Journal of Critical Care (2012) **27**, 702–713

Journal of Critical Care

Nutrition

Why patients in critical care do not receive adequate enteral nutrition? A review of the literature

Hyunjung Kim RN, PhD[a], Nancy A. Stotts RN, EdD[b,*], Erika S. Froelicher RN, PhD[b], Marguerite M. Engler RN, PhD[c], Carol Porter RD, PhD[b]

[a]*Hallym University, Chuncheon, Korea*
[b]*University of California San Francisco, San Francisco, CA 94143-0610*
[c]*National Institute of Nursing Research, National Institutes of Health, Bethesda, MD*

Keywords:
Energy intake;
Enteral nutrition;
Intensive care unit;
Nutritional adequacy;
Protein intake

Abstract Enteral nutrition is frequently used to provide nutrients for critically ill patients. However, only about half of critically ill enterally fed patients receive their energy requirements. Underfeeding is associated with detrimental clinical outcomes including infection, pressure ulcers, impaired wound healing, prolonged hospital stays, and increased morbidity and mortality. This literature review was conducted to identify major barriers to adequate enteral nutrition intake in critically ill adults and to identify gaps in the research literature. Studies (n = 30) reviewed addressed adult patients in critical care, published since 1999, and written in English. Findings showed that factors that explain inadequate enteral nutritional intake include delayed initiation of enteral nutrition and slow advancement of infusion rate, underprescription, incomplete delivery of prescribed nutrition, and frequent interruption of enteral nutrition. Frequent interruption was caused by diagnostic tests, surgical procedures, gastrointestinal intolerance, feeding tube problems, and routine nursing procedures. There are no standardized protocols that address these barriers to receiving adequate enteral intake. Such protocols must be developed, implemented, and tested to address undernutrition and mitigate the negative consequences of inadequate enteral intake.

1. Introduction

Malnutrition is a common and severe problem in patients in critical care units, occurring in 38% to 88% of patients [1,2]. It is associated with detrimental clinical outcomes such as higher risk of infection and pressure ulcers, reduced wound healing, prolonged hospital stays, increased morbidity, and mortality as well as increased costs for care [3,4]. The combination of increased resting energy expenditure and inadequate nutritional delivery contribute to the increased risk of malnutrition in critically ill patients [5]. Adequate nutritional support is crucial to the prevention and treatment of malnutrition.

Enteral nutrition is the preferred route of nutritional support in critically ill patients, but it is frequently associated with underfeeding [6,7]. Mandel and Worthley [8] first reported the inadequacy of enteral nutritional intake in patients on general wards and intensive care units (ICUs)

* Corresponding author. Tel.: +1 415 476 4412; fax: +1 415 476 8899.
E-mail address: nancy.stotts@nursing.ucsf.edu (N.A. Stotts).

0883-9441/$ – see front matter © 2012 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jcrc.2012.07.019

more than 25 years ago. Nonetheless, underfeeding continues to be a frequent problem in enterally fed critically ill patients [9-11].

Over time, studies of critically ill patients have identified likely barriers for inadequate enteral nutritional intake [6,7,12], yet few consistent findings have been demonstrated. Understanding the barriers for enteral nutrition in critically ill patients is essential for health care providers to optimize nutritional support. Protocols can be developed and implemented, which address these barriers to ensure adequate nutritional support. The purpose of this literature review is to identify major barriers contributing to inadequate enteral nutrition intake in critically ill adults and to identify relevant gaps in the research literature.

2. Methods

2.1. Search strategy

A literature search was performed using 4 databases (PubMed, CINAHL, MD Consult, and PsychINFO). Reference lists and related articles were also searched for additional studies. Table 1 shows the key search terms. Parameters set for the literature search were adult patients (>19 years), 1999-2011, published research, and English language. The time frame searched was selected because the reasons for and duration of interruptions of enteral nutrition in critically ill patients were first delineated in 1999 by McClave et al [6], and there have been few subsequent studies.

Studies included described the delivery in enteral nutrition for critically ill adult patients and evaluated the percentage of energy or protein received vs required, the percentage of patients who were adequately or inadequately fed, factors related to inadequate intake, and interruptions in enteral feeding. Studies were excluded if study sample was pediatric patients or the delivery of only parenteral nutrition was evaluated. Reviews, commentaries, editorials, letters, and practical guideline articles also were excluded.

Table 1 Key search terms

Search terms	Results
Enteral nutrition OR enteral feeding	323
Energy intake OR caloric intake	42
Protein intake	40
Hypocaloric intake OR hypercaloric intake	3
Hypercaloric intake	0
Energy balance OR caloric balance	15
Protein balance	53
Nutritional adequacy	10
Manual searching from reference lists	17

Each term was searched by combined with "Intensive care units" using the Boolean operator AND.

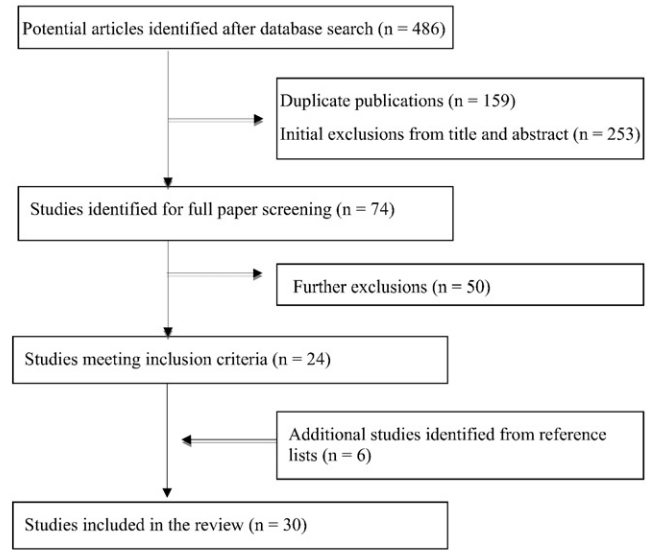

Fig. 1 Flow chart of study selection process.

