ERS Annual Congress Barcelona
7 - 11 September 2013

Postgraduate Course 10
New technology assessment in COPD

Thank you for viewing this document. We would like to remind you that this material is the property of the author. It is provided to you by the ERS for your personal use only, as submitted by the author.

©2013 by the author

Saturday, 7 September 2013
14:00 - 17:30
Room: 4.1 (CC4)
Each book-length issue of the European Respiratory Monograph covers a specific area of respiratory medicine, providing in-depth reviews that give clinicians at all levels a concise, comprehensive guide to symptoms, diagnosis and treatment.

If you’re an ERS member, you automatically have full online access to the Monographs. To join the ERS, visit www.ersnet.org

Find out more at erm.ersjournals.com
Postgraduate Course 10
New technology assessment in COPD

Aims: This course will provide a state-of-the-art review of the cutting edge technologies for the assessment of respiratory and movement biomechanics in COPD; review wearable technologies for the assessment of physical activity in COPD; improve your physiological knowledge about the relationships between energy costs and motion, recent advances regarding alteration of equilibrium in COPD population will be discussed with the experts, with particular regards to the implications of biomechanics during therapeutical intervention such as exercise.

HERMES LINKS ADULT: A.1 Structure and function of the respiratory system, B.1 Airway diseases, D.1 Pulmonary function testing, E.1 Treatment modalities and prevention measures, F. Core generic abilities.

Target audience: Pulmonologists, emergency medicine doctors, respiratory therapists, respiratory physicians, clinical researchers, general practitioners, research fellows, basic scientists.

Chairs: E. Clini (Modena, Italy), L. Puente Maestù (Madrid, Spain)

COURSE PROGRAMME

14:00 Respiratory and movement biomechanics: laboratory assessment
A. Aliverti (Milan, Italy) 5

14:45 Quantifying daily life physical activity: state-of-the-art
T. Troosters (Leuven, Belgium) 33

15:30 Break

16:00 Equilibrium, balance and increased risk of falls related to COPD
P. Hodges (Brisbane, Australia) 45

16:45 Energy expenditure and activity: is it inefficient?
T. Dolmage (Toronto, Canada) 59

Faculty disclosures 89

Faculty contact information 91

Answers to evaluation questions 92
Respiratory and movement biomechanics: laboratory assessment

Andrea Aliverti
Dipartimento di Elettronica, Informazione e Bioingegneria
Politecnico di Milano
Italy
andrea.aliverti@polimi.it

Aims
- to highlight the relevance of biomechanical studies in COPD
- to introduce the basic concepts of biomechanics, kinematics, kinetics
- to introduce the basic concepts of movement biomechanics
- to illustrate the most important and up-to-date methods for studying movement biomechanics
- to introduce the basic concepts of respiratory biomechanics
- to illustrate the most important and up-to-date methods for studying respiratory biomechanics

Summary
In this presentation, it will be shown how modern approaches for human biomechanics science, including methods and instruments, are essential to investigate a long list of still unanswered questions regarding the relationship between movement (of upper and lower limbs and trunk) and respiration in COPD patients. Future studies are needed to address questions like: which are the differences in walking between hyperinflating and non-hyperinflating COPD patients? What is the impact of static hyperinflation and lower diaphragm on walking? What is the impact of the vertical oscillations of the thoracic and especially abdominal contents on breathing mechanics? What is the impact of different abdominal mass on breathing mechanics during walking? What is the interplay between leg strike frequency, abdominal pump function and cardio-respiratory interaction? What is the impact of arm movement on respiratory muscle use? How different exercise modalities (e.g. walking, cycling) influence trunk and limb biomechanics?

References
Evaluation

1. **Kinematics**
   a. describes movements with respect to time and space
   b. describes movements with respect to force
   c. is a synonymous of the term ‘biomechanics’
   d. cannot be applied to respiratory system

2. **Ground reaction forces are measured by**
   a. optical systems
   b. accelerometers
   c. piezoelectric platforms
   d. magnetic system

3. **Inverse Dynamics**
   a. allows to obtain joint kinematics
   b. allows to estimate joint torques
   c. allows to estimate ground reaction forces
   d. does not consider kinematics

4. **Optical plethysmography**
   a. measures chest wall kinematics
   b. measures chest wall kinetics
   c. measures chest wall mechanics
   d. measures respiratory muscle activity

*Please find all correct answers at the back of your handout materials*
Respiratory and movement biomechanics: laboratory assessment

ANDREA ALIVERTI

Politecnico di Milano
Dipartimento di Elettronica, Informazione e Bioingegneria

Faculty disclosure
There are no economic conflicting interests.
Andrea Aliverti (A.A.) is one of the inventors of Opto-Electronic Plethysmography.
The patents are owned by the Politecnico di Milano (Milan, Italy), A.A.’s institution, and licensed to BTS Spa Company.

Introduction

AIMS

• Relevance of biomechanical studies in COPD
• Introduction to biomechanics, kinematics, kinetics
• Movement biomechanics: concepts and methods
• Respiratory biomechanics: concepts and methods
WHY TO STUDY BIOMECHANICS IN COPD?

