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Indirect Calorimetry: Principles and Applications for Managing Critically Ill Patients

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Introduction

The impact of malnutrition and the metabolic response to stress have received a great deal of interest over the last several decades. As part of the overall approach to managing critically ill patients, nutritional support teams were developed to assess and monitor metabolic changes and determine caloric requirements. Patients seen during the immediate postoperative period and those suffering from acute trauma and sepsis are often identified as high-risk patients. Also included in this group are those patients with chronic cardiopulmonary disease. These patients may be challenged by one or more of the following:

1. Weight loss, which can occur in up to 60% of patients due to inadequate caloric intake or increases in caloric expenditure secondary to fever, sepsis, or other stress-related conditions;
2. Muscle catabolism secondary to decreased caloric intake resulting in diminished muscle strength, especially in the muscles of ventilation;
3. Lowered resistance to infections and a depressed immune response; or
4. Failure to wean from mechanical ventilation secondary to increased ventilatory loads associated with increased carbohydrate (CHO) feedings.

The purpose of this review is to summarize the basis tenets of nutritional support for critically ill patients and describe techniques to measure metabolic rate with an emphasis on indirect calorimetry (Table 1).

Malnourishment and Overfeeding

Avoiding malnourishment and overfeeding requires that the proper amount and type of calories be determined during the early phases of the patient's care. It may be difficult to estimate the number of calories that a critically ill patient requires, often leading to a malnourished state. The incidence of malnourishment is high for patients who have either acute or chronic cardiopulmonary disease and especially for those who require prolonged periods of mechanical ventilation.^[1] Frequently affected are those patients with sepsis, burns, trauma, and generalized infections. Malnourishment in this group of patients will often result in respiratory muscle weakness and loss of diaphragmatic tone resulting in ventilator dependency. In addition to this problem, many malnourished patients have demonstrated an impaired response to hypoxemia and hypercapnia, further aggravating their respiratory impairment.^[2]

Overfeeding represents another challenge in managing the critically ill patient. Excessive calories, especially those from high CHO feedings when converted to fat (lipogenesis), results in increased levels of oxygen consumption and metabolic rate. Additionally, high CHO feedings have been shown to increase ventilation requirements and may result in respiratory muscle fatigue or respiratory failure.^[3-6]

Table 1. Metabolism Terms

Anabolism	The constructive phase of metabolism leading to increased lean muscle mass
Caloric replacement	Providing sufficient calories to meet total body energy needs
Calorie (kcal)	A unit of measurement of energy (1 kcal = 1000 calories)
Catabolism	The destructive phase of metabolism where energy sources such as carbohydrates and fats are broken down for energy requirements. In extreme situations, proteins (muscle mass) are broken down for energy.

Determining Caloric Needs

Nutritional assessment can be viewed as a triad of assessment techniques incorporating anthropometric measurements, screening of biochemical indices, and predicting/measuring energy expenditure (Table 2). Energy expenditure (EE) is the general term used to describe the number of calories consumed during a given period of time, usually 24 hours. However, it is more common when referring to EE to indicate if the caloric expenditure refers to a state of basal energy expenditure (BEE), resting energy expenditure (REE), activity energy expenditure (AEE), or total energy expenditure (TEE). Measurements taken at basal levels of metabolism indicate that the subject is at complete rest, fasting, usually in non-REM sleep, has not sustained any stress-related injuries, and has no ongoing infections. These conditions rarely exist in a hospital setting; thus, measurements of BEE are usually adjusted using stress or injury factors. In a critical care environment, most EE measurements are made under resting conditions -- REE. Resting conditions are present when the patient is awake and resting quietly. A study by Weismann and colleagues^[7] demonstrated that even when patients appeared to be resting, activities that occurred up to 30 minutes prior to "resting measurement period" could influence the measured REE. Others have suggested measuring EE during certain activities such as turning, bed baths, or other exercises. Recording the measured energy under resting conditions and adding the measurements made during activities would supply the TEE for a 24-hour period. Each of these subsegments of TEE is useful; however, the REE is most often used as the standard method to express EE.

