Metabolic monitoring in the ICU

Jean-Daniel Chiche, MD PhD

MICU & Dept of Host-Pathogen Interaction
Hôpital Cochin & Institut Cochin, Paris-F
Conflicts of interest - Disclosure

- GE Healthcare
  - Received honorarium for participation to Medical Advisory Board for ventilation & CIS activities (2009-2011)
  - Travel expenses Seoul 2015
- Nestlé Healthcare
  - Received honorarium for participation to Medical Advisory Board
25 years of failed novel intervention trials

- Being less pessimistic...
  - improved ICU outcomes (better general care, less iatrogenic harm)
  - many positive outcome RCTs from doing less (ventilation, sedation, Tx..)
  - excess reliance on protocols, guidelines?

- Starting to understand what may be good for populations .. but for the individual??
It’s all about people!
But we care for individuals
Individuals are unique!

- differing host response to insult
- different trajectory of disease progression
- different severity of disease progression
- affected not just by genes but by age, comorbidity, drugs...

Photo credit: Kallel Koven
Interplay between critical illness & chronic health

Trends in Molecular Medicine, April 2014, Vol. 20, No. 4
CONCLUSIONS AND RELEVANCE In critically ill patients in Australia and New Zealand with severe sepsis with and without shock, there was a decrease in mortality from 2000 to 2012. These findings were accompanied by changes in the patterns of discharge to home, rehabilitation, and other hospitals.
Declining Case Fatality Rates for Severe Sepsis
Good Data Bring Good News With Ambiguous Implications

Theodore J. Iwashyna, MD, PhD; Derek C. Angus, MD, MPH

Figure. Potential Mechanisms of Decreasing Short-term Mortality Among Patients Across a Distribution of Illness Severity

<table>
<thead>
<tr>
<th>Current care</th>
<th>Full recovery</th>
<th>Significant morbidity</th>
<th>Death</th>
</tr>
</thead>
</table>

The global burden of critical illness

- ARF
- Shock
- Infection
- Coma & Neuro dysfunction
- Nutrition
- Transfusion
- AKI
- Organ failure
- Sedation
- Social sciences
- Patients & Family

The global burden of critical illness
Intensive Care Unit–acquired Weakness
Clinical Phenotypes and Molecular Mechanisms

Jane Batt¹,², Claudia C. dos Santos¹,², Jill I. Cameron³, and Margaret S. Herridge⁴

- Neuromuscular dysfunction (neuropathy, myopathy)
- Heterotopic ossification
- Frozen joints
- Compression neuropathies

ICU-acquired weakness

- Abnormalities in memory, attention, and executive function
- Depression
- Post-traumatic stress disorder
- Anxiety

*Am J Respir Crit Care Med Vol 187, Iss. 3, pp 238–246, Feb 1, 2013*
CONCLUSIONS AND RELEVANCE Among these critically ill patients, muscle wasting occurred early and rapidly during the first week of critical illness and was more severe among those with multiorgan failure compared with single organ failure. These findings may provide insights into skeletal muscle wasting in critical illness.
Try the ICU Diet...

![Graph showing change in weight from discharge to 12 months post-discharge.](image-url)
### Table 3. Ability to Exercise and Return to Work and Health-Related Quality of Life among Patients with the Acute Respiratory Distress Syndrome during the First 12 Months after Discharge from the ICU.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>3 Months</th>
<th>6 Months</th>
<th>12 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance walked in 6 min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. evaluated</td>
<td>80*</td>
<td>78†</td>
<td>81‡</td>
</tr>
<tr>
<td>Median — m</td>
<td>281</td>
<td>396</td>
<td>422</td>
</tr>
<tr>
<td>Interquartile range — m</td>
<td>55–454</td>
<td>244–500</td>
<td>277–510</td>
</tr>
<tr>
<td>Percentage of predicted value§</td>
<td>49</td>
<td>64</td>
<td>66</td>
</tr>
<tr>
<td>Returned to work — no./total no. (%)¶</td>
<td>13/83 (16)</td>
<td>26/82 (32)</td>
<td>40/82 (49)</td>
</tr>
<tr>
<td>Returned to original work — no./total no. (%)</td>
<td>10/13 (77)</td>
<td>23/26 (88)</td>
<td>31/40 (78)</td>
</tr>
</tbody>
</table>
Functional Disability 5 Years after Acute Respiratory Distress Syndrome

Margaret S. Herridge, M.D., M.P.H., Catherine M. Tansey, M.Sc., Andrea Matté, B.Sc., George Tomlinson, Ph.D., Natalia Diaz-Granados, M.Sc., Andrew Cooper, M.D., Cameron B. Guest, M.D., C. David Mazer, M.D., Sangeeta Mehta, M.D., Thomas E. Stewart, M.D., Paul Kudlow, B.Sc., Deborah Cook, M.D., Arthur S. Slutsky, M.D., and Angela M. Cheung, M.D., Ph.D., for the Canadian Critical Care Trials Group

Impact of Systemic Aggression

- Age and comorbidities predispose patients to shock and critical illnesses.

