Indirect Calorimetry- Burning Questions?

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Objectives

- To understand what indirect calorimetry is
- To understand how the data is obtained
- To understand its clinical and practical uses

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What is it?

- Indirect calorimetry (IC) is a method for measuring resting energy expenditure (REE) by assessing oxygen consumption (VO2) and carbon dioxide production (VCO2). It's considered the standard for determining REE, especially in critically ill patients. To ensure accurate results, IC measurements should adhere to specific guidelines, including maintaining a steady state, minimizing patient stimuli, and calibrating the device

Break that down please

- Calorimetry-the scientific process of measuring the amount of heat absorbed or released during a physical or chemical change
- Resting Energy Expenditure-the amount of heat absorbed or released at rest
- Used to determine
  - The energy content of foods
  - The heat of chemical reactions
  - The metabolic rate of living organisms (in indirect calorimetry)

What is REE?

- Resting energy expenditure or REE represents the energy expended by the body during a 24 hours **non-active** period to maintain involuntary functions such as substrate turnover, respiration, cardiac output and body temperature regulation.
- Healthy sedentary adult REE constitutes two thirds of the total energy expenditure (TEE) which includes energy needed for nonobligatory expenses such as physical activity and diet-induced thermogenesis

How it works

- The patient breathes into a metabolic cart or a canopy type system that is connected to gas analyzers
- The device will measure VO2-(volume of oxygen consumed per minute)
- VCO2- the volume of carbon dioxide produced per minute
- The values are used to calculate REE- Resting energy expenditure-the calories your body burns at rest
- RQ- Respiratory Quotient- this gives clues about whether the body is burning carbs, fats or protein for energy

Where is this used?

- Critical Care-guides nutrition support in ICU patients to avoid over or underfeeding
- Pulmonary Function Labs- assess metabolic response in patients with lung disease
- Nutrition and Obesity medicine-determines accurate caloric needs for weight management
- Sports and exercise physiology- measures energy expenditure during rest and activity

Pros and Cons

- Pros:
  - More accurate than the Harris Benedict equation
  - Provides individualized data rather than population averages

- Cons:
  - Requires specialized equipment and trained staff
  - Accuracy depends on calibration, steady state measurements and patient cooperation
  - Can be affected by supplemental oxygen, air leaks or ventilator settings

RQ values

- RQ = VCO2/VO2
- It tells you which macronutrients are being oxidized (burned) for energy:
  - 0.7 Fat oxidation (fat burning)
  - Example: during fasting, keto diet, or prolonged exercise the body relies more on fat.
  - 0.85 Mixed fuel (carbs and fats)
  - 1.0 Carbohydrate oxidation (carb burning)- happens after a carb-heavy meal or during high-intensity exercise.
  - Greater than 1.0 overfeeding or anaerobic metabolism- seen when excess calories are given (especially carbs) ,or if the patient is “air hungry and hyperventilating

Clinical/Practical Use

- ICU nutrition
  - High RQ greater than 1.0 may indicate overfeeding or too many carbs in the formula
  - Low RQ –closer to .7 patient is burning fat, possibly underfed or catabolic

- Athletic performance:
  - Athletes use RQ or RER in exercise physiology to understand efficiency- how well are they using carbs or fat at different intensities of exercise

- Weight management:
  - Some weight loss programs use RQ to check whether clients are oxidizing more fat after interventions.

Measuring VO2 and CO2

- IC quantifies the amount of oxygen consumed and carbon dioxide produced by the body, providing a basis for calculating energy expenditure
- Respiratory Quotient (RQ): the ratio of VCO2 to VO2 (VCO2/VO2)
- RQ indicates the type of fuel being used (carbohydrates, fats or protein)

Fuel: which substrate are you?...

- **Substrates:** These are the fuel sources that the body burns to produce energy.
- The three main categories are carbohydrates, fats, and proteins
- Carbohydrates
- Fats
- Proteins
- An RQ of 1.0 indicates that carbohydrates are the primary fuel source being utilized.
- An RQ of 0.7 indicates that fats are the predominant fuel source.
- An RQ between 0.7 and 1.0 suggests a mix of carbohydrates and fats are being used

Why measure REE in critically ill patients?