Table 2. Nutritional Assessment Methods

Anthropometrics	Biochemical Indices	Predicting/Measuring EE
Ideal body weight	Creatinine-heights index	Equations
Triceps skin fold measurements	Lymphocytes count	Calorimetry
Arm circumference	Transferrin and albumin levels	Indirect calorimetry

EE = energy expenditure

Anthropometrics and biochemical indices are used to determine a patient's overall nutritional status, including muscle mass, immune function, protein levels, and muscle wasting secondary to protein-deficient diets. By themselves, anthropometric and biochemical measurements cannot determine the caloric load necessary to maintain a balanced state of nutrition; rather, they help define the patient's current nutritional state (Table 1). Predictive equations and calorimetry express energy requirements using calories as the unit of measurement. Using age, height, weight, and sex, predictive equations calculate BEE, also referred to as basal metabolic rate (BMR). The classic predictive equation was developed by Harris and Benedict in the early 1900s. Widely used by dietitians and nutritionists, this equation is fairly accurate for nonstressed patients. When used to determine caloric loads for critically ill patients, the Harris-Benedict equation has a tendency to underestimate caloric requirements.^[8] To correct these deficiencies, the BMR is multiplied by activity and stress factors. Even with these factors taken into consideration, the equation's accuracy often is not improved. The Roza, Kleiber, Cunningham, and Quebbemann

equations use data similar to the Harris-Benedict equation to predict energy requirements. Like the Harris-Benedict equation, these methods have not demonstrated reliable predictions of EE for ventilated patients.^[9]

Calorimetry measures the number of calories expended by the body during a given period of time. Direct calorimetry does this by a sophisticated method of measuring the patient's heat production. This method, while accurate in a controlled situation, does not lend itself to the critical care environment. Indirect calorimetry measures EE by calculating the patient's metabolic rate through measurements of oxygen consumption (VO_2) and carbon dioxide production (VCO_2). Numerous studies have shown that indirect calorimetry can accurately measure metabolic rate and predict energy requirements for critically ill patients.^[10]

While the focus of this article will be on indirect calorimetry, it should be viewed as one of many assessment strategies that are useful in maintaining a balanced nutritional state for critically ill patients.

Theory and Principle of Indirect Calorimetry

Indirect calorimetry is based on the premise that gas volumes and concentrations exchanged at the mouth reflect cellular metabolic activity. By measuring the difference between inspired and expired levels of oxygen and carbon dioxide, determinants of VO_2 and VCO_2 can be obtained (Table 3). These values are then converted to an REE via a metabolic computer using the Weir equation. The Weir equation also requires the measurement of daily urinary nitrogen (UN) to represent protein metabolism not reflected in exhaled gas analysis. For those institutions where 24-hour UN measurements are not available, a constant can be placed into the algorithm to reflect average daily nitrogen excretion. Using this constant results in a minimal error and has proven to be clinically acceptable and often is referred to as the modified Weir equation.^[11]

Table 3. Indirect Calorimetry Key Terms, Symbol, and Normal Values

Variable	Symbol	Normal Value*
Oxygen consumption	VO_2	250 mL/min (3.6 mL/min/kg IBW)
Carbon dioxide production	VCO_2	200 mL/min (2.9 mL/min/kg IBW)
Respiratory quotient	RQ	0.65-1.25
Respiratory exchange ratio	RER	0.65-1.25 (assumes steady-state conditions)
Energy expenditure	EE	Dependent on measurement conditions
Basal energy expenditure	BEE	Not applicable
Resting energy expenditure	REE	1800-2200 kcal/24 hr (25-30 kcal/kg)

*represents critically ill adults patient; values will vary with sepsis, trauma, and burns
IBW = ideal body weight

Additionally, the measured VO_2 and VCO_2 are used to calculate the respiratory quotient (RQ). The RQ is the ratio of VCO_2 to VO_2 . It reflects the mixture of substrates (fuels) used during metabolism. Each substrate has a corresponding RQ value (Table 4), with a typical Western diet resulting in an RQ of 0.81. The normal range for critically ill patient is 0.65 to 1.25, depending on the blend of nutrients metabolized. As will be discussed later, RQ values less than 0.65 or greater than 1.25 are suspect and usually indicate nonsteady-state conditions.

