

Gastric Residual Volumes in Critical Illness: What Do They Really Mean?

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- Gastric residual volumes • Enteral nutrition
- Intensive care unit • Patient outcome

The use of gastric residual volumes (GRVs) for monitoring enteral nutrition (EN) in the intensive care unit (ICU) setting is highly controversial. Despite the fact that use of GRVs is one of the most common practices in nutrition therapy, few data in the literature supports its efficacy. Although the origins of GRVs are difficult to determine, references to the practice began to appear in the nursing literature in the 1980s.¹ At the time, no data substantiated its use. No subsequent prospective randomized controlled trials suggest that their use improves patient outcomes in the ICU.¹⁻⁴ The practice of GRV monitoring was originally designed to help prevent aspiration pneumonia, yet their use serves as a major barrier to the delivery of EN in the ICU.⁵ As a consequence, ironically, the use of GRVs may actually increase risk for pneumonia because of reduced delivery of EN.^{6,7} Thus, although GRVs were designed to be a safeguard when delivering EN, their use may inadvertently increase risk for the patient.

Obtaining and interpreting GRVs are predicated on several assumptions. Performing GRVs assumes that the practice is well standardized, that GRVs reliably and accurately measure gastric contents, and that the practice distinguishes between normal and abnormal gastric emptying. By performing GRVs, clinicians have assumed that they are easy to interpret, that a tight correlation exists between GRVs and aspiration, and that continuing to provide EN once a high GRV above some designated level has

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been reached will inadvertently lead to pneumonia and adverse outcome. And the test is assumed to be inexpensive with little or no impact on allocation of health care resources. Surprisingly, very little evidence supports any one of these assumptions. Through examining what few data support or refute each of these assumptions, clinicians should hope to reduce reliance on the practice of GRVs and alter interpretation of elevated values. This article not only reviews these assumptions but also makes recommendations for the use and interpretation of GRVs to better promote delivery of EN in patients in the ICU.

ASSUMPTION #1: THE PRACTICE OF GASTRIC RESIDUAL VOLUMES IS WELL STANDARDIZED

The practice of GRVs has numerous technical aspects, and virtually none has been well standardized in the literature. Institutions vary regarding the way in which GRVs are used clinically. Some centers use GRVs as a designated cutoff value above which cessation of tube feeds is mandated, whereas other centers use them as an initiation value below which it is appropriate to advance the rate of feeds. The absolute value for the designated cutoff value varies widely in the literature, from as little as little as 50 mL to as high as 500 mL.^{7,8} Often the designated GRV may vary from one unit to the next within the same institution.⁷ Still other institutions may prohibit the use of GRVs altogether. No clear consensus exists on what the appropriate GRV cutoff level should be nor how they should be used as a monitor for patients in the ICU.^{5,8}

Despite whether the GRV should be discarded or reinfused back into the patient is controversial.^{9,10} Simply discarding the GRV contributes to a reduced delivery of EN. In a small study from the nursing literature in which patients were randomized to have the GRV returned ($n = 8$) or discarded ($n = 10$),¹⁰ no significant differences were seen in the rate of aspiration pneumonia, electrolyte abnormalities, need for tube replacement, or delays in feeding between the groups. In a subsequent larger single-center study of 125 patients, again randomized to have the GRV returned ($n = 63$) or discarded ($n = 62$), the severity and incidence of delayed gastric emptying was significantly lower in the group for which the GRV was returned and reinfused.⁹ Intolerance measures, including diarrhea, nausea, vomiting, and abdominal distention, were no different between the groups. These two trials provide evidence supporting that GRVs below 500 mL should be routinely reinfused into the patient.^{9,10}

Specific aspects of technique may alter the GRV obtained from an individual patient.¹¹ The size of the syringe and the material of the tubing affects the ability to obtain GRVs and the accuracy with which it measures gastric contents.¹¹⁻¹⁴ Silicone has less tensile strength than polyurethane, and therefore tubes made of silicone are more likely to collapse on aspiration. Manual aspiration with a syringe is more likely to collapse a tube than hooking the feeding tube to wall suction over several minutes. Larger-bore tubes have been shown to generate higher GRVs than smaller-bore tubes. In a study of three different sizes of tubes, Metheny and colleagues¹² showed that the mean GRV from 10-French tubes was significantly lower than the mean GRV obtained from either 14- or 18-French tubes (20.1 vs 45.8 mL, respectively; $P < .05$).