Fig. 1 shows the process of evaluation of studies identified. A total of 30 studies met the search criteria and were reviewed for this study; 11 were experimental studies, 2 were quasi-experimental studies, and 17 were nonexperimental studies.

3. Results

3.1. Barriers to the delivery of enteral nutrition

Although enteral nutrition has been considered the criterion standard for nutritional therapy in critically ill patients because of its favorable effects, it frequently fails to provide the desired energy requirements [7]. The average energy provided to critically ill patients by enteral nutrition is between 50% and 95% of requirements [13-17], and the average protein intake with enteral feeding ranges from 38% to 82% of requirements [18-20]. Many studies have evaluated the barriers that affect the delivery of enteral nutrition in critically ill patients. The barriers that have an impact on the adequacy of enteral nutrition have been classified as patient-related factors, feeding method factors (feeding formula, feeding tube site), feeding process factors (feeding initiation time, time to meet target goal), underprescription by physicians, and frequent interruption of enteral nutrition (Tables 2 and 3).

3.1.1. Patient-related factors

Patient-related factors such as age, sex, nutritional status, severity of illness, and mechanical ventilatory support may affect the delivery of enteral nutrition. Krishnan et al [15] examined the relationship between nutritional status (measured with serum albumin levels and body mass index [BMI]), severity of illness (Simplified Acute Physiology

Table 2 Definition of major variables

Variable	Definition
Adequacy of enteral nutrition	Energy and protein intake to meet the patient's energy and protein goals—the goals vary from 70% to 110% of requirements
Patient-related factors	Patient-related factors that affect the delivery of enteral nutrition, including age, sex, nutritional status, severity of illness, and mechanical ventilatory support
Feeding formula	Enteral feeding formula including isotonic formulas and nutrient-dense formulas as a subcategory of polymeric formulas
Feeding tube location	The nasoenteric tube inserted into the stomach, duodenum, or jejunum
Feeding initiation time	Total time from prescription by a physician to insertion of the feeding tube, to confirmation of the feeding tube location, to initiation of enteral feeding–early initiation, late initiation
Time to meet target goal rate	The time to reach the nutritional goal after enteral feeding initiation-immediate goal rate, rapid increasing rate, gradual increasing rate
Underprescription by health care providers	Health care provider's insufficient order for energy and protein, not to meet energy and protein requirements
Frequent interruption of enteral nutrition	Withholding of enteral nutrition that patient should be fed but not receiving

Scores [SAPS] II), and energy intake in patients hospitalized in a medical ICU. Although the mean energy intake was only 50.6% of the American College of Chest Physicians targets, it was not associated with SAPS II or markers of nutritional status. Similar findings were seen in the study conducted by Rubinson et al [16], where the mean energy intake was 49.3% of American College of Chest Physicians recommendations. Baseline patient characteristics including age, SAPS II, sex, serum albumin level, BMI, and duration of mechanical ventilation were similar across categories of energy intake and did not explain differences in energy intake.

Two studies [15,16] used a prospective cohort design and included patients hospitalized in medical ICUs, with mean ages of 54 and 52.6 years. Sample sizes were large (n = 187 and 138, respectively), and study periods were 4 to 6 days. These studies were limited by including only patients in medical ICUs and by their short treatment duration. Furthermore, the adequacy of enteral nutritional intake may be associated with nutritional support practice provided by health care providers rather than with patients' characteristics such as nutritional status or severity of illness. It is not clear whether nutritional practices by health care providers in these studies were uniform. A total of 10% and 18% of patients received only parenteral nutrition. Separate analyses were not done by feeding method or practice, so the relationship between patient factors and energy intake from enteral nutrition could not be determined. Despite these limitations, this set of articles suggests that patient-related factors do not adequately explain the inability to meet energy goals in critically ill patients.

3.1.2. Feeding method factors

3.1.2.1. Feeding formula. Isotonic formula is a standard for enteral nutrition for critically ill patients, but nutrient-dense formulas are preferred in some ICU settings to facilitate nutrient delivery using smaller fluid volumes [37]. Bryk and colleagues [35], in a study of 117 patients in surgical and trauma ICUs, demonstrated that calorically dense enteral formula did not increase the delivery of energy compared with isotonic formula. This study was limited by its retrospective research design. Another issue is that hypertonic formulas may increase the risk for diarrhea and that clinicians, therefore, may stop enteral feeding. Therefore, future research is needed to identify the relationship among hypertonic formulas, diarrhea, feeding interruptions, and energy intake.

A prospective study in critically ill patients demonstrated that the highest energy and protein intakes were achieved with nutrient-dense formulas rather than standard formulas [19]. There were significant differences in energy intake (1600 vs 965 kcal/d) and protein intake (60 vs 36.4 g/d) between the groups. Furthermore, the use of nutrient-dense enteral formulas resulted in overfeeding in energy intake. However, patients on nutrient-dense formulas received only 82% of their protein requirements, although they received more protein than with standard formulas. This finding suggests that protein requirements and intake should be assessed separately from energy intake. However, the descriptive study design precludes inferring a causal relationship between overfeeding and nutrient-dense enteral feeding.

In summary, one prospective study [19] showed that nutrient-dense enteral formulas provide more energy and protein compared with standard formulas, despite inconsistent findings in a retrospective study [35]. Evidence needs to be obtained through randomized clinical trials (RCTs) to validate these findings.