- There is always a metabolic response to injury in a patient
- These changes can reflect a nutritional need doubling or tripling from normal
- The changes in REE will fluctuate during the illness/injury and can change drastically
- Non-septic patients with acute pancreatitis presented a hypermetabolic state with a REE increase of 120% compared to predicted
- Post-burn hypermetabolism was shown to increase REE as high as 100% above normal
- Prolonged bed rest, atrophy of the metabolically active lean body mass and mechanical ventilation have also been reported to decrease REE
- For patients with multiple organ failure the loss of lean body mass is very rapid and resulted in 22% loss in 10 days and no predictive equation showed good agreement compared to REE measured by IC

Clinical Applications-what does it look like?

- Intubated patients- gas sampling is acquired by the circuit connecting to the endotracheal tube to the ventilator
  - Equipment will analyze data breath by breath or mixing chamber analyses

- Canopy mode- used in spontaneously breathing patients via a ventilated canopy hood or a fitted face-mask
  - The head is surrounded by a clear rigid hood and a pump pulls air through the canopy at a constant rate
  - Fitted mask covers patients nose and mouth and measures breath by breath VCO2 and VO2

That’s Weir

- The data is used to calculate REE by Weir’s equation
- Energy Expenditure (kcal/day)=(3.941 x VO_2) +(1.106 x VCO_2) x1440
  - VO_2= liters of O_2 consumed per minute
  - VCO_2= liters of CO_2 produced per minute
  - 1440= number of minutes in a day

  - Oxygen uptake and carbon dioxide output reflect the oxidation of carbs and fats
  - Carbs require more oxygen to fully oxidize than fats do

REEvs TEE

- REE
- Resting energy expenditure is also called RMR or Resting Metabolic rate
- The number of calories you burn at rest in a neutrally temperate environment, while awake and not digesting food
- Accounts for 60-75% of total daily energy needs in most people
- This is what indirect calorimetry measure directly by (VO2@ and VCO2)

TEE

- Total energy expenditure, including:
  - 1. Resting Energy Expenditure
  - 2.Thermic Effect of Food (TEF) approx. 10% of calories burned in digestion/absorption
  - 3. Physical Activity Energy Expenditure (PAEE) highly variable, can by 15-30% or more

  - In ICU patients or bedridden individuals, TEE approximates REE (because activity is minimal)
  - In athletes or active individuals, TEE can be 2-3x REE.

  - Put it together:
    - To get TEE, multiply REE by an activity factor:
    - Sedentary: x 1.2
    - Lightly active: x 1.4-1.5
    - Moderately active: x 1.6-1.7
    - Very active/athlete: 1.8-2.2

Summary

- So, if someone's REE is 1740 kcal/day and they are moderately active (x 1.6):
- TEE = 1,740 x 1.6 or 2,780 kcal/day
- That’s their true daily caloric requirement!

Standards for accurate IC measurements

Steady state: the patient should be in a stable metabolic state with consistent oxygen consumption and carbon dioxide production.

Coefficient of variation of less than 5% for at least 10 minutes

Minimizing stimuli: Measurement should be taken in a quiet environment with minimal patient activity and stimuli like noise or light

Proper calibration- Equipment must be properly calibrated and maintained to ensure accurate gas exchange measurements

Key Guidelines

Steady state-Measurements should be taken during a period of stable oxygen consumption and carbon dioxide elimination, with a coefficient of variation of less than 5% for at least 10 minutes

Patient Stability-Minimize patient stimuli and ensure the patient is at rest before and during the measurement. Avoid changes in ventilator settings, painful procedures, and other factors that could influence metabolic rate

Key Guidelines cont.

