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Application of point-of-care ultrasound in patients receiving enteral nutrition

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Abstract. – OBJECTIVE: **Enteral nutrition (EN) is the first-choice nutritional support, as it is more in line with normal physiological processes. During EN, the major goals to achieve include accurate confirmation of the feeding tube position, monitoring the gastric residual volume, assessing gastrointestinal motility, and monitoring the nutritional status of patients. With rapid development in technology, point-of-care ultrasound (POCUS) has become a more convenient and effective technical tool for monitoring critically ill patients receiving EN. In this review, we have summarized and discussed the value of POCUS in the implementation, monitoring, and evaluation of EN therapy to provide a reference for nutritional support of critically ill patients in critical care settings.**

MATERIALS AND METHODS: This is a narrative review. A literature search for Scopus-indexed articles was performed randomly using PubMed and MEDLINE databases as the primary sources. No specific term was used for the search.

RESULTS: POCUS can be used for positioning of nasogastric and nasointestinal tubes, evaluation of gastric residuals and gastrointestinal motility as well as monitoring of nutritional status.

CONCLUSIONS: POCUS is a real-time, highly repeatable, radiation-free, and non-invasive visual inspection technique, with high application value in assessing the nutritional status of patients receiving EN and guiding the development of further nutritional treatment plans. It is an important diagnostic and monitoring tool that can be used by the clinicians in the ICU.

Key Words:
Point-of-care ultrasound, Enteral nutrition, Nutritional support therapy, Nutritional status.

Introduction

Intensive Care Unit (ICU) provides comprehensive support and treatment for acute organ and life-threatening pathophysiological changes in hospitalized patients. Nutritional support is important for regulating metabolic substrates as well as some metabolic processes[1]. The scope of modern nutritional support has progressed beyond providing energy and restoring positive nitrogen balance. It has evolved from structural support to functional support through regulation of metabolism and immune function and exerting pharmacological nutritional effects. Thus, it has become an important constituent of modern treatment for critical illnesses[2]. The mode of nutrient supply is one of the important factors influencing the effects of nutritional support. Enteral nutrition (EN) is preferred over parenteral nutrition, as it is more in line with normal physiological processes and can maintain the integrity of intestinal structure and function as well as intestinal microbial diversity. EN is mainly delivered via nasogastric and nasointestinal tubes or gastric/intestinal stoma[3].

Accurate assessment of the nutritional status is critical for EN implementation and evaluation of EN efficacy[4]. The principal method for evaluating efficacy of traditional EN therapy is to monitor the gastric residual volume (GRV) through regular withdrawal of gastric juice. However, this method is influenced by many factors including the patient's position, the position and diameter of the feeding tube, method of EN delivery, and measurement methods, which makes it difficult

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to apply this method to evaluate the efficacy of EN therapy in clinical practice[5]. With rapid advances in technology, point-of-care ultrasound (POCUS) has become a more convenient and effective tool for monitoring critically ill patients receiving EN. POCUS is simple, easily reproducible, has good acceptance, ensures EN safety, and allows real-time monitoring of patients. In recent years, POCUS has been used to confirm the position of nasogastric and nasointestinal tubes. It also provides non-invasive assessment of the GRV, gastrointestinal motility, and patients' muscle status, thus allowing comprehensive evaluation of the nutritional status and EN efficacy as well as guiding the development of further nutritional support treatment plans[6]. In this review, we have summarized and discussed the value of POCUS in the implementation, monitoring, and evaluation of EN therapy to provide a reference for nutritional support of critically ill patients in critical care settings (Table I).

Role of POCUS in the Assessment of Indwelling Nasogastric Tube Positioning

Nasogastric tubes are widely used for EN delivery in clinical practice. Liquid food, water, medicines, and nutrient solutions can be delivered via nasogastric tubes to provide the nutrients needed for normal physiological activities of patients, accelerate their recovery and rehabilitation, improve their quality of life, and reduce the incidence of malnutrition and other related complications[7]. However, complications such as accidental placement of the tube into the airway, pneumothorax, mediastinal emphysema, subcutaneous emphysema, pneumonia, pulmonary hemorrhage, empyema, hemothorax, bronchopleural fistula, perforation of the esophagus, or even death can occur during nasogastric tube placement[8-10]. Therefore, accurately assessing the position of the nasogastric tube is critical.

