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SPECIAL ISSUE INSIGHT

Machine-assisted nutritional and metabolic support

Jean Reignier[1,4*], Yaseen M. Arabi[2] and Jean-Charles Preiser[3]

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Nutritional and metabolic support in the intensive care unit (ICU) involves a complex decision-making process addressing a multitude of time-varying biological and clinical parameters. Machine-assisted computer-guided nutritional and metabolic support could help caregivers (a) tailor prescription to individual patients (accounting for nutritional state, weight, gender, type and severity of acute disease and organ failure, course of acute illness and current metabolic state, (b) manage medical nutrition to achieve adequate provision of nutrients, (c) give alerts for failure of nutrition delivery or inadequacy and for variations in patients metabolism and d) detect intolerance to nutritional support (Table 1).

Indirect calorimetry

Indirect calorimetry (IC) is considered the gold standard for measuring energy expenditure and its use is recommended, when available. However, due to technical limitations, in particular in patients with hemodynamic instability or those requiring high level of inspired oxygen fraction, the use of IC is frequently impossible [9]. A recent randomized trial included IC in the early goal-directed nutrition protocol [10]. Although no beneficial effect of early goal-directed nutrition on quality of life 6 months after ICU stay, this trial indicated that IC was feasible and may have a room in the future of critical care.

*Correspondence: jean.reignier@chu-nantes.fr
[4] Service de Médecine Intensive-Réanimation, Centre Hospitalier Universitaire Hôtel-Dieu, 30 Bd. Jean Monnet, 44093 Nantes Cedex 1, France
Full author information is available at the end of the article

Glycemic control

The optimal blood glucose (BG) target is still undefined in the ICU patients, as a result of the major discrepancies between interventional studies comparing tight and liberal glycemic control with insulin therapy. Individualized glycemic control targeting a time-varying BG level or the estimated average BG could be a better option. Unfortunately, a recently published interventional trial aiming to achieve the estimated average BG level did not improve outcome but increased the risk of hypoglycemia [11].

Potential improvements in the performance and safety of glycemic control can be provided by continuous glucose control. Intravascular (central venous or arterial) devices using enzymatic techniques, near-infrared spectroscopy or microdialysis have been evaluated in ICU patients [12]. In terms of clinical benefit, an improved safety reflected by a decrease in the rate of hypoglycemia by a continuous control monitoring (CGM)-guided strategy was confirmed [13]. In contrast, interstitial CGM commonly used in patients with diabetes were found less accurate in unstable ICU patients [14].

Hence, the future of CGM in ICU will probably be related to 3 factors: (a) improvement in the performance of interstitial devices and of the lifespan of intravascular devices, (b) cost-effectiveness, accounting for the decreased rates of complications and reduction in nursing workload, and (c) combination with closed-loop control systems similar to artificial pancreas, which were found to improve the performance of glycemic controlled assessed by the proportion of time spent in the target BG range [15].

Feeding pumps

As compared to gravity feeding, enteral feeding pumps are used worldwide. Many available feeding pumps are considered "smart pumps" with manual and automatic priming, dose setting, advanced memory, flow

Table 1 Examples of machine-assisted nutritional and metabolic support in critically ill patients

Nutritional and metabolic goal	Available devices	Desirable functions	Future directions
Measurement of energy expenditure	Indirect calorimetry Ventilator-derived carbon dioxide consumption (EEVCO2)		Reliable measurements in different clinical settings including hemodynamic instability or high FiO_2
Stable blood glucose control	Intravascular continuous glucose monitoring devices Interstitial continuous glucose monitoring devices	Real-time glucose data Detection of hypoglycemic and hyperglycemic excursions Prediction of impending hypoglycemia Prediction of glycemic variability	Improvement in the performance of interstitial devices and of the lifespan of intravascular devices Cost-effective solutions Combination with closed-loop control systems similar to artificial pancreas
Achievement of adequate enteral feeding	Feeding pumps	Automatic and manual priming Dose setting with target volume alarm The ability to provide incremental increases in flow rate Continuous and intermittent feed programs Advanced memory	Integration of data from feeding pumps into AI algorithms
Monitoring of muscle mass and function	Bioelectrical impedance analysis compound muscle action potential (CMAP) Ultrasound CT scan	Reliable, easy-to-use tool, that is not affected by fluid shifts	Clinical studies evaluating whether a nutrition strategy based on monitoring of muscle mass improve patient-centered outcomes
Assessment of enteral feeding intolerance	Point of care ultrasound	Ability to be performed by ICU intensivist, nurse, or dietitian	Clinical studies evaluating the feasibility for wide implementation and the impact on patient-centered outcomes