Contraindications-Avoid indirect calorimetry in patients with high inspired oxygen concentrations (FiO_2 >60%), elevated PEEP (>or equal to 12), or irregular breathing patterns that affect tidal volume

Patient Preparation-for ventilated patients, ensure the endotracheal tube or tracheostomy tube cuff is sealed, there are no air leaks, and the patient has been at their goal tube feeding or parenteral nutrition rate for at least 12 hours (NO Bolus feeds prior to study)

Key Guidelines cont.

Safety Precautions- use appropriate filters and sterile barriers to prevent contamination. Follow institutional protocols for handling equipment and ensuring patient and staff safety

Interpretation-Consider factors like patient posture (semi-recumbent vs other), and adjust caloric intake based on the measured energy expenditure and patient tolerance.

Monitoring-Continuous monitoring of oxygen consumption and carbon dioxide production helps optimize lung ventilation and assess nutritional requirements

Clinical Applications-Indirect calorimetry is particularly useful patients with obesity, severe malnutrition, those undergoing metabolic stress or those with unstable conditions

Factors limiting IC measurements

- Agitation, fever, sedatives and vasoactive adjustments during measurement
- Air leakages in respiratory circuit
- Dialysis or continuous renal replacement therapy (RRT)
- ECMO
- Mechanical ventilation with PEEP>12
- **Mechanical ventilation with FiO_2 >60%**
- Non-invasive ventilation
- Other gases than O_2, CO_2 and N_2: helium
- Supplemental oxygen in spontaneous breathing patients

FiO2 >60%- why not?

- It's harder to measure accurately when patients are on high FiO2 because of the way the device calculates the VO2 and VCO2

  1. Small differences in O2 make a big impact
     - IC measures oxygen uptake by comparing inspired and expired O2 concentrations.
     - At high FiO2, the fractional difference between inspired and expired O2 becomes very small (e.g. FiO2 0.80 in vs 0.76 out)
     - Because the device relies on detecting this small change, even tiny measurement errors or leaks can lead to large inaccuracies in VO2 and energy expenditure.

  2. Gas analyzers have reduced precision at high O2

  - Many calorimeters use paramagnetic or galvanic O2 sensors, which lose accuracy as FiO2 approaches 100%
  - The higher the FIO2, the harder it is for the device to resolve small changes reliably

FiO2 >60%- why not…Cont..

- 3. Leaks and circuit issues matter more
  - Any leak (around the ET tube cuff, circuit connections, chest tube, etc) dilutes expired gases.
  - At high FiO2, these errors disproportionately affect O2 consumption values
- 4. FiO2 drift and delivery fluctuations
  - Ventilators may not deliver a perfectly stable FiO2, especially at high levels, which introduces variability in the inspired gas measurement
- **Bottom line:**
  - At high FiO2, the margin for error is very narrow because you're trying to measure a small subtraction (VO2=inspired O2-expired O2) from two large numbers. That's why most guidelines caution against relying on indirect calorimetry when FiO2 is above 60%

What can I do instead?

There are a couple of options to measure IC if your patient is on high FiO2's

1. Predictive equations: Harris-Benedict, Mifflin-St Jeor, Penn State, Ireton-Jones
   - Penn State most popular for ICU patients but there is a wide error range (20-30%) especially in burn patients, obesity, sepsis or multi-organ failure.

2. Weight based estimates
   - Quick method: 25-30 kcal/kg/day for most ICU patients with protein needs being estimated
   - Simple but even less accurate that the predictive equations

3. Use of VCO2 only (if available on the ventilator)
   - REE can be estimated from VCO2 alone using a modified Weir equation.
   - More accurate than predictive equations but not as accurate as IC

4. Deferred Indirect Calorimetry
   - Wait until the patient's oxygen needs decrease

5. Close monitoring and Adjustment
   - Watch for weight trends, nitrogen balance/urea excretion, glucose control and CO2 production

Practical Considerations

Fasting- Ideally, patients should be fasted for at least 5 hours prior to measurement, and avoid exercise, nicotine, caffeine and stimulants for at least 4 hours

Ventilator settings- Avoid changing ventilator setting within 30 minutes before or during the measurement

Temperature- Significant body temperature variations (more than 1degree Celsius) can affect the accuracy of the measurement

Dialysis or continuous renal replacement therapy (RRT)—why not?