3.1.2.2. Feeding tube location. The nasoenteric tube inserted into the stomach, duodenum, or jejunum is the most common method used to provide enteral nutrition. Feeding into the duodenum or jejunum (transpyloric feeding) can mitigate the problem of impaired gastric emptying and may increase the amount of enteral nutrition delivered to the patients [38]. Favorable effects of transpyloric feeding on energy and protein intake were reported in 3 studies conducted in medical ICUs. In a study by Kearns et al [10], small intestine–fed patients received greater energy (1157 vs 812 kcal/d) and protein (44 vs 31 g/d) compared with gastric-fed patients. The higher-energy intake in the intestine-fed patients compared with the gastric-fed patients was because more patients in the gastric group had feedings withheld due to high gastric residuals (GRs). Consistent with the findings of this study, Esparza et al [23] reported higher-energy intake in transpyloric-fed patients than in gastric-fed patients. This study was conducted in a sample of 51 patients, over a relatively long period (8 days), but 40% of the patients dropped out. Although high attrition rates can cause bias and limit the reliability of the conclusions, the attrition rates were identical in both groups. However, it is not clear if the characteristics of those who dropped out were similar to those retained. Hsu and colleagues [28] also reported a higher-energy (1658 vs 1426 kcal/d) and higher-protein intake (67.9 vs 58.8 g/d) as well as shorter time to feeding goal rate (32.4 vs 54.5 hours) in duodenal feeding compared with gastric feeding. The authors concluded that duodenal feeding might be more efficient because of the greater peristaltic activity of the duodenum [39].

Similarly, in a descriptive study by Binnekade et al [18], the percentage of days with energy goal achievement was lowest in critically ill patients with gastric tubes (49%) and highest in those with duodenal/jejunal tubes (58%) and needle catheter jejunostomies (76%). They reported that aspirated GR volumes were discarded rather than refed; this could explain the low rates of energy goal achievement. Although the study has a large number of participants (n = 403), selection bias is a possible threat because of the lack of randomization.

In contrast, an RCT by Boivin and Levy [24] demonstrated that gastric feeding was superior to transpyloric feeding for energy balance (74% vs 68% of requirements) in critically ill patients. Another RCT, conducted by White et al [27], showed that patients with gastric feeding had lower-energy deficits (73 vs 167 kcal) and reached the feeding goal rate earlier (8.7 vs 12.3 hours) than those with postpyloric feeding. However, the gastric-fed patients were not as sick, as shown by their lower Acute Physiology and Chronic Health Evaluation II scores; they also had feedings initiated more quickly than those in the postpyloric feeding group. These characteristics are potential confounding factors.

Furthermore, no significant differences were found between the gastric and transpyloric groups in energy and protein intake in 3 RCTs and 1 meta-analysis [22,25,26,36]. Sample sizes were not adequate in any of these RCTs; thus, the studies may not have adequate power to find the difference between gastric feeding and transpyloric feeding if it was present. In addition, despite being a meta-analysis, only 238 patients were included in the analyses by Marik and Zaloga [36]. The sample also was heterogeneous.

To conclude, transpyloric feeding tends to have benefits of energy and protein intake compared with gastric feeding, although there was somewhat adverse result in 2 RCTs. In the studies of the effect of feeding tube location [10,22-25,27], none of the groups achieved the average recommended energy or protein intake, except for the study by Neumann and DeLegge [25]. These data suggest that factors other than tube site influence the inadequacy of enteral nutrition intake.

3.1.3. Feeding process factors

3.1.3.1. Feeding initiation time. The American Society of Parenteral and Enteral Nutrition recommends that nutrition support should be started within 24 to 48 hours after admission to the ICU [40]. Several studies in critically ill patients have examined whether administration of early enteral nutrition is associated with improved nutrient intake compared with delayed enteral nutrition. In an RCT of 28 patients with multiple injuries, Kompan et al [21] provided enteral nutrition within 6 hours or more than 24 hours after admission to the ICU. They showed an energy intake of 80.5% of requirements in the early-feeding group and 60.9% in the later-feeding group. Even in the later-feeding group, the patients received enteral nutrition earlier (24 hours after admission) than reported in other studies with enteral nutrition administration on days 3 to 5 after ICU admission [9,29]. The time variance in the definition of later initiation among studies may influence the effect of later initiation of enteral nutrition.

Ibrahim et al [29] provided enteral nutrition to patients in a medical ICU on either day 1 or 5 after admission. The mean daily energy intake (474 vs 126 kcal, respectively) and protein intake (18.7 vs 5.3 g, respectively) were greater for patients in the early-feeding group compared with those in the later-feeding group. However, the early group had a higher incidence of ventilator-associated pneumonia, diarrhea, and prolonged length of stay (LOS) in the ICU. The findings indicate that the potential for complications associated with early enteral nutrition needs to be considered with the expected benefits of nutrient intake. Several limitations that may contribute to study bias are noted in these studies. These include a single ICU setting, no blinding, small sample size, and quasi-experimental design.

In contrast to the previously mentioned studies, energy intake was equivalent in the 2 groups (nutrition support initiation within 3 days after admission and >3 days afterward) studied by Roberts et al [9]. However, it is not possible to generalize these findings because this study was conducted with mixed populations, there was a small sample size (n = 50), and subjects were not prospectively randomized to groups.

Early initiation of enteral intake may contribute to increased energy intake, although there is no standard definition for early and later enteral feeding. This conclusion is consistent with the recommendation of the American Society of Parenteral and Enteral Nutrition about the early initiation of enteral nutrition in critically ill patients [40].

