

MEASURING GASTROINTESTINAL PARAMETERS

Background of the Invention

Field of the Invention

The present invention relates to the methods of measuring the
5 concentration of dietary formula in gastric content, gastric residual volume,
volume of dietary formula remaining in the stomach and volume of gastric
juice in stomach.

Description of the Prior Art

Enteral nutrition is generally preferred over parenteral nutrition
10 because of its lower cost, lower rate of complications, and effective
preservation of gut structure and function. Many critically ill patients do
not tolerate nasogastric tube feeding, developing manifestations of
intolerance including nausea, vomiting, abdominal distension, and
aspiration.^{1,2} Gastric residual volumes, obtained by the use of nasogastric
15 tube aspiration, are widely used to evaluate feeding tolerance and gastric
emptying. High gastric residual volumes raise concern about intolerance
to gastric feeding and the potential risk for regurgitation and aspiration
pneumonia.^{2,3} Values of gastric residual volumes cited as being high in
patients receiving nasogastric feeding typically range from 75 to 500 mL.⁴⁻⁷
20 Yet, many nurses, dietitians, and physicians use aspirated gastric residual
volumes as dogma and stop enteral feedings regardless of clinical status, if
values exceed the designed cutoff level.^{8,9}

However, the traditional practice of gastric residual volume does not
take into account the fact that the fluids accumulate in the stomach of the
25 patient on nasogastric tube feeding include not only the tube feeding

formula itself, but also swallowed saliva and gastric secretions.⁸ Gastric residual volumes alone cannot distinguish the additional volume of endogenous secretions in a patient who is effectively emptying the volume of exogenous feeding. Therefore, using of aspirated gastric residual
5 volumes as a monitor for gastric emptying is limited by poor sensitivity and inability to aspirate the complete volume of gastric contents. Moreover, traditional use of aspirated gastric residual volumes is insensitive and cannot distinguish the components of retained enteral formula from the large volume of naturally occurring endogenous secretions. Several
10 reports have shown that aspirated gastric residual volumes are poorly correlated with gastric emptying, incidence of regurgitation, and risk of pulmonary aspiration.^{8,9,10}

As a result, there is a need to develop methods to monitoring the dietary formula concentration, true gastric residual volumes, and volume of
15 gastric content in stomach for patients receiving nasogastric feeding.

Brief Description of the Drawings

Figure 1 shows the mathematical basis of dietary formula concentration calculation. Since the Brix values of polymeric diet had a
20 linear additive relationship with the diet formula concentration ($R^2 = 0.99$), which allows to obtain the equation for dietary formula concentration calculation.

Figure 2 shows the mathematical basis of gastric residual volume calculation. Before water dilution, we set the calculated gastric
25 residual volume as Vol.1, % full strength polymeric diet as % Conc.1, and the Brix value of gastric contents as BV1. After 30 mL water dilution in the stomach, we set the gastric volume as Vol.2, % full strength polymeric diet as % Conc.2, and

the Brix value of gastric content as BV2.

Figure 3 shows the mathematical basis of equation and example of dietary formula volume remaining in stomach calculation.

5 Figure 4 shows the monitor of continuous nasogastric tube feeding by the use of Brix value determination and residual volume measurement.

Description of the Invention

10 The Brix value is a measurement of total soluble solids by the use of refractometer in solution which is constant for a pure substance under standard conditions of temperature and pressure. The Brix value correlates closely with the molar fractions of the components. In other words, the overall Brix value of a mixed solution approximates the additive sum of the Brix values of its individual components. Brix values have been used in a number of clinical settings to determine the concentration of
15 mixed substances such as drugs, food, fruit juices, and parenteral nutrition solutions. This refractive method for food content estimation is promising because it produces precise readings with only minimal variability. Furthermore, Brix value measurement is rapid, simple, reproducible, inexpensive, and appropriate for routine bedside monitoring of food
20 content.

Unexpectedly, it is found in the invention that the dietary formula concentration, gastric residual volume, and volume of gastric content in stomach can be measured through Brix value.

Method of Measuring the Concentration of Dietary Formula

The invention provides a method of measuring the percent concentration of dietary formula in gastric content, which comprises the steps of i) infusing dietary formula to the stomach of a subject, ii) obtaining the gastric content over an appropriate time after infusing and measuring BV thereof, and iii) obtaining the percent concentration of dietary formula in the gastric content through the equation: percent concentration of dietary formula = Brix value / slope value; wherein the slope value is obtained from making serial dilutions of the dietary formula to obtain a series of concentrations of the dietary formula, measuring the Brix values of the resulting concentrations of the dietary formula, and then using said resulting concentrations and Brix values to obtain a slope value from a simple regression analysis. Preferably, the slope value is 0.24.

The preferred embodiment of the method of the invention is shown in Figure 1.

According to the invention, any dietary formula can be used in the method of the invention. Preferably, the dietary formula is the dietary formula for gastric tube feeding. More preferably, the dietary formula is liquid dietary formula.

According to the invention, any ranges of the concentration of dietary formula can be monitored by the method of the invention. That is, 0-100% of the dietary formula can be monitored by refractometry.

It is surprisingly found in the invention that the percent concentration of dietary formula in the gastric content are not affected by the body secretions, pH value, temperature and the time of the dietary formula in stomach. The percent concentration of dietary formula also exhibits a linear relationship with the Brix value. The percent concentration of

dietary formula in the gastric content also can be measured through the equation: percent concentration of dietary formula = Brix value /slope value, wherein the slope value is obtained from a simple regression analysis known in the art.

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Method of Measuring the Gastric Residual Volume

The present invention provides a method of measuring the volume of gastric residual volume, which comprises the steps of:

- i) determining the Brix value of said gastric residual volume to obtain a BV1,
- ii) adding appropriate volume of water to said gastric residual volume to form a mixed gastric content,
- iii) infusing said mixed gastric content to the stomach,
- iv) aspirating the resulting gastric content from the stomach,
- v) determining the Brix value of said resulting gastric content to obtain a BV2, and
- vi) obtaining the volume of gastric content through the following equation:

$$\text{BV1} \times \text{said added volume of water} / (\text{BV1} - \text{BV2}) .$$

The preferred embodiment of the method of the invention is shown in the below Figure 2.

According to the invention, any appropriate technique or device can be used in the measurement of Brix value. Preferably, the Brix value can be measured by refractometer.

According to the invention, the “gastric residual volume” refers to dietary formula, body secretions (such as gastric juice and saliva) and the

mixtures thereof.

According to the invention, the “appropriate volume of water” refers to the water used to dilute the gastric content. Preferable, the volume of water ranges from 10 mL to 500 mL.