Methods for assessing the position of the nasogastric tube mainly include auscultation, modified body surface estimate, and imaging[11]. For auscultation, 10 ml of air is insufflated through the nasogastric tube and then a stethoscope is placed over the epigastrium to listen for a whooshing sound. However, the volume of gastric fluid and intra-abdominal bruits may affect auscultation, which can seriously affect its clinical application in the assessment of nasogastric tube positioning. In the modified body surface estimate method, the insertion length of the nasogastric tube is estimated by measuring the distance from the hairline at the center of the forehead to the umbilicus (approximately 53-63 cm), which is obviously longer than the conventional length of a nasogastric tube. This method can improve the effect of gastrointestinal decompression using a nasogastric tube and reduce the occurrence of complications. However, it cannot accurately determine the position of the nasogastric tube[12,13]. Imaging methods used to confirm the position of the nasogastric tube mainly include radiography, gastroscopy, and POCUS. X-ray examination is the gold standard for confirming the position of the nasogastric tube. It can determine the position and placement of the nasogastric tube. However, due to the radiation-related risks, this method is inappropriate for repeated use within a short period. Gastroscopy allows real-time localization of the nasogastric tube under direct vision but is an invasive procedure and cannot ensure correct length of the nasogastric tube[14].

Table I. Application of POCUS in patients receiving enteral nutrition.

Application
Confirmation of nasogastric tube
Confirmation of nasointestinal tube
Assessment of GRV
Assessment of gastrointestinal motility
Monitoring the nutritional status

When compared with the aforementioned methods, POCUS has the advantages of being non-invasive, radiation-free, and highly repeatable[15]. Moreover, it is not affected by the position of the neck and is the most widely used method in the clinic[16,17]. To evaluate the accuracy of POCUS in determining the position of the nasogastric tube, Vigneau et al[16] compared POCUS and X-ray examination to detect the position of the nasogastric tube in 33 adult ICU patients and found that the sensitivities of POCUS and X-ray examination were similar at 97% and 100%, respectively. However, POCUS was significantly faster than X-ray examination (24 min *vs.* 180 min). Thus, POCUS is more suitable for detecting the position of the nasogastric tube in critically ill patients. Moreover, Atalay et al[18] verified the reliability and accuracy of POCUS in detecting the position of the nasogastric tube in critically ill children.

Role of POCUS in the Assessment of Indwelling Nasointestinal Tube Positioning

Nasointestinal tube feeding is the most common form of post-pyloric feeding. For patients who are at a higher risk of reflux and aspiration, or intolerant to nasogastric tube feeding, creating access routes for the nasointestinal tube to deliver nutritional support is recommended[19]. An enteral feeding tube is inserted into the horizontal part of the duodenum or jejunum through the nose. The insertion length is approximately 105–120 cm, which is equivalent to the distance from the tip of the nose to the jejunum[20].

Methods for nasointestinal tube placement mainly include blind placement, gastroscopy-guided tube placement, X-ray-guided tube placement, and electromagnetic navigation-guided tube placement, all of which have various limitations[21]. Although the blind placement technique is widely used in clinical practice, it is more time-consuming and also associated with an increased risk of accidental entry of the tube into the airway. Moreover, multiple placement attempts may result in severe damage. Anesthesia is required during gastroscopy-guided tube placement, leading to higher overall treatment costs for patients. X-ray fluoroscopy-guided tube placement is difficult to perform at the bedside due to the need to move the patients, making it unsuitable for critically ill patients. Moreover, X-ray radiation is harmful to the patients. The cost of using electromagnetic navigation is high, which hinders its popularity in clinical practice. In contrast, POCUS can provide noninvasive, bedside, real-time, and repeatable evaluation of patients who require nasointestinal tube feeding, especially critically ill patients[22].

The most important step in providing EN through a nasointestinal tube is to determine whether the tip of the nasointestinal tube has reached the horizontal part of the duodenum or jejunum. Methods for estimating the position of the nasointestinal tube tip mainly include auscultation, color of the drainage from the nasointestinal tube, pH testing, and the volume of drainage. However, these methods lack objectivity, and their accuracy needs to be further verified[23]. Imaging is the gold standard for determining the position of the nasointestinal tube but has many disadvantages. For example, X-ray examination is usually performed after the nasointestinal tube has been positioned. Thus, if the nasointestinal tube does not enter the jejunum, it needs to be adjusted and monitored repeatedly, which can cause damage to the body and increase radiation exposure to the patients and the operators[24].