- The normal response to aggression involves simultaneous expression of genes involved in the systemic inflammatory, innate immune, and compensatory antiinflammatory responses, as well as suppression of genes involved in adaptive immunity.

- Differences in the magnitude and duration of these changes are associated with complicated outcomes.
Impact of Systemic Aggression

- In addition to organ dysfunction taken into account by SOFA scores, systemic aggression triggers novel pathophenotypes
  - Critical illness neuromyopathy
  - Immune dysfunction
  - Heterotopic ossifications & joints abnormalities
  - Cognitive dysfunction
  - Depression
  - Acute cardiovascular events
  - Dementia
  - Tumor growth, ...
Individuals are unique...

...and so are our treatment approaches!!!

- Regardless of...
  - etiology
  - timing
  - severity
  - confirmed diagnosis
  - age
  - gender
  - co-morbidity
  - ...

Photo credit: Kallel Koven
Frailty as an important determinant of critical illness

- Syndrome of decreased reserve and resistance to stressors, including sepsis
- Results from cumulative declines across multiple physiologic systems
- Defined by ≥3 criteria
  - unintentional weight loss
  - self-reported exhaustion
  - weakness (as evidenced by reduced grip strength)
  - slow walking speed
  - low physical activity
Research Agenda for Frailty in Older Adults: Toward a Better Understanding of Physiology and Etiology: Summary from the American Geriatrics Society/National Institute on Aging Research Conference on Frailty in Older Adults

Jeremy Walston, MD,* Evan C. Hadley, MD,† Luigi Ferrucci, MD, PhD,‡ Jack M. Guralnik, MD, PhD,‡
Anne B. Newman, MD, MPH,§ Stephanie A. Studenski, MD, MPH,¶ William B. Ershler, MD,¶
Tamara Harris, MD,† and Linda P. Fried, MD, MPH*
Most ICU patients have some sort of comorbid state.
The complex ICU patient

- Patients with complex multi-organ failure have prolonged ICU stays – weeks to months
- Some have prior nutritional deficits
- Some (few) have clear contra-indications to EN
- But many of these develop gut dysfunction during their episode:
  - Gut stasis
  - Constipation
  - Ileus
  - Bleeding
The complex ICU patient (2)

- Prolonged ventilation & immobility:
  - Muscle loss

- Continuous Renal Replacement Therapy
  - Nutrient loss

- Underfeeding
  - Protein and calorie deficit
The few things I know about nutrition...

- Use enteral feeding every time it is possible
- Use it early
- Feed with whatever works...
- Use some sort of glycemic control
- Use common sense...

- How much? Fortunately, smart people publish guidelines...
Summary of statements: Intensive care

<table>
<thead>
<tr>
<th>Subject</th>
<th>Recommendations</th>
<th>Grade</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indications</td>
<td>All patients who are not expected to be on a full oral diet within 3 days should receive enteral nutrition.</td>
<td>C</td>
<td>1</td>
</tr>
</tbody>
</table>

Nevertheless, the expert committee recommends that haemodynamically stable critically ill patients who have a functioning gastrointestinal tract should be fed early (<24 h) using an appropriate amount of feed.

No general amount can be recommended as EN therapy has to be adjusted to the progression/course of the disease and to gut tolerance.

Exogenous energy supply:
- during the acute and initial phase of critical illness: in excess of 20–25 kcal/kg BW/day may be associated with a less favourable outcome.
- during the anabolic recovery phase, the aim should be to provide 25–30 kcal/kg BW/day.

Patients with a severe undernutrition should receive EN up 25–30 total kcal/kg BW/day. If these target values are not reached supplementary parenteral nutrition should be given.

erthromycin in patients with intolerance to enteral feeding (e.g. with high gastric residuals).
Body weight vs energy intake

If BMI > 25 or sarcopenic
Ideal BW: (height-100) + (0.25 x (actual BW - (height-100)))
The problem of obesity

FIGURE 2. Comparison of 65% measured REE by IC to weight-based equations (12.5 kcal/kg ABW/day and 23.5 kcal/kg IBW/day) in patients with BMI greater than 50. ABW, actual body weight; IC, indirect calorimetry; IBW, ideal body weight; REE, resting energy expenditure.
Can we predict energy expenditure?
Energy expenditure in healthy subjects

The surest things can change...

- Disease states
- Temperature
- Stress
- Drugs, hormones
- Treatments
- Nutrition
- Physical activity

Energy expenditure over time for men and women.

Change in energy expenditure

Propacetamol

External cooling

British Journal of Anaesthesia 1997; 78: 123–127
# Accurate Determination of Energy Needs in Hospitalized Patients

JOSEPH BOULLATA, PharmD; JENNIFER WILLIAMS, MS, RD; FAITH COTTRELL; LAUREN HUDSON, MS, RD; CHARLENE COMPHER, PhD, RD, FADA

## General Equations

### Harris-Benedict

- **Men**: \( 66.5 + (13.8)(\text{Wt}^a) + (5)(\text{Ht}^b) - (6.8)(\text{A}^c) \)
- **Women**: \( 655 + (9.6)(\text{Wt}^a) + (1.8)(\text{Ht}^b) - (4.7)(\text{A}^c) \)