Walking abnormalities are associated with COPD: An investigation of the NHANES III dataset

Jennifer M. Yentes 1, Harlan Sayles 2, Jane Metz 3, David M. Mannino 4, Stephen I. Bernard 5, Nicholas Stengs 1,6,7

1 Nebraska Biomechanics Core Facility, University of Nebraska at Omaha, 725 N Dodge Street, BPM 207, Omaha, NE 68182, USA
2 College of Public Health, University of Nebraska Medical Center, 4025 N 42nd St, Omaha, NE 68137, USA
3 Biomechanics and Ergonomics, University of Nebraska, 4025 N 42nd St, Omaha, NE 68137, USA
4 Department of Pulmonary and Critical Care Medicine, University of Nebraska Medical Center, 4025 N 42nd St, Omaha, NE 68137, USA

Differences in Walking Pattern during 6-Min Walk Test between Patients with COPD and Healthy Subjects

Jannika Anneren 1, Martijne A. Saris 2, Hans C. M. Zwinderman 3, Paul J. B. M. Steenstra 4, Collin van der Beek 1, Annemiek M. W. J. Scholte 5, Emiel F. M. Wouters 6,3, Kenneth H. Meijer 7,8

1 Karolinska University Hospital, Stockholm, Sweden; 2 Julius Center for Health Sciences and Primary Care, Utrecht University, Utrecht, The Netherlands; 3 Netherlands Organisation for Applied Scientific Research (TNO), Utrecht, The Netherlands; 4 University Medical Center Groningen, Groningen, The Netherlands; 5 University Medical Center Utrecht, Utrecht, The Netherlands; 6 University Medical Center Groningen, Groningen, The Netherlands; 7 University Medical Center Utrecht, Utrecht, The Netherlands; 8 University Medical Center Utrecht, Utrecht, The Netherlands.
Subjects with COPD tend to walk with a forward trunk inclination as compared to controls

- Alterations in the peak hip extension moment in early stance of gait

- Is the primary focus of trunk musculature in patients with COPD on respiratory activity and not on movement?
Patients with COPD have a high susceptibility to falls, which is associated with a worsening of dyspnea perception as related to HRQoL.
BIOMECHANICS, KINEMATICS, KINETICS

- **Biomechanics** is the science concerned with the internal and external forces acting on the human body and the effects produced by these forces.
- **Kinematics** is the branch of biomechanics concerned with the study of movement from a geometrical point of view.
  - describes movements with respect to time and space
- **Kinetics** is the branch of biomechanics concerned with what causes a body to move the way it does
  - examines the forces that produce the movement and result from the movement

KINEMATICS: WHAT MIGHT WE MEASURE?

- **Position**
  - location in space relative to some spatial coordinate system reference (e.g., center of joint, COG, COM, point of contact)
- **Displacement**
  - is the straight line (distance and direction)
- **Distance**
  - the length of the path traversed
- **Center of gravity**
  - the point about which a body’s weight is equally balanced in all directions
  - Spatial components

KINEMATICS: WHAT MIGHT WE MEASURE?

- **Speed**
  - distance / time (m/s)
- **Velocity**
  - displacement / time (m/s)
- **Acceleration**
  - velocity / time (m/s²)
  - Spatial and temporal components
Angular motion
- parts rotate around an axis of rotation

Most movements, even the simplest ones, are likely a combination of both linear and angular motion.
### MEASURING BIOMECHANICS

**Kinematics**
- High speed cinematography
- High speed Videography
- Stroboscopy
- Optoelectric
- Electrogoniometry
- Accelerometry

**Kinetics**
- Pressure and Force transducers
- Force Platform
- Isokinetic dynamometer

**Other**
- Electromyography

### MEASURING KINEMATICS: OVERVIEW OF SYSTEMS

- Optical
- Inertial
- Magnetic
- Electro Mechanical

### MEASURING KINEMATICS BY OPTICAL SYSTEMS

- **Markers are placed on the subjects**
  - Number of markers varies by application/accuracy

- **Cameras used to record movement**
  - Generally 8 or more cameras used (depends on size of scene; studios for MoCap use ~70!)

- **Software detects the markers and triangulates the position of each visible marker relative to camera position**
MEASURING KINEMATICS
BY OPTICAL SYSTEMS

- Process of converting physical motion to digital representation
- Motion is measured and the position in 3D space is calculated
- Hardware used to measure changes
- Software used to calculate position

SETUP

CALIBRATION

ANALYSIS

MEASURING KINEMATICS
BY OPTICAL SYSTEMS

SETUP

CALIBRATION

ANALYSIS

MEASURING KINEMATICS
BY OPTICAL SYSTEMS
MEASURING MOTION

OPTICAL SYSTEMS: MARKERS

- Passive Markers
  - Retroreflective coating
    - Shines back the light sent from a light source beside the camera (like reflectors on a bike)

- Active Markers
  - LEDs used instead of reflectors
  - Camera filters all light except for the LEDs (IR)
  - Synchronized LEDs flash one at a time (at high speed) this makes identifying LEDs easier

OPTICAL SYSTEMS: ACTIVE MARKERS

- RF receiver is worn on the subject
- Used to synchronize LED flashes with cameras’ frame rate
- 1 LED visible per frame(s)
  - Allows faster processing
  - Requires high speed cameras
MEASURING KINEMATICS BY INERTIAL SYSTEMS

- Uses accelerometers and gyroscopes to measure movement
  - Think Wii Remote with higher accuracy
- The more sensors used, the better (more human) the results
- Inertial provides 6 Degree of Freedom (6DoF)
- Sensitive to within 1º of rotation

6DoF:
- translate X, Y, Z
- pitch, yaw, roll

MEASURING KINEMATICS BY MAGNETIC SYSTEMS

- Sensors on the subject measure low-frequency magnetic field created by the source
- Control Unit correlates the locations of the sensors and source within the field
- Benefits:
  - Markers can not be occluded
  - Fewer markers required
- Drawbacks:
  - Interference caused by steel (in building) or other electronic devices (like monitors)