- IC assumes a steady metabolic state and accurate measurement of oxygen consumption (VO2) and carbon dioxide production (VCO2) at the lungs.
- Dialysis interferes with both of those assumptions which is why results are considered invalid or unreliable
- During dialysis 1. fluid shifts occur rapidly 2. electrolytes and acid-base balance change 3. hormonal and stress responses are activated
- All of the above alter metabolism minute to minute, violating the steady-state requirement
- Data obtained during dialysis leads to underestimation of energy expenditure and inaccurate respiratory quotient
- Bottom line: IC measurements during dialysis are unreliable due to 1. Metabolic steady state is lost 2. CO2 is removed outside the lungs 3. VO2/VCO2 no longer reflect true cellular metabolism
- Best practice: perform IC off dialysis – at least several hours after intermittent hemodialysis or during a stable period if the patient is on CRRT (some protocols allow it but interpret with extreme caution)

Air leaks?

- The inability to measure all exhaled gases will invalidate the data being measured
- Leaky trach’s typically yield no data at all in our youngest patients

Is this a good candidate?

- Not all candidates are good candidates to measure IC
  - Spontaneous breathing patients who are claustrophobic, nauseous, vomiting or do not tolerate a face mask etc
  - Spontaneous breathing patients that require supplemental oxygen or on NIV –software limitations
  - Intubated patients on modes like APRV or CPAP- any modality that makes it difficult to differentiate between inspiration and expiration

Burn Patients

Burn Patients

- Burn patients are a unique population when it comes to indirect calorimetry, and their data can be valid if interpreted carefully.
- 1. Time management-
- 2. Control environmental and patient stressors
- 3. Ensure ventilator stability
- 4. Account for burn specific factors
- 5. Run IC long enough to confirm steady state
- 6. Repeat measurements strategically
- 7. Use IC data conservatively
- 8. If IC is not feasible-

Time management

- Best times:
  - After initial resuscitation 48-72 hours post burn
  - When hemodynamically stable
  - Off procedures (no wound care, turning or transport)

  - Avoid IC during:
  - Active dialysis
  - Operative days
  - Dressing changes
  - Agitation, shivering or sever pain episodes

Control environmental and patient stressors

- Burn patients respond metabolically to even small stimuli
- Before starting IC
  - Ensure adequate analgesia and sedation
  - Treat shivering aggressively (warming)
  - Minimize alarms, suctioning or nursing care
  - Keep room temperature consistent

  - **Shivering alone can increase energy expenditure by 50-100%**

Ensure ventilator stability

- FiO_2 should ideally be less than 60%
- No vent changes within 30 minutes of study
- Avoid spontaneous breathing trials during IC
- Ensure tight circuit connections

Burn specific factors

- Keep the following things in consideration:
  - %TBSA burned
  - Post op status
  - Infection/sepsis
  - Use of beta blockers

  - All of them affect metabolic rate and explain variability in results.

Steady state

- Be prepared to run study longer to get steady state
  - Attempt to retrieve at least 20-30 minutes of data
  - Steady state with a CV less than 10% for 10 minutes
  - Discard initial unstable minutes

Repeat measurements strategically

- In burn patients studies should be done roughly every 3-7 days or as needed
- If the patient cannot tolerate the circuit being broken to obtain data due to oxygen needs the study should be delayed
- Avoid studies on days where the patient is having extreme pain, procedures or febrile
- Discuss with the team your concerns prior to testing

Use IC conservatively

- Burn patients are at high risk of overfeeding
- Use IC to guide ranges, not single absolute targets
- Monitor :
  - RQ (watch for greater than 1.0 suggesting overfeeding)
  - CO_2 burden in ventilated patients
  - Glycemic control and triglycerides

If IC is not feasible

- Use predictive equations cautiously
  - Curreri formula tends to overestimate
  - Consider Penn State or Toronto equations with frequent reassessment
  - Default to hypocaloric feeding early, advancing as tolerated