The location of the tip of the feeding tube within the gastrointestinal tract affects the GRV obtained.^{15,16} Percutaneous endoscopic gastrostomy (PEG) tubes are situated on the anterior wall of the stomach. Gastric contents tend to pool in the posterior fundus when patients lie on their back, and in the antrum when they are positioned in the right lateral decubitus position. Only if the patient were in the prone position would a PEG tube be in a dependent position with regard to the gastric pool. Not surprisingly, a study comparing GRVs between PEG tubes and nasogastric tubes

showed significantly lower GRVs with PEG tubes.¹⁵ In this study, 27.4% of GRVs with a nasogastric tube were greater than 100 mL, and 15.1% were greater than 150 mL. In contrast, only 2.5% of GRVs were greater than 100 mL in patients with PEG tubes, and no GRVs were greater than 150 mL.¹⁵ Furthermore, displacing the tip of a nasoenteric tube from the stomach to the small bowel has been shown to decrease the GRV obtained by 50%.¹⁶

These findings indicate that the practice of GRVs is highly variable and not standardized in any fashion. The problem for clinicians, however, is that standardizing the practice might inadvertently encourage reliance on an already inaccurate and unreliable monitor.^{1,17}

ASSUMPTION #2: GASTRIC RESIDUAL VOLUMES RELIABLY AND ACCURATELY MEASURE GASTRIC CONTENTS

Based on the large volume of endogenous gastric and salivary secretions of greater than 5000 mL/d and a routine volume of EN infused between 25 and 125 mL/h, mathematical models have estimated that the GRV for gastric contents should range between 232 and 464 mL/h in patients with normal gastric emptying.¹⁸ A critically ill patient with abnormal gastric emptying would be expected to have higher GRVs. However, two large studies evaluating GRVs in critically ill patients showed that most GRVs measured (among 90%–97% of specimens obtained) were less than 150 mL.^{4,15} This disparity between the actual GRVs obtained and the volume of gastric contents that should be present suggests that the routine practice of GRVs does not accurately predict the volume of gastric contents. This disparity is further supported by the fact that 80% of the time an elevated GRV is an isolated event.¹⁵ If GRVs accurately measured the volume of gastric contents, one would expect a more sequential pattern of elevated GRVs in response to retention and abnormalities in gastric emptying.

Knowing the location of the tip of the tube within the stomach might allow clinicians to position patients in a way that the tip would fall in a dependent position within the pool of gastric contents, yielding a more reliable GRV.¹ If the tip of the tube was known to be in the fundus, then placing the patient in the supine position would put the tip in a dependent position. If the tip were known to be in the antrum, placing the patient in the right lateral decubitus position would place the tube tip in a dependent position.¹

Obtaining an abdominal radiograph after tube placement theoretically should then guide clinicians to the optimal patient positioning to increase reliability of GRVs. Unfortunately, at least two factors jeopardize this consideration. Even if the tube were placed in an appropriate position and the patient repositioned to accommodate this, tubes have been shown to migrate frequently back and forth within the stomach over an 8-hour period.¹⁵ Also, when patients are placed in the supine position, the stomach drapes over the spine, causing the gastric volume to cascade into two separate pools. These two factors alone indicate that standardizing patient position for the practice of GRVs would be irrelevant.¹

ASSUMPTION #3: GASTRIC RESIDUAL VOLUMES DISTINGUISH BETWEEN NORMAL AND ABNORMAL GASTRIC EMPTYING

Numerous factors in the ICU setting cause delayed gastric emptying (**Box 1**). Factors ranging from the clinical insult itself (eg, burns, trauma, surgery, sepsis) to those related to the nutrition therapy (eg, hypoglycemia, electrolyte abnormalities, selection of hyperosmolar formulas) may contribute to delayed gastric emptying in critically ill patients.¹ Using paracetamol absorption as a marker of gastric emptying, one study

Box 1**Factors in the intensive care unit that may cause decreased gastric emptying and thus affect gastric residual volumes**