5 Surprisingly, it is found in the invention that the Brix value measurement may be a new tool to measure the calculated gastric residual volume. The Brix value of the resulting gastric content is measured in vitro to obtain a BV1. The resulting gastric content is added an appropriate volume of water to obtain a mixed gastric content. The
10 resulting mixed gastric content is infused to the stomach of the subject. Then, the gastric content is aspirated from the stomach of the patient again and then the Brix value of the gastric content is measured to obtain a BV2. The equation for obtaining the volume of gastric content can be derived from the following calculation formula:

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$$\begin{aligned} & \text{BV1} \times \text{volume of gastric content before dilution} = \text{BV2} \times (\text{volume} \\ & \text{of gastric content before dilution} + \text{added water volume}) \\ & \text{BV1} \times \text{volume of gastric content} = \text{BV2} \times \text{volume of gastric} \\ & \text{content} + \text{BV2} \times \text{added water volume} \\ 20 & \text{BV1} \times \text{volume of gastric content} - \text{BV2} \times \text{volume of gastric} \\ & \text{content} = \text{BV2} \times \text{added water volume} \\ & \text{volume of gastric content before dilution} \times (\text{BV1} - \text{BV2}) = \text{BV1} \\ & \times \text{added water volume} \\ & \text{volume of gastric content} = (\text{BV2} \times \text{added water volume}) / (\text{BV1} \\ 25 & - \text{BV2}) \end{aligned}$$

As a result, the volume of gastric content can be obtained through the equation: “(BV2 × added water volume) / (BV1 – BV2) ”.

Method of Measuring the Dietary Formula Volume Remaining and
30 **Gastric Juice Volume in Stomach**

The invention provides a method of measuring the dietary formula volume remaining in the stomach, which comprises multiplying the calculated gastric residual volume of the invention by % full strength of dietary formula.

5 According to the invention, the calculated gastric residual volume can be obtained from the method of measuring the gastric residual volume of the invention (as described herein above). According to the invention, any dietary formula can be used in the method of the invention. Preferably, the dietary formula is the dietary formula for nasogastric tube
10 feeding. More preferably, the dietary formula is polymeric formula. The formula volume remaining in the stomach formula can be calculated through the equation: "the volume remaining in the stomach = calculated gastric residual volume $\times$ % full strength of dietary formula". The preferred embodiment of the method of the invention is shown in below
15 figure 3.

The invention further provides a method of measuring gastric juice volume in stomach, which comprises subtracting the dietary formula volume remaining in the stomach from gastric residual volume. The dietary formula volume remaining in the stomach can be obtained as
20 described herein above.

The true gastric residual volume is determined by the dynamic balance between input from infused formula and endogenous secretions, and output related to gastric emptying. On the average, endogenous secretions contribute 1500 mL of salivary secretions and 3000 mL of
25 gastric juice per day. Therefore, developing a method to determine total volume of contents in the stomach and a system to differentiate the exact volume of the component of formula in that mixed solution of gastric

contents might have a place in evaluation of treatment in patients receiving gastric tube feeding. The gastric secretion in stomach was estimated using the equation:

$$\begin{array}{l} 5 \qquad \text{Gastric secretion volume in stomach (i.e. gastric juice)} = \\ \qquad \text{Calculated gastric residual volume} - \text{Volume of dietary formula} \\ \qquad \text{remaining} \end{array}$$

Utility

The invention surprisingly found that i) dietary ranges of nutrients
10 (such as carbohydrate, protein, and fat) could be monitored by refractometry, ii) Brix value is linear additive function of the concentration of nutrients present in a solution and iii) Brix values correlated excellently with the concentrations of diet formula regardless of pH, temperature, and the types of solutions. Taken together, the invention indicates that the
15 Brix value can be used clinically and in research to monitor dietary formula concentrations, and therefore be used in clinical practice to evaluate dietary formula during storage, preparation, and administration.

The invention uses the Brix value measurement of gastric contents to monitor both gastric residual volume and food content in patients receiving
20 nasogastric feeding. Surprisingly, it is found in the invention that the Brix value measurement of gastric juice may be a new tool for monitoring of gastric emptying in patients receiving nasogastric feeding, providing complementary information to traditional use of aspirated gastric residual volume.

25 In the invention, the Brix value measurements for various dilutions of the polymeric diet have minimal variability in vitro. This simple method of the invention permits bedside measurements with a high degree of reproducibility. On the other hand, saliva and gastric secretions have few dissolved substances and therefore have correspondingly low Brix

value, close to that distilled water. Therefore, it is possible to determine whether gastric contents are comprised predominately of diet formula or digestive secretions in patients receiving polymeric diet feeding.

Application of this Brix value measurement of gastric contents would be useful for clinical practice, complementing the use and interpretation of gastric residual volumes, particularly for management of patients receiving nasogastric tube feeding. Gastric residual volume is determined by the dynamic balance between input (endogenous saliva plus gastric juice and exogenous formula) and output (gastric emptying) from the stomach. A low Brix value (especially if there is a steady decrease following bolus infusion) indicates a low concentration of formula remaining and implies adequate emptying of formula from the stomach. This may be confirmed using the dilution technique and the change in Brix value to determine calculated gastric residual volume and specific volume of formula remaining.

A patient carrying a low gastric residual volume associated with low food retention (low Brix value reading) would be interpreted to indicate that the formula is being emptied appropriately, and that there is no retention within the stomach. The risk for aspiration in the presence of low gastric residual volumes would be expected to be minimal, and the patient would be perceived as tolerating feeds. On the other hand, high gastric residual volume associated with high food retention would indicate the presence of delayed gastric emptying, an increased volume of gastric contents as a result of formula being retained in the stomach, and true feeding intolerance. However, patients carrying a low gastric residual volume but showing evidence of high food retention might be interpreted as having evidence of gastric dysmotility. In that case, the low gastric

residual volume might represent a false negative screening monitor caused by the fact that the tip of the feeding tube is not in the pool of gastric juice, or the tip of feeding tube is adherent to the gastric mucosa. Low food retention by several Brix value determinations in a patient with high gastric residual volumes, may give some assurance that formula is being emptied effectively from the stomach. The high gastric residual volumes would thus represent a false positive screening monitor. Feeds could be continued as close clinical assessment is continued.

Certainly the greatest strength of refractometry is its minimal expense and ease of utilization. The assets of refractometry may be two-fold. Minimal change in the Brix values over time following bolus of feeding may highlight or identify poor gastric emptying, that could be missed by traditional use of aspirated gastric residual volumes. Secondly, the dilution techniques of refractometry may provide confirmation or a double-check of the true gastric residual volume and/or the specific volume of enteral formula remaining in the stomach. Serial Brix value measurements may ultimately have greatest application in patients with nausea, vomiting, and early satiety, as a simple clinical test for gastric emptying. Brix value measurements may be used for monitoring of residual food content in the stomach for clinical application.