Table 4. Respiratory Quotients for Various Substrates -- $RQ = VCO_2 \div VO_2$

Fuel Oxidation	RQ

Protein	0.8
Lipids (fats)	0.7
CHO (carbohydrates)	1.0

RQ = respiratory quotient; VCO_2 = carbon dioxide production; VO_2 = oxygen consumption

Steady-State Conditions

Airway measurements of VO_2 and VCO_2 actually represent the respiratory exchange ratio (RER), while the RQ reflects the exchange of those gases at the cellular level. Under steady-state conditions, the RER and RQ are assumed to be equal. A steady-state condition exists when the exchange of gases (oxygen and carbon dioxide) at the cellular level and those measured at the airway are similar. This requires that both perfusion and ventilation are relatively stable during the monitoring period. If rapid changes in either occur, gas measurements at the airway (RER) will not accurately reflect cellular levels (RQ). An appreciation for the importance of steady-state conditions is paramount in analyzing data and determining the validity of an indirect calorimetry study.

Monitoring Philosophies

Indirect calorimetry studies are either performed on a continuous basis over several hours or even days, or may be conducted on an intermittent basis for shorter periods of time. Controversies exist over which method is best suited for critically ill patients. Ideally, data collected for a 24-hour period would give a more universal picture of the patient's EE. Periods of stress, increased metabolism related to activities, fluctuations in cardiac and pulmonary function, and metabolic shifts secondary to circadian rhythms could be accounted for. Technical difficulties with maintaining a continuous connection between patient and metabolic computer, especially in ventilated patients, often occur, and the footprint of some metabolic computers is prohibitive in smaller ICU settings. Advocates of the intermittent studies point out that carefully selected monitoring times, under controlled conditions, will result in an accurate "snapshot" of the patient's overall metabolic status. Minimal interference with nursing procedure and the availability of one metabolic computer to access several patients during the day makes this method desirable. However selecting an appropriate monitoring time that reflects "typical" metabolic function is often difficult considering the rapid changes that occur in patient stress levels and cardiopulmonary status. Patients will often slip in and out of steady-state conditions, and these changes must be accounted for when analyzing the data. Current protocols suggest a minimum time, usually 30 minutes, of resting conditions prior to the onset of data collections. The actual collections of data may vary between 5 and 15 minutes.^[12,13] Whichever method is used, once collected, the data are stored in the metabolic computer and then placed into an interpretation format for analysis and application.

Indirect Calorimetry Equipment

From the earliest system designed by Lavoisier to the first "metabolic carts" in the early 1970s and today's computerized rapid response gas analysis system, the basic premise to measure EE has remained essentially unchanged. In 1784, Antoine Lavoisier devised a method to measure the byproducts of combustion, oxygen consumption and carbon dioxide. Lavoisier is considered to be the father of indirect calorimetry and also is credited with naming oxygen. Early computerized metabolic carts provided serial measurements of VO_2 and VCO_2 and became widely used for measuring exercise levels in athletes. As the mobility and reliability of these carts improved, their use migrated to the critical care arena, and measurements on ventilated patients became available during the late 1970s. The early systems were designed as closed systems based on the principles of Lavoisier's first system. Later systems were designed around breath-by-breath analysis, dilution technique, or mixing chambers technologies. Additionally, these open systems were incorporated into carts that could provide continuous or intermittent studies as previously described. Currently, most indirect calorimetry studies are performed on an intermittent basis using breath-by-breath gas analysis.

Economic Impact of Indirect Calorimetry

The present healthcare environment often dictates that regardless of the clinical efficacy of a test or procedure, patient outcomes and cost must also be considered. The response to stress seen in critically ill patients is well documented. Incidences of hypermetabolism in as many as 35% to 65% of patients have been reported, along with a 15% to 20% incidence of hypometabolism.^[14] These conditions often result in a negative energy balance due the poor prognostic capabilities of predictive equations, leading to longer hospital stays.^[15,16]

Reduced length of stay is a major consideration for the implementation of indirect calorimetry into the standard care of critically ill patients. One study showed that the hospital costs for normally nourished patients compared with malnourished patients were approximately \$28,631 vs \$45,762.^[17] Another study found that patients who received adequate nutritional support in the early phase of their care had a shorter hospital stay compared with those patients who did not receive adequate nutritional support during the onset of their care.^[18] Additional evidence of cost savings through nutritional monitoring was shown by McClave and colleagues.^[19] They compared measured EE to actual calories administered to a group of ventilator-dependent patients. They found that approximately 58% of patients were given 110% of the required calories, as measured by indirect calorimetry, and that 12% of the group was underfed. With only 25% of the patients receiving the appropriate number of calories, the investigators predicted that with accurate caloric measurements and administration protocols, there would be a savings of nearly \$1.3 million per year.

