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Original Article

Standardization of a Multidisciplinary Protocol for Bedside Indirect Calorimetry in Surgical and Critically Ill Patients: Practical Implementation and Troubleshooting

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ABSTRACT

Background: Indirect calorimetry (IC) is considered the reference standard for measuring resting energy expenditure (REE) in critically ill and surgical patients. However, despite strong recommendations from the American Society for Parenteral and Enteral Nutrition (ASPEN) and the European Society for Clinical Nutrition and Metabolism (ESPEN), routine bedside implementation of IC remains limited. This study presented a standardized multidisciplinary protocol for bedside IC and a practical troubleshooting framework for implementation in surgical and intensive care settings.

Methods: The protocol was developed through multidisciplinary collaboration at a tertiary academic center and refined through approximately 300 bedside IC measurements performed in mechanically ventilated and spontaneously breathing patients using ventilator and canopy modes. Implementation framework integrated patient preparation, environmental standardization, ventilator-specific considerations, quality-control procedures, troubleshooting strategies, and interpretation of metabolic parameters, including REE and respiratory quotient (RQ).

Results: The protocol outlined standardized pre-test preparation, device calibration, leak prevention strategies, validity criteria for bedside measurements, and mode-specific operational considerations for ventilator and canopy systems. Common technical challenges including circuit leaks, elevated inspired oxygen fractions, motion artifacts, and sensor instability were discussed alongside practical corrective approaches. Representative clinical cases were presented to illustrate the interpretation of metabolic findings across different clinical scenarios.

Conclusion: This protocol provided a practical roadmap for integrating IC into routine bedside nutritional assessment in critically ill and surgical patients. By standardizing implementation and troubleshooting processes, the protocol may improve the feasibility, reliability, and clinical interpretation of IC in real-world practice.

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Introduction

Accurate assessment of energy expenditure is a cornerstone of nutritional management in critically ill and surgical patients. Inadequate estimation of caloric needs may contribute to adverse clinical outcomes, as both underfeeding and overfeeding are associated with significant metabolic and physiologic consequences (1-5). Underfeeding has been linked to loss of lean body mass, impaired wound healing, prolonged recovery, and immune dysfunction, whereas overfeeding may increase carbon dioxide production, worsen hyperglycemia, promote hepatic steatosis, and complicate liberation from mechanical ventilation. Because metabolic demands fluctuate considerably during acute illness, nutritional requirements in critically ill patients are often difficult to estimate accurately using conventional predictive equations (6-10).

Indirect calorimetry (IC), through measurement of oxygen consumption (VO_2) and carbon dioxide production (VCO_2), is considered the reference standard for measuring resting energy expenditure (REE) in hospitalized patients. Unlike predictive equations, which rely on static anthropometric assumptions, IC provides individualized physiologic assessment and accounts for the dynamic metabolic alterations observed in sepsis, trauma, burns, major surgery, organ dysfunction, and prolonged intensive care unit (ICU) stay (1-4). Previous studies have shown that predictive equations may substantially overestimate or underestimate caloric requirements in critically ill populations, increasing the risk of inappropriate nutritional prescriptions (6, 7).

Consequently, major international societies including the American Society for Parenteral and Enteral Nutrition (ASPEN) and the European Society for Clinical Nutrition and Metabolism (ESPEN) recommend the use of IC whenever feasible to guide nutrition therapy in critically ill patients (1-3). Nevertheless, despite these recommendations, routine bedside implementation remains inconsistent across centers. Several barriers contribute to the underutilization of IC, including device-related complexity, concerns regarding measurement reliability, patient instability, variability between ventilator and spontaneous breathing modes, and lack of standardized operational workflows. Importantly, while current clinical guidelines emphasize the indications and clinical utility of IC, they provide limited practical guidance regarding bedside execution, patient preparation, quality-control procedures, troubleshooting of technical failures, and interpretation of metabolically inconsistent results. This implementation gap is particularly evident in institutions newly introducing IC technology into clinical nutrition practice (4, 11-15).

To address this gap, a multidisciplinary implementation framework was developed at Sina Hospital, Tehran University of Medical Sciences, Tehran, Iran integrating clinical nutrition specialists, intensivists, anesthesiologists, surgeons, and critical care nurses. This research presented a practical, standardized protocol for bedside IC in surgical and critically ill patients, with a specific focus on implementation strategies, quality control, troubleshooting, and real-world clinical interpretation to support broader adoption of IC and improve individualized nutritional management in complex hospital settings.

Materials and Methods

A standardized bedside IC protocol was developed at Sina Hospital, Tehran University of Medical Sciences, through multidisciplinary collaboration among intensivists, anesthesiologists, surgeons, clinical nutrition specialists, and critical care nurses. The protocol was established to improve the reliability and feasibility of routine IC implementation in surgical and critically ill patients and was progressively refined through approximately 300 bedside measurements performed in mechanically ventilated and spontaneously breathing patients. The protocol was designed to address practical barriers frequently encountered during routine implementation, including patient instability, environmental interference, variability in ventilator settings, air leaks, measurement inconsistency, and technical limitations associated with different operational modes. A major objective was to establish a reproducible workflow capable of generating clinically meaningful REE measurements while minimizing technical artifacts. IC measurements were performed using the COSMED Q-NRG+ indirect calorimeter (COSMED, Rome, Italy). This system measures VO_2 and VCO_2 to estimate resting energy expenditure using the modified Weir equation. Depending on patient respiratory status, measurements were obtained using either ventilator mode or canopy mode.

This study presented a practical implementation protocol for bedside IC developed as part of routine clinical practice and quality improvement in a tertiary referral teaching hospital. No experimental intervention beyond standard clinical care was performed. No patient-identifiable information is included in this report. Representative case illustrations were fully anonymized prior to inclusion. Therefore, formal institutional ethical approval and individual informed consent were not required for preparation of this implementation-focused manuscript according to local institutional practice.

A key component of the implementation strategy was a clearly defined multidisciplinary collaboration framework (Figure 1). The clinical nutrition specialist played a central role in determining patient eligibility, evaluating nutritional risk, performing IC measurements, interpreting metabolic data, and integrating IC findings into individualized nutrition prescriptions. The critical care physician or anesthesiologist ensured physiologic stability before testing, optimized ventilator settings when applicable, and assessed hemodynamic suitability for metabolic assessment. Nursing staff coordinated bedside preparation, patient positioning, environmental control, and real-time monitoring during measurement sessions. This collaborative workflow facilitated the integration of IC findings into routine clinical decision-making while minimizing interruptions during bedside measurements.

