emptying in children older than 1 year as compared with those younger than 1 year of age. The reason for this discrepancy is not entirely clear. It may be related to a relatively smaller number of patients in the reviewed studies as compared to our study. However, differences between the type and amount of meal as well as age distribution of the study groups may also be contributory.

Feeding volume

Our data reveal a trend for slower gastric emptying with increased feeding volume in each age group (Table 2 and Fig. 3). We are not aware of any previously published study that shows the effect of feeding volume on gastric emptying of

Table 2 Percent gastric emptying at 1 h and 3 h among all orally fed children, by age and feeding volume

Age (in months), feeding volume	n	% gastric emptying at 1 h			% gastric emptying at 3 h		
		Mean (SD)	Median (IQR)	Range	Mean (SD)	Median (IQR)	Range
0–3 months							
≤60 mL	138	48 (14)	50 (39–58)	17–85	90 (13)	96 (84–100)	47–100
61–90 mL	260	49 (12)	50 (41–58)	23–86	92 (11)	95 (88–99)	43–100
91–120 mL	213	45 (13)	43 (37–53)	13–82	88 (13)	92 (81–99)	37–100
121–150 mL	59	42 (11)	43 (33–47)	21–71	85 (13)	87 (77–96)	46–100
151–180 mL	44	35 (11)	36 (29–43)	15–59	77 (19)	80 (71–94)	35–100
181–210 mL	8	36 (15)	37 (24–43)	18–66	76 (17)	76 (63–91)	52–96
211–240 mL	11	32 (12)	30 (21–36)	18–54	73 (20)	75 (53–94)	45–100
>240 mL	0	NA	NA	NA	NA	NA	NA
>3–6 months							
≤60 mL	22	51 (15)	52 (38–65)	28–76	94 (7)	98 (88–100)	77–100
61–90 mL	70	48 (12)	47 (41–55)	21–78	91 (11)	96 (87–100)	59–100
91–120 mL	139	43 (13)	43 (33–50)	16–82	88 (14)	92 (81–99)	34–100
121–150 mL	76	41 (13)	41 (32–47)	10–72	87 (13)	91 (81–97)	37–100
151–180 mL	94	37 (12)	35 (28–45)	13–72	81 (15)	80 (72–92)	26–100
181–210 mL	28	35 (13)	32 (29–45)	14–68	78 (17)	81 (66–93)	31–100
211–240 mL	33	35 (10)	33 (26–42)	17–54	83 (12)	83 (78–92)	62–100
>240 mL	2	45 (1)	45 (44–46)	44–46	99 (1)	99 (98–100)	98–100
>6–12 months							
≤60 mL	6	45 (10)	44 (39–55)	30–55	91 (12)	96 (85–99)	70–100
61–90 mL	29	51 (16)	49 (40–59)	24–92	90 (12)	95 (83–100)	57–100
91–120 mL	60	49 (15)	50 (40–60)	7–83	90 (12)	96 (84–99)	37–100
121–150 mL	58	42 (16)	43 (29–51)	12–76	85 (15)	91 (77–96)	42–100
151–180 mL	86	41 (14)	40 (32–49)	9–81	83 (17)	90 (72–96)	19–100
181–210 mL	61	38 (12)	35 (29–45)	15–67	79 (15)	78 (70–91)	37–100
211–240 mL	64	37 (14)	36 (26–45)	14–78	78 (15)	80 (68–90)	25–100
>240 mL	7	28 (11)	27 (16–37)	16–47	66 (27)	74 (40–91)	20–95
>12–24 months							
≤60 mL	5	49 (16)	48 (46–55)	27–70	84 (16)	90 (73–94)	62–99
61–90 mL	15	52 (14)	49 (38–62)	34–78	92 (10)	96 (88–100)	68–100
91–120 mL	46	47 (13)	46 (38–58)	21–70	90 (9)	94 (84–99)	67–100
121–150 mL	37	45 (14)	43 (33–55)	20–75	88 (12)	92 (79–98)	51–100
151–180 mL	40	40 (12)	41 (30–51)	10–62	82 (16)	83 (72–96)	38–100
181–210 mL	28	40 (10)	41 (32–47)	16–59	83 (12)	88 (76–91)	48–100
210–240 mL	72	34 (13)	33 (24–41)	11–83	74 (17)	74 (64–88)	26–100
>240 mL	20	31 (11)	31 (24–41)	12–48	70 (18)	68 (60–85)	31–100
>24–60 months							
≤60 mL	1	59 (NA)	59 (59–59)	59–59	97 (NA)	97 (97–97)	97–97
61–90 mL	0	NA	NA	NA	NA	NA	NA
91–120 mL	8	42 (10)	40 (36–48)	28–58	84 (11)	83 (76–92)	69–99
121–150 mL	23	48 (9)	49 (42–54)	27–66	88 (11)	90 (83–97)	58–100
151–180 mL	21	41 (13)	38 (34–44)	24–72	85 (13)	88 (81–94)	48–98
181–210 mL	18	41 (9)	44 (35–50)	21–52	87 (7)	87 (84–93)	73–96
210–240 mL	71	40 (13)	40 (32–49)	11–74	82 (12)	83 (71–92)	56–100
>240 mL	54	43 (10)	43 (38–48)	19–72	80 (15)	81 (70–93)	39–100

