Indirect Calorimetry: Taking the Guess Work Out of Feeding Critically Ill Patients

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Consequences of Malnutrition in Critically Ill Patients

Metabolic stress of acute illness
+ Malnutrition

= Increased healthcare costs¹
= Higher rate of ventilator dependence²
= Longer ICU stays¹
= Higher morbidity and mortality rates²


Pros and Cons of Predictive Equations

PROs
• Convenient
• Used more frequently
• Inexpensive

CONs
• Hundreds of equations and variables to consider
• Accuracy < 40%
• No consensus on how to select equations
• Results vary from clinician to clinician

Pros and Cons of Indirect Calorimetry

PROs
• Accurate
• Gold standard
• Doesn’t have limitations of equations

CONs
• Not always available
  (Newer technology now integrated into ventilator)
• Not all clinicians trained in use and interpretation
• Variable insurance reimbursement
• Equipment is fairly costly
• No clinical trials to prove that it directly improves patient outcomes

What is Indirect Calorimetry (IC)?

- Calculation of heat production by measuring pulmonary gas exchange
- Measurements of inspired and expired O$_2$ and CO$_2$
- Determination of:
  - Resting Energy Expenditure (REE)
  - Respiratory Quotient (RQ)

Calculations for IC

**RESTING ENERGY EXPENDITURE**

REE (Kcal/d) = \([\text{VO}_2 \times 3.94] + [\text{VCO}_2 \times 1.11]\) \times 1,440 min/day

**RESPIRATORY QUOTIENT**

\[
RQ = \frac{\text{VCO}_2 \text{ (carbon dioxide production)}}{\text{VO}_2 \text{ (oxygen consumption)}}
\]

Equipment Options for IC

- Metabolic cart
- Handheld device
- Indirect calorimetry module built in to a mechanical ventilator

Metabolism

Metabolism, measured in calories, is the biochemical process of combining nutrients with oxygen to release the energy needed for the body to function

\[
C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \rightarrow \text{ATP (ENERGY)}
\]

*More simply stated, resting metabolism is the number of calories that the body burns while at rest.*
The Classic Indirect Calorimeter

Indirect Calorimetry Module within Mechanical Ventilator

Handheld and Table Top Indirect Calorimeters
When is IC Helpful?

- When you cannot accurately estimate caloric requirements
- When predictive equations produce an inadequate clinical response in a patient
- When clinical signs suggest under- or over-feeding

SCCM and ASPEN 2016 Guidelines for the Provision and Assessment of Nutrition Support Therapy in the Critically Ill Patient

1. **A3a:** IC should be used to determine energy requirements when available
2. **C3:** Provide at least 80% of estimated or calculated goal energy and protein within 48-72 hours over the 1st week of hospitalization
3. **I1:** Pulmonary failure – High fat low carbohydrate formulations designed to manipulate RQ and decrease CO₂ production are not recommended for use
4. **M4b:** Burn – IC should be used to assess energy needs with weekly repeated measures
5. **Q5:** Obesity – Target energy requirements should be measured by IC. Feed at 65-70% of target

Factors Affecting the Accuracy of Estimates

- Multiple trauma
- Neurological trauma
- Burns
- Multi-system organ failure
- Sepsis
- Systemic inflammatory response syndrome
- Acute or chronic respiratory distress syndrome
- Use of paralytic agents or sedation
- Post-operative organ transplantation
- Large or multiple open wounds
- Malnutrition with altered body composition
  - Underweight
  - Obesity
  - Limb amputation
  - Peripheral edema
  - Ascites

Consequences of Under- or Overfeeding

- Underfeeding¹,²
  - Impairs regeneration of respiratory epithelium
  - Contributes to muscle weakness and respiratory dysfunction
- Overfeeding³,⁵
  - Worsens metabolic stress
  - Increases the work of breathing (can lengthen ventilator dependence)

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How to Conduct IC Measurements

- Intermittent
- Continuous

“Snapshot” studies of ≤ 30 minutes are more common than continuous monitoring.

Results are extrapolated to a 24-hour day

Achieving a Steady State is Key

- Steady state conditions:
  - McClave Definition:
    - 5 minutes with 5% CV in VO$_2$, VCO$_2$
    - 10 minutes with 10% CV in VO$_2$, VCO$_2$
  - Results reflect a steady state for at least 5 consecutive minutes (or follow your unit’s protocols)

  - CV = co-efficient of variation


What to do if You don’t Achieve Steady State?

- Compare predicted VCO$_2$ and VO$_2$ to measured levels
  - Normal Adult VCO$_2$ = 2 - 3 ml/kg/minute
  - Normal Adult VO$_2$ = 3 - 4 ml/kg/minute
  - Note: use the most appropriate reference weight for these calculations

Physiologic Issues that can Affect Results

<table>
<thead>
<tr>
<th>Altered Gases</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevated VCO$_2$</td>
<td>Metabolic acidosis</td>
</tr>
<tr>
<td>Decreased VCO$_2$</td>
<td>Metabolic alkalosis</td>
</tr>
<tr>
<td>Elevated VO$_2$</td>
<td>Sepsis</td>
</tr>
<tr>
<td>Decreased VO$_2$</td>
<td>Hypothermia</td>
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<td></td>
<td>Pancreatic</td>
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</tbody>
</table>

Situations Where $\text{VCO}_2$ May Be Elevated

- Metabolic acidosis
- Hyperventilation
- Hypermetabolism
- Overfeeding

$\uparrow$ RQ

Situations Where $\text{VCO}_2$ May Be Decreased

- Metabolic alkalosis
- Hypoventilation
- Hypometabolism
- Gluconeogenesis
- Starvation/ketosis
- Underfeeding