IC was preferentially performed in hemodynamically stable surgical and critically ill patients when individualized nutritional assessment was clinically indicated. Measurements were

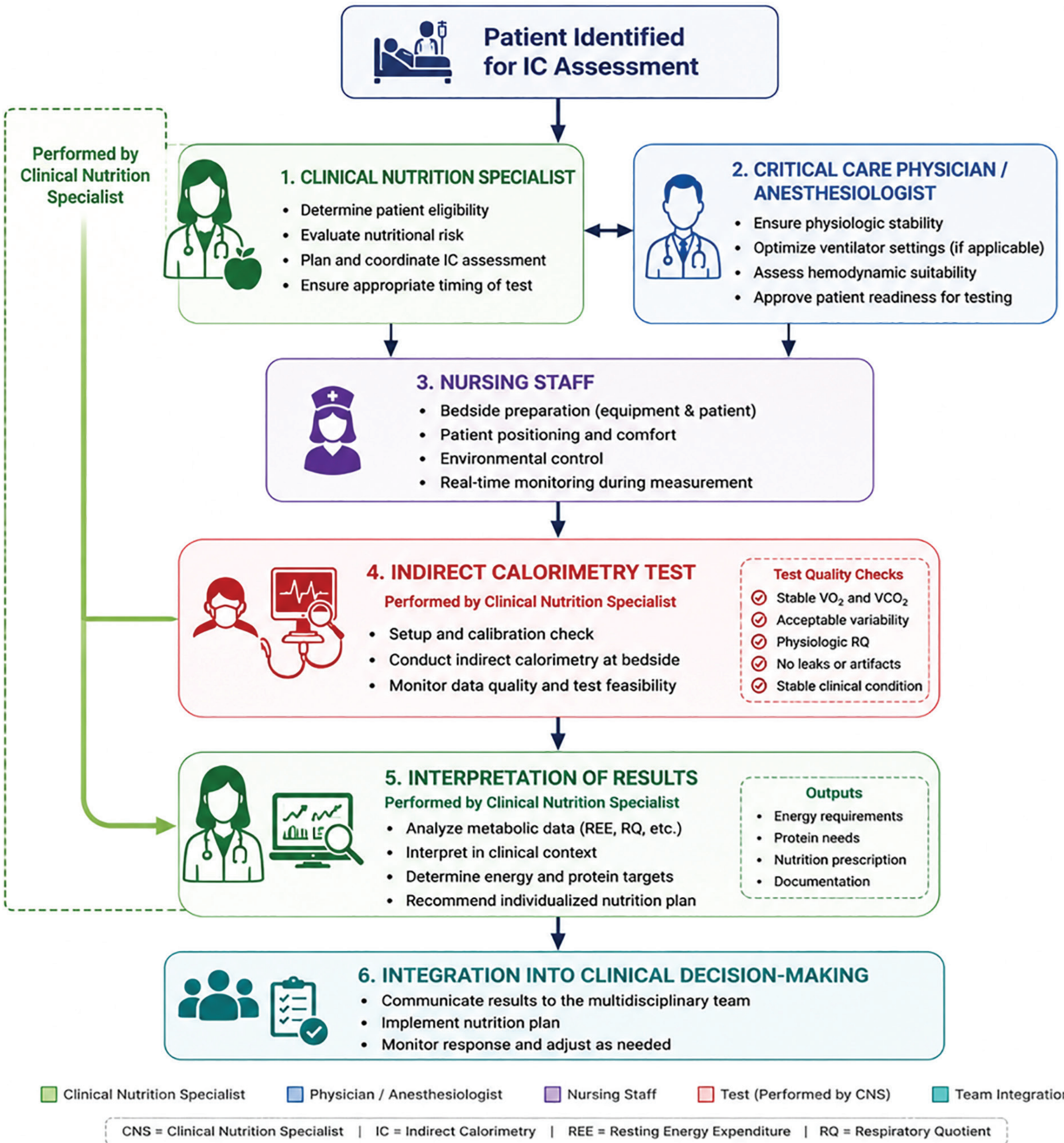


Figure 1: Multidisciplinary workflow for implementation of indirect calorimetry in clinical practice. The clinical nutrition specialist coordinated patient eligibility assessment, nutritional risk evaluation, indirect calorimetry measurement, metabolic data interpretation, and individualized nutrition prescription. Critical care physicians/anesthesiologists ensured physiologic and hemodynamic stability, while nursing staff supported bedside preparation, positioning, and real-time monitoring during measurement acquisition.

considered particularly valuable in patients with suspected metabolic instability, prolonged ICU stay, major surgery, sepsis, trauma, severe malnutrition, prolonged mechanical ventilation, or discrepancies between expected and observed nutritional responses. Because bedside metabolic measurements are highly sensitive to physiologic fluctuations and environmental conditions, strict pre-test preparation criteria were implemented to improve reproducibility.

To minimize measurement artifacts and diet-induced thermogenesis, the following preparation protocol was implemented: (i) Fasting period of approximately 4-6 hours, when clinically feasible. (ii) Temporary interruption of enteral or parenteral nutrition 2-4 hours before testing whenever patient safety permitted. (iii) Minimization of physical activity for at least 2 hours before measurement. (iv) Stable vasoactive medication requirements for at least 30 minutes before data acquisition. (v) Avoidance of active nursing procedures, physiotherapy, suctioning, repositioning, or painful interventions immediately before testing. (vi) Maintenance of stable room temperature (22-26°C) to reduce environmental variability. Patients were positioned comfortably in a resting state and encouraged to avoid unnecessary movement or conversation during measurement. Whenever feasible, measurements were postponed in the presence of severe agitation, excessive respiratory distress, uncontrolled pain, or abrupt hemodynamic instability.

For mechanically ventilated patients, IC was performed using the ventilator integration mode of the COSMED Q-NRG+ system. The device was connected to the ventilator circuit through manufacturer-recommended interfaces to preserve a closed respiratory system and minimize external gas contamination. Prior to measurement initiation, the following conditions were verified: (a) Stable ventilator settings for at least 30 minutes. (b) Fraction of inspired oxygen ($FiO_2 \leq 0.60$) whenever feasible. (c) Absence of clinically significant air leaks within the ventilator circuit. (d) Acceptable patient–ventilator synchrony. (e) Stable sedation requirements.

Because elevated oxygen concentrations may compromise oxygen sensor precision and affect VO_2 calculations, measurements performed at higher FiO_2 levels were interpreted cautiously. After calibration, data acquisition continued for approximately 20-30 minutes (with a minimum standard measurement duration of 5 minutes, according to the device protocol), allowing sufficient time to achieve physiologic steady state. Measurements were accepted when respiratory variables demonstrated relative stability and no major artifacts or interruptions occurred. Ventilator mode generally demonstrated greater measurement precision because of its relatively closed respiratory circuit and lower susceptibility to environmental interference (Table 1).

Canopy mode was used for spontaneously breathing patients, including postoperative surgical patients and selected individuals receiving non-invasive respiratory support. In this mode, a transparent canopy hood or face mask interface was positioned to capture expired gases while minimizing environmental contamination. Because canopy systems were inherently more vulnerable to air dilution and patient movement, special attention was paid to environmental stability and patient

Table 1: Standardized workflow for ventilator mode measurement.

Step	Procedure
1	Verify hemodynamic stability
2	Confirm stable ventilator settings
3	Ensure $FiO_2 \leq 0.60$ when possible
4	Inspect circuit integrity and ET cuff pressure
5	Perform gas and flow calibration
6	Begin measurement (20–30 min)
7	Review signal stability and variability
8	Interpret REE and RQ values clinically

ET: Endotracheal tube, REE: Resting energy expenditure, RQ: Respiratory quotient.

Table 2: Operational comparison of ventilator and canopy modes.