3.1.3.2. Time to meet target goal rate. Stable patients tolerate a fairly rapid progression of enteral nutrition, reaching their nutritional goal within 48 to 72 hours of initiation [40]. Desachy et al [17] demonstrated that when feeding was provided immediately after admission at optimal flow rates, there was a significant improvement in energy intake compared with a gradual increase in rate of feeding (95% vs 76% of requirements), although high GR volumes

Table 3 Adequacy of enteral nutrition and related barriers in critically ill patients

Author/Year	Population		Independent variables						Dependent variables				
	n	ICU	Patient factors	Method factors	Process factors	Under order	Interruption	Other	Energy		Protein		Other
									Intake (balance)	% Goal (patients)	Intake (balance)	% Goal (patients)	
Randomized controlled trial													
Taylor et al (1999) [20]	82	NICU, trauma ICU			Goal vs gradual rate					60% vs 37%		69% vs 38%	
Kompan et al (1999) [21]	28	SICU			Initiate: <6 vs >24 h				1340 ± 473 vs 703 ± 701 kcal	80.5% vs 60.9%			
Kearns et al (2000) [10]	44	MICU		G vs D					812 ± 122 vs 1157 ± 86 kcal	47% vs 69%	31 ± 5 vs 44 ± 4 g/d		
Day et al (2001) [22]	25	NICU		G vs D					NS	NS (none)	NS	None	
Esparza et al (2001) [23]	51	MICU		G vs T						64% vs 66%			Aspiration: NS
Boivin and Levy (2001) [24]	40	Mixed ICUs		G vs T						74% vs 68%			
Neumann and DeLegge (2002) [25]	60	MICU		G vs D					NS	100% vs 100%			Achieved goal rate: 28.8 vs 43.0 h
Davies et al (2002) [26]	73	Mixed ICUs		G vs J					NS				GRV: 32% vs 74% of patients
Desachy et al (2008) [17]	100	MICU, SICU			Goal vs gradual rate				1715 ± 331 vs 1297 ± 331 kcal (−406 ± 729 vs-2310 ± 1340 kcal)	95% vs 76%			High GRV: 26% vs 10%
White et al (2009) [27]	104	General ICU		G vs P					(−73 vs −167 kcal)				Achieved target goal: 8.7 vs 12.3 h
Hsu et al (2009) [28]	121	MICU		G vs D					1426 ± 110 vs 1658 ± 118 kcal		58.8 ± 4.9 vs 67.9 ± 4.9 g		Achieved target goal: 54.5 vs 32.4 h
Quasi-experimental study													
Ibrahim et al (2002) [29]	150	MICU			Initiate: 1 vs 5 d				474 ± 400 vs 126 ± 115 kcal		18.7 ± 15.4 vs 5.3 ± 5.3 g		Pneumonia: 49.3% vs 30.7% Diarrhea: 13.3% vs 4.0% LOS: 13.6 vs 9.8 d
Rice et al (2005) [14]	55	MICU, SICU, trauma, NICU					+	ICU	NS (with ICU)	Overall 50%–70% (overall 25%)			Achieved goal rate: 23 vs 43 h Average stop: 8 h (for first 48 h)

Prospective descriptive study												
Krishnan et al (2003) [15]	187	MICU	Alb, BMI, SAPS					NS	Overall 50.6%			
Rubinson et al (2004) [16]	138	MICU	Alb, BMI, SAPS				Age, sex, LOV	NS	Overall 49.4%			
Villet et al (2005) [30]	48	SICU					Time flow	(−1270 vs −625 kcal/d) (1 vs 4 wk)				
Dvir et al (2004) [31]	50	General ICU					Time flow	(Mean cumulative: −4767 kcal)				High negative energy balance: 1-3 d
Hise et al (2007) [11]	77	MICU, SICU					ICU	(−1045 kcal/d: SICU, −784 kcal/d: MICU)	50%: SICU; 56%: MICU			
McClave et al (1999) [6]	44	MICU, CCU			+	+			(Overall 14%)			Order: 65% of requirement Interruption: 83.7%, 19.6% of patients, feeding time
De Jonghe et al (2001) [13]	51	MICU			+				Overall 71.2%			Order: 78% of requirement
Elpern et al (2004) [32]	39	MICU				+			Overall 64%			Average stop 2.3 h/patient per day
O'Leary-Kelley et al (2005) [7]	60	MICU, SICU, CCU				+			(Overall 30%)			Underfeed: overfeeding = 68.3%: 1.7% of patients Average stop: 7 h/d
Reid (2006) [19]	32	General ICU		Standard vs caloric dense		+		975 vs 1600 kcal (overall median balance: −3985 kcal)	60% vs 103%	36.4 vs 60 g	51% vs 82%	Underfeeding: 50% of feeding days Overfeeding: 19% of feeding days
Petros and Engelmann (2006) [33]	61	MICU				+		23.2 ± 7.5 vs 10.4 ± 6.1 kcal kg^{-1} d^{-1}				Interruption: 32.1% of feeding days
O'Meara et al (2008) [12]	59	MICU/				+	Time flow	(Negative balance on all study days)				Initiated time: 39.7 h Stop: 6 h/d per patient
Kim [34] (2010)	47	NICU				+			(Overall 52.1%)			Underfeed: overfeeding = 37.2%: 10.7% of patients

(*continued on next page*)

Table 3 (*continued*)

Author/Year	Population		Independent variables						Dependent variables				
	n	ICU	Patient factors	Method factors	Process factors	Under order	Interruption	Other	Energy		Protein		Other
									Intake (balance)	% Goal (patients)	Intake (balance)	% Goal (patients)	
Retrospective descriptive study													
Roberts et al (2003) [9]	50	MICU, SICU, trauma, CCU/			Initiate: 3 d vs later		+		(3 d vs later: NS)	Overall 77.4%		Overall 58.2%	
Binnekade et al (2005) [18]	403	General ICU	SAPS	G vs D vs NCJ, formula kinds				Time flow		G vs D vs NCJ: 49% vs 58 vs 76% [1 vs 5 d]: 39% vs 51%		Overall 54%	Success factor (OR): semielemental formula (3.02), caloric dense formula (1.62), low GRV (1.51)
Bryk et al (2008) [35]	117	SICU, trauma		Standard vs caloric dense					NS				Caloric dense: increased LOS, LOV
Meta-analysis study													
Marik and Zaloga (2003) [36]	238	Mixed ICUs		G vs P									WMD NS