The following Examples are offered by way of illustration and not by way of limitation.

EXAMPLES

Example 1 Use of Brix value to Monitor Dietary Formula
Concentration in Gastric Juice

Materials and Methods

Brix values for nutrients such as minerals, vitamins mixtures, carbohydrate, protein, fat, and polymeric diet were determined with a refractometer (N.O.W 507-1, Nippon Optical Works; Tokyo, Japan). A solution of minerals (Ringer' s solution) was obtained from YF Chemical Corporation (Taipei, Taiwan), and consisted of sodium chloride (8.6 mg/ml), potassium chloride (0.3 mg/ml), and calcium chloride (0.33 mg/ml). Vitamins (Lyo-povigen, a parenteral vitamin mixture) was also obtained from YF Chemical Corporation (Taiwan), and contained vitamin A palmitate (12 IU/ml), vitamin D2 (1 IU/ml), vitamin E (0.005 IU/ml), vitamin C (0.5 mg/ml), vitamin B1 (0.05 mg/ml), vitamin B2 (0.01 mg/ml), vitamin B6 (0.015 mg/ml), niacinamide (0.1 mg/ml), and d-panthenol (0.025 mg/ml). Carbohydrate (Carb-aid, Corn starch) and protein (Whey-aid, lactoalbumin) were purchased from Nutritec-Enjoy Nutrition Center, Taiwan. Fat (Intralipid) was purchased from Frenius Kabi AB, Uppsala, Sweden. Fullstrength polymeric diet (Osmolite HN, Ross, OH, USA) contained carbohydrate (17 g/100 ml), protein (5.3 g/100 ml), and fat (4.1 g/100 ml).

Statistical analysis

Results are presented as the mean $\pm$ SEM. Correlation coefficients following linear regression analysis were used to evaluate the relationship between Brix values and dietary formula concentrations. Differences were considered statistically significant when $P < 0.05$.

Results

Brix values of nutrients

The Brix values of nutrients and dietary formula are listed in Table 1.

Distilled water, minerals, and vitamins contained little dissolved material

and had correspondingly low Brix values of 0 ± 0 , 1.2 ± 0.1 , and 0.4 ± 0.1 , respectively. On the other hand, carbohydrate (17 g/100 ml), protein (5.3 g/100 ml), fat (4.1 g/100 ml), and full-strength polymeric diet had high concentrations of dissolved nutrients and correspondingly high Brix values of 12.1 ± 0.6 , 6.5 ± 0.1 , 6.0 ± 0.1 , and 23.5 ± 0.1 , respectively.

Table 1 Brix values of nutrients

Nutrient	Brix value (% Brix)
Distilled water	0 ± 0
Minerals (Ringer's solution)	1.2 ± 0.1
Vitamins (parenteral vitamin mixture)	0.4 ± 0.1
Carbohydrate (17 g/100ml)	12.1 ± 0.6
Protein (5.3 g/100ml)	6.5 ± 0.1
Fat (4.1 g/100 ml)	6.0 ± 0.1
Polymeric diet (full-strength)	23.5 ± 0.1

Results presented are mean $\pm$ SD. Polymeric diet (Osmolite HN).

We investigated whether the molar refractivities in solution of mixed nutrients were additive. Three concentrations (50%, 100% and 200%) of each pure Brix values of nutrients are additive in a mixture Table 2 shows Brix values of pure nutrients (such as carbohydrate, protein, and fat) and mixtures of these. Three dilutions (50%, 100% and 200% of the starting concentration) of carbohydrate, protein, and fat were made with distilled water. Brix value was a linear additive function of the solute concentration, regardless of whether the solute was carbohydrate, protein, or fat.

Table 2 Brix values of pure and mixed nutrients

Nutrient	Brix value (% Brix)
Carbohydrate (5.3 g/100ml)	4.8 ± 0.6
Carbohydrate (17 g/100ml)	12.4 ± 0.6
Carbohydrate (34 g/100ml)	25.8 ± 0.6
Protein (2.6 g/100 ml)	3.1 ± 0.1
Protein (5.3 g/100ml)	6.3 ± 0.1
Protein (10.5 g/100 ml)	11.4 ± 0.1
Fat (2.1 g/100ml)	3.1 ± 0.1
Fat (4.1 g/100ml)	6.0 ± 0.1
Fat (8.2 g/100ml)	11.9 ± 0.1
Carbohydrate ^a + protein ^b	19.2 ± 0.1
Carbohydrate ^a + protein ^b + fat ^c	23.0 ± 0.1

^aCarbohydrate: 17 g/100 ml.

^bProtein: 5.3 g/100 ml.

^cFat: 4.1 g/100 ml. Results presented are mean $\pm$ SD.

For nutrient solutions, consisting of some combination of

carbohydrate (17 g/100 ml), protein (5.3 g/100 ml), and fat (4.1 g/100 ml), Brix value was also an additive function of the component concentration. For example, a mixture of carbohydrate (17 g/100 ml) and protein (5.3 g/100 ml) had a Brix value of 19.2 ± 0.1 , and a mixture of carbohydrate (17 g/100 ml), protein (5.3 g/100 ml), and fat (4.1 g/100 ml) had a Brix value of 23.0 ± 0.1 , which was close to the Brix value (23.5 ± 0.1) of full-strength polymeric diet.

Brix values of nutrients at various pHs and temperatures Table 3 shows the effect of pH on the Brix value of serially diluted polymeric diet formula. Invariably, Brix values correlated excellently with the polymeric diet formula concentration at each pH ($P < 0.001$). However, the Brix values of the polymeric diet formula were lower at pH 1 and 4 than at pH 7 and 8. The decrease of Brix value may be due to the protein denaturation that occurs in very acid solutions. Table 4 shows the effect of temperature on the Brix values of serially diluted polymeric diet formula. The Brix values correlated excellently with the concentrations of diet formula at all temperatures investigated ($P < 0.001$).

Table 3 Brix values of polymeric diet at various pH values

pH	% Full-strength polymeric diet						R^2
	0	12.5	25	50	75	100	
pH 1	0 ± 0	3.2 ± 0.1	5.0 ± 0.1	9.6 ± 0.8	13.1 ± 0.1	17.2 ± 0.1	0.98
pH 4	0 ± 0	2.1 ± 0.1	4.2 ± 0.2	9.0 ± 1.0	12.4 ± 0.3	18.8 ± 0.1	0.98
pH 7	0 ± 0	3.0 ± 0.1	6.1 ± 0.1	12.3 ± 0.1	17.9 ± 0.1	23.8 ± 0.1	1.00
pH 8	0 ± 0	3.0 ± 0.1	6.1 ± 0.1	12.3 ± 0.1	17.8 ± 0.2	23.4 ± 0.1	0.99

Brix values (% Brix) of polymeric diet (Dantrolene 11%) diluted in distilled water and pH adjusted to different values. Results are presented as means $\pm$ SEM.