Parameter	Ventilator mode	Canopy mode
Patient type	Intubated	Spontaneously breathing
Measurement precision	Higher	Moderate
Leak susceptibility	Lower	Higher
Patient cooperation	Minimal	Required
Environmental sensitivity	Lower	Higher
Stabilization time	Faster	Longer

cooperation. Whenever oxygen supplementation was required, clinicians attempted to stabilize respiratory support before measurement. In patients receiving low-flow oxygen, testing was delayed whenever clinically feasible to minimize measurement distortion. Particular caution was exercised in patients requiring high-flow oxygen therapy or non-invasive ventilation because gas leakage may reduce measurement reliability. Patients were instructed to remain calm, avoid unnecessary talking, and minimize movement throughout the testing period. Compared with ventilator mode, canopy measurements frequently required longer stabilization periods and more careful troubleshooting (Table 2).

Reliable IC requires rigorous quality control. Therefore, mandatory calibration procedures were performed before every measurement session according to manufacturer recommendations for the COSMED Q-NRG+ system, as shown in Figure 2. Practical implementation revealed several recurring technical challenges that frequently affected measurement quality. Consequently, a structured troubleshooting approach was incorporated into routine workflow (Table 3). The most common challenge was air leakage, particularly in canopy mode and around endotracheal tube cuffs. Even minor leaks may substantially alter gas exchange measurements and produce misleading REE and respiratory quotient estimates. Systematic inspection of tubing connections and interface sealing therefore became mandatory before initiating data acquisition.

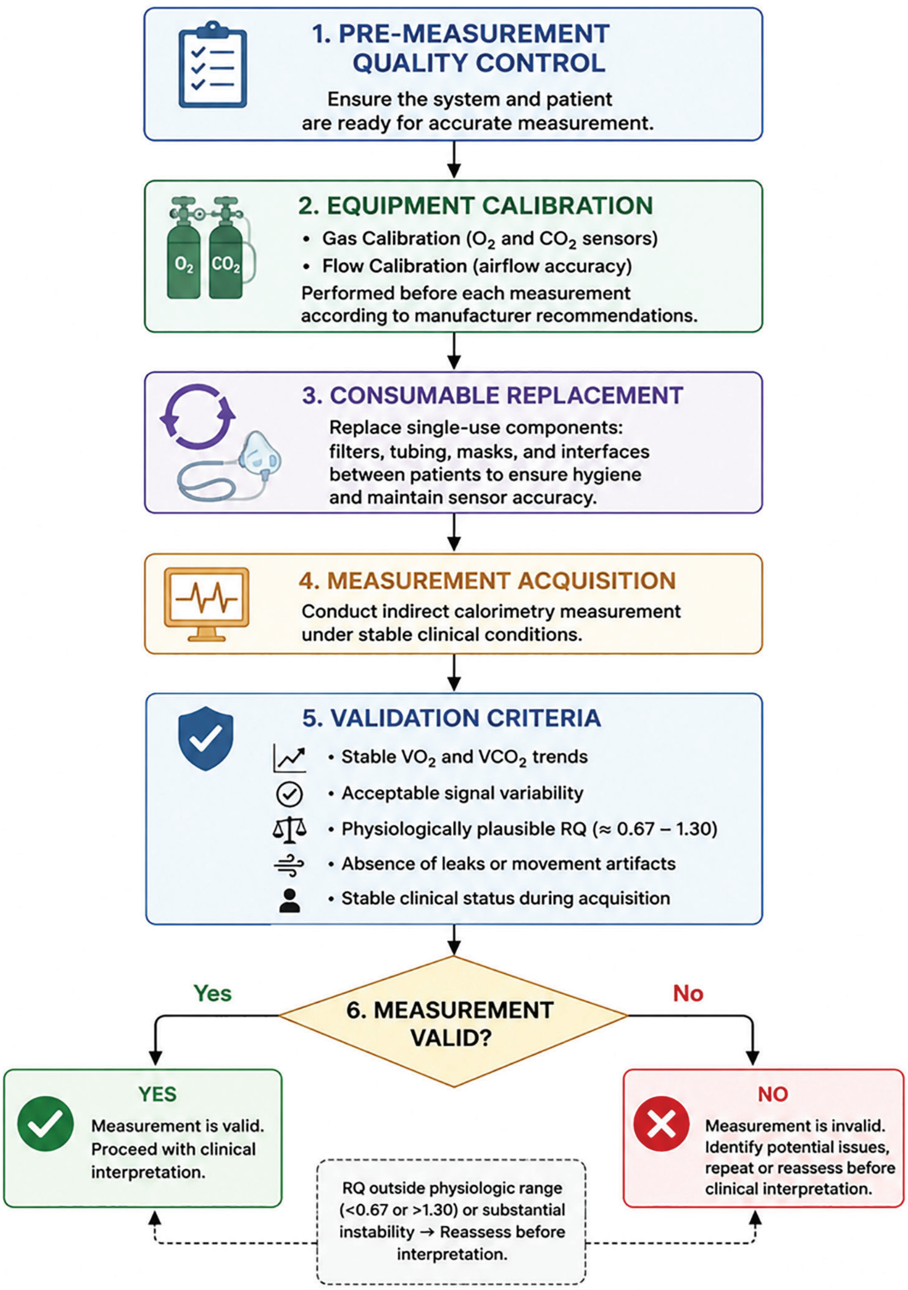


Figure 2: Quality control workflow for indirect calorimetry measurements, including calibration procedures, consumable replacement, validation criteria, and decision-making for measurement acceptance or reassessment prior to clinical interpretation.

Table 3: Troubleshooting common technical problems in indirect calorimetry.

Problem	Potential effect	Recommended action
Circuit leak	Invalid REE/RQ	Inspect tubing and seals
Patient movement	Signal instability	Pause and repeat
High FiO_2	VO_2 inaccuracy	Interpret cautiously
Calibration drift	Unrealistic values	Recalibrate system
Environmental instability	Sensor interference	Stabilize room conditions

REE: Resting energy expenditure, RQ: Respiratory quotient.

Motion-related artifacts represented another frequent source of instability. Patient movement, coughing, speaking, discomfort, anxiety, and inadequate analgesia frequently produced transient fluctuations in measured gas concentrations. When substantial signal instability occurred, measurements were paused and repeated only after re-establishing resting conditions. Environmental disturbances, including excessive humidity, unstable ambient temperature, and cleaning-related chemical exposure, occasionally affected sensor performance. Testing environments were therefore standardized whenever possible. High oxygen concentrations (FiO_2>0.60) were also associated with reduced measurement reliability. Because oxygen sensor precision decreases at elevated inspired oxygen fractions, interpretation in these settings required increased clinical caution.

Results

Implementation of bedside IC across approximately 300 measurements revealed substantial variability in metabolic demands among surgical and critically ill patients. Throughout routine clinical practice, measured resting energy expenditure (mREE) frequently differed from predictive equation–based estimates, particularly in patients with systemic inflammation, prolonged intensive care unit stay, postoperative stress, organ dysfunction, or prolonged sedation. In hyperinflammatory conditions, including sepsis, severe trauma, and major postoperative stress, mREE frequently exceeded predicted energy expenditure, consistent with hypermetabolic physiology. In these situations, IC provided clinically meaningful information to guide gradual adjustment of caloric and protein delivery while reducing the risk of underfeeding.