Limitations and Technical Issues

Indirect calorimeters are designed to be user friendly; however, technical limitations and difficulties do occur and must be understood by those responsible for ordering and conducting the study. These limitations can be addressed in 3 categories: influence of inspired oxygen levels ($F_{I}O_2$), failure to obtain and maintaining steady-state condition, and system leaks. Additionally as with any highly technically piece of equipment, calibration and proper training of the operator are crucial.

The level of $F_{I}O_2$ will influence the validity of the calculations made by the metabolic computer. The problem is 2-fold, with one issue related to the sensitivity of the oxygen analyzer and other with the way VO_2 is calculated.

Oxygen consumption measurements often suffered due to the response time of the oxygen analyzer, especially as oxygen concentrations rise 50% or greater. However with improved response times, as seen in the newer systems, this problem has somewhat been alleviated. The other issue is somewhat more complex and deals with the way that VO_2 is calculated. The equation used for this calculation assumes that inspired and expired volumes are essentially the same. However, this is not the case, and even in normal individuals the exhaled volume is slightly smaller than the inspired volume. Thus, an error is present in the calculation for VO_2 , but the magnitude is insignificant at ambient levels of inspired oxygen. The magnitude of the error increases as the level of inspired oxygen increases. This error, in combination with the accuracy problem, limits inspired oxygen levels to 60%.

As previously mentioned, steady-state conditions are necessary to accurately predict cellular metabolism through measurements of gas exchange in the airways. If a patient has rapid changes in minute ventilation during a study (hyper or hypoventilation), the measured carbon dioxide at the airway will not accurately reflect cellular levels of carbon dioxide. Thus, VCO_2 will be artificially higher when the patient hyperventilates and lower during periods of hypoventilation. This is a common problem during mechanical ventilation, especially when a mode that allows for spontaneous ventilation is used. Less of a problem is the production of carbon dioxide from nonmetabolic sources such as isocapnic buffering secondary to metabolic acidosis. Wide swings in cardiac output could also lead to nonsteady-state conditions requiring careful observation of the patient's cardiopulmonary status prior to and during the indirect calorimetry study.

System leaks, especially during mechanical ventilation, are a common problem. Failure to capture all of the exhaled volume into the metabolic computer will result in measurement errors. Care should be taken to ensure a tight seal around all circuit fittings as well as on the artificial airway cuff. Post-op surgical patients with abdominal or gastric incisions are a common source of error. Intestinal drains and collection bags may allow metabolically produced carbon dioxide to leak into the surrounding environment, resulting in erroneous RQ and REE measurements. Similar problems have also been observed in patients with chest tubes and bronchopleural fistulas.

Objectives for Indirect Calorimetry

Regardless of the limitations and technical issues, indirect calorimetry has a proven value in the nutritional management of the critically ill patient. The objectives of indirect calorimetry include^[20]:

1. To accurately measure the REE and RQ to guide nutritional support;
2. To allow determinations of substrate utilization in conjunction with UN measurements;
3. To determine VO_2 as a guide for monitoring the work of breathing and targeting adequate oxygen delivery; and
4. To assess the contribution of metabolism to ventilation.

Clinical Applications of Indirect Calorimetry

As previously stated, the nutritional management of many patients with known nutritional deficiencies may not be adequately managed through the use of predictive equations alone. It is these patients who will benefit the most from indirect calorimetry. While not exhaustive, patients who exhibit one or more of the following conditions listed in Table 5 should be considered for indirect calorimetry studies.

Table 5. Indications for Indirect Calorimetry Studies

- Severe sepsis
- Multiple trauma
- COPD
- Exhibiting hyper- or hypometabolic symptoms
- Failure to wean from mechanical ventilation
- Flow dependency oxygen consumption
- Increased oxygen cost of breathing
- Failure in responding to traditional nutritional support regimens

COPD = chronic obstructive pulmonary disease

Unfortunately, not all patients who fit in one or more of the above categories are good candidates for a study. Selecting patients to monitor requires a thorough understanding of the limitations of indirect calorimetry and the patient's condition.