Table 4 Brix values of polymeric diet at various temperatures

Temp	% Full-strength polymeric diet						R^2
	0	12.5	25	50	75	100	
4°C	0 ± 0	3.2 ± 0.1	6.1 ± 0.2	12.0 ± 0.1	17.8 ± 0.4	23.4 ± 0.1	0.99
25°C	0 ± 0	3.0 ± 0.1	6.0 ± 0.1	12.0 ± 0.2	17.8 ± 0.2	23.2 ± 0.1	0.99
37°C	0 ± 0	3.0 ± 0.1	6.1 ± 0.1	12.1 ± 0.1	18.3 ± 0.1	23.5 ± 0.1	0.99

Brix values (% Brix) of polymeric diet (Dantrolene 11%) diluted in distilled water equilibrated to different temperatures. Results are presented as means $\pm$ SEM.

Brix values of polymeric diet in fasting gastric juice Table 5 shows

the effect of gastric juice dilution on the Brix value of the polymeric diet formula. The Brix value measurements of polymeric diet in fasting gastric juice were made at 5, 30, 120 and 240 min, respectively. We found that Brix values correlated closely with the concentration of polymeric diet diluted in fasting gastric juice at each time with minimal variability ($R^2 < 0.98$). Therefore, polymeric diet formula concentration in gastric contents can be estimated on the basis of the linear regression equation: Brix value = $0.24 \div (\text{full strength polymeric diet}\%)$. For instance, a Brix value of 6.0 and 12 in gastric contents corresponds to a 25% and 50% full-strength polymeric diet concentration.

Table 5 Table 5 Brix values of polymeric diet in gastric juice

Time (min)	% Full-strength polymeric diet						R^2
	0	12.5	25	50	75	100	
5	2.0 $\pm$ 0.4	4.6 $\pm$ 0.3	6.8 $\pm$ 0.4	12.1 $\pm$ 0.8	16.9 $\pm$ 0.2	21.2 $\pm$ 0.4	0.99
30	2.1 $\pm$ 0.4	4.6 $\pm$ 0.4	6.8 $\pm$ 0.3	12.2 $\pm$ 0.7	18.1 $\pm$ 0.2	23.3 $\pm$ 0.4	0.98
120	2.0 $\pm$ 0.4	4.7 $\pm$ 0.3	6.9 $\pm$ 0.6	12.0 $\pm$ 0.7	17.8 $\pm$ 0.5	22.2 $\pm$ 0.4	0.98
240	2.0 $\pm$ 0.4	4.8 $\pm$ 0.5	7.0 $\pm$ 0.8	12.0 $\pm$ 0.8	17.6 $\pm$ 0.7	23.2 $\pm$ 0.4	0.98

Brix values (% Brix) of polymeric diet (Osmolite HN) diluted in fasting gastric juice. Results are presented as mean $\pm$ SEM (n=6).

Example 2 Monitoring Bolus Nasogastric Feeding by the Brix Value Determination of Gastric Contents

Materials and Methods

All BV measurements were made using a hand-held refractometer (Model N.O.W. 507-1, Nippon Optical Works, Tokyo, Japan), whose Brix scale of 0-32 could be read in 0.2 increments. The refractometer was calibrated with distilled water before each measurement. One or two drops of the specimen fluid were placed on a designated window for observation, all measurements made at room temperature using natural light. In this way, the concentration of soluble solids in solution was measured at the bedside for each specimen.

Brix values for a polymeric diet (Osmolite HN, Abbott Laboratories, Columbus, Ohio) and three solutions (distilled water, fasting saliva, and

gastric juice) were determined with the refractometer. Serial dilutions of the polymeric formula (100%, 50%, 25%, 12.5%, 6.2%, and 0%) were made with three of the solutions (distilled water, saliva, and gastric juice). The Brix value was measured in vitro for each dilution of the polymeric formula.

Patients receiving bolus nasogastric feeding were eligible for this study. All subjects were fed the full strength polymeric diet via a 14 French nasogastric feeding tube. The polymeric diet composition was 16.7% protein, 54.3% carbohydrate, and 29.0% lipid. Caloric requirements were calculated using the Harris-Benedict equation. A total of 250 mL of the polymeric diet was administered by bolus infusion every 3-6 hours in the 24 hours prior to the study. Aspirated gastric residual volumes were obtained before each bolus feed by aspiration of the feeding tube. Aspirated gastric residual volumes were obtained first in the supine position, and then in the right lateral decubitus position. Following this preliminary period of monitoring, patients were arbitrarily divided into two groups based on traditional use of aspirated gastric residual volume; patients with low gastric residual volumes (<75 mL) placed in group 1, and patients with higher gastric residual volumes (>75 mL on at least two occasions) were placed in group 2. In total, 25 subjects were recruited into group 1 (age: range = 59-84, mean $\pm$ SD = 75.9 $\pm$ 6.6 years) and 18 patients into group 2 (age: range = 44-79, mean $\pm$ SD = 70.6 $\pm$ 10.6 years). Informed consent was obtained from all patients (or their representatives) prior to entry into the study.

After overnight fasting, all remaining gastric juice was aspirated from the stomach via the nasogastric tube using a 60 mL syringe. Then, all subjects received bolus infusion of 250 mL of the polymeric diet.

Immediately after feeding, an attempt was made to thoroughly mix the food content in the stomach by aspirating and reinfusing of the nasogastric tube three times with a 60 mL syringe.

Sequential Brix value determinations were made on 2 mL samples of gastric contents at 0, 30, 60, 120, and 180 minutes intervals. At 180 minutes, any fluid remaining in the stomach was aspirated. Its volume was recorded as the aspirate gastric residual volume, the Brix value measurement made, and then the contents were reinstalled into the stomach.

Since the Brix values of polymeric diet had a linear additive relationship with the diet formula concentration ($R^2 = 0.99$), which allows the derivation of the equation for dietary formula concentration calculation (Figure 1). With such a high degree of correlation, the % concentration of the formula (% full strength polymeric diet) at any dilution may be calculated from the measured Brix value.

Traditional use of gastric residual volume obtained by aspiration via a syringe may be wholly inaccurate and unreliable in measuring true volume of contents present in the stomach at any given time. We designed the water dilution test to calculate the gastric residual volume (Figure 2). An added dilutional 30 mL volume of distilled water was infused via the nasogastric tube. The stomach contents again were thoroughly mixed (using a 60-mL syringe, filled and emptied 3 times), and a 2 mL sample was obtained for a final Brix value measurement. The water dilution test (determining Brix values before and after instillation of 30 mL of distilled water) takes advantage of the relationship between the % concentration of formula at any dilution and the measured Brix values shown in Figure 1, and may be used to calculate the true volume of contents (Figure 2) and the specific volume of formula remaining in the stomach (Figure 3).