With the advances in POCUS for intensive care, it is widely used to determine the position of the nasointestinal tube due to its convenience, rapidity, accuracy, visualization, and dynamic reproducibility. Zhang et al[25] used different methods to detect the position of the nasointestinal tube in critically ill patients and reported that the sensitivity, specificity, positive predictive value, negative predictive value, and accuracy were 78.6%, 25.0%, 94.5%, 6.6%, and 75.2%, respectively for the auscultation method, and 72.7%, 75.0%, 97.9%, 14.2%, and 72.0%, respectively for the withdrawal method. The sensitivity, specificity, and accuracy were 100% for POCUS, indicating its superiority over the auscultation and withdrawal methods for detecting the position of the nasointestinal tube. Ye et al[26] used X-ray examination and computed tomography (CT) as gold standards for comparison with a POCUS contrast agent in 45 critically ill patients to detect the position of the nasointestinal tube. The results showed that POCUS had a success rate of 95.6%. The tube was positioned successfully in the first attempt in 39 patients, with an average time of 1.6±0.5 min. The tube was positioned successfully after several attempts in four patients, with an average time of 5.1±0.5 min. These results indicated that the POCUS contrast agent with EN fluid as the mixing medium can safely, accurately, and conveniently determine the position of the nasointestinal tube. The key to determining the position of the nasointestinal tube with POCUS is to detect the tram-track sign of the nasointestinal tube in the horizontal part of the duodenum. This method can determine whether the tip of the nasointestinal tube has entered the jejunum. However, it is often difficult to visualize the duodenum in patients with abdominal distention, obvious pneumatosis intestinalis, or obesity[26].

Role of POCUS in the Assessment of GRV

Early EN maintains the integrity of the gastrointestinal mucosal barrier, reduces the activation of intestinal inflammatory factors, and prevents enterogenic infections. However, the incidence of feeding intolerance is higher, accounting for approximately 30.5% of all critically ill patients, which is an important concern in nutritional support therapy[27]. Increased GRV is an early sign of EN intolerance, which may lead to aspiration, malnutrition, prolonged duration of mechanical ventilation, longer hospitalization, and increased mortality[28]. Therefore, gastric motility of patients can be dynamically observed to a certain extent by monitoring the GRV, and the EN protocol can be adjusted accordingly to ensure its safety and reduce the incidence of complications[29].

Although GRV monitoring has been extensively used in clinical practice, the criteria for GRV monitoring have not been standardized. In 2016, the American Society for Parenteral and Enteral Nutrition[30] suggested that attention should be paid to patients who had a GRV of 200–500 mL and EN should not be stopped when the GRV is <500 mL without the signs of EN intolerance such as nausea, vomiting, and abdominal distention. However, the European Society of Intensive Care Medicine guidelines (2017)[31] suggested that early EN is not recommended for critically ill adult patients with a GRV >500 ml every six hours. Currently, GRV monitoring is routinely performed during EN, which is especially important for critically ill patients who are at a higher risk of reflux and aspiration.

There are various methods for monitoring the GRV in ICU. (1) Intra-abdominal pressure measurement: Intra-abdominal pressure levels represent the patients' intestinal function, which can reliably reflect gastrointestinal mucosal damage and assist in GRV assessment. However, intra-abdominal pressure measurement can be influenced by human factors and has low accuracy[32]. (2) Withdrawal technique: Currently, aspirating the gastric contents via a syringe or a gastrointestinal decompression device is the most commonly used method for GRV monitoring. This method is simple, inexpensive, non-invasive, and easy to perform. However, in actual clinical application, the monitoring results are affected by various factors such as the gauge of the gastric tube and the method of aspiration. Thus, its accuracy needs further improvement[33].

POCUS has the advantages of simplicity, non-invasiveness, and dynamic real-time monitoring, which facilitate GRV calculation by determining the antral cross-sectional area (CSA). Hence, the use of POCUS has steadily increased in clinical practice. POCUS can quantitatively measure the gastric contents (liquid or solid). It also allows quantitative evaluation by calculating antral CSA via measurement of two perpendicular diameters of the antrum and GRV estimation[34]. Delayed gastric emptying has been noted in patients with diabetes. Rabab et al[35] used POCUS to detect gastric emptying in 25 fasting diabetic patients and the results were compared with those from 25 healthy controls. The results showed that antral CSA and GRV were higher in diabetic patients than in healthy controls (CSA: 13.8 [9.5-19.5] mm^2 *vs.* 8.8 [5.5-10.5] mm^2, $p<0.001$; GRV: 177 [96-275] mL *vs.* 83 [50-109] mL, $p<0.001$). GRV calculated using POCUS was consistent with the gastric contents aspirated from the nasogastric tube, indicating that diabetic patients had a high GRV even eight hours after fasting. Another study showed that monitoring GRV using POCUS significantly reduced the incidence of reflux and aspiration when compared to monitoring with the withdrawal method (8.3% *vs.* 27.8%, $p=0.032$ and 2.8% *vs.* 16.7%, $p=0.047$, respectively)[36]. Therefore, POCUS may be more suitable for monitoring GRV compared to the withdrawal method.