- Hyperglycemia
- Opiates
- Dopamine
- Increased intracranial pressure
- Electrolyte abnormalities
- Ischemia
- Hypoxia
- Sepsis
- Burns, trauma, surgery
- Hyperosmolar formulas

showed that patients in the ICU had a greater than threefold delay in gastric emptying compared with normal volunteers.¹⁹ Manometric studies in critically ill patients show a virtual absence of gastric migrating motor complexes within the stomach.²⁰ Surprisingly though, duodenal contractions are maintained in critically ill patients. One of the benefits of early EN delivery is restoration of normal gastrointestinal physiology and the stimulation of contractility.^{21,22}

An early study evaluated the accuracy with which GRVs differentiated normal from abnormal gastric emptying through comparing the practice with physical examination and abdominal radiographs.¹⁵ A total of 26 subjects were studied over an 8-hour period, with GRVs checked every 2 hours, and a physical examination with abdominal radiograph performed at the beginning and end of the testing. Physical examination was scored for evidence of hypertimpany, abdominal distention, and hypoactive bowel sounds. The abdominal radiographs were scored for presence of air and fluid levels, dilated air-filled loops of small bowel, and gaseous distention of the stomach. Results showed that physical examination findings correlated significantly with radiographic findings ($P = .016$). However GRVs failed to correlate with either physical examination or radiographic findings.¹⁵

Studies directly comparing gastric emptying with GRVs have shown poor correlation. In a study again using the paracetamol absorption test as a measure of gastric emptying, Landzinski and colleagues²¹ showed that in patients determined to be intolerant with high GRVs (defined by a single GRV >150 mL), 100% had abnormal gastric emptying. In contrast, of the patients determined to be tolerant with low GRVs (defined by all GRVs <150 mL), still 70% had abnormal gastric emptying.²¹ In a similar fashion, Cohen and colleagues²³ showed that 25% of intolerant patients with high GRVs had normal gastric emptying, whereas Tarling and colleagues²⁴ showed that 57% of tolerant patients with normal GRVs had abnormal gastric emptying. These studies confirm that GRVs are inaccurate and unreliable in distinguishing normal from abnormal gastric emptying.

ASSUMPTION #4: GASTRIC RESIDUAL VOLUMES ARE EASY TO INTERPRET

The routine practice of GRVs fails to distinguish the factors that contribute to the volume of gastric contents: endogenous secretion, water flushes, and infusion of

enteral formula. Although the average daily production of salivary and gastric secretions has been estimated to be as high as 3 to 5 L/d, several clinical factors exist in the ICU setting that may alter this volume.¹ Salivary output may be reduced in the absence of chewing and may be totally variable among oral, gastric, or small bowel feeding. Gastric secretion may be increased in the presence of head injury or burns, or reduced in the presence of atrophic gastritis or therapy with proton pump inhibitors. Water flushes after medication infusion, and on a regular basis to prevent clogging of the tubes, are usually poorly documented in the nursing notes. The variability in these factors alone renders the interpretation of GRVs incredibly difficult.¹

A simple modification in the practice of GRVs, using refractometry, may improve the ease of interpretation considerably.²⁵ Refractometry is a standard tool to measure solute in a solution. The Brix value of a particular formula (as measured by refractometry) essentially determines the concentration of the formula, because serial dilution reduces the measurement in a linear mathematical relationship. In this manner, refractometry can be used to determine what portion of the total GRV comprises the volume of formula. The volume of formula in the stomach derived from the GRV through refractometry can then be compared with the volume of formula infused initially with the EN therapy. This alteration in the interpretation of GRVs dramatically improves interpretation of gastric emptying. A recent survey of clinicians compared data from traditional GRV with those on aspirated volume of formula determined with refractometry, obtained simultaneously in the same patients.²⁶ When clinicians used data from volume of formula instead of those from traditional GRVs, they were significantly more likely to interpret that the patient was having normal or even rapid gastric emptying (84% vs 33%, respectively; $P < .05$),²⁶ to conclude that the patient was tolerating infusion of the EN (85% vs 36%; respectively, $P < .05$), and to decide to continue the EN based on this interpretation (80% vs 34%, respectively; $P < .05$). These data suggest that traditional use of GRVs is difficult to interpret, generates false signals to suggest delayed gastric emptying, and may inadvertently lead to cessation of delivery of EN.

ASSUMPTION #5: A TIGHT CORRELATION EXISTS BETWEEN GASTRIC RESIDUAL VOLUME AND ASPIRATION

Aspiration is probably the most feared complication of EN in the ICU setting and one of the main arguments for continued use of GRV. The practice of GRVs is predicated on the assumption that a tight correlation exists between GRVs and aspiration. Although data from the literature suggest a thread of correlation between GRVs and aspiration, the relationship is tenuous at best. Therefore, for clinicians, GRVs are an inaccurate measure of risk for aspiration.