Key Differences in Burn Patients

- Hypermetabolism
- Elevated Resting Energy Expenditure (REE)
- Increased Oxygen Consumption (VO2) and Carbon Dioxide Production (VCO2)

Hypermetabolism

- Severe burns (especially >20% total body surface area) cause a marked increase in metabolic rate—sometimes up to 2-3 times normal.
- This is due to systemic inflammatory response, elevated catecholamines, cortisol and increased protein turnover

Elevated Resting Energy Expenditure (REE)

- Indirect calorimetry usually shows **VERY High REE** in burn patients compared to healthy individuals or patients with other illnesses
- Predictive equations (like Harris-Benedict) often Underestimate energy needs

Increased Oxygen Consumption (VO2) and Carbon Dioxide Production (VCO2)

- Due to tissue repair, infection, and fever, both VO2 and VCO2 are typically elevated

Is the data valid?

Yes, indirect calorimetry is valid and considered the gold standard for determining energy needs in burn patients- if properly conducted

Calorie need fluctuates substantially over the course of critical illness, and nutrition delivery is often influenced by:

- hypocaloric feeding regimen
- lack of feeding access
- intolerance of feeding
- feeding-delay for procedures

Lean body mass is the strongest determinant of resting energy expenditure, but age, sex, medications, and metabolic stress also influence the calorie requirement.

Accuracy can be affected by…

- Air leaks (especially in ventilated patients or with facial burns)
- Pain, shivering, agitation, which may falsely elevate readings
- Improper fasting or timing- which alters metabolic status
- Equipment calibration errors- especially in high humidity or high-CO2 settings

Tips:

- Direct measurement> predictive equations in burn patients
- Measure REE frequently (every 3-7 days) as metabolic needs change with healing and treatment
- Ensure the patient is hemodynamically stable during testing for reliable data- this is challenging!

Illness and REE

Effects on REE	Factors	
↑	• Burns • Hyperventilation • Hyperthermia • Hyperthyroidism, pheochromocytoma • Inflammation (interleukins, interferons, tumor necrosis factors etc.) • Metabolic acidosis	• Morbid obesity • Overfeeding • Physical agitation • Sepsis • Stress (epinephrine, cortisol, glucagon etc.)
↓	• Coma/deep sleep • General anesthesia • Heavy sedation • Hypothermia • Hypothyroidism • Hypoventilation	• Gluconeogenesis • Metabolic alkalosis • Paralysis • Sarcopenia, cachexia • Starvation/underfeeding/ketosis

Who’s contributing to what?

- Cho/REE% is the carbohydrate contribution to REE
- Tells the percentage of the patients measured energy expenditure is being derived from carbohydrate oxidation at rest
- Fat/REE- same as above except its fat and not carbs
- Protein/REE%-- protein…
- Its calculated based on the RQ- RQ closer to 1.0 means most energy is coming from carbohydrates.
- An RQ closer to 0.7 means most energy is coming from fat
- Protein is usually estimated or assumed

Urinary N2 (g/day)

- Urinary N2= the amount of nitrogen excreted in urine per day, expressed in grams
- Since nitrogen comes almost entirely from protein breakdown, measuring urinary nitrogen allows estimation of protein oxidation and thus the protein contribution to energy expenditure
- Typically, it's obtained from 24-hour urine urea nitrogen (UUN) collection, sometimes adjusted with a small factor for non-urea nitrogen losses
- In practice:-1 g of urinary nitrogen is approximately 6.25 g of protein oxidized- so if a patient has a 12g N2/day, that reflects about 75 g protein/day being metabolized
- When urinary nitrogen isn't available the system will usually assume a fixed protein oxidation often 10-15% of total REE.
- In short, Urinary N2 g/day is a marker of protein breakdown, and its key for refining the accuracy of energy substrate calculations in indirect calorimetry.