+ indicates reported; NS, nonsignificant; MICU, medical ICU; SICU, surgical ICU; NICU, neurologic ICU; CCU, coronary care unit; Alb, albumin; G, gastric; D, duodenal; T, transpyloric; J, jejunal; NCJ, needle catheter jejunostomy; LOV, length of ventilation; GRV, GR volume; OR, odds ratio; WMD, weighted mean difference.

were more frequent. Similarly, patients receiving enteral nutrition with rapidly increasing administration rates in a medical ICU had a greater energy intake than those with a gradual increase in rates (23.2 vs 10.4 kcal kg^{-1} d^{-1}) [33]. There was a greater energy intake (60% vs 37% of requirements) and protein intake (69% vs 38% of requirements) in head-injured patients with the provision of immediate goal rate when compared with those with the gradual increasing rate [20].

In conclusion, providing enteral nutrition using an immediate goal rate or rapid increasing rate improves energy intake in critically ill patients compared with that with a gradual increasing rate. However, enteral nutrition regimens with strictly defined protocols were followed in studies by Desachy et al [17] and Taylor et al [20] and resulted in greater intake. In addition, prokinetics were provided in the study by Desachy et al [17]. Consistently following nutrition protocols and the use of prokinetics could be moderators in improving energy intake. These study findings need to be confirmed in studies where prokinetics are not used.

3.1.4. Underprescription by health care providers

Although technical problems in administration of enteral nutrition contribute to the inadequately delivered energy intake, underprescription also needs to be considered. In a study by McClave et al [6], physicians prescribed a daily mean volume that was 65.6% of the requirements, but only 78.1% of the volume prescribed was infused in critically ill patients in a medical ICU and coronary care unit. Thus, patients received a mean volume that was 51.6% of goal. Similar results were demonstrated by De Jonghe et al [13], with 78% of the energy requirements prescribed and 71.2% of the requirements effectively delivered.

Nutritional intervention is frequently neglected in the ICU because enteral nutrition is usually a lower priority compared with other critical care interventions that provide for neurologic, hemodynamic, or respiratory stability. This clinical situation may contribute to the inadequate prescription of enteral nutrition. Furthermore, physicians may be unaware of the actual nutrition received by the patient. Failure to recognize that the prescribed amount of enteral nutrition was not received [6] combined with underprescription and poor delivery of prescribed energy results in inadequate nutritional support.

3.1.5. Frequent interruption of enteral nutrition

Enteral nutrition is usually withheld in patients in critical care until emergent medical problems are stabilized; often it is not started or restarted for days [14]. Across several studies, enteral nutrition was interrupted in critically ill patients, on average, 2.3 to 7.0 hours daily per patient [7,12,14,32]. Feeding was on hold for 19.6% to 32% of the total feeding time [6,33]. Patients received only 50% to 76% of the energy required in the studies [14,32,34]. Major reasons for interruptions are summarized in Table 4.

3.1.5.1. Procedures and tests. Most interruptions in feeding occur because of procedures and tests at the bedside and in the operating room. McClave et al [6] reported that the longest cessation of enteral nutrition was due to procedures, accounting for 35% of the interruption time (the total time that feeding was withheld). Procedures resulted in discontinuation of enteral nutrition in 39% patients and tests accounted for disruption of feeding in 27% of patients. About 66% of events (the occurrence that caused the feeding to be withheld) were avoidable and potentially correctable. In a study by O'Leary-Kelley et al [7], more than 40% of patients were affected by procedures or scheduled surgery, accounting for 24.8% of the interruption time. Similar results were reported in studies by Kim et al [34] (30% of events), Rice et al [14] (41% of events), Elpern et al [32] (35.7% of the interruption time), and Boivin and Levy [24] (36% of events).

Most procedures and radiologic studies requiring the patient to be in a supine position or nothing by mouth may lead to the cessation of enteral feeding for fear of aspiration. However, patients in the ICU frequently have diagnostic tests and procedures that require withholding of enteral nutrition for several hours [7]. Of interest, not all procedures require fasting. Furthermore, enteral nutrition may not be immediately restarted after a procedure is completed. In addition, ICU nurses may not compensate for the formula volume delayed by procedures or tests. If procedures and tests could be completed when scheduled rather than being delayed, unnecessary withholding of enteral nutrition could possibly be prevented. Well-designed protocols to replace volumes held due to interrupted enteral nutrition may guide health care providers in helping patients achieve goal volumes after procedures.

3.1.5.2. Gastrointestinal intolerance. Studies have demonstrated that a significant percentage of patients in the ICU develop gastrointestinal (GI) intolerance, resulting in the interruption of enteral nutrition [7,9,33]. High GRs and GI intolerance including diarrhea, vomiting, emesis, abdominal pain, or distention were the most common factors cited by Roberts et al [9] (66% of patients) and Petros and Engelmann [33] (41.5% of events). Similarly, O'Leary-Kelley et al [7] found that GI intolerance occurred in 36.7% of patients but accounted for 19.8% of the interruption time. Kim et al [34] reported lower rates of GI intolerance, 15.2% of patients and 10.5% of events.

Although an elevated GR is a frequent cause for interruption of enteral nutrition, very few data support the use of GRs to monitor enteral nutrition [6]. Patients who are more critically ill may have more GI dysfunction, which may lead to inadequate nutrition support, compared with those who are less ill [9]. Therefore, it is necessary to consider the severity of disease when evaluating GI function. It is important to study reliable markers of intolerance to enteral nutrition. The use of prokinetics may also improve tolerance.