In a study using a very sensitive and specific marker for aspiration (yellow colorimetric microspheres in tracheal secretions), cutoff values for GRV ranging from 150 to 400 mL were shown to have an unacceptably low sensitivity for aspiration events of only 1.9% to 8.1%.⁴ The positive predictive value of this monitor over the same range of cutoff values (the GRV above which aspiration would be expected to have occurred) was only 36.1% to 37.5%. The negative predictive value (the GRV below which no aspiration would occur) was only 70.0% to 70.3%.⁴ In fact, the incidence of aspiration documented by this very sensitive and specific marker did not change over a wide range of cutoff values for GRV (from 0–50 mL to 400–500 mL).⁴ Taken together, these data indicate that GRVs are a poor monitor with a very low sensitivity and specificity for detecting aspiration events in the ICU. The quality of this marker did not change by varying the cutoff value for GRV from 150 to 400 mL.⁴

Nonetheless, two other studies using a different marker for aspiration showed a thread of correlation between GRVs and aspiration.^{14,27} Using the presence of pepsin in tracheal secretions as a surrogate marker of aspiration, patients with a high frequency of aspiration were shown to be more likely to have GRVs greater than 200 mL than those with a low frequency of aspiration (75% incidence of GRVs >200 mL vs 25%, respectively; $P = .08$).²⁷ In a second study using the same marker, Metheny and colleagues¹⁴ showed that when high GRVs were present, the risk of aspiration increased significantly. However, in both studies, results showed no significant correlation between GRVs and aspiration when specifically evaluated.^{14,27}

ASSUMPTION #6: CONTINUING ENTERAL NUTRITION AFTER OBTAINING A HIGH GASTRIC RESIDUAL VOLUME LEADS TO PNEUMONIA AND ADVERSE OUTCOME

Despite whether aspiration is involved as the mediating event, another key assumption made when practicing GRVs is that continuing to provide EN after a high GRV has been obtained will lead to pneumonia and other adverse patient outcomes. Again, scant evidence from the literature suggests a thread of correlation between high GRVs and pneumonia. In a study by Mentec and colleagues,¹³ GRVs alone correlated with increased sedation, use of catecholamines (as pressor agents), and reduced caloric intake. When GRVs were combined with vomiting to define “upper digestive intolerance,” that combination of events correlated significantly to pneumonia, ICU length of stay, and ICU mortality.¹³ Closer evaluation of the data, however, showed that GRVs alone did not correlate with ICU mortality, hospital mortality, or incidence of pneumonia.¹³

This particular assumption, however, has led clinicians to fear that increasing the cutoff value for GRV will lead to increased aspiration and pneumonia. Conversely, through self-assurance, clinicians believe that decreasing the value will actually protect patients against aspiration and pneumonia. Data from four prospective controlled trials randomizing patients to two different cutoff levels for GRV show that these beliefs are baseless.^{4,6,28,29}

In a study by Taylor and colleagues,⁶ patients randomized to a 200-mL cutoff value for GRV received a significantly greater percentage of goal calories than those randomized to a 150-mL cutoff value (59% of goal calories vs 36%, respectively; $P < .05$). Similarly, in a study by Montejo and colleagues,²⁹ patients randomized to a 500-mL cutoff value for GRV received a significantly greater percentage of goal calories than those randomized to a 200-mL cutoff value (89% vs 83%, respectively; $P < .05$).

In a study randomizing patients to 150 versus 250 mL for the cutoff value for GRVs, Pinilla and colleagues²⁸ found that the incidence of vomiting and gastrointestinal intolerance was no different between groups. In a study from Louisville, randomizing patients to 200 versus 400 mL as the cutoff value for GRVs, the incidence of regurgitation and aspiration were the same between the groups.⁴

Remarkably, in the study by Taylor and colleagues,⁶ patients randomized to 150 mL GRV had significantly higher overall complications than the group randomized to 200 mL (61% vs 37%, respectively; $P < .05$). In the Montejo and colleagues²⁹ study, gastrointestinal complications were higher in the patients randomized to 200 mL GRV than in those randomized to 500 mL (63.6% vs 47.8%, respectively; $P < .05$).