Before water dilution, the unknown gastric residual volume is set as Vol.1, % full strength polymeric diet as % Conc.1, and the Brix value of gastric contents as BV1. After 30 mL water dilution in the stomach, the gastric volume is set as Vol.2, % full strength polymeric diet as % Conc.2, and the Brix value of gastric content as BV2. Therefore, we calculated the gastric residual volume (Vol.1) as following derived equation (Figure 2).

1. Since the formula calories do no change by the distilled water dilution in the stomach, the gastric formula calories are equal before and after water dilution (equation 3a: $\text{Vol.1 (kcal)} = \text{Vol.2 (kcal)}$).
2. The gastric formula calories = total gastric volume $\times$ % full strength polymeric diet, we substitute into equation 3b: $\text{Vol.1} \times \% \text{ Conc.1} = \text{Vol.2} \times \% \text{ Conc.2}$.
3. $\text{Vol.2} = \text{Vol.1} + 30 \text{ mL}$, we substitute into equation 3c: $\text{Vol.1} \times \% \text{ Conc.1} = (\text{Vol.1} + 30 \text{ mL}) \times \% \text{ Conc.2}$.
4. Substituting the product $\text{BV} \div 0.24$ for % full strength formula concentration, which generates from figure 2, obtain the equation (3d: $\text{Vol.1} \times (\text{BV1} \div 0.24) = (\text{Vol.1} + 30 \text{ mL}) \times (\text{BV2} \div 0.24)$).
5. Both sides of which may be multiplied by 0.24 to obtain equation 3e: $\text{Vol.1} \times \text{BV1} = (\text{Vol.1} + 30 \text{ mL}) \times \text{BV2}$.

6. The calculated GRV is obtained by equation (3f: Vol.1 =
(BV2 × 30 mL) ÷ (BV1 – BV2)).

To monitor whether the gastric residual volume is rich in dietary formula or gastric secretions, we designed the equation to calculate the formula volume remaining in the stomach: formula remaining in the stomach = % Concentration at 180 min × calculated gastric residual volume at 180 min (Figure 3).

Results are presented as mean values ± SEM. The Student's t test was used to assess differences in results between patients in group 1 and group 2. A p value of less than 0.05 was considered to be statistically significant.

Results

The full strength polymeric diet was shown to have a high concentration of dissolved nutrients and thus had a correspondingly high mean BV of 23.2 ± 0.3. Distilled water, saliva, and fasting gastric juice had much lower mean BVs of 0 ± 0, 1.3 ± 0.4, and 1.9 ± 0.6 respectively.

Table 1 shows the mean Brix values of the polymeric diet diluted with the three different solutions (distilled water, saliva, and gastric juice) in vitro. The Brix values of polymeric diet had a linear additive relationship with the diet formula concentration in the water ($R^2 = 0.99$) (Figure 1). Results show that the mean Brix values of the serial dilutions of the polymeric diet were similar, regardless of whether the diluent was saliva ($R^2 = 0.98$) or fasting gastric juice ($R^2 = 0.98$) (Table 1).

TABLE 1. The Brix Values for the polymeric diet diluted with different solutions *in vitro*

Solution	% Full strength of polymeric diet (Osmolite HN)					
	0	6.2	12.5	25	50	100
Distilled water	0 ± 0	2.1 ± 0.4	3.5 ± 0.8	6.0 ± 0.9	12.2 ± 0.8	23.2 ± 0.3
Saliva	1.3 ± 0.4	2.2 ± 0.6	4.4 ± 0.6	7.3 ± 0.7	12.4 ± 0.9	23.2 ± 0.5
Gastric juice	1.9 ± 0.6	4.4 ± 1.4	5.4 ± 1.3	7.8 ± 1.4	13.3 ± 1.2	23.2 ± 0.4

Results are presented as mean values for six separate determinations ± SEM.

TABLE 2. Serial Brix values and gastric residual volumes (GRVs) for patients in group 1 (low GRVs)

Patient no.	Brix value of gastric juice					Residual volume (mL)		
	0 min	30 min	60 min	120 min	180 min	Aspirated GRV	Calculated GRV	Formula remaining
1	13.9	12.2	5.3	8.5	9.6	30	23	9
2	22.3	14.3	14.3	14.3	14.8	0	3	2
3	23.4	19.5	13.7	10.3	11.6	70	115	56
4	22.6	14.6	13.2	12.4	10.1	10	31	13
5	11.9	10.4	8.2	4.6	4.9	10	215	44
6	21.5	13.5	12.3	9.4	8.5	30	-	-
7	22.4	13.2	12.5	7.2	8.7	20	-	-
8	23.3	20.4	14.3	10.3	9.1	79	68	26
9	14.5	11.3	9.4	5.4	5.3	32	92	20
10	12.9	10.6	8.3	5.3	4.3	12	185	33
11	13.3	9.2	8.4	5.0	4.2	10	-	-
12	14.8	10.3	8.3	6.4	4.8	15	-	-
13	17.6	12.3	10.4	7.4	4.6	70	62	12
14	17.7	12.4	9.7	7.5	4.4	78	80	15
15	14.8	10.3	8.3	6.4	4.8	15	-	-
16	20.2	18.4	15.3	4.6	3.5	8	45	7
17	17.2	14.5	10.2	4.4	2.6	32	-	-
18	16.5	12.5	9.3	3.6	2.5	30	-	-
19	16.4	12.4	9.3	3.5	2.3	5	-	-
20	22.3	14.4	10.0	5.4	2.9	9	16	2

21	22.3	21.2	20.5	3.3	2.7	1	-	-
22	20.9	17.4	14.3	3.7	2.3	5	47	4
23	26.2	16.3	14.1	12.3	2.0	8	30	3
24	23.8	12.7	10.6	4.3	1.5	0	15	1
25	26.0	15.6	15.2	13.4	1.3	0	48	3
Mean $\pm$	19.6 $\pm$	14.0 $\pm$	11.4 $\pm$	7.1 $\pm$ 0.8	5.1 $\pm$	18 $\pm$ 5*	67 $\pm$ 15*	6 $\pm$ 2*
SEM	1.0	0.8	0.8		0.9*			

(* $p < 0.05$ from mean value group 1 versus group 2)

Immediately following a 250 mL polymeric diet bolus feeding, the mean BVs of the gastric contents in vivo were shown to be lower both in group 1 and group 2 (19.6 $\pm$ 1.0 versus 20.3 $\pm$ 1.1, respectively) than the mean values for the polymeric formula made in vitro (23.2 $\pm$ 0.3). This decrease in the Brix value most likely was due to the dilutional effect of endogenous gastric juices present in the stomach at the time of feeding.