### Mifflin-St Jeor

- **Men**: \( 5 + (10)(\text{Wt}^a) + (6.25)(\text{Ht}^b) - (5)(\text{A}^c) \)
- **Women**: \( -161 + (10)(\text{Wt}^a) + (6.25)(\text{Ht}^b) - (5)(\text{A}^c) \)

### Ireton-Jones 1992

- **Men**: \( 1,925 + (5)(\text{Wt}^a) - (10)(\text{A}^c) + (281)(\text{G}^d) + (292)(\text{Tr}^e) + (851)(\text{B}^f) \)
- **Women**: \( 451 + (10)(\text{Wt}^a) - (10)(\text{A}^c) + (281)(\text{G}^d) + (292)(\text{Tr}^e) + (851)(\text{B}^f) \)

### American College of Chest Physicians

- **(25)(\text{Wt}^a)**

## Obesity

### Ireton-Jones for obese individuals

- **Men**: \( 1,444 + (606)(\text{G}^d) + (9)(\text{Wt}^a) - (12)(\text{A}^c) + (400)(\text{V}^o) \)
- **Women**: \( 580 + (606)(\text{G}^d) + (9)(\text{Wt}^a) - (12)(\text{A}^c) + (400)(\text{V}^o) \)

### Harris-Benedict (using adjusted body weight)

- **Hamwi × 1.3**
  - **Men**: \( 48.2 + (2.7)(\text{in of height over 5 ft}) \)
  - **Women**: \( 45.5 + (2.3)(\text{in of height over 5 ft}) \)

- **James × 1.3**
  - **Men**: \( (1.1013)(\text{Wt}^a) - (0.01281)(\text{BMI}^h)(\text{Wt}^a) \)
  - **Women**: \( (1.07)(\text{Wt}^a) - (0.0148)(\text{BMI}^h)(\text{Wt}^a) \)

## Ventilated Patients

### Swinamer

- \( -4,349 + (945)(\text{BSA}^i) - (6.4)(\text{A}^c) + (108)(\text{Temp}^j) + (24.2)(\text{RR}^k) + (81.7)(\text{TV}^l) \)

### Penn State

- \( -6,433 + (\text{Harris-Benedict})(0.85) + (\text{V}_e^m)(33) + (\text{T}_m^n)(175) \)

---

**Figure.** Equations for predicting resting energy expenditure (kcal/d).

- ^a^Weight (kg).
- ^b^Height (cm).
- ^c^Age (y).
- ^d^Sex (1 = man, 0 = woman).
- ^e^Trauma (1 = present, 0 = not present).
- ^f^Burns (1 = present, 0 = not present).
- ^g^Ventilated (1 = present, 0 = not present).
- ^h^BMI = Body mass index (calculated as kg/m²).
- ^i^BSA = Body surface area (m²).
- ^j^Temperature (°C).
- ^k^RR = Respiratory rate (breaths per minute).
- ^l^TV = Tidal volume (L).
- ^m^Minute ventilation (L/min).
- ^n^Maximum temperature (°C).
Accurate Determination of Energy Needs in Hospitalized Patients

JOSEPH BOULLATA, PharmD; JENNIFER WILLIAMS, MS, RD; FAITH COTTRELL; LAUREN HUDSON, MS, RD; CHARLENE COMPHR, PhD, RD, FADA

<table>
<thead>
<tr>
<th>Patient group</th>
<th>Measured REE (kcal/d) mean±SD</th>
<th>Predicted REE (kcal/d) mean±SD</th>
<th>Accurate predictions (%)</th>
<th>Maximum underprediction (%)</th>
<th>Maximum overprediction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients (n=395)</td>
<td>1,617±355</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HBb</td>
<td>1,478±301</td>
<td></td>
<td>43</td>
<td>28</td>
<td>78</td>
</tr>
<tr>
<td>HB multiplied by a factor of 1.1</td>
<td>1,626±331</td>
<td></td>
<td>61</td>
<td>34</td>
<td>62</td>
</tr>
<tr>
<td>Aux</td>
<td>1,406±226</td>
<td></td>
<td>25</td>
<td>25</td>
<td>35</td>
</tr>
</tbody>
</table>

| Ventilated patients (n=141)          | 1,730±402                    |                                |                           |                             |                           |
| SWNi                                 | 1,696±360                    |                                | 45                        | 33                          | 116                       |
| PSUj                                 | 1,536±327                    |                                | 43                        | 25                          | 56                        |
| HB multiplied by a factor of 1.1     | 1,729±326                    |                                | 55                        | 34                          | 62                        |

Conclusions No equation accurately predicted REE in most hospitalized patients. Without a reliable predictive equation, only indirect calorimetry will provide accurate assessment of energy needs.
Assessment of resting energy expenditure in mechanically ventilated patients¹–³

Christophe Faisy, Emmanuel Guerot, Jean-Luc Diehl, Jacques Labrousse, and Jean-Yves Fagon

**Conclusion:** Our results suggest that REE estimated on the basis of body weight, height, minute ventilation, and body temperature is clinically more relevant than are the usual predictive equations for metabolically stable, mechanically ventilated patients.