In fact, two additional studies have evaluated the impact on patient outcome of eliminating the practice of GRVs altogether.^{30,31} In a small nursing study by Powell and colleagues,³⁰ the incidence of aspiration pneumonia was no different between study patients in whom no residual volumes were used and controls in whom routine

use of GRVs was performed. The incidence of tube clogging, however, was reduced 10-fold in the study patients in whom GRVs were not used (7.7% incidence vs 66.7% in controls; $P < .05$).³⁰ In a second prospective before-and-after study, patients for whom no GRVs were used had a lower incidence of intolerance, a higher volume of EN infused, and no difference in vomiting or ventilator-associated pneumonia compared with controls in whom routine GRVs were performed.³¹

Further irony regarding this assumption that continuing EN after a high GRV or raising the cutoff value for GRV will lead to pneumonia and adverse outcome is the fact that the use of GRVs often leads to inappropriate cessation of EN, and the risk for subsequent pneumonia may actually increase. In a study by Meissner and colleagues,³² a narcotic antagonist was infused through the feeding tube to patients on mechanical ventilation receiving fentanyl to promote gastrointestinal motility. Greater contractility in study patients led to a greater volume of EN infused (1200 vs 1000 mL, respectively; $P < .05$) and a significant reduction in the incidence of pneumonia (36% vs 55%, respectively; $P < .05$) compared with controls who received placebo.³² In the study by Taylor and colleagues,⁶ patients randomized to the protocol with a higher cutoff value for GRV and who received nearly twice the volume of EN had a significant reduction in the incidence of infection (85% vs 61%, respectively; $P < .05$) and a nonsignificant reduction in the incidence of pneumonia (63% vs 44%, respectively) compared with controls.

These data suggest that a tenuous yet unreliable relationship exists among GRVs, aspiration, and pneumonia. In an effort to protect patients through use of GRVs, clinicians may inadvertently cause more frequent cessation of EN and the risk of pneumonia may actually increase. Changing the cutoff level for GRVs does nothing to improve the accuracy or predictability of GRVs as a marker for aspiration or pneumonia. The failure of GRVs to accurately predict aspiration or pneumonia precludes reliance on this monitor in the critical care setting.

ASSUMPTION #7: GASTRIC RESIDUAL VOLUMES ARE AN INEXPENSIVE "POOR MAN'S TEST" FOR GASTRIC EMPTYING AND TOLERANCE OF ENTERAL NUTRITION

When performing GRVs, most clinicians assume the practice is an inexpensive, simplistic method for gauging tolerance for EN and gastric emptying. However, every nursing duty in the ICU represents an allocation of health care resources. Parrish and McClave¹ showed that a nurse spends an average of 5.25 minutes performing GRV tests. Thus, the allocation of health care resources (in 2006 U.S. dollars) for a nurse on a median salary to perform GRVs on 100 patients (every 4 hours for a 3-day average ICU length of stay) would be \$453,600.¹ This cost represents a significant allocation of resources for a monitor that is inaccurate and unreliable. This time might be better spent elevating the head of the bed, providing good oral hygiene, developing and enforcing an EN protocol, or calculating and readjusting volume-based feeds to make up for lost time required for diagnostic tests.

SUMMARY

Despite the fallacies of every one of the assumptions made when performing GRVs, clinicians are unlikely to stop performing this routine test in the ICU. Therefore, efficacy of EN therapy can only improve if clinicians are able to modify their response to and interpretation of GRVs (**Box 2**).¹

Clinicians may continue to check GRVs every 4 hours after initiation of EN, being careful to return aspirated contents less than 500 mL to the patient. In the absence of other signs of intolerance, stopping the delivery of EN for any GRV less than 400

Box 2**Summary of recommendations for using gastric residual volumes in an enteral nutrition protocol**