$\downarrow$ RQ

Situations Where $\text{VO}_2$ May Be Elevated

- Sepsis
- Hypermetabolism
- Hyperthermia
- Shivering / agitation / pain / excessive movement
- Increased minute ventilation
- Overfeeding

$\uparrow$ REE

Situations Where $\text{VO}_2$ May Be Decreased

- Paralysis
- Coma
- General anesthesia
- Sedation
- Analgesics
- Muscle relaxants
- Hypothermia
- Fasting
- Starvation
- Hypothyroidism
- Sleep
- Advanced age

$\downarrow$ REE
Recommendations to Improve IC Measurements:
Patient → Equipment → Environment

- Do measurements in a quiet, thermoneutral environment
- Rest patient in supine position > 30 min. prior to the study
- Do the study ~ 1 hr after an intermittent feeding if thermogenesis is included in the REE; 4 hr after the feeding if it is not
- Ensure that the rate and composition of continuously infused nutrients is stable at least 12 hr prior to the study


Recommendations to Improve IC Measurements:
Patient → Equipment → Environment

- IC measurements may not be valid within:
  - 8 to 12 hrs of general anesthesia
  - 90 minutes of changes in ventilatory settings
  - 3 to 4 hrs of hemodialysis
  - 1 hr of any painful procedures


Technical Issues that can Affect Results

- Keep FiO₂ constant during the measurement
- Mechanical ventilation with FiO₂ ≥ 60
- Mechanical ventilation with PEEP > 12 cm H₂O
- Hyper/hypoventilation (alters the body’s CO₂ stores)
- Leak(s) in the sampling system
- Moisture in the system can affect the oxygen analyzer
- Continuous system flow > 0 L/min during exhalation
- Inability to collect all expiratory flow


Interpretation of the Measured REE

- In general, feed critically ill patients 100% REE without adding activity or stress factors
- Provide sufficient protein (1.5-2.0 gm/kg)
- Re-evaluate REE when indicated

McClave SA et al. JPEN 27:16-20, 2003
Interpretation of RQ

- Historically used to determine substrate utilization.¹
  - **CAUTION:** This varies by patient and condition²
    - Stress response
    - Underlying pulmonary disease
    - Acid/base abnormalities
    - Pharmacologic agents
  - **RECOMMENDATION:** Use RQ to validate test results and to gauge whether RQ is within normal biological range (0.67 to 1.3)³⁷

Designing a Nutrition Regimen

- Consider the phase of the patient’s response to metabolic stress
  - Stress phase, or ebb phase (12 – 24 hr.)
  - Catabolic phase, or flow phase (7 – 10 days)
  - Anabolic phase (variable time, may last for months)
  - Adjust nutritional support according to phase of metabolic stress
  - In all phases, provide a balanced mix of protein:carbs:fat at approximately 20%: 50%: 30%


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![Graph showing the relationship between injury, inflammation, and MODS phases.](image1)

![Graph showing the relationship between REE and REEp.](image2)

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Energy Considerations for Each Phase of the Stress Response

- **Stress and catabolic phases = metabolic support**
  - Preserve lean body mass without overfeeding
  - High protein feedings \( \leq 100\% \) of REE

- **Anabolic phase**
  - Marked rise in energy requirements
  - Focus on nutrition repletion and recovery
  - Patients may be fed up to 130\% of their measured REE
  - Ongoing aggressive protein delivery

Interpretation of the Measured REE

- In general, feed critically ill patients 100\% REE without adding activity or stress factors
- Provide sufficient protein (1.5-2.0 gm/kg)
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Patient Case

- 44 y.o. female
- Diagnosis: Necrotizing Fasciitis
- PMH:
  - HTN
  - Asthma
  - Hypothyroidism
  - Morbid obesity
- PSH:
  - Appendectomy
  - Hysterectomy
  - Oophorectomy

The Patient’s Nutrition Status

- Ht: 5’8”
- Wt: 188kg  BMI: 63!
- Sedentary; in usual state of health until admission
Review of Clinical Course

- Sepsis w/ respiratory failure
- OR: Right BKA
- Post-operative complications:
  - C. Diff diarrhea
  - Poor wound healing
  - UTI

What is the Patient’s Predicted Energy Expenditure?

- HBE (BEE x 1.3-1.6)  2156-2653 kcals/d
- Swinamer                    2955 kcals/d
- IJEE(v)                     2196 kcals/d
- 20-25 kcal/kg               1900-2375 kcals/d
- Mifflin-St. Jeor            2559 kcals/d

Is this patient is a good candidate for IC?

- YES!
  - Sepsis
  - Obesity
  - Altered body surface area secondary to BKA
  - Respiratory failure
  - Hypermetabolism
  - Wound healing

Indirect Calorimetry Studies

- Hospital Day #8 1st study: Valid
  - REE 2259 calories/day; RQ 0.83

- Hospital Day #15 2nd study: Valid
  - REE 2730 calories/day; RQ 0.83
Potential Benefits of Using IC

- Prevention of over- or underfeeding
- Reduced resource utilization & associated cost savings
- Improved outcomes
  - Fewer days on mechanical ventilation
  - Shorter ICU LOS

Summary

- Indirect calorimetry (IC) is the gold standard for determining energy expenditure in critically ill patients
- IC is objective and accurate
- The REE does not need to be adjusted by stress or activity factors
- Use the RQ primarily to validate test results
- IC is a valuable tool for
  - monitoring patient response to metabolic stress
  - monitoring nutrition interventions
  - optimizing nutrition