Conversely, some patients demonstrated substantially lower metabolic expenditure than predicted values, particularly during prolonged sedation, reduced physiologic reserve, advanced age, or severe organ dysfunction. In such circumstances, reliance solely on predictive equations may increase the risk of inadvertent overfeeding. Importantly, implementation experience emphasized that a single IC measurement should not be considered definitive. Because metabolic requirements fluctuate throughout the course of critical illness, repeated measurements at clinically relevant intervals—typically every 3–5 days or following major physiologic changes—were considered preferable to isolated assessments.

Furthermore, respiratory quotient (RQ) interpretation was incorporated into bedside nutritional decision-making while recognizing its inherent limitations. Although RQ may provide useful insight regarding substrate utilization patterns, interpretation was consistently performed within the broader clinical context and never used in isolation. Based on cumulative bedside experience and repeated metabolic assessments, a practical interpretation framework was developed to support clinical understanding of measured resting energy expenditure and RQ findings in both ventilator- and canopy-mode IC (Table 4). This framework is intended to facilitate interpretation within the broader clinical context rather than serve as a prescriptive nutritional protocol. To demonstrate the practical implementation and interpretation of bedside IC, representative clinical examples obtained using the COSMED Q-NRG+system were presented.

Case 1: This representative canopy-mode IC assessment was obtained in a 78-year-old female patient. Measured REE was 1715 kcal/day, corresponding to approximately 114% of predicted energy requirements, while RQ was markedly reduced (RQ=0.52). The measured energy expenditure exceeded predicted values, suggesting a relatively hypermetabolic state despite advanced age. However, the extremely low RQ indicated near-exclusive fat oxidation (100%) with negligible carbohydrate utilization, potentially reflecting prolonged fasting, inadequate carbohydrate intake, altered substrate availability, ketogenic metabolism, or severe metabolic stress. Although very low RQ values may occasionally result from technical factors or transient physiologic conditions, the overall trend strongly favored predominant lipid metabolism during the measurement period.

Measurement variability remained within clinically acceptable limits (VO_2 variability=7%, VCO_2 variability=6%), supporting reasonable signal stability and interpretability.

Table 4: Practical framework for interpretation of indirect calorimetry findings in ventilator- and canopy-mode measurements.

Parameter	Numeric status	Ventilator: possible interpretation	Canopy: Possible interpretation	Potential associated clinical/ laboratory findings	Potential clinical considerations
Measured REE	90–110% predicted	Relatively stable metabolic status in ICU	Controlled disease state or postoperative recovery	Stable CRP, albumin, hemoglobin, controlled pain	Nutritional prescription may be guided by measured REE with adequate protein provision (approximately 1.3–1.5 g/kg/ day) and periodic reassessment
	>120–130% predicted	Hypermetabolic response (e.g., SIRS, sepsis, burns)	Surgical stress, uncontrolled pain, wound infection	Elevated CRP/ WBC, reduced albumin	Consider increased metabolic demand, optimize protein intake, and minimize overfeeding while reassessing clinical stressors
	<80–90% predicted	Deep sedation, reduced organ function, malnutrition	Prolonged immobility or postoperative undernutrition	Low hemoglobin/ albumin, electrolyte abnormalities	Gradual nutritional advancement, optimization of protein intake, and reassessment of sedation, endocrine, or malabsorption-related factors may be warranted
	>150% predicted	Severe hypermetabolism, septic shock, or possible measurement artifact	Major inflammatory postoperative response	Markedly elevated CRP, fever, agitation	Technical reassessment (e.g., leaks, movement artifact, calibration) should be considered; if confirmed, cautious nutritional escalation may be appropriate
	<70% predicted	Multiple organ dysfunction or severe metabolic suppression	Severe postoperative weakness or malnutrition	Markedly reduced albumin, hypoglycemia, electrolyte depletion	Conservative feeding with close monitoring of electrolyte abnormalities and refeeding risk may be appropriate
RQ	0.85–0.95	Mixed substrate utilization (expected physiologic range)	Balanced postoperative nutrition	Stable glucose metabolism, absence of ketosis	Maintenance of the current nutrition regimen with routine reassessment may be appropriate
	>1.0	Possible carbohydrate overfeeding or lipogenesis	High-carbohydrate intake or excessive feeding	Hyperglycemia, metabolic instability	Reassessment of carbohydrate provision and glycemic management may be indicated
	<0.70	Starvation, underfeeding, predominant fat oxidation	Postoperative underfeeding or ketosis	Positive ketones, reduced glucose	Nutritional adequacy and refeeding risk should be evaluated, with cautious advancement of energy provision
	0.70–0.85	Predominant fat/protein catabolism	Pre/ postoperative malnutrition	Reduced albumin, phosphate depletion, weight loss	Increased protein provision and reassessment of overall nutritional adequacy may be beneficial
Special considerations	RQ outside physiologic range (≈0.6–1.3)	Potential technical error (ventilator leak, calibration issue, patient movement)	Hood leakage, anxiety, patient motion	Noninterpretable metabolic values	Repetition of the measurement after correction of technical or environmental factors is recommended

REE: Resting energy expenditure, RQ: Respiratory quotient, ICU: Intensive care unit, CRP: C-reactive protein, WBC: White blood cells.

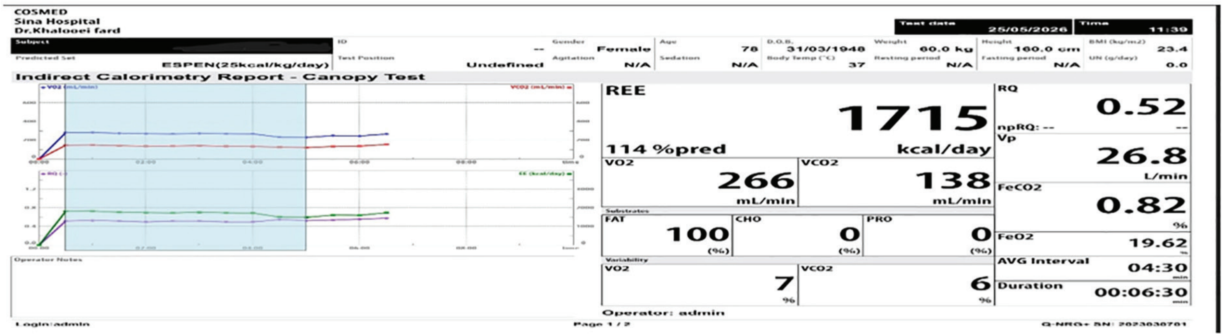
The absence of substantial carbohydrate oxidation further reinforced the metabolic pattern observed. Clinical interpretation suggested that predictive equations alone would have underestimated actual caloric requirements in this patient. Given the markedly low RQ, careful evaluation of nutritional intake, fasting duration, glycemic management, and substrate distribution would be clinically appropriate. Nutritional planning would likely favor gradual caloric optimization while ensuring balanced macronutrient provision, particularly adequate carbohydrate availability when clinically indicated (Figure 3a).