The serial changes in Brix values for gastric content for the two groups following the bolus polymeric diet feeding are shown in Tables 2 and 3. Mean serial Brix value measurements decreased in both groups after bolus feeding. For patients in group 2, the decrease was less, such that at 180 minutes patients in group 2 had a significantly higher mean Brix value for gastric contents than those patients in group 1 (10.1 $\pm$ 0.7 versus 5.1 $\pm$ 0.9, respectively, $p < 0.01$). Tables 2 and 3 also show that the aspirated gastric residual volume at 180 minutes was significantly higher for patients in group 2 than for those in group 1 (72 $\pm$ 12 versus 18 $\pm$ 5 mL, respectively, $p < 0.01$).

TABLE 3. Serial Brix values and gastric residual volumes (GRVs) for patients in group 2 (higher GRVs)

Patient no.	Brix value of gastric juice					Residual volume (mL)		
	0 min	30 min	60 min	120 min	180 min	Aspirated GRV	Calculated GRV	Formula remaining
1	16.4	14.5	11.2	11.3	12.3	15	89	46
2	13.4	12.4	12.4	8.5	9.3	30	26	10
3	17.8	14.1	12.4	13.4	12.3	35	138	71
4	22.1	19.2	16.3	14.4	14.4	190	197	118
5	19.2	18.2	16.2	15.1	11.2	37	82	38
6	23.3	19.2	16.5	15.5	13.0	210	165	89
7	20.2	19.6	18.2	15.3	10.6	47	215	95
8	29.1	25.0	22.1	15.5	14.2	65	79	47
9	29.0	24.5	20.3	14.7	14.2	55	55	33
10	23.1	19.3	13.3	10.2	11.4	70	125	60
11	23.3	17.2	14.4	12.3	11.2	74	104	49
12	12.5	9.3	7.7	6.2	5.5	65	108	25
13	21.2	17.4	13.7	9.3	8.6	60	93	33
14	21.5	18.4	14.6	10.2	8.2	70	68	23
15	14.2	12.5	8.8	6.7	5.1	75	-	-
16	22.2	18.5	12.2	8.6	5.3	85	-	-
17	15.2	14.2	12.2	8.3	9.1	40	48	18
18	22.4	17.2	10.2	8.8	6.7	65	-	-
Mean $\pm$	20.3 $\pm$	17.3 $\pm$	14.0 $\pm$	11.3 $\pm$	10.1 $\pm$	72 $\pm$ 12*	106 $\pm$ 14*	50 $\pm$ 8*
SEM	1.1	1.0	0.9	0.8	0.7*			

(* $p < 0.05$ from mean value group 1 versus group 2)

The mean calculated gastric residual volume was shown to be significantly higher for patients in group 2 than for those in group 1 (106 $\pm$ 14 versus 67 $\pm$ 15 mL, respectively, $p < 0.05$). Using the final Brix value (before water dilution) to derive the % full strength polymeric diet concentration, in combination with the calculated gastric residual volume, the specific Volume formula present at 180 minutes was determined for

both groups. The Volume formula remaining was significantly higher for patients in group 2 compared to those in group 1 (50 ± 8 versus 6 ± 2 mL, respectively, $p < 0.05$).

As shown in Tables 2 and 3, use of refractometry in combination with traditional use of gastric residual volume identified 4% (1/25) of patients in group 1 with low gastric residual volumes who might have possible gastric dysmotility ($> 20\%$ of the initial 250 mL bolus volume of formula remaining at 180 minutes). Use of refractometry together with gastric residual volumes helped assure that 72% (13/18) of patients in group 2 with higher gastric residual volumes had sufficient gastric emptying ($< 20\%$ of initial 250 mL volume of formula remaining).

Example 3 Continuous Nasogastric Tube Feeding: Monitoring by Brix value and Traditional Gastric Residual Volumes

Materials and methods

After monitoring for 24 hours, 36 patients on continuous enteral tube feeding with a full strength polymeric diet (Osmolite HN) were entered in this study and divided into 2 groups based on their pattern of traditional aspirated gastric residual volumes over the monitoring period. Patients with lower aspirated gastric residual volumes (< 75 mL) were placed in Group 1, while patients with higher aspirated gastric residual volumes (> 75 mL on at least 2 occasions) were placed in Group 2. Aspirated gastric residual volumes were obtained by aspiration of the feeding tube using a 60-ml syringe, first in the supine position, and then in

the right lateral decubitus position. Upon entry, all gastric contents were aspirated, the volume recorded (aspirated gastric residual volume), Brix value measurements by refractometry performed, and the contents reinstalled but diluted with 30 mL additional water. Then a small amount
5 was reaspirated, and repeat Brix value measurements were made. Three hours later, the entire procedure was repeated a second time.

The Brix values were measured using a hand-held refractometer, whose Brix scale of 0-32 could be read in 0.2 increments. The refractometer was calibrated with distilled water before each measurement.
10 One or two drops of the specimen fluid were placed on a designated window for observation using daylight at room temperature. In this way, the concentration of soluble solids in solution was measured at the bedside for each specimen.

The Brix value ratio, an indirect measure of the amount of formula
15 retained in the stomach, was calculated by the product of post-dilution Brix value $\div$ pre-dilution Brix value. An estimate of the true volume of gastric contents remaining in the stomach (Figure 3), or the calculated gastric residual volumes (Figure 2), was determined by the equation: pre-dilution Brix value $\times$ calculated gastric residual volumes = post-dilution Brix value
20 $\times$ (calculated gastric residual volumes + 30 mL) (Figure 2). The specific component of that volume remaining that was comprised of formula was estimated using the equation: Volume of dietary formula

remaining in stomach = calculated gastric residual volumes $\times$ [(pre-dilution Brix value $\div$ 0.24)/100] (Figure 3).

Results are presented as mean values $\pm$ SEM. The Student's *t* test was used to assess differences in results between patients in Group 1 and Group 2. A *p* value of less than 0.05 was considered to be statistically significant.

Results

No patient in either group demonstrated nausea, vomiting, aspiration, or evidence of clear intolerance of enteral tube feeding. Table 1 shows the raw data of gastric residual volumes for the patients in Group I. Patients in Group 1 with lower aspirated gastric residual volumes based on the pre-study period of monitoring, continued to demonstrate very low aspirated gastric residual volumes following entry into the study, with 93% (43/44) of the aspirated gastric residual volumes obtained on the first and second measurements being < 75 mL. In contrast, patients in Group 2 (again differentiated by higher gastric residual volumes on pre-study monitoring) continued to show higher aspirated gastric residual volumes following entry into the study, with only 11% (3/28) of aspirated gastric residual volumes on both measurements < 75 mL (Table 2). Mean aspirated gastric residual volumes was significantly higher for those patients in Group 2 compared to those in Group 1 on both first (124 ± 7

versus 14 ± 2 mL, respectively, $p < 0.05$) and second (75 ± 10 versus 15 ± 4 mL, respectively, $p < 0.05$) measurements.