MEASURING KINEMATICS BY ELECTROMECHANICAL SYSTEMS
MEASURING KINEMATICS
BY ELECTROMECHANICAL SYSTEMS

- Exoskeletal suit is worn by the subject
  - Aluminum or plastic rods connect multiple potentiometers which simulate joints
  - Gyroscopes on hips and upper back used to measure rotation
  - Change in voltage is measured (analog to digital) and position is calculated

MEASURING BIOMECHANICS

- Kinematics
  - High speed cinematography
  - High speed Videography
  - Stroboscopy
  - Optoelectric
  - Electromyography
  - Accelerometry

- Kinetics
  - Pressure and Force transducers
  - Force Platform
  - Isokinetic dynamometer

- Other
  - Electromyography
CLINICAL GAIT ANALYSIS REPORTS

- Single sensor
- Spatial-temporal gait parameters
- Report
- Normative data

GAIT PARAMETERS

- Time percent of cycle
  - Double support
  - L. Single support
  - Double support
  - R. Swing phase
  - L. Swing phase
  - Double support
  - R. Swing phase
  - L. Single support
  - Double support
  - L. Swing phase
  - R. Swing phase
  - Double support
  - L. Swing phase
  - R. Swing phase
  - Double support
  - L. Swing phase
  - R. Swing phase
  - Double support
GAIT PARAMETERS

- Swing Time
- Stance Time
- Single and double support Time
- Gait cycle Time
- Step length
- Stride length
- Stride width (base of support)
- Speed
- Cadence

Parkinson disease
Spatial-temporal gait parameters are indicators of rehabilitation treatment efficacy, especially the pharmacological one. Spatial parameters (as the step length) are for example DOPA-dependent, unlike the temporal parameters (DOPA-resistant).

Prevention of the fall risk in elder subjects
Reduced speed and stride length and increased double support time are associated with fear of falling, resulting from an adaptation to a gait pattern that ensure a safer walking approach. But, when these parameters show short-term variability, they become an independent predictive factor of falling.

A VERY SIMPLE EXAMPLE: A LOWER LIMB MODEL

Hypotheses
- Planar motion (sagittal plane)
- Joints are modelled using cylindrical hinges (1 dof)

Experimental model
Joint centres:
- Hip (H)
- Knee (K)
- Ankle (A)
- Metatarsus-phalanx-V toe

Joint k
H
K
A
M

20
FLEXION-EXTENSION ANGLES OF THE LOWER LIMB JOINTS DURING WALKING

MORE COMPLEX KINEMATIC MODELS

INVERSE DYNAMICS
EVALUATION OF RESPIRATORY FUNCTION

Ventilation  Diffusion  Perfusion

Respiratory mechanics
- Force (Pressure)
- Displacement (Volume)
- Velocity (Flow)

"active" components
- respiratory muscle action
  - force
  - work
  - power
  - endurance
  - fatigue

"passive" components
- mechanical properties
  - compliance
  - resistance
  - inertance
  - impedance

Statics
- force, F
- work, W
- power, P
- energy, E

Dynamics
- displacement, x
- velocity, x'
- acceleration, x''
- force, F
- work, W
- energy, E

Energetics
- heat, Q
- temperature, T
- entropy, S

Mechanical system ↔ Respiratory system

- position, x ↔ volume, V
- velocity, x' ↔ flow, V'
- acceleration, x'' ↔ var. flow, V''
- force, F ↔ pressure, P
- rigidity, K ↔ elastance, E
- (distensibility, 1/K) ↔ (compliance, C)
- friction, B ↔ resistance, R
- mass, M ↔ inertance, I

F = Kx + Bx' + Mx''

P = EV + RV + I\dot{V}

E = 1/C
Respiratory Muscle length ⇔ Pressure
Respiratory Muscle force ⇔ Maximal expiration Elastic recoil of resp. System (Prs)
Maximal inspiration
PE max
PI max
FRC
TLC
RV

RESPIRATORY SYSTEM: A SIMPLE MODEL
Airways (AW)
Lung (L)
Chest wall (CW)
MEASUREMENT OF CHEST WALL MOTION

"Chest wall = all parts of the body outside the lung which share changes in the volume of the lungs"

During breathing, chest wall varies not only volume, but also shape.

Measurement has to be done in several points of the thoraco-abdominal wall.

RESPIRATORY INDUCTIVE PLETHYSMOGRAPHY (RIP)

Wearable shirts with strain gauges

SYSTEMS BASED ON STRUCTURED LIGHT: THE ORIGINS

Morgan et al, Thorax, 2004
**SYSTEMS BASED ON STRUCTURED LIGHT: RECENT EVOLUTIONS**

Chen et al. Journal of Biomedical Optics, 2010

**OPTO-ELECTRONIC PLETHYSMOGRAPHY**

**COMPARTMENTAL VOLUMES**

Gauss theorem

\[ \nabla = \int \frac{\rho}{\rho} F dV - \int F \cdot n dS \]
END-EXPIRATORY / END-INSPIRATORY VOLUMES DURING EXERCISE

DYNAMIC HYPERINFLATION IN COPD: BREATH-BY-BREATH MEASUREMENT

COPD: END INSPIR./ END EXP. VOLUMES DURING EXERCISE


CHEST WALL ASYNCHRONIES

Rib cage asynchronies:
- RCp volume variations
- RCA volume variations
- AB volume variations

Thoraco-abdominal asynchronies
- relative action and coordination of the rib cage muscles and the diaphragm

QUANTIFICATION OF CHEST WALL ASYNCHRONIES BY LISSAJOUS LOOPS

phase shift (degrees) = arcsin(m/s)