**REE (M) =** 14 x kg + 5 x cm – 7 x years

**REE (F) =** 10 x kg + 1.8 x cm – 5 x years
Development and current use of parenteral nutrition in critical care – an opinion paper

Mette M Berger and Claude Pichard

Figure 3 Relationship between two commonly used equations and the value of energy expenditure. Indirect calorimetry study shows that both equations overestimated and underestimated energy expenditure in an unpredictable manner.

A

n = 165

R² = 0.347

B

R² = 0.260

Target 25-30 kcal/actual BW

Target based on corrected ideal BW

Critical Care 2014, 18:478
Undernutrition vs Overnutrition

Autophagia? Tissue repair?

Outcome
- life span
- mortality
- length of stay

Energy
- Consumption
- Intake

Optimum

- weakness
- impaired mobility
- difficult weaning
- pneumonia
- pressure sore
- impaired wound healing

- hyperglycemia
- getting fat
- fever
- difficult weaning
- infection
Overnutrition & Lung Function

- Nutrient intake & consumption
  - increase in metabolic rate
  - increase in CO$_2$ production
  - increase in minute ventilation

- High glucose intake induces lipogenesis
  - RQ > 1 + further increase in CO$_2$ production

- In case of weaning failure / high minute ventilation (> 150 ml.kg$^{-1}$.min$^{-1}$) in otherwise unstressed patient, consider the possibility of overnutrition / high glucose intake
Do We Have a problem?

- Is it plausible that an initial nutritional deficit may have a detrimental effect?
  - To what extent is the concept of relative underfeeding merely an excuse for poor performance?

- If this is true, how might we address it?
Energy deficit has significant consequences on outcome
ICU cumulated energy balance & outcome

- Patients at risk of organ failure
- Indirect calorimetry determinations of target

Bartlett et al. Surgery, 92: 772, 1982
Negative impact of hypocaloric feeding and energy balance on clinical outcome in ICU patients

Stéphane Villet\textsuperscript{a}, René L. Chiolero\textsuperscript{b}, Marc D. Bollmann\textsuperscript{b}, Jean-Pierre Revelly\textsuperscript{b}, Marie-Christine Cayeux RN\textsuperscript{b}, Jacques Delarue\textsuperscript{c}, Mette M. Berger\textsuperscript{b, *}

\textsuperscript{a}Anesthésiologie, Centre Hospitalier Universitaire Vaudois (CHUV), 1011 Lausanne, Switzerland
\textsuperscript{b}Soins Intensifs Chirurgicaux et Centre des Brûlés CHUV-BH 08.660, CH 1011 Lausanne, Switzerland
\textsuperscript{c}EA-948 Oxylipides, Laboratoire Régional de Nutrition Humaine, CHU de Brest, 29200 Brest, France

Received 29 January 2005; accepted 30 March 2005
Figure 1 Progression of energy delivery compared to energy target over 4 weeks: the figure shows that energy delivery increases with time, reducing daily deficit.

Figure 2 Relation between the progressive negative energy balance and the number of infectious complications.

Table 3 Plasma proteins.

<table>
<thead>
<tr>
<th>Protein</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Ref. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>P/n</td>
<td>33/48</td>
<td>16/16</td>
<td>11/11</td>
<td>7/7</td>
<td></td>
</tr>
<tr>
<td>Albumin</td>
<td>22.2 ± 5.2</td>
<td>22.4 ± 4.6</td>
<td>22.9 ± 5.3</td>
<td>22.0 ± 5.5</td>
<td>35–45 g/l</td>
</tr>
<tr>
<td>Prealbumin</td>
<td>0.17 ± 0.08</td>
<td>0.15 ± 0.08</td>
<td>0.15 ± 0.06</td>
<td>0.17 ± 0.06</td>
<td>0.2–0.4 mg/l</td>
</tr>
<tr>
<td>CRP</td>
<td>142 ± 98</td>
<td>96 ± 60</td>
<td>91 ± 82</td>
<td>80 ± 60</td>
<td>&lt;10 mg/l</td>
</tr>
</tbody>
</table>

P/n: number of patients with visceral albumin/prealbumin determinations among patients present during the same period.
Negative impact of hypocaloric feeding and energy balance on clinical outcome in ICU patients

Stéphane Villet\textsuperscript{a}, René L. Chiolero\textsuperscript{b}, Marc D. Bollmann\textsuperscript{b}, Jean-Pierre Revelly\textsuperscript{b}, Marie-Christine Cayeux RN\textsuperscript{b}, Jacques Delarue\textsuperscript{c}, Mette M. Berger\textsuperscript{b,*}
Impact of energy deficit calculated by a predictive method on outcome in medical patients requiring prolonged acute mechanical ventilation

Christophe Faisy\textsuperscript{1,2*}, Nicolas Lerolle\textsuperscript{1,2}, Fahmi Dachraoui\textsuperscript{1,2}, Jean-François Savard\textsuperscript{1,2,3}, Imad Abboud\textsuperscript{1,2}, Jean-Marc Tadie\textsuperscript{1,2} and Jean-Yves Fagon\textsuperscript{1,2}