Limitations for Patient Selection

Prior to ordering an indirect calorimetry study, patients should be assessed to determine if they are good candidates for this procedure. Criteria for inclusion are based on several factors in addition to their overall medical condition. Those patients who exhibit wide fluctuations in ventilation or cardiac output are usually not good candidates, as will be discussed (Table 6). Additionally, patients in the immediate postoperative period (< 24 hours postsurgery) and those who have had recent wound or burn debridement are often too unstable to obtain an accurate reflection of metabolic rate. In addition to these situations, the patient's daily routine should be assessed to assure that a "resting period" of at least 30 minutes prior to the study is possible and that during the actual data collection the patient should not be disturbed or have significant changes made in their medications.

Table 6. Ideal and Acceptable Conditions for Indirect Calorimetry Studies

Variable	Ideal % Change	Acceptable % Change
Minute ventilation	Less than 5%	No greater than 10%
Cardiac output	Less than 5%	No greater than 10%
F _I O ₂ setting	Less than 0.5%	No greater than 2%
Oxygen consumption	Less than 2%	No greater than 5%
Carbon dioxide production	Less than 2%	No greater than 5%

Conditions for Conducting a Study

After identifying a patient and having ordered a study, environmental and logistical issues need to be considered. As previously mentioned, there are 2 different philosophies concerning metabolic data collection. One school of thought suggests that the patient be monitored for a minimum of 12 hours, on a continuous basis, to obtain an accurate reflection of the TEE that would include periods of rest, sleep, and activity. Those who support the intermittent approach to monitoring advocate using a carefully selected period in which conditions are such that a resting measurement of EE can be obtained. While both approaches have their individual merits and drawbacks, the intermittent approach is the most widely used.

Selection of the time period is critical in performing an intermittent study. The patient needs to be resting but not asleep during the study, and the room should be quiet and at 20-25° C. Just as important, the time period leading up to the study must be free of any strenuous activity. Activities that should be avoided prior to a study include range-of-motion activities, chest x-ray, bathing, visitors, respiratory care procedures (especially chest physical therapy), and other activity that would take the patient out of their normal resting metabolic rate. Weissman and Kemper demonstrated that many of the above mentioned activities can increase VO₂ and VCO₂ upwards to 40% above resting levels.^[7] Additionally, the recovery period from similar activities may take as long as 30 minutes, following completion of the procedure, to restore resting conditions. If repeat measurements are to be performed, they should be scheduled at approximately the same time of day to cancel out any diurnal influences on the measurements.

The ventilator circuit should be free of leaks and comfortably attached to the patient. Any changes in ventilator setting, especially in F_IO₂, positive end expiratory pressure rate, and tidal volume should be performed at least 30 minutes prior to the study. Airway suctioning prior to the study should be followed by a 30-minute recovery period, especially if the patient is preoxygenated prior to suctioning, and should be avoided during the actual collection of

data. Additionally, pulse oximetry and/or arterial blood gases obtained prior to study are useful in establishing baseline values.

Collection of Data

Once the patient is attached to the metabolic computer, data are collected for 5 minutes to establish baseline reading. Data collected during the study should be scrutinized for errors and also for indications that the patient is not in a steady state (Table 7). Many metabolic computers will automatically alert the operator if this occurs and also will indicate any deviations from steady-state in the data record. Following a period of approximately 15 minutes of collecting data, the test can be terminated, the metabolic computer disconnected from the ventilator circuit, and the data then interpreted.

Table 7. Acceptable Ranges for Indirect Calorimetry Data

Variable	Acceptable Range
RQ	0.65-1.25 consistent with nutritional intake
VO ₂	± 5% from baseline value
VCO ₂	± 5% from baseline value
Minute ventilation	± 10% from baseline value

Repeat measurements are often required, and, as previously mentioned, these studies should be performed during the same time of day or activity levels as the previous study. Additionally, if changes are made in the patient's nutritional management (amount or type of calories provided), a period of a least 12 hours should elapse prior to performing the new study.

Interpreting the Data

Current metabolic computers provide a multitude of indices derived from the data listed in Table 8. However, an initial assessment of the patient's nutritional status can be made by analyzing a few key pieces of information. The REE represents the number of calories that a patient is burning and is expressed in units of Kcal per 24 hours. Because the REE is an actual expression of metabolic rate, the patient's overall diet can be adjusted to assure that the proper number of calories is being provided. The RQ is used to determine the mixture of substrates used in generating the REE (Table 7). Issue of flow-dependent oxygen consumption may be evaluated in part by observing VO₂ levels, and this parameter may also be useful in assessing the work of breathing. Carbon dioxide production is useful in the calculation of alveolar dead space and also in identifying the cause of increased minute ventilation requirements.