Agostoni, Mognoni, J. Appl. Physiol. 1966

0° = perfectly synchronous
180° = perfectly out-of-phase

POSITIVE ANGLES (clockwise direction):
- Rib cage is leading on the abdomen

NEGATIVE ANGLES (counterclockwise direction):
- The abdomen is leading on the rib cage

OTHER METHODS

Lissajous loop analysis
- Cross correlation method
- Least squares fitting method
- First derivative of the normalized difference
LOWER RIB CAGE ASYCHRONY IN COPD

Aliverti et al, ERJ, 2009

LOWER RIB CAGE ASYCHRONY IN COPD IS RELATED TO THE PATTERN OF CHEST WALL DYNAMIC HYPERINFLATION DURING EXERCISE

Aliverti et al, ERJ, 2009

EFFECT OF POSTURE ON ASYCHRONY

UNANSWERED QUESTIONS IN COPD

- which are the differences in walking between hyperinflating and non-
  hyperinflating COPD patients?
- what is the impact of static hyperinflation and lower diaphragm on
  walking?
- what is the impact of the vertical oscillations of the thoracic and
  especially abdominal contents on breathing mechanics? and what is the
  impact of different abdominal mass on breathing mechanics during
  walking?
- what is the interplay between leg strike frequency, abdominal pump
  function and cardio-respiratory interaction?
- what is the impact of arm movement on respiratory muscle use?
- how different exercise modalities (e.g. walking, cycling) influence trunk
  and limb biomechanics?
Quantifying daily life physical activity: state-of-the-art

Prof. Thierry Troosters
U.Z Gasthuisberg
Labo Ademspierven Pneumologie
Heresstraat 49
3000 LEUVEN BELGIUM
thierry.troosters@med.kuleuven.be

Summary
Enhancing Physical Activity (PA) has become an important goal for therapy in lung disease. Physical activity is classically defined as all movements of the body that result in energy expenditure beyond resting energy expenditure\(^1\). The engagement of people in physical activity is an ‘active choice’ of the patient which depends of the patient’s exercise capacity, his/her motivation to use this capacity in everyday life and external factors such as climate and day length. When measured in a valid way, knowledge on physical activity can be used as an outcome measure, or it can serve as a guide to coach patients towards a more active life style.

The assessment of physical activity can, hence, only be assessed in real life, in relatively uncontrolled conditions. Physical activity is by nature variable from day to day, which poses a problem for clinical studies to achieve sufficient statistical power. Several challenges should be addressed when discussing the use of activity monitors in clinical trials: 1) the validity of the monitor, 2) managing the variability of outcomes 3) interventions should be geared towards behavioural change.

Patients need to have the commitment to wear the monitor long enough and for sufficient number of days. Monitors with high usability facilitate the ease of wearing. Typically adherence with monitor wearing is satisfactory, even in multicentre trials.

1) Validity of the activity monitors
Activity monitors need to be small and wearable and should not hinder the movement of a patient, monitors should also allow for long periods of assessment, which means battery life and memory should be as large as possible. Typically the contemporary monitors consist of accelerometers that measure the acceleration of the body in one, two, or three dimensions. To better estimate energy expenditure some manufacturers have integrated other bodily signals such as heart rate, temperature galvanic skin resistance. Context information can be provided by GPS technology (for outdoor activity), but this is not yet implemented in many monitors. The challenge of the use of monitors in patients is the low movement intensity, which makes it difficult to pick up movements. Few studies have looked at the validity of monitors in COPD. The most comprehensive effort in terms of validation of activity monitors was made by the PROactive consortium (An IMI-JU project www.PROactivecopd.com) that first did a systematic review of the literature and next conducted a laboratory study and a field validation study with 6 activity monitors. Three monitors passed a priori criteria of validity: The sensewear armband, the Actigraph GTX3 and the Dynaport Minimod. It should be mentioned that none of the monitors provides an accurate assessment of energy expenditure, but the assessment of the movements of patients is provided adequately\(^2\)\(^-\)\(^4\).

2) Managing the variability
Day to day variability is inherent to physical activities as no two days are the same. Variability can be considered as noise on a signal. Part of this noise is due to inaccuracies in the measurement, part of this noise unpredictable (random) and part of the noise is predictable (and can be accounted for in adequate statistics). Variability induced by the measurement related mostly to either inaccuracy in the obtained signals (e.g. driving a car may be picked up as movement by a poor activity monitor) or by differences in wearing time (i.e. compliance). Sufficient hours of assessment are needed to obtain
meaningful signals. Comparable hours of assessment are needed in pre-post designs to minimize variability. Typically 8-10h of assessment during waking hours is a minimum to obtain meaningful data. In order to minimize ‘random’ day-to-day variability, a minimum of four days of assessment is needed to get a sufficient estimate of a patient’s physical activity level in pre-post intervention designs. Some of the variability in PA signals is not random. For example seasonal variability is expected. One ‘marker’ of season that can easily be introduced into statistical analysis is daylight time. Our group has shown that the variability on treatment effects can be reduced substantially when this variable is introduced as a covariate in the analysis. A second ‘predictable source of variability is when weekends are included in the analysis. Whereas weekends are an integral part of a patient’s life, the weekends tend to be more variable in terms of PA. Leaving the weekends out of the analysis again proved to reduce the variability in pre-post designs.

In summary beyond the selection of a valid activity monitor, and the appropriate outcome, several steps can be undertaken to minimize the variability in physical activity, without impacting on the assessed treatment effect. First, ensuring sufficient and comparable hours of assessment, second, ensuring sufficient number of days of assessment, third, taking into account the season of assessment as a covariate, and last, avoiding weekends in the analysis.