- Check GRV every 4 hours
- Return contents to patient if less than 500 mL
- If first GRV greater than 400 mL, initiate the following:
 1. Continue EN at the current rate
 2. Turn patient to the right lateral decubitus position if possible for 30 minutes
 3. Begin reglan, 10 mg, intravenously, every 6 hours
 4. Begin narcan, 8 mg, in 10 mL of saline through feeding tube every 6 hours
 5. Recheck GRV in 4 hours
- Only if second consecutive GRV 4 hours later is greater than 400 mL, hold EN and:
 1. Recheck GRV every 2 hours, restart EN when GRV is less than 400 mL
 2. If no signs of intolerance, restart at same rate
 3. If evidence of intolerance present, consider reducing rate by 25 mL/h or to baseline of 25 mL/h

to 500 mL is inappropriate. For the first GRV greater than 400 mL, EN should be continued at its current rate, the patient should be turned over to the right lateral decubitus position (to put the antrum in the dependent position and promote gastric emptying), and prokinetic therapy with metoclopramide, 10 mg, should be initiated intravenously every 6 hours. If the patient is on opioid narcotics, clinicians could consider an infusion of naloxone, 8 mg, in 10 mL of saline through the feeding tube every 6 hours. If a second GRV 4 hours later is greater than 400 mL, then holding EN while the patient is being reassessed may be appropriate. GRVs should be rechecked every 2 hours at that point, with EN restarted once the GRV drops to less than 400 mL. If no other signs of tolerance are present, the EN may be started at the same rate. If other signs of intolerance are present (eg, abdominal distention, hypoactive bowel sounds, failure to pass stool or gas), then reducing the rate by 25 mL/h or to a baseline of 25 mL/h may be wise. Checking GRVs is more important on initiation of EN. Once EN has been infused successfully for 48 to 72 hours, clinicians should be encouraged to stop checking GRVs and simply follow physical findings for any clinical signs of intolerance.¹

Early and adequate delivery of EN has been linked to improved patient outcomes. EN therapy in critically ill patients in the ICU is difficult, and excessive emphasis on GRVs tends to impede its delivery. The current use of GRVs is based on several flawed assumptions with little scientific basis. GRVs should never be interpreted in a vacuum, without paying attention to signs on physical examination of intolerance and intestinal ileus. Having protocols in place improves the interpretation and response to elevated GRVs, reduces inappropriate cessation, and promotes a greater percentage of goal calories of EN delivered. Once tolerance of EN is established, ceasing the performance of GRVs may be appropriate to better allocate nursing time and health care resources.

REFERENCES

1. Parrish RP, McClave SA. Checking gastric residual volumes: a practice in search of science? *Pract Gastroenterol* 2008;32(10):33–47.

2. McClave SA, Dryden GW. Critical care nutrition: reducing the risk of aspiration. *Semin Gastrointest Dis* 2003;14(1):2–10.
3. Elpern EH, Stutz L, Peterson S, et al. Outcomes associated with enteral tube feedings in a medical intensive care unit. *Am J Crit Care* 2004;13(3):221–7.
4. McClave SA, Lukan JK, Stefater JA, et al. Poor validity of residual volumes as a marker for risk of aspiration in critically ill patients. *Crit Care Med* 2005;33(2):324–30.
5. Poulard F, Dimet J, Martin-Lefevre L, et al. Impact of not measuring residual gastric volume in mechanically ventilated patients receiving early enteral feeding: a prospective before-after study. *JPEN J Parenter Enteral Nutr* 2010;34(2):125–30.
6. Taylor SJ, Fettes SB, Jewkes C, et al. Prospective, randomized, controlled trial to determine the effect of early enhanced enteral nutrition on clinical outcome in mechanically ventilated patients suffering head injury. *Crit Care Med* 1999;27(11):2525–31.
7. Adam S, Batson S. A study of problems associated with the delivery of enteral feed in critically ill patients in five ICUs in the UK. *Intensive Care Med* 1997;23(3):261–6.
8. Edwards SJ, Metheny NA. Measurement of gastric residual volume: state of the science. *Medsurg Nurs* 2000;9(3):125–8.
9. Juve-Udina ME, Valls-Miró C, Carreño-Granero A, et al. To return or to discard? Randomised trial on gastric residual volume management. *Intensive Crit Care Nurs* 2009;25(5):258–67.
10. Booker KJ, Niedringhaus L, Eden B, et al. Comparison of 2 methods of managing gastric residual volumes from feeding tubes. *Am J Crit Care* 2000;9(5):318–24.
11. Metheny N, Reed L, Worsack M, et al. How to aspirate fluid from small-bore feeding tubes. *Am J Nurs* 1993;93(5):86–8.
12. Metheny NA, Stewart J, Nuetzel G, et al. Effect of feeding-tube properties on residual volume measurements in tube-fed patients. *JPEN J Parenter Enteral Nutr* 2005;29(3):192–7.
13. Mentec H, Dupont H, Bocchetti M, et al. Upper digestive intolerance during enteral nutrition in critically ill patients: frequency, risk factors, and complications. *Crit Care Med* 2001;29(10):1955–61.
14. Metheny NA, Schallom L, Oliver DA, et al. Gastric residual volume and aspiration in critically ill patients receiving gastric feedings. *Am J Crit Care* 2008;17(6):512–9 [quiz: 520].
15. McClave SA, Snider HL, Lowen CC, et al. Use of residual volume as a marker for enteral feeding intolerance: prospective blinded comparison with physical examination and radiographic findings. *JPEN J Parenter Enteral Nutr* 1992;16(2):99–105.
16. Esparza J, Boivin MA, Hartshorne MF, et al. Equal aspiration rates in gastrically and transpylorically fed critically ill patients. *Intensive Care Med* 2001;27(4):660–4.
17. Metheny NA. Residual volume measurement should be retained in enteral feeding protocols. *Am J Crit Care* 2008;17(1):62–4.
18. Lin HC, Van Citters GW. Stopping enteral feeding for arbitrary gastric residual volume may not be physiologically sound: results of a computer simulation model. *JPEN J Parenter Enteral Nutr* 1997;21(5):286–9.
19. Heyland DK, Tougas G, King D, et al. Impaired gastric emptying in mechanically ventilated, critically ill patients. *Intensive Care Med* 1996;22(12):1339–44.
20. Dive A, Moulart M, Jonard P, et al. Gastrointestinal motility in mechanically ventilated critically ill patients: a manometric study. *Crit Care Med* 1994;22(3):441–7.