IQR interquartile range, *NA* not applicable, *SD* standard deviation

A nonparametric test for trend was used to examine whether gastric emptying values declined across feeding volume categories. *P*-values <0.05 were considered statistically significant. In all instances, *P*<0.01 except for the 1-h values in >24- to 60-month-old children (*P*=0.12)

milk in infants and children using scintigraphic techniques. However, Schmitz et al. [17] used magnetic resonance imaging (MRI) to measure gastric emptying halftime of diluted raspberry juice in 14 healthy volunteer children, 8–12 years old. Each child was studied twice within a week, once with a feeding volume of 3 mL/kg body weight and once with 7 mL/kg. The study found no difference in emptying halftime between the two studies in each patient [17].

Feeding route

All study subjects consumed their test meal by mouth except 246 patients in whom part of their meal was administered through a nasogastric tube because they were either unable or unwilling to drink an age-appropriate volume of formula/milk within approximately 10 min. Our data show faster gastric emptying at 1 h (*P*=0.00) and 3 h (*P*=0.00) in those fed

part of their meal by nasogastric tube as compared with those fed exclusively by mouth (Table 1). This is in concordance with the result of the study by Chen et al. [12]. The reason for faster gastric emptying with nasogastric tube feeding is not clear. The most reasonable explanation seems to be an inadvertent slightly distal position of the tube in the antropyloric region in some patients, although feeding through a nasogastric tube is always monitored on the persistence scope of the gamma camera and the tube is withdrawn if it appears to be more distally positioned.

Gastroesophageal reflux

The relation between gastric emptying and gastroesophageal reflux remains controversial. In the present study, we did not find any significant difference between gastric emptying of the patients with mild, moderate, severe or no gastroesophageal reflux regardless of the feeding route (Table 1). Seibert et al. [9] reported no firm association between gastroesophageal reflux and delayed emptying in 49 infants and children, 15 with and 34 without gastroesophageal reflux. Rosen and Treves [10] also found no association between gastroesophageal reflux and the rate of gastric emptying. Di Lorenzo et al. [11] reported no difference between gastric emptying of patients with or without gastroesophageal reflux in children <3 years of age. However, in children older than 6 years they found significantly delayed gastric emptying in those with reflux compared with those without reflux [11]. On the other hand, studies by Hillemeier et al. [13] and Aktas et al. [14] found that patients with high-grade gastroesophageal reflux had prolonged gastric emptying. Another recent study, by Argon et al. [15], of 108 patients found that gastric emptying was not delayed in patients with one or two reflux episodes, although for patients with three or more reflux episodes, gastric emptying time was prolonged. They also found a mild statistical correlation between the number of reflux episodes and gastric emptying halftime in patients with gastroesophageal reflux and concluded that the relationship between gastroesophageal reflux and delayed gastric emptying could not be ignored. Their results supported delayed gastric emptying to be a pathogenetic factor in gastroesophageal reflux in infants and children [15].

1-h versus 3-h gastric emptying

The standardized technique used at CNMC is different from the techniques described for measuring gastric emptying of milk/formula in previously published reports. At CNMC, both the 1-h and 3-h gastric emptying are measured, and a 3-h result of less than 80% is consistent with delayed gastric emptying. The cutoff of 80% is based on our institutional experience, but is also validated by the range of 3-h gastric emptying (median: 91%, IQR 81–98%) in the group of 205 orally fed patients who did not demonstrate gastroesophageal reflux in this study, perhaps the group closest to normal children.