3.1.5.3. Feeding tube problem. Feeding tube patency and displacement are also important factors that affect adequacy of enteral nutrition. In the study of McClave et al

Table 4 Type of interruption for enteral nutrition

Author	Year	Sample size		Type of interruption									
				Feeding tube problem	GR	GI intolerance	Procedure	Surgery	Radiology	Nursing care	Hemodynamic	Airway	Other
McClave et al [6]	1999	44	% of patients affected	41	45	[a]	[39]		27	30	[a]	NR	31
			% of total interruption time	7.7	15.1	[a]	[35.0]		4.6	1.4	[a]	NR	36.2
			% of avoidable	67	70	[a]	[80]		52	99	[a]	NR	52
Boivin and Levy [24]	2001	40	% of total interruption events	19	17	NR	NR	13	23	11	4	12	NR
Roberts et al [9]	2003	50	% of patients affected	NR	38	28	NR	NR	NR	NR	NR	NR	NR
Elpern et al [32]	2004	39	% of total interruption time	2.7	11.5	9.2	[35.7]			NR	13.5	NR	11.2
Rice et al [14]	2005	55	% of total interruption events	3	4	5	[41]			2	6	15	3
O'Leary-Kelley et al [7]	2005	60	% of patients affected	24.9	21.7	15.0	15.0	23.3	13.3	33.3	NR	30	21.6
			% of total interruption time	11.1	6.6	13.2	1.4	23.4	6.9	2.5	NR	28.8	5.9
Reid [19]	2006	32	% of total interruption events	5	14	7	[8]		3	16	NR	21	12
Petros and Engelmann [33]	2006	61	% of total interruption events	6.0	31.9	9.6	[30.7]		10.8	NR	NR	NR	10.8
O'Meara et al [12]	2008	59	% of total interruption events	17.3	9.7	NR	10.9	5.2	4.5	24.8	2.1	14.2	11.3
			% of total interruption time	25.6	13.3	[a]	7.9	7.7	5.0	2.3	3.7	11.7	22.8
Kim et al [34]	2010	47	% of patients affected	NR	8.7	6.5	4.3	6.5	4.3	NR	6.5	19.6	15.2
			% of total interruption events	NR	6.5	4.0	4.0	24.2	1.6	NR	10.5	25.8	23.4

Other: transfer, high blood sugar, high bilirubin, dialysis, medication, GI bleeding, equipment/formula problem, ICU doctors, dietitian.
NR indicates not reported.
[a] Categorized into "other" in original article, although categorized into a specific type of interruption in this review.

[6], dislodgement of the feeding tube occurred in 41% of the patients but accounted for only 7% of withheld feedings. These findings are in contrast to those of O'Meara et al [12]. In their study, the longest interruptions were due to problems related to the feeding tube, and these accounted for 25.6% of the interruption time (17.3% of events). The time required to replace the tube often led to delays in feeding of up to 8 hours. Multiple steps for tube replacement including tube insertion, radiologic check, physician's confirmation, and actual provision of enteral nutrition after confirmation could increase the interruption time. Therefore, there is a need to simplify or modify the process for tube replacement [12].

3.1.5.4. Nursing procedures. Routine nursing procedures (ie, patient baths, dressing changes, changing of bed linens) also led to interruption of enteral nutrition. Interruptions occurred in 33.3% of patients but accounted for only 2.5% of the interruption time in the study of O'Leary-Kelley et al [7]. Nursing procedures accounted for 24.8% of the total interruptions, but only 2.3% of the interruption time in the study by O'Meara et al [12]. Moreover, nursing procedures accounted for 30% of the patients and 1.4 hours of the total feeding time in the classic study of McClave et al [6]. Although all patients received routine nursing procedures, the researchers did not record interruptions of less than 15 minutes. The time limitation could lead to underestimation of feeding interruption. McClave et al [6] suggest that procedure interruptions could be avoided or corrected 99% of the time by strict protocols for infusion of enteral nutrition. Enteral nutrition is often discontinued whenever patients are placed in the supine position for routine nursing care because of fear of aspiration. Swanson and Winkelman [41] suggest that placing the patient briefly in the supine position for routine nursing care should not require cessation of enteral nutrition. The effect of this positioning recommendation on aspiration rate has not been tested.

3.1.5.5. Others. Other interruptions in enteral nutrition in critically ill patients are due to airway management, hemodynamic instability, suspected GI bleeding, equipment or formula problems, high blood sugar levels, high bilirubin levels, dialysis, medications, and transfers [6,7,12,14,34]. Other interruptions also include unexplained stopping of feedings by nurses, physicians, or dietitians [12].

To conclude, frequent interruptions of enteral nutrition may be a critical barrier of adequate enteral nutritional support. Procedures, diagnostic tests, GI intolerance, problems of the feeding tube, and routine nursing procedures are major reasons for interruptions [6,7,12]. Almost all studies evaluated interruptions and nutritional adequacy for 2 to 4 days, except for Petros and Engelmann [33] (7 days), Kim et al [34] (7 days), and O'Meara et al [12] (10 days). Most addressed acutely ill patients, and there might be differences in results between acutely and chronically ill patients. Additional study is needed to address longer-term recording of the relationship between feeding interruptions and nutritional adequacy for chronically critically ill patients.

4. Discussion

This review confirms that underfeeding is common in enterally fed patients who are critically ill. The average energy intake was 50% to 95% of requirements, and only 14% to 52% of patients achieved their goal energy intake during the ICU stay [6,14,15,17,30,34]. The average protein intake was 38% to 82% of requirements [18-20]. These studies that evaluated the adequacy of enteral nutritional intake have the different length of study periods, despite the fact that most energy deficits occur during the first 3 days of hospitalization [31]. Furthermore, the studies used different methods for evaluation of energy or protein requirements and included heterogeneous ICU patients. Regardless of limitations, it is evident that a large proportion of critically ill patients are still underfed.