Table 1. GRVs for Group 1 patients (low residual volume) receiving continuous tube feeding

Patient no.	Infusion rate (ml/hr)	First measurement (ml)			Second measurement (ml)		
		Asp GRV	Cal GRV	Formula remaining	Asp GRV	Cal GRV	Formula remaining
1	75	45	78	39	6	35	33
2	30	40	40	12	15	56	24
3	75	30	55	24	3	79	72
4	75	25	74	17	85	90	14
5	65	20	35	24	4	38	35
6	20	15	75	6	20	60	9
7	45	12	33	32	20	59	35
8	60	10	32	28	5	35	32
9	75	10	34	32	5	37	31
10	50	10	31	23	4	37	28
11	30	10	37	32	35	66	23
12	55	10	37	35	12	35	32
13	30	10	31	26	5	35	29
14	45	8	32	30	3	32	30
15	40	8	34	31	20	97	23
16	30	7	31	29	5	32	30
17	70	7	40	40	11	49	36
18	70	7	36	36	32	69	32
19	70	7	40	40	11	49	36
20	70	6	33	31	5	33	30
21	60	6	33	31	10	33	31
22	30	10	34	31	3	39	34
Mean $\pm$ SEM	53 ± 4	$14 \pm 2^*$	$41 \pm 3^*$	$29 \pm 2^*$	$15 \pm 4^*$	$50 \pm 4^*$	$31 \pm 2^*$

Legend: GRV = gastric residual volume, Asp GRV = aspirated gastric residual volume, Cal GRV = calculated gastric residual volume (* $p < 0.05$ for mean value Group 1 versus Group 2).

Table 2. GRVs for Group 2 patients (high residual volume) receiving continuous tube feeding

Patient no.	Infusion rate (ml/hr)	First measurement (ml)			Second measurement (ml)		
		Asp GRV	Cal GRV	Formula remainin g	Asp GRV	Cal GRV	Formula remaining
1	40	145	104	19	18	39	37
2	70	142	130	51	110	146	62
3	75	140	171	65	110	149	71
4	40	110	200	33	10	37	34
5	40	98	88	18	9	43	39
6	30	128	138	135	97	62	27
7	35	120	116	114	95	50	26
8	30	110	140	141	85	47	22
9	30	160	150	87	80	132	62
10	40	155	110	69	90	115	61
11	30	138	132	75	86	117	51
12	70	130	180	72	100	180	77
13	30	85	193	72	78	119	47
14	30	78	282	110	80	193	72
Mean ± SEM	42 ± 4	124 ± 7*	152 ± 13*	76 ± 10*	75 ± 10*	102 ± 15*	49 ± 5*

Legend: GRV = gastric residual volume, Asp GRV = aspirated gastric residual volume, Cal GRV = calculated gastric residual volume (* $p < 0.05$ for mean value Group 1 versus Group 2).

Tables 3 and 4 show the pattern of the first and second Brix value measurements pre- and post-dilution. In general, patients in Group 1 tended to show of pattern of high pre-dilution Brix values dropping further to lower post-dilution Brix values than those patients in Group 2 (which

showed the opposite pattern - low pre-dilution Brix values dropping to a less extent to higher post-dilution Brix values). Only the difference in post-dilution Brix values between the two groups on both measurements reached statistical significance.

5

Table 3. Brix values for Group 1 patients (low residual volume) receiving continuous tube feeding

Patient no.	First measurement			Second measurement		
	Pre-dilution Brix value	Post-dilution Brix value	Brix value ratio	Pre-dilution Brix value	Post-dilution Brix value	Brix value ratio
1	12.0	7.4	62%	23.0	3.0	13%
2	7.4	1.8	24%	10.4	4.8	46%
3	10.6	4.8	45%	22.0	13.6	62%
4	5.4	3.2	59%	3.6	2.4	67%
5	16.0	2.4	15%	22.6	4.6	20%
6	2.0	1.2	60%	3.6	1.8	50%
7	23.4	2.0	9%	14.2	7.0	49%
8	21.0	1.6	8%	22.2	3.0	14%
9	22.6	2.4	11%	20.2	3.6	18%
10	18.0	0.4	2%	18.0	3.4	19%
11	21.0	4.0	19%	8.4	4.6	55%
12	22.6	4.2	19%	22.0	3.0	14%
13	20.0	0.6	3%	20.0	3.0	15%
14	22.8	1.4	6%	22.6	1.4	6%
15	22.0	2.4	11%	5.8	4.0	69%
16	22.2	1.0	5%	22.6	1.2	5%
17	23.8	6.0	25%	17.6	6.8	39%
18	23.6	4.0	17%	11.0	6.2	56%
19	23.8	6.0	25%	17.6	6.8	39%
20	22.4	2.0	9%	22.0	1.8	8%
21	23.0	2.0	9%	22.2	2.2	10%

22	22.0	2.6	12%	20.8	4.8	23%
Mean $\pm$ SEM	18.5 $\pm$ 1.4	2.9 $\pm$ 0.4*	20 $\pm$ 4%*	16.9 $\pm$ 1.4	4.2 $\pm$ 0.6*	32 $\pm$ 5%*

* $p < 0.05$ for mean value Group 1 versus Group 2

Table 4. Brix values for Group 2 patients (high residual volume) receiving continuous tube feeding

Patient no.	First measurement			Second measurement		
	Pre- dilution	Post-dilution Brix value	Brix value ratio	Pre- dilution	Post- dilution	Brix value ratio
	Brix value			Brix value	Brix value	
1	4.5	3.2	71%	22.7	5.4	24%
2	9.5	7.3	77%	10.2	8.1	79%
3	9.1	7.5	82%	11.4	9.1	80%
4	4.0	3.4	85%	22.3	4.0	18%
5	5.0	3.3	66%	22.0	6.5	30%
6	23.5	18.4	78%	10.4	5.4	52%
7	23.6	17.5	74%	12.4	5.0	40%
8	24.2	19.0	79%	11.0	4.0	36%
9	14.0	11.2	80%	11.4	8.8	77%
10	15.0	10.9	73%	12.7	9.4	74%
11	13.6	10.5	77%	10.5	7.8	74%
12	9.6	8.0	83%	10.2	8.5	83%
13	9.0	7.6	84%	9.5	7.1	75%
14	9.4	8.4	89%	9.0	7.6	84%
Mean $\pm$ SEM	12.4 $\pm$ 1.9	9.7 $\pm$ 1.4*	79 $\pm$ 2%*	13.3 $\pm$ 1.3	6.9 $\pm$ 0.5*	59 $\pm$ 7%*

* $p < 0.05$ for mean value Group 2 versus Group 1

This pattern in Group 1 patients suggested that gastric contents

were comprised of enteral formula of fairly high concentration (as evidenced by pre-dilution Brix values close to the in vitro Brix values of 23.2 for full strength Osmolite HN) that was of very small volume (as evidenced by the tremendous drop in Brix values with dilution by a small
5 30 mL volume of distilled water). The opposite pattern in Group 2 patients, in contrast, suggested greater dilution by endogenous secretions (as evidenced by pre-dilution Brix values less than the Brix value of 23.2 for full strength Osmolite HN) and greater total volume (as evidenced by the lesser drop in Brix values with dilution by a small 30 mL volume of
10 distilled water).