Gastric emptying in children during the first hour after feeding, as it is used in the previously published reports, is quite variable and may not be a reliable measure of gastric emptying. Among our study subjects, 930 of 1,515 (61%) who had "slow" 1-h gastric emptying of <50% exhibited 3-h emptying of ≥80% (Fig. 4). The limited utility of 1-h gastric emptying measurement has also been reported by Gelfand and Wagner [8].

In an attempt to find the 1-h gastric emptying level(s) that would exclude delayed gastric emptying and obviate the need for further delayed imaging, we compared the 1-h gastric emptying of all study patients at selected cutoffs with their 3-h gastric emptying (Table 4 and Fig. 4). Table 4 shows the results of the ROC analyses and Fig. 4 is a visual display of

Table 3 Percent gastric emptying at 1 h and 3 h for different age groups of orally fed children

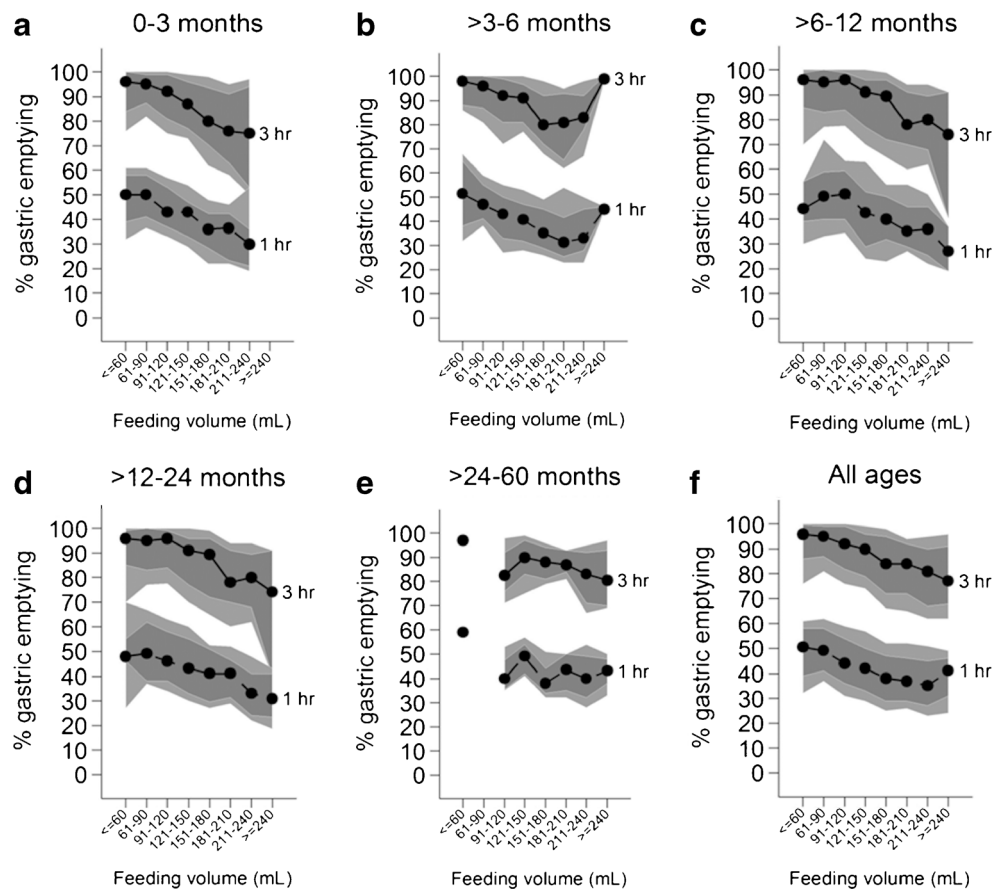| Age group	n	% gastric emptying at 1 h			% gastric emptying at 3 h		
		Median	IQR	P^a	Median	IQR	P^a
0–3 months	828	46	37–56	<0.01[b]	94	83–99	<0.01[b]
>3–6 months	508	42	32–51		91	79–98	<0.05[c]
>6–12 months	424	42	31–53		90	76–97	
>12–24 months	300	40	31–50		86	72–95	
>24–60 months	213	42	35–49		86	75–93	