Case 2: This representative canopy-mode assessment was obtained in a 17-year-old male patient. Measured resting energy expenditure was 2199 kcal/day, corresponding to approximately 103% of predicted requirements, while RQ remained within physiologic range (RQ=0.74). Measured energy expenditure closely approximated predicted requirements, suggesting an overall metabolically stable state without evidence of marked hypo- or hypermetabolism. The RQ indicated predominant fat oxidation (88%) with limited carbohydrate utilization (12%), a pattern commonly observed during resting conditions, mild fasting states, or reduced recent carbohydrate intake. Measurement quality appeared satisfactory, with low variability for oxygen consumption and carbon dioxide production (VO_2 variability=6%, VCO_2 variability=7%), supporting acceptable reliability of the recorded values. Substrate utilization remained physiologically plausible and did not suggest clinically meaningful overfeeding or starvation. This case illustrated a scenario in which predictive equations reasonably approximated measured metabolic demands. Clinical interpretation supported maintenance of nutritional therapy close to estimated caloric requirements; while ensuring adequate macronutrient balance according to age, physiologic condition, and clinical objectives (Figure 3b).

Case 3: This representative canopy-mode IC assessment was obtained in a 69-year-old female patient. Measured resting energy expenditure was 1506 kcal/day, corresponding to approximately 108% of predicted energy requirements, while RQ remained within physiologic limits (RQ=0.77). Measured resting energy expenditure modestly exceeded predicted values, suggesting mild hypermetabolism relative to standard predictive estimates. RQ remained within a physiologic range and indicated predominant fat oxidation (78%) with moderate carbohydrate utilization (22%), a metabolic profile compatible with resting conditions and adequate metabolic flexibility. Measurement quality was considered clinically robust, particularly given the low oxygen consumption variability (VO_2 variability=4%) and acceptable carbon dioxide production stability (VCO_2 variability=7%). These findings supported overall confidence in the reliability of the assessment. This case further demonstrated the limitations of relying solely on predictive equations for nutritional planning, as measured expenditure slightly exceeded estimated requirements. Clinical interpretation favored individualized energy prescription guided by measured caloric expenditure while maintaining balanced nutrient delivery and avoiding both underfeeding and excessive caloric provision (Figure 3c).

Case 4: This representative canopy-mode IC assessment was obtained in a 57-year-old female patient. Measured REE was 1709 kcal/day, corresponding to approximately 85% of predicted energy requirements, while RQ was reduced (RQ=0.73). The measured energy expenditure was moderately lower than predicted values, suggesting a relative hypometabolic state compared with estimated caloric requirements. However, the low RQ indicated predominant fat oxidation (93%) with minimal carbohydrate utilization (7%), reflecting a metabolic profile largely dependent on lipid substrates during the measurement period. Such findings may be associated with fasting, reduced carbohydrate intake, insulin resistance, altered substrate utilization, or adaptive metabolic responses during illness or physiologic stress. Measurement stability appeared clinically acceptable, with low variability in oxygen consumption (VO_2 variability=3%) and carbon dioxide production (VCO_2 variability=4%), supporting the reliability and interpretability of the assessment. The relatively stable gas exchange pattern further strengthened confidence in the observed predominance of lipid metabolism. Clinical interpretation suggested that reliance solely on predictive equations may have overestimated actual caloric requirements in this patient. Given the predominance of fat oxidation and reduced carbohydrate utilization, assessment of nutritional intake, fasting status, glycemic control, and macronutrient distribution would be clinically relevant. Nutritional planning would likely emphasize individualized caloric adjustment with balanced macronutrient provision, particularly ensuring adequate carbohydrate intake when clinically appropriate (Figure 3d).

Case 5: This representative ventilator-mode IC assessment was obtained in a 44-year-old male patient. Measured REE was 1419 kcal/day, corresponding to approximately 81% of predicted energy requirements, while RQ was 0.82.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Dr.Khalooei fard
Test date 25/05/2026
Time 11:39
Subject [redacted]
Gender Female
Age 78
D.O.B. 31/03/1948
Weight 60.0 kg
Height 160.0 cm
BMI (kg/m2) 23.4
Predicted Set ESPEN(25kcal/kg/day)
Test Position Undefined
Agitation N/A
Sedation N/A
Body Temp (°C) 37
Resting period N/A
Fasting period N/A
UN (g/day) 0.0
Indirect Calorimetry Report - Canopy Test
REE 1715 kcal/day
114 %pred
VO2 266 mL/min
VCO2 138 mL/min
Substrates
FAT 100 (%)
CHO 0 (%)
PRO 0 (%)
Variability
VO2 7 %
VCO2 6 %
RQ 0.52
npRQ: --
Vp 26.8 L/min
FeCO2 0.82 %
FeO2 19.62 %
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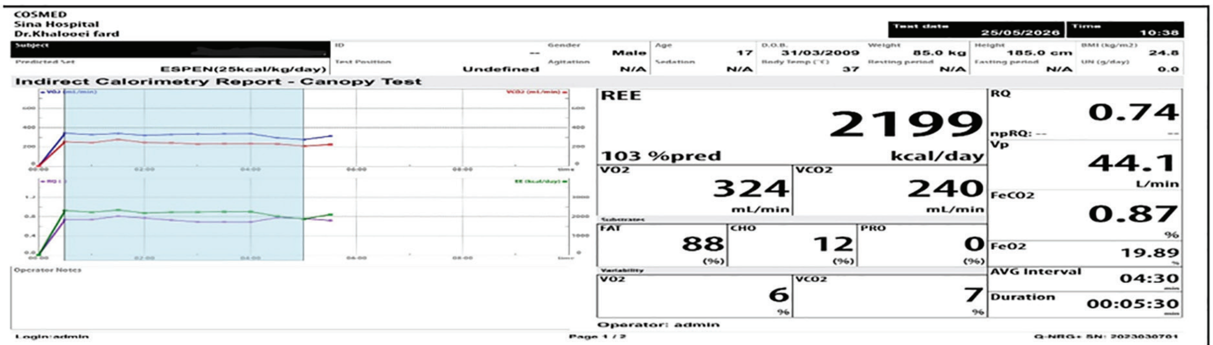
Page 1 / 2
Q-NRG+ SN: 2023030701