Role of POCUS in the Assessment of Gastrointestinal Motility

Gastric motility refers to the contraction and peristalsis of gastric smooth muscles, including the strength and frequency of gastric muscle contractions. Detection of gastric motility can effectively evaluate the gastrointestinal function of patients and assist in adjusting their mode of nutrition and nutritional support plan[37]. The criteria for evaluating gastric motility include gastric emptying time, gastric electrical activity, gastric volume, gastric compliance, and intragastric pressure[38].

Gastric pressure can directly reflect gastric contraction[39]. A pressure catheter is inserted into the stomach to measure the changes in intragastric pressure caused by gastric contractions during the interdigestive and digestive phases. This method allows intragastric pressure monitoring and provides insights into the circadian rhythms of the upper gastrointestinal tract. However, measurement of gastric pressure requires a longer recording time, and analysis of the results is complex, which limits the popularity of this method in clinical practice.

Gastric electrical activity is mainly monitored by electrogastrogram (EGG)[40]. Electrical signals are recorded after fasting for 30 min and after a meal for 30–60 min. The EGG variables measured in this method include dominant frequency, dominant power, percentage of normal gastric rhythm, percentage of bradygastria, percentage of tachygastria, and the power ratio before and after a meal. EGG is a simple technique, which is the first choice for determining gastric motility disorders. However, although EGG provides clear information on the frequency of gastric contractions, it cannot directly reflect the gastric motility and volume changes.

In 1980, McDicken et al[41] used real-time POCUS to record dynamic images of gastric contractions. POCUS has been routinely utilized in clinical practice for the evaluation of gastric motility in patients with gastrointestinal disorders. Gilja et al[42] used POCUS to evaluate gastric accommodation and the proximal gastric volume by measuring the proximal gastric area and maximum diameter. They used POCUS to assess the cross-section of gastric antrum, body, and fundus of 18 fasting healthy volunteers who received 250 mL of water, 500 mL of water, 500 mL of effervescent water, and a solid meal. The findings revealed a linear correlation between antral CSA and gastric volume >300 ml, but not between antral CSA and gastric volume <300 ml, suggesting that POCUS can determine the presence and properties of gastric contents (gas, liquid, or solid). A prospective observational study by Taskin et al[43] evaluated the correlation between ultrasonographic gastric antral measurements and GRV in critically ill patients receiving EN. The receiver operating characteristic curve analysis showed that gastric antral CSA was significantly related to GRV ≥250 ml (area under the curve: 0.969, 95% confidence interval: 0.94-0.99, $p<0.0001$). In addition, POCUS can assess gastric motility by measuring the gastric emptying time. Christiane et al[44] found that gastric antral CSA was significantly correlated with fasting time ($r=-0.53$, $p<0.0001$) in 22 infants who received either breast or formula milk. Gastric antral CSA measured at approximately 3 h (199±16 [175-225] min) after feeding was similar to that before feeding. The mean gastric emptying time calculated using a linear regression model was 218 min, indicating that complete gastric emptying could be achieved in infants who had breast or formula milk 4 h before surgery. With further advances in detection technologies and devices, three-dimensional POCUS can directly observe the distribution of food in the stomach, calculate the total gastric volume/proximal volume ratio at different times, and evaluate the changes in gastric accommodation after a meal with greater accuracy than traditional POCUS. However, three-dimensional POCUS is a complex technique that is easily affected by the presence of gas in the stomach. Therefore, its clinical application value needs further exploration[45].

Role of POCUS in Monitoring the Nutritional Status of Patients

Malnutrition and rapid decline in nutritional status are common in critically ill ICU patients. The incidence of malnutrition in ICU patients is 40-100%. Different conditions can lead to rapid weight loss. Patients with single organ failure can lose approximately 5% of their body weight, while patients with multiple organ failure can lose up to 25% of their body weight[46]. The diagnosis of malnutrition is recommended to be confirmed if patients have two or more of the following conditions: insufficient energy intake, weight loss, loss of muscle mass, loss of subcutaneous fat, localized or generalized fluid accumulation, acute disease or injury, chronic disease, or changes in the functional status[47].

Skeletal muscle wasting is more common in critically ill patients and is associated with poor prognosis including longer duration of mechanical ventilation, longer hospitalization, and increased 1-year mortality.