3) Designing studies to improve PA
Even when variability is controlled as much as possible, studies may have difficulties showing increased amounts of PA after interventions. Indeed, changing PA is only seen after successful behavioural change of the patient. A change in exercise tolerance surely can facilitate such a change of behaviour, but it is no guarantee. In the next few years more efforts should be taken to alter the physical activity behaviour. This may involve changing self-efficacy, changing health beliefs, and alleviating practical barriers to physical activity.

References
Physical activity monitoring
A state of the art
thierry.troosters@med.kuleuven.be

Outline

- When do you want to use PA monitors
- What monitors can be used
- How should these be used
- How to work with PA monitor data

When do you want to assess PA

- Physical activity / Exercise tolerance / functional status

- Physiology
  - Disease process
  - Motivation

- Physiological
  - Comorbidity
  - Season
  - Behavior
  - Self efficacy
  - Health beliefs

- Functional capacity
- Functional Reserve
- Functional Performance
- Functional Capacity Utilization
When do you want to assess PA

• What do you expect/hope from your intervention?

<table>
<thead>
<tr>
<th>Risk of outcome</th>
<th>Relevance to pt</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

- Athens
- Edinburgh
- Leuven
- London
- Groningen

Data from PROactive consortium

Assessment of the amount of PA

<table>
<thead>
<tr>
<th>Possible problems related to PA</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient intentional movements (type, intensity)</td>
<td>Accelerometry, gyroscopes, in-house video, GPS</td>
</tr>
<tr>
<td>Specific movements (upper-lower limb)</td>
<td>Limb mounted sensors (acceleration, gyroscopes, pressure)</td>
</tr>
<tr>
<td>Patients unintentional movements (sleep, tremor)</td>
<td>Limb mounted accelerometer, UV video</td>
</tr>
<tr>
<td>Events (falls, stumbles)</td>
<td>Video system, smart accelerometer</td>
</tr>
<tr>
<td>Energy balance (obesity research)</td>
<td>DLW, caloric chamber, energy estimates</td>
</tr>
<tr>
<td>Metabolic Equivalent of Tasks</td>
<td>(indirect) calorimetry, VO2, Heart rate</td>
</tr>
</tbody>
</table>

Real life assessment
Outline

- When do you want to use PA monitors
- What monitors can be used
- How should these be used
- How to work with PA monitor data

Step 1 Systematic literature review

Literature review reveals gaps and provides potentially interesting monitors

40 monitors tested in Literature in ‘adult/elderly or patients with chronic disease’
- 12 uni-axial, 3 bi-axial, 16 tri-axial accelerometers
- and 9 multi-sensor devices.

16 out of 134 studies in chronic disease (5 in COPD)
6 monitors further tested

- Sensewear Armband (METS)
- Dynaport Minimod (METS)
- Actigraph GT3X (VMU)
- Actiwatch (Counts)
- RT3 (VMU)
- Oxycor Mobile (Criterion) (VO2)
- Kenz Lifecorder (Activity-score)

Lab and field validation of 6 activity monitors

- VO2 (METs)
- Actigraph

Van Remoortel, Raste PLoS one 2012
Lab and field validation of 6 activity monitors

What are monitors good at?

What are monitors not good at?

Clinical relevance?

Is VO2 important is one wants to capture Activity

YES if collected in the context of health, morbidity

NO if collected in the context of how much your patient moves

Picking up changes in VO2 that are not movement dependent (e.g. uphill, terrain, backpack, etc. . . )
Lab and field validation of 6 activity monitors

Did the monitor Bother you?  
Willingness to wear monitor  
Did you feel your privacy invaded?

Summary of PROactive monitor validation
Do these monitors measure the same?

Outline

- When do you want to use PA monitors
- What monitors can be used
- How should these be used
- How to work with PA monitor data

Questions to be asked

- How many days?
  - Cross sectional questions 2 days
  - Longitudinal questions 4 days
- How many hours per day?
  - Longer requirements = more missing data
  - 8 to 10 hours is a good compromise
- How often?
  - Depending on question. Important: seasonality
How many days per week?

<table>
<thead>
<tr>
<th>Valid days in a week (8h)</th>
<th>Valid days in a week (10h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Outline

- When do you want to use PA monitors
- What monitors can be used
- How should these be used
- How to work with PA monitor data

Minimizing variability to maximize power

- Choice of the outcome measure from the monitor
- Number of days to have robust measure of PA
- ‘Post processing’
**Is the chosen outcome important?**

<table>
<thead>
<tr>
<th>Steps</th>
<th>Time (weeks)</th>
<th>Mean METS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>3981 ± 2602</td>
<td>50 ± 56</td>
</tr>
<tr>
<td>Effect</td>
<td>346 ± 2364</td>
<td>15 ± 63</td>
</tr>
</tbody>
</table>

Effect (% base) | 23% | 30% | 4% |

SD effect (% effect) | 249% | 420% | 508% |

**Demeyer Submitted**

**Is the analysis technique important?**

No decline as more days are assessed.