A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Dr.Khalooei fard
Test date 25/05/2026
Time 10:38
Subject [redacted]
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Weight 85.0 kg
Height 185.0 cm
BMI (kg/m2) 24.8
Predicted Set ESPEN(25kcal/kg/day)
Test Position Undefined
Agitation N/A
Sedation N/A
Body Temp (°C) 37
Resting period N/A
Fasting period N/A
UN (g/day) 0.0
Indirect Calorimetry Report - Canopy Test
REE 2199 kcal/day
103 %pred
VO2 324 mL/min
VCO2 240 mL/min
Substrates
FAT 88 (%)
CHO 12 (%)
PRO 0 (%)
Variability
VO2 6 %
VCO2 7 %
RQ 0.74
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Vp 44.1 L/min
FeCO2 0.87 %
FeO2 19.89 %
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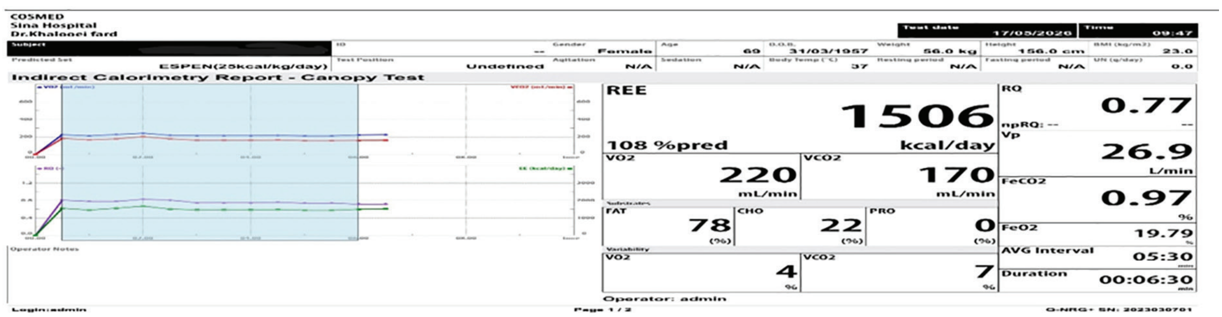
B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Height 156.0 cm
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Predicted Set ESPEN(25kcal/kg/day)
Test Position Undefined
Agitation N/A
Sedation N/A
Body Temp (°C) 37
Resting period N/A
Fasting period N/A
UN (g/day) 0.0
Indirect Calorimetry Report - Canopy Test
REE 1506 kcal/day
108 %pred
VO2 220 mL/min
VCO2 170 mL/min
Substrates
FAT 78 (%)
CHO 22 (%)
PRO 0 (%)
Variability
VO2 4 %
VCO2 7 %
RQ 0.77
npRQ: --
Vp 26.9 L/min
FeCO2 0.97 %
FeO2 19.79 %
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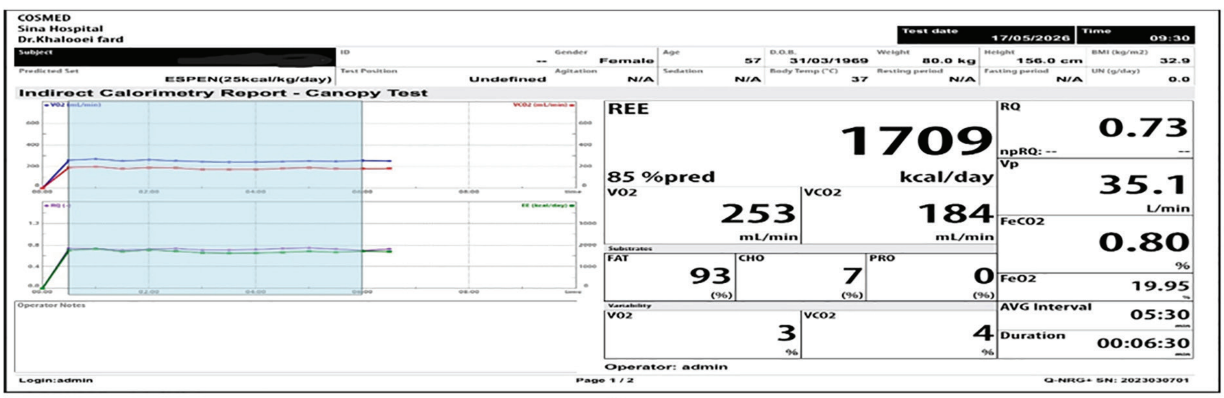
C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Test Position Undefined
Agitation N/A
Sedation N/A
Body Temp (°C) 37
Resting period N/A
Fasting period N/A
UN (g/day) 0.0
Indirect Calorimetry Report - Canopy Test
REE 1709 kcal/day
85 %pred
VO2 253 mL/min
VCO2 184 mL/min
Substrates
FAT 93 (%)
CHO 7 (%)
PRO 0 (%)
Variability
VO2 3 %
VCO2 4 %
RQ 0.73
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Vp 35.1 L/min
FeCO2 0.80 %
FeO2 19.95 %
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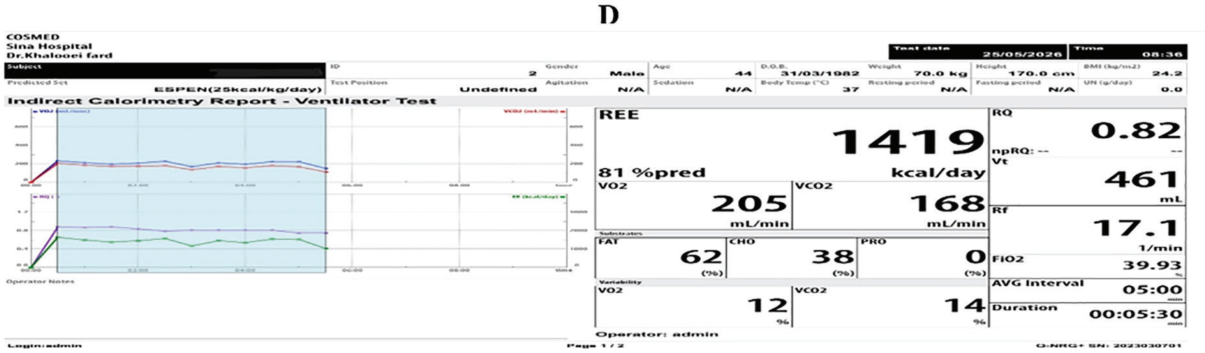
D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Height 170.0 cm
BMI (kg/m2) 24.2
Predicted Set ESPEN(25kcal/kg/day)
Test Position Undefined
Agitation N/A
Sedation N/A
Body Temp (°C) 37
Resting period N/A
Fasting period N/A
UN (g/day) 0.0
Indirect Calorimetry Report - Ventilator Test
REE 1419 kcal/day
81 %pred
VO2 205 mL/min
VCO2 168 mL/min
Substrates
FAT 62 (%)
CHO 38 (%)
PRO 0 (%)
Variability
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VCO2 14 %
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npRQ: --
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Rf 17.1 1/min
FiO2 39.93 %
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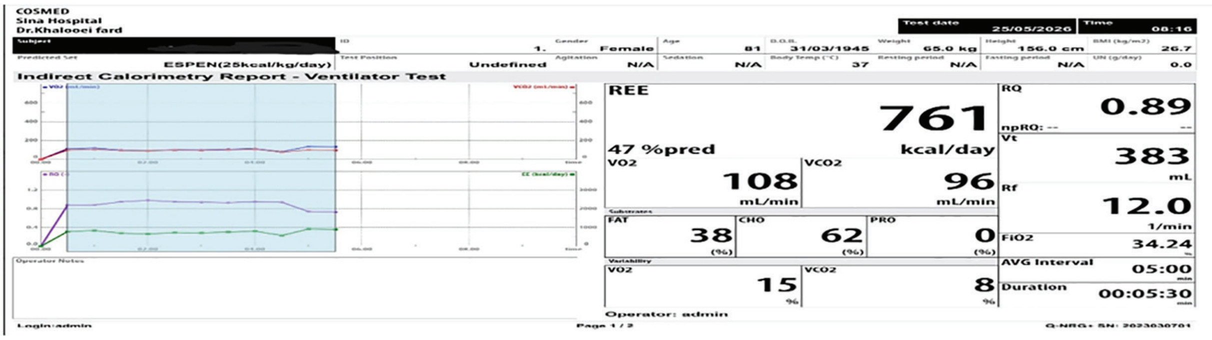