Puthucheary et al[48] observed a decrease of 12.5% in the rectus femoris CSA (RF-CSA) on day 7 and 17.7% on day 10 in critically ill patients after ICU admission. Moreover, there was a significant association between change in the RF-CSA and the length of ICU stay, indicating that skeletal muscle wasting occurred early in critically ill patients. Therefore, skeletal muscle wasting is an important factor affecting the prognosis and quality of life of critically ill patients and has received increasing attention for monitoring the nutritional status of these patients. CT is the principal method for the measurement of skeletal muscles, which can analyze the entire muscle by measuring the CSA of a specific muscle. Other methods used to measure skeletal muscles include dual-energy X-ray absorptiometry and magnetic resonance imaging. However, these imaging methods are only limited to stable patients who can undergo examinations outside the patients' room, but unsuitable for critically ill patients in the ICU. In addition, these imaging methods involve exposure to high doses of radiation and cannot be used for daily monitoring of critically ill patients[49].

With the widespread application of POCUS in the ICU, peripheral skeletal muscle POCUS has become the most commonly used tool for the diagnosis of skeletal muscle wasting and risk stratification due to its rapid and non-invasive nature. POCUS can measure the thickness and CSA of the upper and lower limb muscles. The thumb adductor pollicis muscle thickness (APMT), quadriceps muscle layer thickness (QMLT), and RF-CSA are the most commonly measured parameters using POCUS[50]. (1) APMT: This parameter is significantly associated with the nutritional status. It can predict malnutrition after surgery, with good sensitivity and specificity. APMT can assess the nutritional status and predict mortality in critically ill patients. Caporossi et al[46] found that APMT values of both hands were significantly lower in severely malnourished patients when compared to patients with normal nutritional status. Moreover, the risk of death was approximately six times higher in patients with abnormal APMT values than in those with normal APMT values. In patients undergoing major abdominal surgery, the risk of postoperative death was approximately 25% higher in patients with low APMT values. These patients also had a higher incidence of postoperative complications. (2) QMLT: The quadriceps femoris muscle includes the rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius. For critically ill patients who are immobilized, quadriceps muscle size and function as well as persistent quadriceps muscle injuries are considered important contributors to reduced exercise capacity, and increased morbidity and mortality. Thus, these factors have important implications for patient prognosis. The quadriceps femoris muscle is surrounded by well-defined fascia. Hence, QMLT is easy to identify and measure, especially in patients with acute renal failure. QMLT is not affected by fluid overload and rapid transfer of body fluids and has unique advantages over other forms of assessment[51]. However, the VALIDUM study[52] suggested that assessment of the nutritional status using QMLT may not be accurate in patients with low muscle mass, and other predictive factors such as age, gender, and body mass index need to be considered. (3) RF-CSA: During immobilization, the type II fibers from the postural muscles are initially consumed and subsequently replaced by type I fibers. Hence, rectus femoris is maximally consumed during immobilization. A study by Palakshappa et al[53] involving patients with sepsis showed a moderate correlation between muscle strength and the rate of change in the RF-CSA at seven days after admission. However, there was no significant correlation between muscle strength and static RF-CSA measurements at admission or on day 7. Similarly, Puthucheary et al[54] found that 10 days after ICU admission, reduction in the RF-CSA was greater in mechanically ventilated patients who developed muscle weakness than in those who did not. Moreover, changes in muscle thickness did not correlate with muscle weakness. Changes in the RF-CSA may provide a more accurate assessment of muscle strength rather than muscle thickness.

Limitations and Future Prospects

The main disadvantages of POCUS are as follows: POCUS needs to be performed by highly skilled operators to obtain consistent measurements and minimize measurement errors. Presence of gas in the stomach might lead to errors in POCUS findings due to comet-tail artifacts (reverberation artifacts). POCUS is unsuitable for obese patients or those with anatomical variations of the stomach. POCUS cannot be used for evaluation of cases where the fundus is located posterior to the rib cage, making it difficult to observe the gastric structures. In addition, POCUS is highly dependent on operator's skills for evaluating skeletal muscles. Excessive compression with the probe, probe orientation, and the presence of subcutaneous edema can markedly alter the POCUS images and influence the results[55].

Conclusions

POCUS is a real-time, highly repeatable, radiation-free, and non-invasive visual inspection technique. It has high application value in assessing the nutritional status of patients receiving EN and in guiding further nutritional treatment plans, contributing to improvement in the prognosis of critically ill patients. It is an important diagnostic and monitoring tool that can be used by the clinicians in the ICU.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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