**Hecht COPD 2009**

**Is the analysis technique important?**

\[
\theta = 0.2165108 + 2 \tan^2 \left(0.9671396 \tan(0.00860 X (\pi - 180))\right)
\]

\[
\phi = \sin^{-1}\left(0.899795 \cos \theta\right)
\]

\[
D = 24 - \frac{24 - 150}{\sin^{-1}\left(0.899795 \cos \theta\right)}
\]

Model of Forsythe, et al. with a daylength coefficient of 0.8333 and a latitude of 50.78° [24].
## Conclusions

- Physical activity monitors should be used as a remote, but patient centered outcome.
- The PROactive project validated three monitors for use in COPD, a blueprint to validate new monitors was provided.
- The use of monitors depend on the question asked. For longitudinal questions a minimum of 4 days with 8 hours can be advised.
- Post processing is in its infancy, but clearly analyses can be adjusted for known sources of variability such as daylight time.
Equilibrium, balance and increased risk of falls related to COPD

Paul W. Hodges
Centre for Clinical Research Excellence in Spinal Pain, Injury and Health
School of Health and Rehabilitation Sciences
The University of Queensland
Brisbane, Qld 4072
Australia
p.hodges@uq.edu.au

Aims
- Overview the problem of balance and falls in COPD
- Review key concepts in balance and equilibrium
- Consider relationship between balance and falls
- Present evidence for compromised balance in COPD
- Discuss possible mechanisms for compromised balance in COPD
- Consider the inter-relationship between balance disorders and other conditions common in COPD such as back pain and incontinence
- Review methods to assess balance in clinical and laboratory settings
- Consider rehabilitation options for management of balance disorders in COPD

Summary
Falls are a major issue for the ageing population and are common in people living with chronic obstructive pulmonary disease (COPD). Falls incidence increases with age and have a complex aetiology. Although balance ability is a major determinant, other features contribute such as cognitive decline, fear of falling and environmental factors [1]. Many of the issues that underlie balance decline in COPD are similar to those of ageing, but some are specific to or compounded by the pathophysiology of the array of issues associated with COPD. This paper provides an overview of balance control mechanisms, how this changes in people with COPD, and provides an overview of options for assessment and rehabilitation of balance disorders in this group, with the view to reduce the incidence of falls.

Falls in COPD
Falls have a devastating effect on quality of life and high relationship to mortality in the elderly [2]. The incidence of falls is greater for people with COPD than the general population and has been estimated at 25-46% for people with this condition [3-5]. This rate is second only to that associated with knee osteoarthritis amongst the major chronic disease that affect the community [3]. Although falls risk is multifactorial, balance presents as an important determinant. Performance on standard clinical balance measures discriminate fallers from non-fallers [6] and decreased balance performance is associated with increased risk of falls in COPD [7]. Assessment and management/prevention of balance disorders requires a thorough understanding of the multiple determinants of effective balance control and consideration of the COPD-related factors that can compromise balance and increase the risk of falling.

Balance/Equilibrium concepts
Balance is a complex phenomenon that involves the complex interplay of multiple systems [8]. These systems/components can be summarised as follows:
- Musculoskeletal system – muscle strength; muscle stiffness; muscle endurance; range of motion; physical capacity; posture/body alignment; joint range of motion
- Sensory system – sensory information of body position with respect to gravity and the environment, and the body segments with respect to each other, from vestibular,
somatosensory and visual systems; integration of sensory information and re-weighting of sensory information

- **Motor strategies** – anticipatory strategies; reactive strategies; tonic activation
- **Cognitive control** – attention; learning
- **Orientation in space** – perceived vertical; internal representation of body; adaptation to environment

The maintenance of equilibrium requires a constant flow of sensory input regarding the position of the body with respect to gravity and the environment, and the body segments relative to each other. Inputs are derived from multiple potential sources of information (vision, vestibular and somatosensory) with adjustable weighting of each dependent on the availability and reliability. The nervous system continually adjusts muscle activation either in the form of modulation of tonic muscle activation to effect muscle stiffness, or adaptive strategies of muscle activity in response to unexpected perturbations, or anticipatory muscle activation strategies in advance of predictable perturbations. These postural strategies are matched to the environmental context and updated with experience. Their efficacy depends on the potential of the musculoskeletal systems to exert forces that are sufficient to meet the demands. COPD can effect many aspects of this multisystem function.

**Balance and falls in COPD: Incidence and mechanisms**

COPD is characterised by a range of respiratory and non-respiratory manifestations that could have an impact on many of the determinants of balance performance, directly or indirectly, and therefore increase the risk for falling. Some COPD-specific factors that have been associated with poor balance performance and falls are: lower limb muscle weakness [9], dyspnoea, hypoxemia [10], nutritional depletion, malnutrition, depression, cognitive impairments, medication use [11], and reduced physical activity levels [9]. These factors have direct and indirect relationships to balance and falls and the mechanisms underpinning the associations have been considered in greater detail.

Musculoskeletal compromise such as muscle weakness is a major determinant of balance decline and falls in the general population [12]. Muscle weakness is largely due to deconditioning which is common in this population due to multiple aspects of COPD such as malnutrition, bed rest during exacerbations, and activity limitation secondary to dyspnoea.

Medication use by people with COPD compounds the effects of the condition. Systemic corticosteroids increase muscle weakness. Cardiac and hypertensive medications lead to postural orthostatic hypotension and syncope.

Cognitive decline could explain balance deficits as a result of reduced ability to dual task. Recent data have provided additional insight into the possible mechanisms that underpin balance decline in COPD [13]. Laboratory measures of ground reaction forces from force plates provide evidence of compromised balance in the mediolateral direction, but not anteroposterior direction. A key implication of balance compromise in this plane is that it is dependent on torques generated at the hip rather than the ankle. This is accompanied by reduced motion at the hips and spine in the frontal plane, associated with augmented activation of abdominal muscles (Smith and Hodges, unpublished data). Such abdominal muscle activation is in addition to the augmented expiratory activation of these muscles. These changes provide a plausible explanation for balance compromise that could be targeted with interventions. Additional, data point to reduced postural function of the diaphragm in people with COPD [14, 15].