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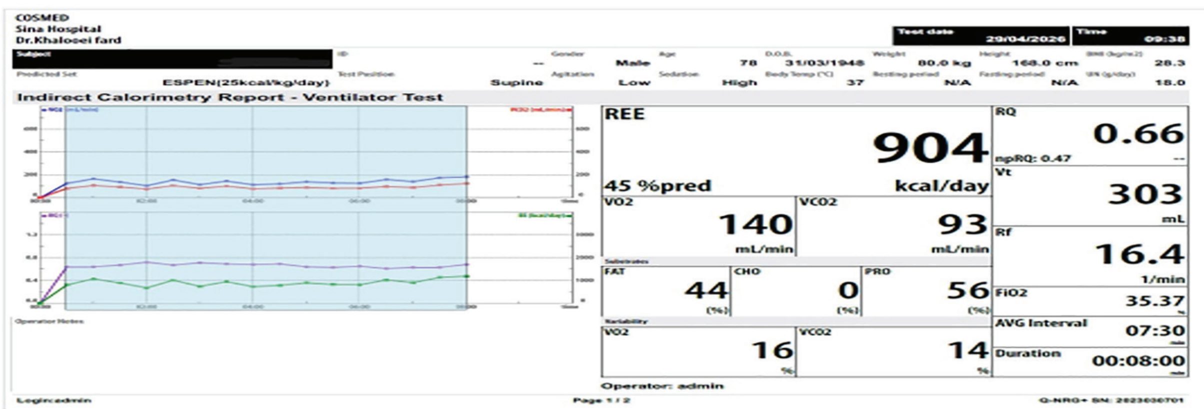

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Figure 3: Representative indirect calorimetry measurements obtained using canopy-mode and ventilator-mode systems across patients with different metabolic patterns. (a) Canopy-mode indirect calorimetry in an elderly female patient demonstrating elevated measured resting energy expenditure with a markedly low respiratory quotient, suggestive of predominant fat oxidation. (b) Canopy-mode indirect calorimetry in an adolescent male demonstrating resting energy expenditure close to predicted values and a physiologic respiratory quotient. (c) Canopy-mode indirect calorimetry in an older female patient demonstrating measured energy expenditure slightly above predicted requirements with physiologic substrate utilization. (d) Canopy-mode indirect calorimetry in a middle-aged female patient demonstrating measured resting energy expenditure below predicted values with a low respiratory quotient suggestive of predominant fat oxidation. (e) Ventilator-mode indirect calorimetry in a mechanically ventilated middle-aged male patient demonstrating resting energy expenditure slightly below predicted values with a respiratory quotient consistent with mixed substrate utilization. (f) Ventilator-mode indirect calorimetry in an elderly female patient demonstrating markedly reduced measured resting energy expenditure with a respiratory quotient suggestive of predominant carbohydrate oxidation. (g) Ventilator-mode indirect calorimetry in an 82-year-old female patient demonstrating severe hypometabolism with a respiratory quotient indicative of exclusive carbohydrate oxidation and potential lipogenesis. (h) Ventilator-mode indirect calorimetry in a 78-year-old male patient demonstrating reduced resting energy expenditure with a respiratory quotient suggestive of predominant fat oxidation.

The measured energy expenditure was lower than predicted values, suggesting a mild hypometabolic state relative to estimated caloric needs. The RQ was within a physiologically expected range and indicated mixed substrate oxidation, with approximately 62% fat oxidation and 38% carbohydrate utilization, reflecting a relatively balanced metabolic pattern without exclusive dependence on a single fuel source. Measurement variability remained within acceptable clinical limits (VO_2 variability=12%, VCO_2

variability=14%), although slightly higher variability compared with ideal steady-state measurements may indicate modest physiologic fluctuation during the recording period. Nonetheless, the consistency of substrate utilization patterns supported reasonable interpretability of the findings. Clinical interpretation suggested that predictive equations may have modestly overestimated caloric requirements in this patient. The relatively balanced substrate utilization profile indicated metabolic flexibility without severe nutritional imbalance, although ongoing evaluation of nutritional adequacy, ventilatory status, and clinical stress response would remain important. Nutritional management would likely favor carefully titrated caloric provision to avoid both underfeeding and overfeeding, with maintenance of balanced macronutrient delivery (Figure 3e).

Case 6: This representative ventilator-mode IC assessment was obtained in an 81-year-old female patient. Measured REE was 761 Kcal/day, corresponding to approximately 47% of predicted energy requirements, while RQ was 0.89. The measured energy expenditure was substantially lower than predicted values, suggesting a marked hypometabolic state, potentially reflecting advanced age, reduced lean body mass, decreased physiologic activity, chronic illness, sedation effects, or metabolic adaptation to illness. Despite the markedly reduced caloric expenditure, the RQ remained relatively elevated and indicated predominant carbohydrate oxidation (62%) with lower fat utilization (38%). Measurement variability remained within clinically interpretable limits (VO_2 variability=15%, VCO_2 variability=8%), although the somewhat elevated VO_2 variability may indicate mild physiologic instability during measurement. Nevertheless, overall signal quality appeared adequate for clinical interpretation. Clinical interpretation suggested that predictive equations would substantially overestimate caloric requirements in this patient, potentially increasing the risk of overfeeding if IC findings were not considered. The predominance of carbohydrate utilization may reflect current nutritional support composition, glucose administration, or altered metabolic preference during illness. Nutritional planning would likely prioritize conservative individualized caloric delivery with close reassessment of energy requirements and careful macronutrient optimization to avoid metabolic complications associated with overfeeding, particularly excess carbohydrate administration (Figure 3f).

Case 7: This representative ventilator-mode IC assessment was obtained in an 82-year-old female patient (BMI: 25.7 kg/m²). Measured REE was 675 kcal/day, corresponding to only 39% of predicted energy requirements based on the ESPEN (25 kcal/kg/day) standard. The RQ was 1.07. The measured energy expenditure was substantially lower than predicted values, suggesting a profound hypometabolic state. This marked reduction may reflect advanced age, significant loss of lean body mass, the effects of sedation, or metabolic adaptation to critical illness. Despite the extremely low caloric expenditure, the RQ was elevated (1.07), indicating exclusive carbohydrate oxidation (100%) with no fat utilization (0%). An RQ greater than 1.0 was often physiological evidence of net lipogenesis, typically occurring when carbohydrate intake exceeded the patient's immediate oxidative capacity. The steady-state criteria strictly met with measurement variability remaining well within clinical limits (VO_2 variability=6%, VCO_2 variability=3%). This low variability indicated high physiologic stability during the 8-minute measurement period, confirming that the data was highly reliable for clinical decision-making. Clinical interpretation suggested that standard predictive equations (which would estimate ~1750 kcal/day for this patient) would overestimate caloric requirements by more than 150%. Relying on such equations would pose a severe risk of overfeeding, potentially leading to hepatic steatosis, increased ventilator dependence due to excess CO_2 production, and metabolic distress. The current metabolic profile suggested that the patient might already be receiving excessive carbohydrate or total caloric support relative to her severely depressed metabolic rate. Nutritional planning should prioritize a highly conservative, individualized caloric delivery, with an immediate reduction in carbohydrate load and a shift toward fat utilization to normalize the RQ and avoid metabolic complications (Figure 3g).