$EEVCO_2$ energy expenditure estimated by ventilator-derived carbon dioxide consumption, *FiO_2* fraction of inspired oxygen, *CT* computed tomography, *ICU* intensive care unit

rate selection (1–600 ml/h) with incremental increases if needed, bolus, and intermittent and continuous feeding programs, and alarms indicating obstruction [1]. Regarding containers of enteral nutrition (EN) formula and tubes, closed systems are preferred to open systems because of 24-h hanging times, lower nurse workload, increased microbial safety and lower rates of tube disconnection.

Artificial intelligence and nutrition support in the ICU

Given the complex data required for nutritional support decision-making in the critically ill patient, smart algorithms would be of high interest. Studies on computer-assisted decision support system showed improved compliance with protocols and orders, although, current systems did not show an effect on patients outcome. Artificial intelligence (AI) is a step forward by including large amounts of data (such as clinical, laboratory, hemodynamic and respiratory parameters) on a continuous basis to generate patient-specific and time-varying predictions [16]. Such a system should be able to receive and integrate multiple data from different devices including intravenous pumps, nutrition pumps, electronic medical records, bedside physiological monitors, continuous renal replacement therapy machines and others [17].

Measurement of muscle mass

Loss of muscle mass is the hallmark of catabolic state and is associated with increased morbidity and mortality in the critically ill [2]. Bioelectrical impedance analysis (BIA) is a non-invasive technique, validated to evaluate body composition of patients without critical illness. BIA requires only electrodes placed on limbs of the patient, allowing measurements of two whole body electrical parameters, namely resistance and reactance, and thus, calculation of phase angle, an index of cell membrane integrity [3]. In critically ill patients, low phase angle has been associated low muscle area and low muscle density and with higher 28-day mortality [3, 4]. However, BIA is affected by fluid shifts in the critically ill patients, limiting its reliability. Other techniques such as compound muscle action potential (CMAP), ultrasound and computed tomography (CT) scan have been utilized for the assessment of muscle mass and function [5]. Future studies are needed to evaluate whether a nutrition strategy based on monitoring of muscle mass would improve patient-centered outcomes.

Assessment of gut dysfunction by ultrasounds

Studies demonstrated that monitoring of residual gastric volume (RGV) by aspiration of the gastric content was not associated with decreased risk of nosocomial pneumonia and other adverse events in mechanically ventilated patients [6]. However, early detection of gut dysfunction may be of importance given the rate of intolerance in the critically ill patients and the risk of severe complications such as gut ischemia in the severely ill patients, in particular those with shock requiring vasopressive drugs [7]. Monitoring of gut function with ultrasound has been evaluated by assessing gastric residual volume and exploring small intestine motility, thus detecting early gut dysfunction [8].

In conclusion, machine-assisted nutritional and metabolic support has the potential of addressing some of the universal challenges in clinical practice, such as inadequacy of nutritional support, feeding intolerance and assessment of muscle mass and in integrating complex data into a time-varying algorithms that are responsive to the dynamic physiologic needs of critically ill patients.

Author details

[1] Nantes Université, CHU Nantes, Médecine Intensive Réanimation, UIC8, 44000 Nantes, France. [2] King Saud bin Abdulaziz University for Health Sciences (KSAU-HS) and King Abdullah International Medical Research Center (KAIMRC), Riyadh, Saudi Arabia. [3] Department of Intensive Care, Erasme University Hospital, Université Libre de Bruxelles, Brussels, Belgium. [4] Service de Médecine Intensive-Réanimation, Centre Hospitalier Universitaire Hôtel-Dieu, 30 Bd. Jean Monnet, 44093 Nantes Cedex 1, France.

Declarations

Conflicts of interest

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