\textit{British Journal of Nutrition} (2009), 101, 1079–1087
Impact of energy deficit calculated by a predictive method on outcome in medical patients requiring prolonged acute mechanical ventilation

Christophe Faisy¹,²*, Nicolas Lerolle¹,², Fahmi Dachraoui¹,², Jean-François Savard¹,²,³, Imad Abboud¹,², Jean-Marc Tadie¹,² and Jean-Yves Fagon¹,²

![Graph showing ICU mortality (%) vs. energy deficit (kJ/d of mechanical ventilation).](image)

- For energy deficit  < 4866 (n 10), ICU mortality % = 30%
- For energy deficit 4866–5393 (n 9), ICU mortality % = 78%, OR 8.17
- For energy deficit 5394–6268 (n 9), ICU mortality % = 89%, OR 18.67
- For energy deficit > 6268 (n 10), ICU mortality % = 90%, OR 21

*British Journal of Nutrition (2009), 101, 1079–1087
Impact of energy deficit calculated by a predictive method on outcome in medical patients requiring prolonged acute mechanical ventilation

Christophe Faisy\textsuperscript{1,2,*}, Nicolas Lerolle\textsuperscript{1,2}, Fahmi Dachraoui\textsuperscript{1,2}, Jean-François Savard\textsuperscript{1,2,3}, Imad Abboud\textsuperscript{1,2}, Jean-Marc Tadie\textsuperscript{1,2} and Jean-Yves Fagon\textsuperscript{1,2}

Fig. 4. Kaplan–Meier analysis of intensive care unit (ICU) survival rate in patients with mean energy deficit $\geq 5021 \text{ kJ (1200 kcal)/d}$ of mechanical ventilation (\(\text{—}\); \(n\) 25) and with mean energy deficit $<5021 \text{ kJ (1200 kcal)/d}$ of mechanical ventilation (\(<\); \(n\) 13). *Values were significantly different ($P = 0.01$; log-rank test).
Hospitalized mechanically ventilated patients are at higher risk of enteral underfeeding than non-ventilated patients.


Figure 1: Evolution of energy delivery in percent of estimated energy needs in non-ventilated and ventilated patients during first 5 days of enteral nutrition support. Unpaired t-test between groups: Day 1 $P = 0.006$; Day 2 $P < 0.001$; Day 3 $P < 0.001$; Day 4 $P < 0.001$; Day 5 $P = 0.02$.

Figure 2: Evolution of protein delivery in percent of estimated protein needs in non-ventilated and ventilated patients during first 5 days of enteral nutrition support. Unpaired t-test between groups: Day 1 $P < 0.001$; Day 2 $P < 0.001$; Day 3 $P < 0.001$; Day 4 $P < 0.001$; Day 5 $P = 0.003$.
Early ICU Energy Deficit Is a Risk Factor for *Staphylococcus aureus* Ventilator-Associated Pneumonia

Christophe Faisy, MD, PhD; Maria Candela Llerena, MD; Magali Savalle, MD; Jean-Luc Mainardi, MD, PhD; and Jean-Yves Fagon, MD, PhD

![Graph showing energy balance and Staphylococcus aureus-positive BAL](image)

- **Cumulated energy balance (kcal) before BAL**
  - $>-4730\ n=18$: 1 (11.1%)
  - $-4731\ to\ -10300\ n=36$: 10 (29.7%) OR = 3.08
  - $-10301\ to\ -15875\ n=19$: 8 (38.8%) OR = 5.82
  - $<-15875\ n=3$: 2 (66.6%) OR = 16

$\chi^2 = 6.3\ 
P = .01^*$
Predictive equations showed proportional bias

- Overestimation of low REE values
- Underestimation of high REE values

Correction by regression analysis did not improve results

Conclusions: The REE predictive equations are not adequate to predict REE in malnourished hospitalized older patients. There is an urgent need for either a new accurate REE predictive equation, or accurate easy-to-use equipment to measure REE in clinical practice.
Measuring energy expenditure in the ICU
Energy expenditure measurements

- Living organisms consume $O_2$ & generate heat due to cellular respiration
  - Nutrients + $O_2 \rightarrow$ ATP + heat

- Direct calorimetry
  - Body heat radiation is captured by circulating water in a highly isolated environment
  - $EE = \text{Water volume (ml/sec)} \times T \text{ (water in - out)}$
  - Precision $\pm 1\%$

- Indirect calorimetry
  - Expired vs. inspired $O_2$ & $CO_2 \rightarrow EE$
  - Precision $\pm 1-5\%$
### Indirect calorimetry: parameters

<table>
<thead>
<tr>
<th></th>
<th>( \text{O}_2 ) (ml)</th>
<th>( \text{CO}_2 ) (ml)</th>
<th>RQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose</td>
<td>828.8</td>
<td>828.8</td>
<td>1.00</td>
</tr>
<tr>
<td>Lipids</td>
<td>2019.3</td>
<td>1427.3</td>
<td>0.70</td>
</tr>
<tr>
<td>Proteins</td>
<td>966.3</td>
<td>773.9</td>
<td>0.80</td>
</tr>
</tbody>
</table>

\[ \text{RQ} = \frac{\text{O}_2 \text{ consumption}}{\text{CO}_2 \text{ production}} \]

**Interpretation**

<table>
<thead>
<tr>
<th>RQ range</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7 - 0.85</td>
<td>lipolysis</td>
</tr>
<tr>
<td>0.7 - 0.95</td>
<td>glycolysis</td>
</tr>
<tr>
<td>( \geq 1.0 )</td>
<td>lipogenesis</td>
</tr>
</tbody>
</table>
Are Patients Fed Appropriately According to Their Caloric Requirements?

