AARC Clinical Practice Guideline

Metabolic Measurement Using Indirect Calorimetry During Mechanical Ventilation—2004 Revision & Update

MMMV 1.0 PROCEDURE:
Metabolic measurements using indirect calorimetry for determination of oxygen consumption ($\dot{V}_{O_2}$), carbon dioxide production ($\dot{V}_{CO_2}$), respiratory quotient (RQ), and resting energy expenditure (REE) as an aid to patient nutritional assessment and management;[1-5] assessment of weaning success and outcome;[6-8] assessment of the relationship between O_2 delivery ($\dot{D}_{O_2}$) and $\dot{V}_{O_2}$;[1,9,10] and assessment of the contribution of metabolism to ventilation.[11,12] This guideline addresses metabolic measurement during mechanical ventilation.

MMMV 2.0 DESCRIPTION/DEFINITION:
Metabolic measurements use an indirect calorimeter to measure $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ via expired gas analysis. The measurements of $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ are used to calculate RQ ($\dot{V}_{CO_2}/\dot{V}_{O_2}$) and REE using the Weir equation:[13]

$$REE = [\dot{V}_{O_2}\,(3.941) + \dot{V}_{CO_2}\,(1.11)]\ 1440\ \text{min/day}.$$

The measurement of REE in mechanically ventilated neonatal, pediatric, and adult patients has been shown to be more accurate than published formulas used to predict REE,[14-38] to reduce the incidence of overfeeding and underfeeding,[14-28] and to decrease costs associated with total parenteral nutrition (TPN).[28] Measurement of REE and RQ has been shown to be helpful in designing nutritional regimens to reduce $\dot{V}_{CO_2}$ in patients with chronic obstructive pulmonary disease (COPD) and patients requiring mechanical ventilation.[15,39-44] Despite this evidence, studies demonstrating improved outcome, decreased time spent on the ventilator, or shorter ICU/hospital stay are lacking.

The objectives of metabolic measurements by indirect calorimetry are

2.1 To accurately determine the REE of mechanically ventilated patients to guide appropriate nutritional support[14-38]
2.2 To accurately determine RQ to allow nutritional regimens to be tailored to patient needs[14-44]
2.3 To accurately determine REE and RQ to monitor the adequacy and appropriateness of current nutritional support[14-44]
2.4 To allow determination of substrate utilization when urinary nitrogen values are concomitantly measured[45-47]
2.5 To determine the O_2 cost of breathing as a guide to the selection of ventilator mode, settings, and weaning strategies[6-8]
2.6 To monitor the $\dot{V}_{O_2}$ as a guide to targeting adequate $\dot{D}_{O_2}$[1]
2.7 To assess the contribution of metabolism to ventilation[11,12]

MMMV 3.0 SETTING:

3.1 Mechanically ventilated patients
- **3.1.1** In the hospital
- **3.1.2** In the extended care facility

MMMV 4.0 INDICATIONS:
Metabolic measurements may be indicated

4.1 In patients with known nutritional deficits or derangements.[14-38] Multiple nutritional risk and stress factors that may considerably skew prediction by Harris-Benedict equation include
- **4.1.1** Neurologic trauma[20-27,35]
- **4.1.2** Paralysis[27]
- **4.1.3** COPD[15,23,26,44]
- **4.1.4** Acute pancreatitis[18,36]
- **4.1.5** Cancer with residual tumor burden[16]
- **4.1.6** Multiple trauma[22,25,28,37,38]
- **4.1.7** Amputations[25]
- **4.1.8** Patients in whom height and weight cannot be accurately obtained
- **4.1.9** Patients who fail to respond adequately to estimated nutritional needs[21]
- **4.1.10** Patients who require long-term acute care[48]

4.1.11 Severe sepsis[18,34]

4.1.12 Extremely obese patients[49]

4.1.13 Severely hypermetabolic or hypometabolic patients

4.2 When patients fail attempts at liberation from mechanical ventilation to measure the O_2 cost of breathing and the components of ventilation[6-8,50]

4.3 When the need exists to assess the $\dot{V}_{O_2}$ in order to evaluate the hemodynamic support of mechanically ventilated patients[1,9,10]

4.4 To measure cardiac output by the Fick method[51,52]

4.5 To determine the cause(s) of increased ventilatory requirements[11,12,53]

MMMV 5.0 CONTRAINDICATIONS:
When a specific indication is present, there are no contraindications to performing a metabolic measurement using indirect calorimetry unless short-term disconnection of ventilatory support for connection of measurement lines results in hypoxemia, bradycardia, or other adverse effects.[54,55]

MMMV 6.0 HAZARDS/COMPLICATIONS:
Performing metabolic measurements using an indirect calorimeter is a safe, noninvasive procedure with few hazards or complications. Under certain circumstances and with particular equipment the following hazards/complications may be seen.

