ELSEVIER Clinical Skills

Mechanical Ventilation: Metabolic Measurement Using Indirect Calorimetry (Respiratory Therapy)

ALERT

Because of the level of technical and patient assessment skills required, metabolic measurements using indirect calorimeters should be performed by individuals who are trained and competent in indirect calorimetry.

OVERVIEW

Indirect calorimetry is considered the gold standard technique for assessing resting energy requirements through metabolic measurements of the oxygen consumption (V_{O_2}) and carbon dioxide production (V_{CO_2}) in mechanically ventilated patients.

An indirect calorimeter, in an open- or closed-circuit design, is used to measure metabolic measurements of V_{O_2} and V_{CO_2} via expired gas analysis. The test involves measuring the amount of oxygen the patient inhales and the amount of carbon dioxide he or she exhales. The measurements of V_{O_2} and V_{CO_2} are then used to calculate the respiratory quotient (RQ), where RQ = ($V_{CO_2} \div V_{O_2}$), and to predict the resting energy expenditure (REE) (kilocalories per day) using the Weir equation, where REE (kcal) = [V_{O_2} L/min(3.941) + V_{CO_2} L/min(1.11)] × 1.44.[1] In other words, from these gas exchange data, the number of calories burned per minute is determined. Total test duration is approximately 30 minutes.[2]

Indirect calorimetry measures the resting metabolic rate, or the number of calories the body burns at rest. Indirect calorimetry for metabolic measurements is used to:

- Accurately determine the patient's RQ to allow nutritional regimens to be adjusted to the patient's needs
- Accurately determine the REE and the RQ to monitor the adequacy and appropriateness of current nutritional support and, in mechanically ventilated patients, to guide appropriate nutritional support
- Assess the contribution of metabolism to ventilation
- Determine the oxygen demand of breathing as a guide to the selection of ventilator mode, settings, and weaning strategies
- Monitor the patient's V_{O_2} as a guide to targeting oxygen delivery

These factors can decrease the number of days the patient is on ventilatory support in the intensive care unit.

Factors affecting the accuracy of caloric requirement estimates include:[1,2]

- Burns
- Gas leaks from the patient or ventilator system that prevent the collection of expired gases
- Multiple traumas
- Multisystem organ failure
- Neurologic trauma
- Peritoneal and hemodialysis treatments that remove carbon dioxide across the dialysis coil membrane so it cannot be measured by the indirect calorimeter
- Sepsis
- Use of paralytic agents or sedation
- Maintenance of equipment
- Competence in the specific manufacturer's calibration instructions

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During open-circuit measurement, factors that cause inaccurate measurement of the REE and the RQ include:[1]

- Anesthetic gases or gases other than oxygen, carbon dioxide, and nitrogen in the ventilation system
- Bias flow from flow-triggering systems or intermittent mandatory ventilation systems or specific ventilator characteristics that prevent the ventilator from separating inspired and expired gases
- Connection of the indirect calorimeter to certain ventilators, which causes an adverse effect on the triggering mechanism
- Fraction of inspired oxygen (F_{IO_2}) greater than 0.6[1]
- Inadequate duration of the measurement period
- Inappropriate calibration
- Increased expiratory resistance, pressure measurement, or maintenance of the ventilator
- Instability of delivered F_{IO_2} because of changes in source gas pressure and ventilator blender or mixing characteristics
- Leaks within the calorimeter
- Total circuit flow exceeding the internal gas flow of the indirect calorimeter that incorporates the dilutional principle
- Water vapor causing sensor malfunction

During closed-circuit measurement, factors that cause inaccurate measurement of the REE and the RQ include:[1]

- Functional residual capacity (FRC) changes resulting in changes in spirometer volume that are unassociated with V_{O_2}
- Increased compressible volume and resistance that results in difficulty triggering the ventilator and increased work of breathing
- Increased compressible volume in the circuit that prevents adequate tidal volume delivery, resulting in alveolar hypoventilation and changes in V_{CO_2}/V_{O_2}
- Leaks drawing gas into the system during spontaneous breathing measurements that add volume to the system and cause erroneously low V_{O_2} readings
- Short duration of the measurement period (a function of carbon dioxide absorber life and V_{CO_2}) that may not allow the REE state to be achieved

Metabolic measurements should be repeated according to the patient's clinical status and indications for performing the test. More frequent measurement may be necessary in patients with a rapidly changing clinical course as recognized by hemodynamic instability and spiking fevers.[1] Patients in the immediate postoperative period and those being weaned from mechanical ventilation may also need more frequent measurement.

EDUCATION

- Explain the procedure to the patient and family.
- Explain to the patient and family that the test takes about 30 minutes after a period of rest.[2]
- Encourage questions and answer them as they arise.

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ASSESSMENT AND PREPARATION

Assessment

1. Perform hand hygiene before patient contact.
2. Introduce yourself to the patient.
3. Verify the correct patient using two identifiers.
4. Assess the patient to determine if metabolic measurements are indicated.

a. Patients with known nutritional deficits.
b. Patients who have failed attempts at liberation from mechanical ventilation.

5. Assess the patient's hemodynamic support.
6. Assess the patient's need for increased ventilatory requirements.

> Rationale: Indirect calorimetry is indicated to determine the cause of the increased ventilatory requirement.

7. Assess the stability level of the delivered F_{IO_2}.

> Rationale: The stability level of the delivered F_{IO_2} may cause inaccurate measurement of the REE and the RQ during open-circuit measurement, and an F_{IO_2} that is greater than 0.6[1] causes inaccurate V_{O_2} measurements.