Once the RQ and REE have been successfully measured, this information is used in assessing the nutritional management of the patient. Typically, caloric intake should match, and in some cases exceed, the REE with a balanced mixture of substrate and nutrients. Activities, changes in ventilator settings, and other factors will alter the actual metabolic rate from the value measured under resting conditions, requiring an increase in the total calories provided to the patient. Several studies have identified problems when either the caloric load or mix of substrates does not match the patient's underlying disease state. Most common is excessive administration of CHO to patients receiving mechanical ventilation.^[3] Excessive CHO calories administration results in the lipogenesis (conversion of CHO to lipids), leading to an increase in carbon dioxide production and oxygen consumption. Ventilator patients who already have an underlying ventilatory impairment may not be able to handle the increase in carbon dioxide production and will require increased mechanical support, potentially leading to ventilator dependency.^[4] Regulation of lipids and proteins completes the balanced nutritional support that all critically ill patients, especially those receiving mechanical ventilation, will require.

Table 8. Using RQ Ratio to Determine Substrate Utilization

RQ	Condition
1.0	Carbohydrate metabolism
0.71	Lipid metabolism
0.80	Protein metabolism
0.85	Mixed substrate metabolism
< 0.65	Nonsteady-state condition -- hypoventilation/ketosis
> 1.25	Nonsteady state condition -- hyperventilation/isocapnic buffering

Case Study 1

A 63-year-old male was admitted to the hospital with a diagnosis of pulmonary emphysema. He was well known to the medical staff and had several prior admissions related to complications from this emphysema. The patient complained of shortness of breath for the last several days at home, and, on admission, pulse oximetry showed an arterial saturation of 87% on 3 LPM of oxygen via nasal cannula. The patient's condition rapidly deteriorated in the emergency department; after several attempt to stabilize his ventilation, the patient was intubated and transferred to the medical intensive care unit where he was placed on a mechanical ventilator. On physical exam, the patient exhibited signs of muscle wasting and malnutrition. Enteric feedings were begun using a standard mixture of 10% lipids, 60% CHO, with a balance of proteins and minerals that supplied approximately 2100 kcal per 24 hours. The patient's condition stabilized during the next 24 hours. Attempts to withdraw ventilator support over the next several days were not successful due to hypercapnia (increased CO₂) when support from the ventilator was reduced. On day 4 of admission, an indirect calorimetry study was ordered with the following results (Table 9).

Table 9. Case Study 1 -- Data

REE	1950 kcal/24 hr
RQ	0.98
VO ₂	4.1 mL/min/kg
VCO ₂	3.6 mL/min/kg

The information from the indirect calorimetry study indicated that while the total number of calories being delivered was appropriate, the patient was being given an excessive CHO load. This was confirmed by the RQ measurement of 0.98. The elevated carbon dioxide production and oxygen consumption levels were contributing to the patient's inability to support his ventilation unaided from the ventilator. The patient's feedings were adjusted to reflect a balance of nutrients that would minimize VCO₂ levels and encourage ventilator withdrawal. This patient exhibited the classic response to excessive CHO calories. While the total number of calories was adequate, as measured by the REE, the mixture of substrates was not appropriate considering the patient's underlying condition.

Case Study 2

A 23-year-old male suffering chest trauma from a motor vehicle accident was 4 day post-admit to the surgical intensive care unit. His ventilation was partially supported using synchronized intermittent mandatory ventilation (SIMV) at a rate of 10 breaths per minute with pressure support (PS) set at 10 cm H₂O. The patient was alert and responding to commands. Attempts to reduce the PS below 10 cm H₂O resulted in the patient becoming tachypneic with arterial oxygen desaturation. When PS levels were restored back to 10 cm H₂O, the patient's conditions

improved dramatically. A metabolic study was ordered to measure VO_2 and determine if the reduction in PS was leading to an increase the work of breathing. The patient was placed on a metabolic cart at a PS level of 10 cm H_2O , and baseline values were obtained (Table 10). PS levels were then reduced in 2-cm H_2O increments until the patient either became tachypneic or his saturation fell below 90%. All other setting remained the same.