Stephen A. McClave, MD; Cynthia C. Lowen, RD; Melissa J. Kleber, RD; Jack F. Nicholson, RRT; Sharon C. Jimmerson, RD; J. Wesley McConnell, MD; and Laura Y. Jung, BSHSA

Distribution of measured EE in 335 patients on MV as % of predicted EE (HB)
Indirect calorimetry in practice...

- **Indications**
  - Body weight $\leq 80\%$ or $\geq 130\%$ IBW
  - Major stress
  - Hyperthyroidia, pheochromocytoma
  - Shivering, spasms, plegia, coma,
  - Long-term ICU stay & mechanical ventilation
  - Difficult weaning

- **Limitations**
  - High pressure regimen $\rightarrow$ leaks
  - Hyper / hypoventilation $\rightarrow$ $\Delta PH$
  - Insufficient duration
  - Non-collaboration, agitation
Indirect calorimetry in the ICU

The Tools
Comparison of three indirect calorimetry devices and three methods of gas collection: A prospective observational study

Séverine Graf, Véronique Laurence Karsegard, Valérie Viatte, Nadine Maisonneuve, Claude Pichard, Laurence Genton

A. Deltatrac II® vs. QuarkRMR®

B. Deltatrac II® vs. CCMexpress® (C)

C. Deltatrac II® vs. CCMexpress® (F)

D. Deltatrac II® vs. CCMexpress® (M)

Indirect calorimetry in mechanically ventilated patients. A systematic comparison of three instruments

Martin Sundström, Inga Tjäder, Olav Rooyackers, Jan Wernerman

*Results:* There was no difference in mean REE measurements between Deltatrac, 1749 ± 389 kcal/24 h and Quark RMR, 1788 ± 494 kcal/24 h \( (P = 0.166) \). CCM Express produced 64% higher mean REE values \( (2876 ± 656 \text{ kcal/24 h}) \) than Deltatrac \( (P < 0.0001) \). All instruments registered different values for RQ and expiratory minute volume.

*Conclusion:* Available instruments for indirect calorimetry give conflicting estimates of energy expenditure in mechanically ventilated patients. Whilst the Quark RMR compares better with the Deltatrac than CCM Express, the mechanisms behind this difference needs to be further explored.
Comparison of metabolic monitors in critically ill, ventilated patients

Pierre Singer, M.D.\textsuperscript{a,*}, Ira Pogrebetsky, M.D.\textsuperscript{a}, Joelle Attal-Singer, M.D.\textsuperscript{b}, and Jonathan Cohen, M.D.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Deltatrac II</th>
<th>M-COVX</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{VO}_2$ (mL/min)</td>
<td>$305.3 \pm 62.6^\dagger$</td>
<td>$307.2 \pm 90.4^\ddagger$</td>
</tr>
<tr>
<td>$\text{VCO}_2$ (mL/min)</td>
<td>$222 \pm 49.3^\dagger$</td>
<td>$241.0 \pm 69.9^\ddagger$</td>
</tr>
<tr>
<td>$\text{REE}$ (kcal/d)</td>
<td>$2041.1 \pm 420.6^\dagger$</td>
<td>$2067.9 \pm 592.6^\dagger$</td>
</tr>
<tr>
<td>RQ</td>
<td>$0.73^\dagger$</td>
<td>$0.79^\dagger$</td>
</tr>
<tr>
<td>$\text{VCO}_2$</td>
<td>$222 \pm 49.3^\dagger$</td>
<td>Available, see above</td>
</tr>
<tr>
<td>$\text{ETCO}_2$</td>
<td>Not available</td>
<td>38.1 $\pm$ 7.9$^\ddagger$</td>
</tr>
<tr>
<td>$\text{FiO}_2$</td>
<td>Not recorded</td>
<td>0.43$^\S$</td>
</tr>
<tr>
<td>$\text{VCO}_2$</td>
<td>Available, see above</td>
<td>241.0 $\pm$ 69.9$^*$</td>
</tr>
</tbody>
</table>

Conclusion: Poor agreement was found between the Deltatrac II and M-COVX or Evita 4 metabolic monitors, despite a good correlation between measurements, leading to the conclusion that the M-COVX and Evita 4 provide less accurate measurements of metabolic gas exchange in stable ventilated patients. These devices can be used for daily nutritional assessment and continuous monitoring, but the Deltatrac II remains the method of choice for metabolic measurement.
Indirect calorimetry in the ICU
What can we do with it?
- Patients randomized to receive enteral nutrition with an energy target determined
  - repeated indirect calorimetry measurements; study group, n=56
  - according to 25 kcal/kg/day; control group, n=56