21. Landzinski J, Kiser TH, Fish DN, et al. Gastric motility function in critically ill patients tolerant vs intolerant to gastric nutrition. *JPEN J Parenter Enteral Nutr* 2008;32(1):45–50.
22. Kompan L, Kremzar B, Gadzijev E, et al. Effects of early enteral nutrition on intestinal permeability and the development of multiple organ failure after multiple injury. *Intensive Care Med* 1999;25(2):157–61.
23. Cohen J, Aharon A, Singer P. The paracetamol absorption test: a useful addition to the enteral nutrition algorithm. *Clin Nutr* 2000;19:233–6.
24. Tarling MM, Toner CC, Withington PS, et al. A model of gastric emptying using paracetamol absorption in intensive care patients. *Intensive Care Med* 1997;23:256–9.
25. Chang WK, McClave SA, Chao YC. Enhancing interpretation of gastric residual volume by refractometry. *Nutr Clin Pract* 2004;19:455–62.
26. McClave SA, Chang WK, Mikola D, et al. Use of refractometry to determine volume of formula remaining in the stomach improves interpretation of gastric residual volume and facilitates delivery of enteral nutrition. *JPEN* 2009;33(2):223.
27. Metheny NA, Clouse RE, Chang YH, et al. Tracheobronchial aspiration of gastric contents in critically ill tube-fed patients: frequency, outcomes, and risk factors. *Crit Care Med* 2006;34(4):1007–15.
28. Pinilla JC, Samphire J, Arnold C, et al. Comparison of gastrointestinal tolerance to two enteral feeding protocols in critically ill patients: a prospective, randomized controlled trial. *JPEN J Parenter Enteral Nutr* 2001;25(2):81–6.
29. Montejo-Gonzales JC, Minambres E, Bordeje L, et al. Gastric residual volume during enteral nutrition in ICU patients. The REGANE study. Preliminary results [abstract]. *Intensive Care Med* 2007;33(Suppl 2):S108.
30. Powell KS, Marcuard SP, Farrow ES, et al. Aspirating gastric residuals causes occlusion of small-bore feeding tubes. *J Parenter Enteral Nutr* 1993;17:243–6.
31. Poulard F, Dimet J, Martin-Lefevre L, et al. Impact of not measuring gastric residual volume in mechanically ventilated patients receiving early enteral feeding: a prospective before-after study. *JPEN* 2010;34(2):125–30.
32. Meissner W, Dohrn B, Reinhart K. Enteral naloxone reduces gastric tube reflux and frequency of pneumonia in critical care patients during opioid analgesia. *Crit Care Med* 2003;31(3):776–80.