**Inter-relationship between balance, breathing disorders, back pain and continence: Mechanisms and implications**

Recent work has highlighted an important interrelationship between breathing disorders, back pain and continence. Epidemiological work highlights cross-sectional [16] and longitudinal associations between these conditions [17], and this may be explained by neuromuscular adaptations in each condition. Back pain is more prevalent in people with breathing disorders and incontinence than those
without [16], and the presence and/or development of breathing disorders and incontinence predict the development of back pain in women [17]. Current work highlights a potential mechanism to underlie this interaction; i.e. modification of trunk muscle activation. Activation of the trunk muscles is modified in COPD, back pain and incontinence. For instance, activation of oblique abdominal muscles is augmented: in COPD to aid expiration and coughing, but may limit chest wall expansion if sustained; in back pain to protect the spine, but with an associated increased load on the spine [18]; and in many women with incontinence as an ineffective and counterproductive method to attempt to maintain urinary continence [19]. Such adaptation of abdominal muscle activation has been argued to explain compromised balance performance in back pain [20] and breathing disorders [13] as a result of associated restriction of trunk motion/moments. The interrelationship between these common comorbidities requires further consideration in balance disorders in COPD as a risk factor that is potentially modifiable with treatment.

Assessment of balance
Balance assessment can be undertaken with a range of measures from comprehensive laboratory measures that probe the various physiological contributions to balance performance or more general clinical measures. A recent systematic review of balance assessment in COPD identified three frequently used clinical measures for postural control and fear of falling; Berg Balance Scale, the Short Physical Performance Battery, and the Activities-specific Balance Confidence scale [10]. Some of the commonly used clinical tests of balance and fear of falling are:

- Berg Balance Scale (BBS) – Rates the performance of 14 test items related to postural control constructs linked to maintaining and changing body positions (e.g. transfers, reaching, turning around, and single-legged stance)
- Short Physical Performance Battery (SPPB) – Measures balance in 3 subscales
- Balance Evaluation Systems Test (BESTest) – 36-item comprehensive clinical balance assessment tool that evaluates six subsystems of balance control (Biomechanical constraints; Stability limits/verticality; Anticipatory adjustments/transitions; Postural responses; Sensory orientation; Stability in gait) as judged by time or performance criteria
- Sensory Organization Test (SOT) – Tests postural sway and the contributions of each sensory system in standing. The test involves modification of the support surface and visual surround to individually study the contribution of sensory systems to postural sway.
- Functional Reach Test (FRT) – Single domain measure of maximum reach distance
- One-Leg Stance (OLS) – Single domain measure of time of standing on one leg
- Sit-to-Stand Test – Measure of number of repetitions of performance of task
- Activities-specific Balance Confidence (ABC) scale – Measure of the fear of falling using 16 items rated from 0% (no confidence) to 100% (complete confidence).

Laboratory measures of balance provide detailed analysis of specific components of balance control and can involve measures of ground reaction forces using force plates, body motion using three-dimensional movement analysis systems, and muscle activity using electromyography. Balance is generally probed by investigation of features of kinematics, kinetics and muscle activation during quiet stance, dynamic balance tasks, and adjustments associated with predictable (to study anticipatory postural adjustments) and unpredictable (to study reactive postural adjustments) perturbations using paradigms such as support surface translation, voluntary limb movements and gait initiation.

Considerations for rehabilitation
Balance rehabilitation for the prevention of falls in the general population has been studied extensively, but has received limited attention in the COPD literature. A range of interventions are used in clinical practice to address the multiple factors associated with balance control; from interventions that address sensory modalities and muscle strengthening to environmental interventions. Conventional pulmonary rehabilitation programs to not routinely address these issues [21] and this is an area that requires further development.
Conclusion

Balance impairment and falls are a major issue in COPD. Patients require careful assessment to identify the underlying mechanisms. Targeted intervention for balance rehabilitation and falls prevention require consideration, particularly in pulmonary rehabilitation programs.

References


Evaluation

1. Balance ability is dependent of which of the following systems/components;
   a. Sensory system
   b. Musculoskeletal system
   c. Cognitive control
   d. Motor strategies
   e. All of the above

2. Which of the following is not a clinical test of balance;
   a. Berg Balance Scale (BBS)
   b. Short Physical Performance Battery (SPPB)
   c. Physical Activity Scale for the Elderly (PASE)
   d. Balance Evaluation Systems Test (BESTest)
   e. Sensory Organization Test (SOT)

3. Balance may be compromised in the mediolateral direction (frontal plane) by;
   a. Ankle muscle weakness
   b. Reduced moments/movement at the hip and spine in the frontal plane
   c. Non-steroidal anti-inflammatory drug use
   d. Ankle joint stiffness
   e. None of the above

4. Compromised balance has not been related to which of the following manifestations of COPD;
   a. Lower limb muscle weakness
   b. Dyspnoea
   c. Medication use
   d. Reduced FEV1
   e. Reduced physical activity levels

5. Which of the following statements about balance impairment in COPD is not true;
   a. Amongst chronic diseases, incidence of falls in COPD is second only to knee osteoarthritis
   b. Falls are a debilitating sequelae of COPD
   c. Balance rehabilitation and falls prevention are a standard component of current pulmonary rehabilitation programs for COPD
   d. Multiple tests of balance have been used to study balance which makes comparison of studies difficult.