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Study group (n = 56)</th>
<th>Control group (n = 56)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean RER (kg/day)</td>
<td>1.076 ± 0.468</td>
<td>1.238 ± 0.468</td>
<td>0.6</td>
</tr>
<tr>
<td>Mean energy delivered/day (kcal/day)</td>
<td>2,086 ± 460</td>
<td>1,480 ± 356</td>
<td>0.01</td>
</tr>
<tr>
<td>Mean enterally delivered energy/day (kcal/day)</td>
<td>1,515 ± 756</td>
<td>1,316 ± 456</td>
<td>0.09</td>
</tr>
<tr>
<td>Mean parenterally delivered energy/day (kcal/day)</td>
<td>571 ± 754</td>
<td>164 ± 294</td>
<td>0.001</td>
</tr>
<tr>
<td>Route of administration (n)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enteral</td>
<td>34</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Parenteral</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Enteral and parenteral</td>
<td>19</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Mean protein delivered/day (g/day)</td>
<td>76 ± 16</td>
<td>53 ± 16</td>
<td>0.001</td>
</tr>
<tr>
<td>Mean daily energy balance (kcal)</td>
<td>186 ± 206</td>
<td>-312 ± 481</td>
<td>0.001</td>
</tr>
<tr>
<td>Cumulative energy balance (kcal)</td>
<td>2,008 ± 2,177</td>
<td>-3,550 ± 4,591</td>
<td>0.01</td>
</tr>
<tr>
<td>Maximum negative energy balance (kcal)</td>
<td>15.7 ± 883</td>
<td>-3,895 ± 4,144</td>
<td>0.01</td>
</tr>
<tr>
<td>Daily mean blood glucose (mg/dL)</td>
<td>119.6 ± 21.8</td>
<td>127.3 ± 33.7</td>
<td>0.82</td>
</tr>
</tbody>
</table>
The tight calorie control study (TICACOS): a prospective, randomized, controlled pilot study of nutritional support in critically ill patients
The tight calorie control study (TICACOS): a prospective, randomized, controlled pilot study of nutritional support in critically ill patients
The tight calorie control study (TICACOS): a prospective, randomized, controlled pilot study of nutritional support in critically ill patients
Optimisation of energy provision with supplemental parenteral nutrition in critically ill patients: a randomised controlled clinical trial

Claudia Paula Heidegger, Mette M Berger, Séverine Graf, Walter Zingg, Patrice Darmon, Michael C Costanza, Ronan Thibault, Claude Pichard

Lancet 2013; 381: 385-93
Optimisation of energy provision with supplemental parenteral nutrition in critically ill patients: a randomised controlled clinical trial

Claudia Paula Heidegger, Mette M Berger, Séverine Graf, Walter Zingg, Patrice Darmon, Michael C Costanza, Ronan Thibault, Claude Pichard

By Day3:
-3856±1311 kcal

Day 4-8: 248±1479 kcal

Day 4-8: -2220±2478 kcal
Optimisation of energy provision with supplemental parenteral nutrition in critically ill patients: a randomised controlled clinical trial

Claudia Paula Heidegger, Mette M Berger, Séverine Graf, Walter Zingg, Patrice Darmon, Michael C Costanza, Ronan Thibault, Claude Pichard

![Graph showing proportion without nosocomial infection over time with SPN and EN groups.](image)

Number at risk
- SPN: 153, 148, 99
- EN: 152, 147, 71

Lancet 2013; 381: 385-93
Increase of Oxygen Consumption during a Progressive Decrease of Ventilatory Support Is Lower in Patients Failing the Trial in Comparison with Those Who Succeed

Giacomo Bellani, M.D., Ph.D.,* Giuseppe Foti, M.D.,† Ester Spagnolli, M.D.,‡ Manuela Milan, M.D.,§ Alberto Zanella, M.D.,§ Massimiliano Greco, M.D.,† Nicolò Patroniti, M.D.,* Antonio Pesenti, M.D.||

| Success: n= | 2 | 5 | 12 | 12 | 11 | 10 | 5 |
| Failure: n=  | 5 | 13| 16 | 16 | 15 | 14 | 8 |

\[ \text{VO}_2 (\% \text{ of VO}_2^{\text{REST}}) \]

Pressure Support (difference from resting level, cmH\textsubscript{2}O)

Anesthesiology 2010; 113:378–85
Correlation between respiratory drive (expressed as P0.1) & VO₂

SUCCESS
Continuous Monitoring of Oxygen Consumption in Patients Undergoing Weaning from Mechanical Ventilation

Keisuke Miwa  Masahiro Mitsuoka  Shinzo Takamori  Akihiro Hayashi
Kazuo Shirouzu

Respiration 2003;70:623–630
Metabolic monitoring
Any other use?
Bedside measurement of FRC

N₂ wash-out / wash-in

- Volume and concentration of Nitrogen captured
- Change Oxygen concentration
- Calculate change in Nitrogen
- Calculate FRC through metabolic monitoring

• FRC = VN₂/N₂%\text{start} - N₂%\text{end}
• N₂% = 1 - EtO₂–EtCO₂
• VN₂ = V_Ti x N₂%\text{in} - V_Te x N₂%\text{out}, where:
  - N₂%\text{in} = 1 - FiO₂
  - N₂%\text{out} = 1 - EtO₂ – EtCO₂