8. Assess the patient for any recent period of sedation holiday, agitation, or hemodynamic or respiratory instability.

> Rationale: The patient needs to remain in a calm and restful state during metabolic measurement to obtain the most accurate indirect calorimetry data.

Preparation

1. Ensure that the patient rests quietly before testing.

> Rationale: Allowing the patient to rest before testing permits his or her temperature, level of awareness, and body metabolism to stabilize.[2]

2. Ensure that the testing environment is quiet.
3. Determine the design of the indirect calorimeter (open- or closed-circuit).
4. Calibrate the indirect calorimeter on the day of measurement and more often if errors in measurement are suspected.
5. Ensure that the calibration gas mixture is relevant to the concentration of gas to be measured clinically.
6. Gather clean tubing, low-resistance bacteria filters, gas analyzers (oxygen and carbon dioxide), and a flow and volume measuring device.
7. Ensure that the ventilator circuit and tubing to the calorimeter are leak free.
8. If using an open-circuit design, make available a method of stabilizing F_{IO_2}.
9. Turn on the indirect calorimeter before the start of testing, based on manufacturer's instructions, to warm up the dilution pump.

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PROCEDURE

1. Perform hand hygiene and don gloves.
2. Verify the correct patient using two identifiers.
3. Explain the procedure to the patient and ensure that he or she agrees to treatment.
4. Position the patient comfortably in bed, usually in a supine or semi-Fowler position.
5. Connect the patient to a stand-alone device (metabolic cart) or follow the manufacturer's instructions for the specific indirect calorimeter used to initiate measurement on a ventilator that contains an integrated calorimeter.
6. After the patient reaches the desired steady state, measure until an average interval is achieved (a period of less than 5 consecutive minutes[1] in which variations of V_{O_2} and V_{CO_2} are less than 5%).[1]
7. Repeat metabolic measurements as necessary for unstable patients.
8. Disconnect the patient from the indirect calorimeter.
9. Remove gloves and perform hand hygiene.
10. Document the procedure in the patient's record.

MONITORING AND CARE

1. Observe the patient before and during the measurement to determine if he or she is at a steady state.
2. Evaluate the measurement results with consideration of the patient's condition and nutritional intake.
3. Monitor the patient's comfort level and movement during the test.
4. Monitor the equipment's functionality.
5. Monitor the patient's F_{IO_2} stability.
6. Monitor the patient to determine whether he or she is responding to current nutritional therapy.
7. Observe the patient for signs and symptoms of pain. If pain is suspected, report it to the authorized practitioner.

EXPECTED OUTCOMES

- Patient obtains steady state.
- Both REE and RQ are accurately assessed.
- Both REE and RQ are accurately measured.
- RQ rests in the normal physiologic range (0.67 to 1.3).[1,2]
- RQ is consistent with the patient's nutritional intake.
- Variations of V_{O_2} and V_{CO_2} are less than 5% for a 5-minute data collection.[1]

UNEXPECTED OUTCOMES

- Hypoxemia
- Bradycardia
- Patient discomfort
- Reduction in alveolar ventilation
- Decrease in the trigger sensitivity of the ventilator, resulting in increased patient work of breathing in closed-circuit calorimeters
- Erroneous results causing incorrect patient management
- Increased work of breathing or dynamic hyperinflation
- Inaccurate measurement of REE and RQ

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- RQ outside the normal physiologic range (0.67 to 1.3),[1] suggesting technical errors in measurement

DOCUMENTATION

- Patient and family education
- Patient's vital signs
- Ventilator settings
- Current nutritional support
- Adverse reactions
- Test quality
- F_{IO_2} stability
- Unexpected outcomes and related interventions

OLDER ADULT CONSIDERATIONS

- If older patients are hard of hearing, speak clearly and loudly enough for them to hear the information given.

REFERENCES

1. American Association for Respiratory Care (AARC). (2004). AARC clinical practice guideline: Metabolic measurement using indirect calorimetry during mechanical ventilation—2004 revision & update. *Respiratory Care, 46*(9), 1073-1079. (classic reference)* (Level VII)
2. Mtaweh, H. and others. (2018). Indirect calorimetry: History, technology, and application. *Frontiers in Pediatrics, 6*, 257. doi:10.3389/fped.2018.00257

ADDITIONAL READINGS

American Society for Parenteral and Enteral Nutrition and Society of Critical Care Medicine. (ASPEN). (2016). Guidelines for the provision and assessment of nutrition support therapy in the adult critically ill patient: Society of Critical Care Medicine (SCCM) and American Society for Parenteral and Enteral Nutrition (ASPEN). *Journal of Parenteral and Enteral Nutrition, 40*(2),159-211. doi: 10.1177/0148607115621863

*In these skills, a "classic" reference is a widely cited, standard work of established excellence that significantly affects current practice and may also represent the foundational research for practice.

Elsevier Skills Levels of Evidence

- Level I - Systematic review of all relevant randomized controlled trials
- Level II - At least one well-designed randomized controlled trial
- Level III - Well-designed controlled trials without randomization
- Level IV - Well-designed case-controlled or cohort studies
- Level V - Descriptive or qualitative studies
- Level VI - Single descriptive or qualitative study
- Level VII - Authority opinion or expert committee reports

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Supplies

- Calibration gas mixture
- Gloves
- Flow and volume measuring device
- Gas analyzers (oxygen and carbon dioxide)
- Indirect calorimeter
- Low-resistance bacteria filters
- Tubing

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