A review of the literature indicates that there are multiple barriers that impact the delivery of adequate enteral nutrition in critically ill patients. Of the patient factors, nutritional status and severity of illness do not explain inadequacy of enteral nutrition [15,16]. Among feeding method factors, nutrient-dense formula was associated with overfeeding in energy requirements in one study [19]. Two studies showed that transpyloric feeding was not harmful to patients in the ICU and could have favorable effects on energy and protein intake [23,24].

Of the feeding process factors, early initiation of enteral nutrition and rapid progression to goal rates contributed to the achievement of goal energy and protein intakes compared with late initiation and gradually increasing the rate of enteral nutrition [17,20,29]. Underprescription of enteral nutrition combined with insufficient delivery of prescribed nutritional goal resulted in inadequate nutritional intake [6,13]. In addition, study findings consistently indicated that repeated interruption of enteral nutrition resulted in significant underfeeding in patients hospitalized in the ICU [6,7,12,34]. Interruptions were mainly caused by diagnostic or surgical procedures, GI intolerance of enteral nutrition, displacement or obstruction of the feeding tube, and routine nursing procedures.

Different indications for disposition of GR volumes and the use of prokinetics may be confounding factors in the amount of energy delivered. Prokinetic agents increase energy intake by improving the gastric-emptying rate. If the permitted limit for GR volumes is too low, it can lead to frequent and unnecessary interruptions of enteral nutrition. However, there is a lack of research evaluating GRs as a measure of tolerance to enteral nutrition [32].

Interruption of enteral nutrition is often due to avoidable causes such as routine nursing procedures and surgical or diagnostic procedures [6]. This suggests that the manner in which enteral nutrition is delivered needs to be modified to promote adequate intake. In addition, when an interruption occurs, enteral nutrition may be started at a slower rate than before the interruption and then increased to the target rate. This rate-dependent strategy can result in an even greater deficit in intake [12]. Thus, the development of standardized feeding protocols to prevent unnecessary cessation and to replace enteral nutrition volume caused by interruptions may maximize the delivery of enteral nutrition in ICUs; these approaches need to be developed and implemented.

Although barriers including patient-related factors, underprescription, and frequent interruptions can contribute to inadequate nutritional intake of patients in the ICU, a cause-and-effect relationship between these factors and nutritional adequacy cannot be inferred because these factors were not evaluated in the experimental designs. Furthermore, RCTs had small samples and were heterogeneous, so they were most likely underpowered to detect the effect of the intervention being studied. These limitations may have led to inconsistent or inaccurate findings.

5. Conclusion and implications

Although enteral nutrition administration has improved over the years in terms of skills, materials, and formulas [18], this review article has highlighted major barriers contributing to inadequate enteral nutrition in critically ill patients. Inadequate enteral nutrition is associated with many barriers, and the contribution of these varied across studies. Significant barriers are interruptions of enteral nutrition, and they may be avoided or compensated for by implementing protocols for nutritional support.

There are several recommendations for future research resulting from this review of the literature. Consistent study data that demonstrate the barriers that are responsible for the delivery of enteral nutrition in ICU patients are required. Studies that address each barrier and ways to prevent it are needed. Future research needs to address strategies to prevent or compensate for the feeding interruption. In addition, research using randomized experimental design with a larger sample is warranted. The development of standardized protocols for the delivery of enteral nutrition is the ultimate goal of future studies.

Several implications for clinical practice follow from this review. Adequate enteral nutrition prescription is needed to meet the nutrient requirements of critically ill patients. Interventions are needed to assure that the prescribed enteral nutrition is delivered without unnecessary interruptions. For them, awareness of health care providers who are responsible for the prescription and delivery of nutrition should be raised first. Health care providers should strictly implement the feeding protocols and continuously monitor the adequacy of nutritional support in critically ill patients.

This review provides a foundation for the development of interventions designed to improve enteral nutrition practices. The goal is to decrease the incidence of underfeeding associated with inadequate delivery of enteral nutrition and to optimize nutrition in the critically ill. Health care providers in the ICU need to develop and implement enteral nutrition protocol with their knowledge and skills, thereby influencing patient nutrition and clinical outcomes. It is necessary to strive for consistent standards to supply the patient with optimum nutrition.