Metabolic stability is mandatory

Cecilia Olegård, MD*, Søren Søndergaard, MD, PhD*, Erik Houltz, MD, PhD†, Stefan Lundin, MD, PhD*, and Ola Stenqvist, MD, PhD*

Cecilia Olegård, MD*, Sören Søndergaard, MD, PhD*, Erik Houltz, MD, PhD*, Stefan Lundin, MD, PhD*, and Ola Stenvqvist, MD, PhD*
Accuracy and precision of end-expiratory lung-volume measurements by automated nitrogen washout/washin technique in patients with acute respiratory distress syndrome

Jean Dellamonica, Nicolas Lerolle, Cyril Sargentini, Gaetan Beduneau, Fabiano Di Marco, Alain Mercat, Jean-Christophe M. Richard, Jean-Luc Diehl, Jordi Mancebo, Jean-Jacques Roubuy, Qin Lu, Gilles Bernardin and Laurent Brochard

Critical Care 2011, 15:R294

![Graph showing relationship between EELV (mL) and largest difference (mL) with PEEP levels indicated.](image)

- Low PEEP
- High PEEP
- Mean low PEEP
- Mean high PEEP

$p = 0.004$
Accuracy and precision of end-expiratory lung-volume measurements by automated nitrogen washout/washin technique in patients with acute respiratory distress syndrome

Jean Dellamonica$^{1,2,5}$, Nicolas Lerolle$^{3,6}$, Cyril Sargentini$^8$, Gaetan Beduneau$^6$, Fabiano Di Marco$^6$, Alain Mercat$^6$, Jean-Christophe M Richard$^3$, Jean-Luc Diehl$^3$, Jordi Mancebo$^7$, Jean-Jacques Roub$^8$, Qin Lu$^8$, Gilles Bernardin$^2$ and Laurent Brochard$^{1,9,10}$
Bedside measurement of FRC

What can we expect?

- Establish a patient’s baseline FRC
- Evaluate the progression of acute lung injury
- Assess whether a specific therapy or a change in ventilation improves FRC
- Evaluate the effect of recruitment maneuvers
- Patient-tailored physiological determination of the “best PEEP”
PEEP-induced changes in lung volume in acute respiratory distress syndrome. Two methods to estimate alveolar recruitment

Strain high PEEP = (EELV at high PEEP – FRC)/(FRC + Rec_{mes})

Strain low PEEP = (EELV at low PEEP – FRC)/FRC
Rec_{estim} = -136 + 1.2 \times \text{Rec}_{mes}

P = 0.0002
PEEP-induced changes in lung volume in acute respiratory distress syndrome. Two methods to estimate alveolar recruitment.
Decremental PEEP trials to set PEEP?
- a practical alternative -

**Recruitment maneuver (RM)**

- $P_{aw} \ 40 \ cmH_2O \ x 40 \ sec$, then
- $P_{plat} \ \leq \ 30 \ cmH_2O$, $PEEP= PEEP_{dr} + 2 \ cmH_2O$

**ABG 10 min after RM**

- Adjust RR & $V_T$ for pH $> 7.25$
- Wean $FiO_2$ for $SpO_2 = 88-93 \%$

**Decrease PEEP \ 2 \ cmH_2O/5 \ min**

- stop @ "PEEP$_{dr}$", with $SpO_2 < \text{target}$

**Maintenance**

**Deflation**
Decremental PEEP trials

- Volume difference can represent either recruited or de-recruited volume.
- CRF measurements during a decremental PEEP trial following a recruitment maneuver can identify:
  - the response to recruitment manoeuvre
  - the level of PEEP where de-recruitment occurs.
FRC-guided PEEP setting in ALI - 1

![Graph showing FRC (mL) and SpO2 (%) vs. PEEP (cmH2O)]
FRC-guided PEEP setting in ALI

**Graphs:**
- **FRC (mL)**
  - Y-axis: 800 to 1800
  - X-axis: 6 to 16 PEEP (cmH2O)
  - Data points: (6, ?), (8, ?), (10, ?), (12, ?), (14, ?), (16, ?)

- **CO (L/min)**
  - Y-axis: 6 to 10
  - X-axis: 6 to 16 PEEP (cmH2O)
  - Data points: (6, ?), (8, ?), (10, ?), (12, ?), (14, ?), (16, ?)
FRC-guided PEEP setting in ALI -2
FRC-guided PEEP setting in ALI -2

Volume expansion 1500 mL saline serum
FRC-guided PEEP setting in ALI -2

Graphs showing the relationship between FRC (mL), SpO₂ (%), and PEEP (cmH₂O).
Summary

- Metabolic monitoring can be implemented in the ICU and has potential useful clinical applications in the critically ill
  - Optimization of nutrition therapy
  - Weaning

- Determination of FRC is potentially helpful to
  - Evaluate the progression of acute lung injury
  - Assess the efficiency of specific therapies or changes in ventilation strategies (PEEP setting, recruitment maneuvers, prone position, …)