6.1 Closed circuit calorimeters may cause a reduction in alveolar ventilation due to increased compressible volume of the breathing circuit.[5,56-58]

6.2 Closed circuit calorimeters may decrease the trigger sensitivity of the ventilator and result in increased patient work of breathing.[5,56-58]

6.3 Short-term disconnection of the patient from the ventilator for connection of the indirect calorimetry apparatus may result in hypoxemia, bradycardia, and patient discomfort.[54,55]

6.4 Inappropriate calibration or system setup may result in erroneous results causing incorrect patient management.[1,4,5]

6.5 Isolation valves may increase circuit resistance and cause increased work of breathing and/or dynamic hyperinflation.

6.6 Inspiratory reservoirs may cause a reduction in alveolar ventilation due to increased compressible volume of the breathing circuit.[59]

6.7 Manipulation of the ventilator circuit may cause leaks that may lower alveolar ventilation.

MMMV 7.0 LIMITATIONS OF PROCEDURE:
Limitations of the procedure include

7.1 Accurate assessment of REE and RQ may not be possible[60-63] because of patient condition or certain bedside procedures or activities.

7.2 Inaccurate measurement of REE and RQ may be caused by leaks of gas from the patient/ventilator system preventing collection of expired gases including

7.2.1 Leaks in the ventilator circuit[1,4,5]

7.2.2 Leaks around tracheal tube cuffs or uncuffed tubes[1,4,5]

7.2.3 Leaks through chest tubes or bronchopleural fistula[64]

7.3 Inaccurate measurement of REE and RQ occurs during peritoneal and hemodialysis due to removal across the membrane of CO_2 that is not measured by the indirect calorimeter[1,4,5,17]

7.4 Inaccurate measurement of REE and RQ during open circuit measurement may be caused by

7.4.1 Instability of delivered oxygen concentration (F_{IO_2}) within a breath or breath to breath due to changes in source gas pressure and ventilator blender/mixing characteristics[65,66]

7.4.2 $F_{IO_2} > 0.60$[1,4,5,65,66]

7.4.3 Inability to separate inspired and expired gases due to bias flow from flow-triggering systems, IMV systems, or specific ventilator characteristics[1,4,5,67,68]

7.4.4 The presence of anesthetic gases or gases other than O_2, CO_2, and nitrogen in the ventilation system[66]

7.4.5 The presence of water vapor resulting in sensor malfunction

7.4.6 Inappropriate calibration[69]

7.4.7 Connection of the indirect calorimeter to certain ventilators, with adverse effect on triggering mechanism, increased expiratory resistance, pressure measurement, or maintenance of the ventilator[5]

7.4.8 Total circuit flow exceeding internal gas flow of indirect calorimeter that incorporates the dilutional principle[70]

7.4.9 Internal leaks within the calorimeter[71]

7.4.10 Inadequate length of measurement[72-75]

7.5 Inaccurate measurement of REE and RQ during closed circuit measurement may be caused by

7.5.1 Short duration of the measurement period (a function of CO_2 absorber life and $\dot{V}_{CO_2}$) that may not allow REE state to be achieved[5,56-58]

7.5.2 Changes in functional residual capacity (FRC) resulting in changes in spirometer volume unassociated with $\dot{V}_{O_2}$[5,56-58]

7.5.3 Leaks drawing gas into the system during spontaneous breathing measurements that adds volume to the system and cause erroneously low $\dot{V}_{O_2}$ readings[5,56-58]

7.5.4 Increased compressible volume in the circuit that prevents adequate tidal volume delivery resulting in alveolar hypoventilation and changes in $\dot{V}_{CO_2}/\dot{V}_{O_2}$[5,56-58]

7.5.5 Increased compressible volume and resistance that results in difficulty triggering the ventilator and increased work of breathing[5,56-58]

MMMV 8.0 ASSESSMENT OF NEED:

Metabolic measurements should be performed only on the order of a physician after review of indications (MMMV 4.0) and objectives.

MMMV 9.0 ASSESSMENT OF TEST QUALITY AND OUTCOME:

9.1 Test quality can be evaluated by determining whether

9.1.1 RQ is consistent with the patient's nutritional intake[1-5]

9.1.2 RQ rests in the normal physiologic range (0.67 to 1.3)[1-5]

9.1.3 Variability of the measurements for $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ should be $\leq 5\%$ for a 5-minute data collecton[72-75]

9.1.4 The measurement is of sufficient length to account for variability in $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ if the conditions in 9.1.3 are not met[72-75]

9.2 Outcome may be assessed by comparing the measurement results with the patient's condition and nutritional intake.

9.3 Outcome may be assessed by observation of the patient prior to and during the measurement to determine if the patient is at steady state.