Case 8: This representative ventilator-mode IC assessment was obtained in a 78-year-old male patient. The patient weighed 80.0 Kg, had a height of 168.0 cm, and a BMI of 28.3 kg/m². Measured REE was 904 Kcal/day, corresponding to approximately 45% of predicted energy requirements based on the ESPEN reference set (25 Kcal/Kg/day). The RQ was 0.66, with a non-protein respiratory quotient (npRQ) of 0.47. The measured energy expenditure was substantially lower than predicted values, suggesting a marked hypometabolic state. This might reflect advanced age, reduced lean body mass, sedation effects, supine positioning, or metabolic adaptation to illness. Despite the reduced caloric expenditure, the RQ was low, indicating predominant fat oxidation (44%) with minimal to no carbohydrate oxidation (0%) and a relative contribution from protein metabolism (56%). Such a low RQ/npRQ pattern was consistent with a fasting-like or catabolic metabolic state. Measurement variability remained modestly elevated but still clinically interpretable (VO_2 variability=16%, VCO_2 variability=14%), suggesting acceptable though not ideal physiologic stability during the measurement period. Overall, the signal quality appears sufficient for cautious interpretation. Clinical interpretation suggested that standard predictive equations would likely overestimate caloric requirements in this patient, increasing the risk of overfeeding if IC was not considered. The low RQ and npRQ indicated that the patient was primarily relying on fat and protein oxidation rather than carbohydrate utilization, which might reflect inadequate carbohydrate intake, fasting physiology, or catabolic stress. Nutritional planning should therefore emphasize individualized conservative caloric delivery, with close reassessment of energy needs and careful macronutrient balancing to avoid unnecessary carbohydrate loading and to support the patient's current metabolic state (Figure 3h).

Discussion

IC is widely regarded as the reference standard for measuring resting energy expenditure in critically ill patients and is recommended by major international nutrition societies whenever feasible (1-3). Nevertheless, despite its recognized physiologic advantages over predictive equations, implementation in routine bedside practice remains inconsistent across many institutions (2, 4). The present report described a practical multidisciplinary framework for implementation of bedside IC in surgical and critically ill patients, emphasizing operational feasibility, troubleshooting strategies, and clinically interpretable workflow. Rather than proposing a novel measurement technology, the principal contribution of this report lies in standardizing practical execution and reducing barriers to implementation in real-world settings.

One of the most important observations during implementation was the frequent discrepancy between measured resting energy expenditure and predictive equation–derived estimates. This finding aligns with previous literature demonstrating limited accuracy of predictive equations in critically ill populations (6, 7). Metabolic demands in ICU patients are dynamic and may fluctuate substantially because of inflammation, infection, trauma, sedation, organ dysfunction, surgical stress, and recovery phase transitions (8). In hypermetabolic states—including sepsis, trauma, burns, and major surgery-energy expenditure may increase substantially above predicted values, increasing the risk of cumulative energy deficit if nutritional prescriptions are based exclusively on conventional equations (11, 16, 17).

Conversely, hypometabolic states may emerge in patients with deep sedation, advanced age, severe organ dysfunction, or reduced physiologic reserve, potentially increasing the risk of overfeeding when estimated requirements are used without physiologic confirmation (12). A key operational feature of this protocol was differentiation between ventilator mode and canopy mode implementation. Ventilator mode generally offered greater technical precision because of its relatively closed respiratory system and lower susceptibility to environmental interference. In contrast, canopy-mode measurements required increased vigilance regarding air leaks, patient movement, oxygen administration, and environmental contamination (13). Practical troubleshooting emerged as another cornerstone of implementation. Circuit leaks, movement-related instability, elevated inspired oxygen concentrations, and calibration drift represented the most frequent technical barriers to obtaining reliable measurements. Consistent with previous reports, standardization of preparation, environmental conditions, and calibration substantially improved measurement quality (14, 15).

Interpretation of RQ also warrants careful clinical consideration. Although elevated RQ values may suggest carbohydrate overfeeding and lower values may indicate predominant fat oxidation or reduced carbohydrate utilization, isolated interpretation may be misleading in the presence of technical artifacts or acute physiologic instability (18). For this reason, our protocol emphasized contextual interpretation integrating clinical status, laboratory findings, ventilatory support, and recent nutritional interventions. Importantly, IC should not be viewed as a one-time intervention but rather as a dynamic monitoring strategy. Repeated measurements may provide more clinically meaningful guidance than isolated assessments, particularly in patients undergoing rapid metabolic transitions during prolonged ICU admission or postoperative recovery (2, 19, 20). The multidisciplinary implementation model described in this report—including coordinated collaboration between nutrition specialists, intensivists, anesthesiologists, surgeons, and nursing staff—facilitated translation of metabolic measurements into individualized nutritional care plans. Such integration may represent an important step toward broader adoption of precision nutrition approaches in critical care settings (19-21).

This protocol provided several practical advantages for bedside implementation of IC. First, it addressed a frequently overlooked implementation gap by translating guideline recommendations into a reproducible operational workflow. Second, the protocol incorporated troubleshooting strategies for common technical problems that frequently compromised bedside reliability. Third, inclusion of both ventilator and canopy modes broadened applicability across diverse surgical and critical care populations. Finally, incorporation of representative clinical cases illustrated real-world interpretation of metabolic data and might improve clinician familiarity with bedside IC.

Several limitations should be acknowledged in this study. First, this report represented a practical implementation framework rather than a prospective interventional study. Although the protocol was refined through extensive clinical experience involving approximately 300 bedside measurements, systematic quantitative analysis of patient outcomes was not performed. Second, measurement reproducibility and inter-operator variability were not formally evaluated. Third, implementation experience originated from a single tertiary referral center, potentially limiting generalizability to institutions with different patient populations, staffing structures, or equipment availability. Finally, because IC performance might vary according to device type, operational details described in this report primarily reflect implementation using the COSMED Q-NRG+ system.

Conclusion

This report presented a practical multidisciplinary protocol for implementation of bedside IC in surgical and critically ill patients. By standardizing patient preparation, measurement procedures, troubleshooting strategies, and interpretation of metabolic variables, the protocol addressed an important gap between international guideline recommendations and bedside clinical practice. Implementation experience suggests that standardized workflows may improve the feasibility, reliability, and clinical interpretability of IC in routine hospital settings. Through integration of ventilator and canopy measurement strategies and incorporation of practical troubleshooting algorithms, this framework may facilitate broader adoption of individualized metabolic assessment and precision nutritional support in critically ill and surgical populations.

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Authors' Contribution

RK: Conceptualization, protocol development, clinical implementation, manuscript drafting, and interpretation of metabolic data. LSH: Clinical supervision, ICU implementation, manuscript review, and critical revision. A.N.: Anesthesiology consultation, critical care coordination, and methodological review. HS: Intensive care implementation and technical oversight. HAA & RH: Surgical coordination and clinical interpretation.

Conflict of Interest

The authors declare that they have no competing financial or non-financial interests related to this work.

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