Case study 1

[redacted] Kevin

SnapShot

Non-Hospital

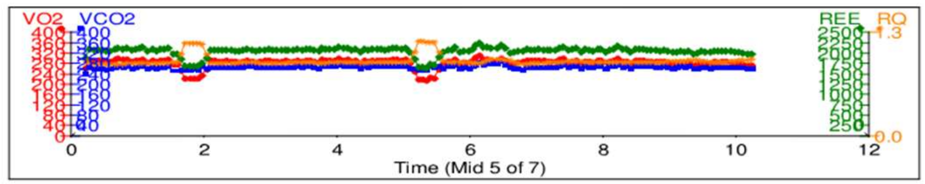
- Perforated appendicitis
- Severe sepsis with septic shock
- AKI (acute kidney injury)
- Hypokalemia
- Transaminitis
- Lactic acidosis
- Acute hypoxemic respiratory failure
- Coagulopathy
- Hypocalcemia
- Hypomagnesemia
- Bandemia
- Postprocedural pneumothorax
- Hypophosphatemia
- Oliguria
- Anasarca

Post Test Comments: Indirect calorimetry study completed. Good patient effort and cooperation. Data obtained. Study uneventful.

Peak Cough Flow

MIP-(disposable device)

MEP-(disposable device)



	Mean Value	Pred	-	-	-
Time (min)	10:17				
FIO2 (%)	29.36				

REE (Kcal/day)	2043	1682			
RQ	0.94				
REE/Pred (%)	121				

RR (br/min)	16				
Vt BTPS (mL)	327				
VE BTPS (L/min)	5.2				

VCO2 (mL/min)	267				
VO2 (mL/min)	284				

Urinary N2 (g/day)					
CHO/REE (%)	83				
Fat/REE (%)	17				
Prot/REE (%)					

REE_Covar (%)	6				

Hx

- 9y male who presents to the ED with abdominal pain and emesis. Per mom he was dx with strep throat on Thursday 8/7, started on Cephalexin. Had some abdominal pain but was thought to be due to strep, pain worsened on Sunday. He has been having vomiting and some diarrhea. No fevers. Also having some difficulties breathing. Seen at PCP who called 911 and pt brought to the ED.
-
- In the ED he tachycardic, tachypnea, placed on 3L NC, was started on fluid bolus (received several). Labs with significant electrolyte imbalance, pH of 7.33, PCO25, base excess -10 with a bicarb of 13. Potassium was 2.4 with a sodium of 131. roponin is significantly elevated. Cardiology is aware of this result and will notify the echo tech for the echocardiogram in the emergency department
- Electrolytes are remarkable for elevated BUN and creatinine, LFTs are elevated and CRP is significant elevated. Nephrology also consulted in the ED. He is not recommend IV contrast due to AKI.
- US: Appendix not visualized with secondary signs of appendicitis (Category 3); it should be noted that secondary sign used for category 3 characterization is increased echogenicity of the periappendiceal fat, but the mesenteric fat is diffusely echogenic, more in keeping with diffuse inflammatory process. Surgery consulted
- CT without contrast obtained: Dilated appendix with multiple appendicoliths consistent with acute appendicitis.
- 2. Generalized pattern of peritonitis with fluid in multiple locations as described above. Intraperitoneal free air is present consistent with perforation."
-

Questions?

References:

- Sigurdsson TS, Lindberg L. Indirect Calorimetry Overestimates Oxygen Consumption in Young Children: Caution is Advised Using Direct Fick Method as a Reference Method in Cardiac Output Comparison Studies. Pediatr Cardiol. 2020 Jan;41(1):149-154. doi: 10.1007/s00246-019-02238-5. Epub 2019 Nov 18. PMID: 31741015; PMCID: PMC6987070.
- Walker RN, Heuberger RA. Predictive equations for energy needs for the critically ill. Respir Care. 2009 Apr;54(4):509-21. PMID: 19327188.
- Sion-Sarid R, Cohen J, Houri Z, Singer P. Indirect calorimetry: a guide for optimizing nutritional support in the critically ill child. Nutrition. 2013 Sep;29(9):1094-9. doi: 10.1016/j.nut.2013.03.013. PMID: 23927944.