The mean Brix value ratios for the two groups reflected these distinct patterns. The mean Brix value ratio was significantly higher for those patients in Group 2 compared to those in Group 1 on both the first ($79 \pm 2\%$ versus $20 \pm 4\%$, respectively, $p < 0.05$) and second ($59 \pm 7\%$
15 versus $32 \pm 5\%$, respectively, $p < 0.05$) measurements. For those patients in Group 1, Brix value ratios on all measurements for all patients were $< 70\%$ (Table 3). For those patients in Group 2, the Brix value ratios on the first measurement were $> 70\%$ on all but one patient (patient # 5) (Table 4). When measured the second time, 6 of the 14 patients (patients # 1, 4-8)
20 showed that the Brix value ratios had fallen to $< 70\%$.

As a whole, patients in Group 1 had a volume of formula estimated to be remaining on both measurements that was very low,

reinforcing the pattern shown by Brix value ratios (Table 1). In one patient (patient #22) where the volume of formula was greater than the hourly feeding rate, aspirated gastric residual volumes and calculated gastric residual volumes were < 40 mL. Overall, 95% (21/22) of the Group 1 patients had a volume of formula remaining on both measurements that was less than the hourly feeding rate.

In contrast to those patients in Group 1, patients in Group 2 showed evidence of reduced gastric emptying and greater volume of retained formula (Table 2). Comparing the formula estimated to be remaining with the hourly infusion rate, six patients (patients #9-14) showed concurrence on both measurements for evidence of retention of formula and decreased or impaired gastric emptying. For these six patients, the volume of formula remaining was estimated to be greater than the hourly infusion rate on both measurements. In these six, both the first and second Brix value ratios were $> 70\%$. Traditional aspirated gastric residual volumes, however, was insensitive and failed to identify these patients, being ≤ 100 mL on two of the six first round of measurements, and six out of six on the second round of measurements. Three patients from Group 2 (patients #6-8), who on initial measurement showed retention of formula, improved on follow-up measurement indicating adequate gastric emptying of the formula. Five patients could be identified (patients #1-5) with high aspirated gastric residual volumes from

Group 2 who had a volume of formula remaining estimated to be less than the hourly infusion rate, assuring adequate gastric emptying all along.

The results of this study demonstrate how refractometry may be used in conjunction with traditional aspirated gastric residual volumes to create a strategy by which to monitor patients on continuous gastric feeding (Figure 4). Traditional use of aspirated gastric residual volumes performed every 4 hours should be preserved as the mainstay for initial monitoring. Patients who continue to have aspirated gastric residual volumes < 75 mL, as shown in this study, appear to be at low risk, should have good tolerance and sufficient gastric emptying, and do not require refractometry assessment (unless clinical suspicion of intolerance increases, based on abdominal distension, reduced passage of gas and stool, increasing nausea, or regurgitation and vomiting) (Figure 4). If patients are found to have aspirated gastric residual volumes > 75 mL on ≥ 2 occasions, then the simple Brix value dilution test should be performed. If the Brix value ratio is $< 70\%$, as this study has shown, there is a low likelihood for retention of formula and feeds may continue. Only if the Brix value ratio is $> 70\%$ on ≥ 2 occasions (performed every 4 hours), should the clinician calculate the volume of formula (Volume of dietary formula) remaining in the stomach. The finding that the Volume of dietary formula is greater than the hourly infusion rate would alert the clinician to the possibility of delayed gastric emptying with

retention of formula, and that feeds may be continued with caution under close observation (continuing to perform Brix value dilution tests with aspirated gastric residual volumes every 4 hours).

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What is claimed is:

1. A method of measuring the concentration of dietary formula in gastric content, which comprises the steps of i) infusing dietary formula to the stomach of a subject, ii) obtaining the gastric content over an appropriate time after infusing and measuring Brix value thereof, and iii) obtaining the percent concentration of dietary formula in the gastric content through the equation: percent concentration of dietary formula = Brix value /slope value, wherein the slope value is obtained from making serial dilutions of the dietary formula to obtain a series of concentrations of the dietary formula, measuring the Brix values of the resulting concentrations of the dietary formula, and then using said resulting concentrations and Brix values to obtain a slope value from a simple regression analysis.
2. The method of Claim 1, wherein the slope value is 0.24.
3. The method of Claim 1, wherein the dietary formula is the formula for gastric tube feeding.
4. The method of Claim 1, wherein the dietary formula is liquid dietary formula.
5. A method of measuring gastric residual volume, which comprises the steps of:
 - i) determining the Brix value of said gastric residual volume to obtain a BV1,
 - ii) adding appropriate volume of water to said gastric residual volume to form a mixed gastric content,

- iii) infusing said mixed gastric content to the stomach,
- iv) aspirating the resulting gastric content from the stomach,
- v) determining the Brix value of said resulting gastric content to obtain a BV2, and
- 5 vi) obtaining the volume of gastric content through the following equation:

$$\text{BV1} \times \text{said added volume of water} / (\text{BV1} - \text{BV2}) .$$

- 6. The method of Claim 5, the Brix value is measured by
10 refractometer.
- 7. A method of measuring the volume of dietary formula remaining in the stomach, which comprises multiplying the calculated gastric residual volume of the invention by % full strength of dietary formula.
- 15 8. The method of Claim 7, wherein the dietary formula is the formula for gastric tube feeding.
- 9. The method of Claim 7, wherein the dietary formula is liquid dietary formula.
- 10. A method of measuring gastric juice volume in stomach, which
20 comprises subtracting the dietary formula volume remaining in the stomach from gastric residual volume.
- 11. The method of Claim 10, wherein the dietary formula is the formula for gastric tube feeding.
- 12. The method of Claim 10, wherein the dietary formula is liquid
25 dietary formula.