MMMV 10.0 RESOURCES:

10.1 Indirect calorimeter, open- or closed-circuit design

10.1.1 The calibration gas mixture should be relevant to the concentration of gas to be measured clinically.[1-5]

10.1.2 The indirect calorimeter should be calibrated on the day of measurement and more often if errors in measurement are suspected.[1-5]

10.1.3 When the measurement results are suspect and/or when repeated calibration attempts are marked by instability, the indirect calorimeter may be tested via an independent test method (burning ethanol or other substance with a known RQ or adding known flows of CO_2 and nitrogen to simulate $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$).[76-79] As a simple test, ventilation of a leak-free system should yield $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ values of near 0. Routinely scheduled measurement of normal control subjects (volunteers) may be useful.

10.2 A method of stabilizing F_{IO_2} during open-circuit measurements should be available and may include

10.2.1 An air-oxygen blender connected between the gas source and the ventilator inlets for high pressure gas[65]

10.2.2 An inspiratory mixing chamber between the ventilator main flow circuit and the humidifier (See MMMV 6.6)[59]

10.2.3 Ventilator changes, which may include mode, inspiratory flow rate, PEEP, or tidal volume to improve patient-ventilator synchrony[53]

10.3 An isolation valve, double-piloted exhalation valve, or other device to separate inspiratory and expiratory flow should be incorporated when using continuous flow in the ventilator circuit.[67] (see MMMV 6.5)

10.4 Personnel: Due to the level of technical and patient assessment skills required, metabolic measurements using indirect calorimeters should be performed by individuals trained in and with the demonstrated and documented ability to

10.4.1 Calibrate, operate, and maintain an indirect calorimeter

10.4.2 Operate a mechanical ventilator, including knowledge of the air-oxygen blending system, the spontaneous breathing mechanisms, and the alarm and monitoring functions

10.4.3 Recognize metabolic measurement values within the normal physiologic range and evaluate the results in light of the patient's current nutritional and clinical status

10.4.4 Assess patient hemodynamic and ventilatory status and make recommendations on appropriate corrective/therapeutic maneuvers to improve or reverse the patient's clinical course. A relevant credential (eg, RRT, CRT, RN, or RPFT) is desirable.

10.5 A hood canopy system in combination with airway sampling may be employed to capture gas that leaks around an uncuffed endotracheal tube.[80]

10.6 If a stable F_{IO_2} cannot be achieved, $\dot{V}_{CO_2}$ may be used to estimate REE by assuming an RQ of 0.83[81] and the largest expected error is an

10.6.1 Underestimation of 25% for RQ of 1.2

10.6.2 Overestimation of 19% for RQ of 0.67

10.7 A simultaneous measure of P_{aCO_2} and $\dot{V}_{CO_2}$ will allow calculation of pulmonary dead space and components of ventilation using the Bohr equation:[82]

$$V_E = \dot{V}_{CO_2} \text{ x } 0.863\ P_{aCO_2} \text{ x } (1-V_D/V_T)$$

MMMV 11.0 MONITORING:

11.1 The following should be evaluated during the performance of a metabolic measurement to ascertain the validity of the results

11.1.1 Clinical observation of the resting state (See MMMV 9.3)

11.1.2 Patient comfort and movement during testing

11.1.3 Values in concert with the clinical situation

11.1.4 Equipment function

11.1.5 Results within the specifications listed in 9.1.3 or 9.1.4

11.1.6 F_{IO_2} stability

11.2 Measurement data should include a statement of test quality and list the current nutritional support, ventilator settings, F_{IO_2} stability, and vital signs.

MMMV 12.0 FREQUENCY:

12.1 Metabolic measurements should be repeated according to the clinical status of the patient and indications for performing the test. The literature suggests that more frequent measurement may be necessary in patients with a rapidly changing clinical course as recognized by

12.1.1 Hemodynamic instability[60]

12.1.2 Spiking fevers[60]

12.2 Patients in the immediate postoperative period and those being weaned from mechanical ventilation may also need more frequent measurement.[60]

MMMV 13.0 INFECTION CONTROL:

Metabolic measurements using indirect calorimetry are relatively safe procedures, but a remote possibility of cross-contamination exists either via patient-patient or patient-caregiver interface. The following guidelines should be followed when a metabolic measurement is performed.

13.1 Standard Precautions should be exercised whenever there is potential for contamination with blood or other body fluids.[83]

13.2 Appropriate use of barriers and handwashing is recommended.[83,84]

13.3 Tubing used to direct expiratory gas from the ventilator to the indirect calorimeter should be disposed of or cleaned between patients.

13.4 Connections used in the inspiratory limb of the circuit proximal to the humidifier should be wiped clean between patients; equipment distal to the humidifier should be disposed of or subjected to high-level disinfection between patients.

13.5 Bacteria filters may be used to protect equipment in both the inspired and expired lines, but caution should be used that moisture does not increase filter resistance resulting in poor gas sampling flow or increased resistance to exhalation.

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