IQR interquartile range

[a] Dunn's test (with a Bonferroni adjustment for multiple comparisons) was used to examine all ten possible pair-wise age group comparisons at 1 or 3 h. P-values <0.05 were considered statistically significant. Nonsignificant values are not shown

[b] Values were higher among 0- to 3-month-old children when compared to each of the four older age groups

[c] Values were higher among >3- to 6-month-old children when compared to each of the three older age groups

Fig. 3 Distribution of gastric emptying values at 1 and 3 h in each age group with different feeding volumes. *Black circles* depict the median values. *Dark gray areas* indicate the 25th to 75th percentile boundaries. *Light gray areas* indicate the 15th to 85th percentile boundaries. Note the trend for slower gastric emptying with increasing feeding volume

the relationship between gastric emptying at 1 h and at 3 h. The data show that 731 of 758 (96.4%) patients who had 1-h gastric emptying of ≥50% and nearly all of those with 1-h emptying of ≥60% exhibited 3-h emptying of ≥80% (Fig. 4). Therefore, 1-h gastric emptying of ≥50% appears to

Fig. 4 Relationship between 1-h and 3-h gastric emptying values of 2,273 patients with dividing boundaries at 50% for 1-h and 80% for 3-h values: The number of patients in each quadrant is listed. Note 731 of 758 (96.4%) children with 1-h gastric emptying of ≥50% had a 3-h gastric emptying of ≥80%. But 930 of 1,515 (61.4%) patients with 1-h gastric emptying of <50% also had a 3-h gastric emptying of ≥80%

be acceptable as normal gastric emptying and may reduce or obviate the need for further delayed imaging.

The significance of fast gastric emptying in children is not clear except for dumping syndrome. This rare disorder is easily detected by inspecting dynamic 10-s images.
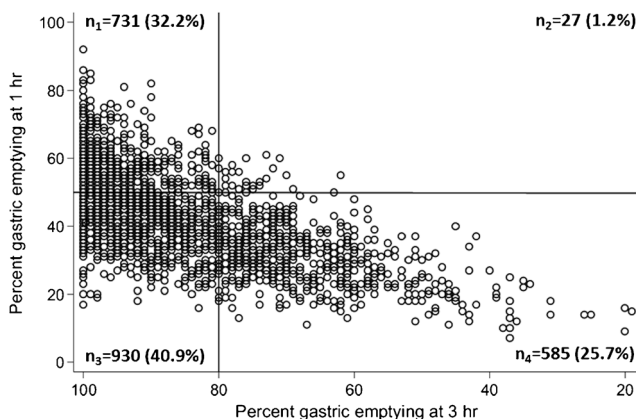
Limitations of the study

There are some limitations to our study, primarily its retrospective nature. Another limitation is the use of either cow's

Table 4 Ability of different 1-h gastric emptying cutoffs to correctly identify patients with "normal" gastric emptying (≥80%) at 3 h

1-h gastric emptying cutoff	Sensitivity	Specificity
≥65%	9.5%	100.0%
≥60%	17.0%	99.5%
≥55%	29.2%	98.4%
≥50%	44.0%	95.6%
≥45%	59.9%	91.2%
≥40%	77.7%	81.9%
≥35%	87.2%	65.4%
≥30%	93.6%	45.1%
≥25%	98.3%	25.8%

milk or milk-based formula as the meal, although the majority of our patients (all patients younger than 6 months of age) did receive formula rather than cow's milk. In addition, in the ambulatory patients (but not in infants), remaining in the supine position for 1 h after feeding is not entirely physiological and may have affected gastric emptying.

Conclusion

Gastric emptying in infants and children is related to age, feeding volume and route of administration. There appears to be no correlation between gastroesophageal reflux and gastric emptying. The tabulated age-specific gastric emptying range in this large series may serve as a reasonable surrogate for normal values of gastric emptying of milk/formula. We suggest ≥80% as a cutoff value for normal 3-h gastric emptying with milk in infants and children up to 5 years of age. One-hour emptying measurements may not be reliable for detecting delayed gastric emptying.

Compliance with ethical standards

Conflicts of interest   None

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