References

[1] Barr J, Hecht M, Flavin KE, et al. Outcomes in critically ill patients before and after the implementation of an evidence-based nutritional management protocol. Chest 2004;125:1446-57.
[2] Sungurtekin K, Sungurtekin U, Oner O, et al. Nutrition assessment in critically ill patients. Nutr Clin Pract 2008;23:635-41.
[3] Martin CM, Doig GS, Heyland DK, et al. Multicentre, cluster-randomized clinical trial of algorithms for critical-care enteral and parenteral therapy (ACCEPT). Can Med Assoc J 2004;170:197-204.
[4] Terekeci H, Kucukardali Y, Top C, et al. Risk assessment study of the pressure ulcers in intensive care unit patients. Eur J Intern Med 2009; 20:394-7.
[5] Parrish CR, McCray SF. Nutrition support for the mechanically ventilated patient. Crit Care Nurse 2003;23:77-80.
[6] McClave SA, Sexton LK, Spain DA, et al. Enteral tube feeding in the intensive care unit: factors impeding adequate delivery. Crit Care Med 1999;27:1252-6.
[7] O'Leary-Kelley CM, Puntillo KA, Barr J, et al. Nutritional adequacy in patients receiving mechanical ventilation who are fed enterally. Am J Crit Care 2005;14:222-31.
[8] Mandel E, Worthley J. Skeletons in the hospital closet revisited: the management of enteral nutrition. Nutr Support Serv 1986;6:44-7.
[9] Roberts SR, Kennerly DA, Keane D, et al. Nutrition support in the intensive care unit. Adequacy, timeliness, and outcomes. Crit Care Nurse 2003;23:49-57.
[10] Kearns PJ, Chin D, Mueller L, et al. The incidence of ventilator-associated pneumonia and success in nutrient delivery with gastric versus small intestinal feeding: a randomized clinical trial. Crit Care Med 2000;28:1742-6.
[11] Hise ME, Halterman K, Gajewski BJ, et al. Feeding practices of severely ill intensive care unit patients: an evaluation of energy sources and clinical outcomes. J Am Diet Assoc 2007;107:458-65.
[12] O'Meara D, Mireles-Cabodevila E, Frame F, et al. Evaluation of delivery of enteral nutrition in critically ill patients receiving mechanical ventilation. Am J Crit Care 2008;17:53-61.
[13] De Jonghe B, Appere-De-Vechi C, Fournier M, et al. A prospective survey of nutritional support practices in intensive care unit patients: what is prescribed? What is delivered? Crit Care Med 2001;29:8-12.
[14] Rice TW, Swope T, Bozeman S, et al. Variation in enteral nutrition delivery in mechanically ventilated patients. Nutrition 2005;21: 786-92.
[15] Krishnan JA, Parce PB, Martinez A, et al. Caloric intake in medical ICU patients: consistency of care with guidelines and relationship to clinical outcomes. Chest 2003;124:297-305.
[16] Rubinson L, Diette GB, Song X, et al. Low caloric intake is associated with nosocomial bloodstream infections in patients in the medical intensive care unit. Crit Care Med 2004;32:350-7.
[17] Desachy A, Clavel M, Vuagnat A, et al. Initial efficacy and tolerability of early enteral nutrition with immediate or gradual introduction in intubated patients. Intensive Care Med 2008;34:1054-9.
[18] Binnekade JM, Tepaske R, Bruynzeel P, et al. Daily enteral feeding practice on the ICU: attainment of goals and interfering factors. Crit Care 2005;9:R218-25.
[19] Reid CL. Frequency of under and overfeeding in mechanically ventilated ICU patients: causes and possible consequences. J Hum Nutr Diet 2006;19:13-22.
[20] 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;27:2525-31.
[21] 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;25:157-61.
[22] Day L, Stotts NA, Frankfurt A, et al. Gastric versus duodenal feeding in patients with neurological disease: a pilot study. J Neurosci Nurs 2001;33:148-60.
[23] Esparza J, Boivin MA, Hartshorne MF, et al. Equal aspiration rates in gastrically and transpylorically fed critically ill patients. Intensive Care Med 2001;27:660-4.
[24] Boivin MA, Levy H. Gastric feeding with erythromycin is equivalent to transpyloric feeding in the critically ill. Crit Care Med 2001;29:1916-9.
[25] Neumann DA, DeLegge MH. Gastric versus small-bowel tube feeding in the intensive care unit: a prospective comparison of efficacy. Crit Care Med 2002;30:1654-61.
[26] Davies AR, Froomes PR, French CJ, et al. Randomized comparison of nasojejunal and nasogastric feeding in critically ill patients. Crit Care Med 2002;30:586-90.
[27] White H, Sosnowski K, Tran K, et al. A randomised controlled comparison of early post-pyloric versus early gastric feeding to meet nutritional targets in ventilated intensive care patients. Crit Care 2009; 13:R187-94.
[28] Hsu CW, Sun SF, Lin SL, et al. Duodenal versus gastric feeding in medical intensive care unit patients: a prospective, randomized, clinical study. Crit Care Med 2009;37:1866-72.
[29] Ibrahim EH, Mehringer L, Prentice D, et al. Early versus late enteral feeding of mechanically ventilated patients: results of a clinical trial. JPEN J Parenter Enteral Nutr 2002;26:174-81.
[30] Villet S, Chiolero RL, Bollmann MD, et al. Negative impact of hypocaloric feeding and energy balance on clinical outcome in ICU patients. Clin Nutr 2005;24:502-9.
[31] Dvir D, Cohen J, Singer P. Computerized energy balance and complications in critically ill patients: an observational study. Clin Nutr 2006;25:37-44.
[32] 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: 221-7.
[33] Petros S, Engelmann N. Enteral nutrition delivery and energy expenditure in medical intensive care patients. Clin Nutr 2006;25: 51-9.
[34] Kim H, Shin JA, Shin JY, et al. Adequacy of nutritional support and reasons for underfeeding in neurosurgical intensive care unit patients. Asian Nurs Res 2010;4:102-10.
[35] Bryk J, Zenati M, Forsythe R, et al. Effect of calorically dense enteral nutrition formulas on outcomes in critically ill trauma and surgical patients. JPEN J Parenter Enteral Nutr 2008;32:6-11.
[36] Marik PE, Zaloga GP. Gastric versus post-pyloric feeding: a systemic review. Crit Care 2003;7:46-51.
[37] Nisim AA, Allins AD. Enteral nutritional support. Nutrition 2005;21: 109-12.
[38] Heyland DK, Dhaliwal R, Drover JW, et al. Canadian clinical practice guidelines for nutrition support in mechanically ventilated, critically ill adult patients. JPEN J Parenter Enteral Nutr 2003;27:355-71.
[39] Dive A, Moulart M, Jonard D. Gastroduodenal motility in mechanically ventilated critically ill patients: a manometric study. Crit Care Med 1994;22:441-7.
[40] A.S.P.E.N.. Guidelines for the provision and assessment of nutrition support therapy in the adult critically ill patient: Society of Critical Care (SCCM) and American Society of Parenteral and Enteral Nutrition (A.S.P.E.N). JPEN J Parenter Enteral Nutr 2009;33:277-316.
[41] Swanson RW, Winkelman C. Special feature: exploring the benefits and myths of enteral feeding in the critically ill. Crit Care Nurse 2002; 24:67-74.