Table 10. Case Study 2 -- PS Titration Data

PS Level	VO_2 (mL/min/kg)	SaO_2 (%)	Rate (breath/min)
10	3.9	96	18
8	3.9	95	20
6	4.4	90	29
4	6.8	88	36
6	5.1	91	33
8	4.4	93	28
10	4.0	95	22

Based on these and other findings, the PS level was maintained at 10 cm H_2O and the SIMV rate was gradually decreased over several days, and eventually the patient was placed on continuous positive airway pressure. At this point, the PS was slowly reduced and eventually the patient was extubated and placed on supplemental oxygen.

The changes in VO_2 and spontaneous respiratory rate suggest that the patient was experiencing increased work loads as the level of pressure was reduced. Note how the VO_2 and spontaneous respiratory rate migrated back to baseline levels once the PS was returned to 10 cm H_2O . Frequently, patients need to slowly exercise their respiratory muscles through a gradual strengthening process. This is often accomplished by slowly reducing the number of mechanical breaths and allowing the patient to assume a greater portion of the ventilatory load through their spontaneous activity. As was seen in this patient, respiratory muscle conditioning was needed prior to decreasing the level of pressure support.

Case Study 3

A 53-year-old female who was post-op 5 days following a cholecystectomy had failed several ventilator weaning trials. The patient was conscious and responding to commands while breathing spontaneously between the ventilator breaths. A metabolic study was ordered to determine if her nutritional status and feedings were hindering ventilator weaning. After an initial period to establish baseline values, the following data were collected (Table 11).

Table 11. Case Study 3 Data

Data Collected	5 min	10 min	15 min	20 min	30 min
Ventilation (L/min)	12.2	15.7	8.6	14.3	16.7
RQ	0.98	1.26	0.76	1.11	1.28
REE (kcal/24 hr)	2245	1824	1402	2600	2075

The study was terminated after 30 minutes and no data were reported for interpretation. This is an example of a patient who did not reach steady-state conditions. The wide fluctuations in her ventilation, attributed to her spontaneous breathing, made it impossible for the metabolic computer to get a true reading of carbon dioxide production and oxygen consumption. This was evident by the wide range of RQ readings. Note how the RQ at the

10- and 30-minute marks were outside the acceptable range, greater than 1.25, and the remaining RQ values were not consistent between each 5-minute recording period. Under these conditions, it is best to terminate the study, report that acceptable data cannot be obtained, and then have the study repeated when the patient's ventilation becomes more stable.

Summary

Indirect calorimetry is a valuable tool available to practitioners who treat critically ill patients. Knowledge of the metabolic response to sepsis, injury, and burns is crucial in managing these patients. With the information available from indirect calorimetry, accurate assessments of EE and substrate utilization are now possible. Determining the appropriate number as well as the type of calories may reduce the incidences of malnutrition as well as problems associated with overfeeding patients, especially those who require mechanical ventilation. The initial cost and maintenance of an indirect calorimeter can be justified by showing its usefulness not only in determining dietary needs but also as a tool for ventilator management and diagnosing cardiopulmonary failure. The future of indirect calorimetry will rely on practitioners recognizing potential applications for its use and the timely application of data derived from those studies.

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Contents of *Indirect Calorimetry: Principles and Applications for Managing Critically Ill Patients* [<http://cme.medscape.com/viewprogram/4704>]

1. Indirect Calorimetry: Principles and Applications for Managing Critically Ill Patients [<http://cme.medscape.com/viewarticle/515891>]

CME/CE Information

CME/CE Released: 11/09/2005; Valid for credit through 11/09/2006

This activity has expired.

The accredited provider can no longer issue certificates for this activity. Medscape cannot attest to the timeliness of expired CME activities.

Target Audience

This activity is intended for physicians, nurses, and other healthcare providers who care for critically ill patients in the intensive care unit.

Goal

The goal of this activity is to provide current data on the metabolic assessment of critically ill patients with indirect calorimetry.

Learning Objectives

Upon completion of this activity, participants will be able to:

1. Discuss the theories and principles of indirect calorimetry.
2. Identify the limitations associated with nutritional assessment of critically ill patients.
3. Apply data derived from indirect calorimetry in a patient care setting.

Credits Available

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