Please find all correct answers at the back of your handout materials
EQUILIBRIUM, BALANCE AND INCREASED RISK OF FALLS RELATED TO COPD

PAUL W. HODGES

Centre For Clinical Research Excellence In Spinal Pain, Injury and Health
School of Health and Rehabilitation Sciences
The University of Queensland
Brisbane, Qld 4072 Australia

Introduction

AIMS

• Aim 1 Overview the problem of balance and falls in COPD
• Aim 2 Review key concepts in balance and equilibrium
• Aim 3 Consider relationship between balance and falls
• Aim 4 Present evidence for compromised balance in COPD
• Aim 5 Discuss possible mechanisms for compromised balance in COPD
• Aim 6 Consider the inter-relationship between balance, breathing disorders, back pain and incontinence
• Aim 7 Review assessment of balance
• Aim 8 Consider rehabilitation of balance disorders in COPD

Falls in COPD

• Falls are a major issue for the ageing population
• Devastating effect on quality of life and high relationship to mortality (Salkeld, Cameron et al. 2000)
• Incidence in COPD greater than the general population
• Second only to knee osteoarthritis
Falls in COPD

- Falls risk is multifactorial
- Balance is an important determinant
- Standard clinical balance measures discriminate fallers from non-fallers (Roig et al. 2009)
- Assessment and management/prevention of balance disorders requires understanding of balance

Balance/equilibrium concepts

- Balance - complex interplay of multiple systems (Shumway-Cook and Woollacott 2006)

Balance

- **Musculoskeletal system**
  - Muscle strength; muscle stiffness; muscle endurance; range of motion; physical capacity; posture/body alignment; joint range of motion,

- **Sensory system**
  - Sensory information of body position with respect to gravity, environment, from vestibular, somatosensory and visual systems; integration of sensory information and re-weighting of sensory information,
Balance

- **Motor strategies**
  - selection of motor strategy (anticipatory strategies; reactive strategies; tonic activation)
- **Cognitive control**
  - attention; learning,
- **Orientation in space**
  - perceived vertical; internal representation of body; adaptation to environment.

Balance and Falls in COPD: Incidence and Mechanisms

- Respiratory and non-respiratory manifestations of COPD can compromise balance
- COPD-specific factors associated with poor balance performance and falls
  - Lower limb muscle weakness
  - Dyspnoea
  - Hypoxemia
  - Nutritional depletion and malnutrition
  - Depression
  - Cognitive impairments
  - Medication use
  - Reduced physical activity levels

Musculoskeletal Compromise

- **Muscle weakness**
- **Determinant of balance decline and falls in the general population** (Moreland et al. 2004)
  - Deconditioning
    - Malnutrition
    - Bed rest during exacerbations
    - Activity limitation secondary to dyspnoea
Medication use

• Systemic corticosteroids
  — Increase muscle weakness

• Cardiac and hypertensive medications
  — Postural orthostatic hypotension and syncope

Cognitive decline

• Reduced ability to dual task

Mediolateral postural control

• Ground reaction forces
  — Compromised balance in the mediolateral direction, but not anteroposterior direction

• Dependent on torques generated at the hip rather than the ankle

• Reduced motion at the hips and spine in the frontal plane and augmented abdominal muscle activity (Smith and Hodges, unpublished data)

• Reduction postural function of the diaphragm (Hodges et al. 2000, Janssens et al. 2013)
Inter-relationship between breathing disorders, balance, back pain and urinary incontinence

- Epidemiology
- Cross-sectional and longitudinal associations between conditions
  - Back pain - more prevalent in people with breathing disorders and incontinence than those without (Smith et al. 2006)
  - Presence and/or development of breathing disorders and incontinence predict the development of back pain in women (Smith et al. 2013)

- May have neuromuscular mechanism
  - Activation of the trunk muscles is modified in COPD, back pain and incontinence
  - e.g., Augmented activation of oblique abdominal muscles
  - COPD - aid expiration and coughing - limit chest wall expansion if sustained
  - Back pain - protect spine - inc. spine load (Hodges et al. 2013)
  - Incontinence - ineffective and counterproductive attempt to maintain continence (Smith et al. 2007)
  - Adaptation of abdominal muscles may compromise balance
  - Back pain (Mok et al. 2011) and breathing disorders (Smith et al. 2010)
  - Restriction of trunk motion/moments

- Potentially modifiable risk factor to consider for treatment

Assessment of balance

- Multiple clinical and laboratory tests of balance and fear of falling
Clinical tests of balance

- Berg balance scale (BBS)
  - Performance of postural control constructs linked to maintaining and changing a range of basic body positions (e.g. Transfers, reaching, turning around, and single-legged stance)

- Short physical performance battery (SPPB)
  - Measures balance in 3 subscales

- Balance evaluation systems test (BESTest)
  - Comprehensive clinical balance assessment tool that evaluates six subsystems of balance control (biomechanical constraints; stability limits/verticality; anticipatory adjustments/translations; postural responses; sensory orientation; stability in gait) as judged by time or performance criteria

- Sensory organization test (SOT)
  - Tests postural sway and the contributions of each sensory system in standing

- Functional reach test (FRT)
  - Single domain measure of maximum reach distance

- One-leg stance (OLS)
  - Single domain measure of time of standing on one leg

- Sit-to-stand test (STS)
  - Measures of number of repetitions of performance of task

- Activities-specific balance confidence (ABC) scale
  - Measure of the fear of falling
Laboratory tests of balance

- Detailed analysis of specific components of balance control
  - Ground reaction forces using force plates
  - Body motion using three-dimensional movement analysis systems
  - Muscle activity using electromyography

Laboratory tests of balance

- Kinematics, kinetics and muscle activation during
  - Quiet stance
  - Dynamic balance tasks
  - Adjustments associated with predictable (to study anticipatory postural adjustments) and unpredictable (to study reactive postural adjustments) perturbations

Considerations for rehabilitation

- Limited attention in the COPD literature
- Not included in conventional pulmonary rehabilitation programs (Beauchamp et al. 2010)
- Many interventions are available to address
Conclusion

• Balance impairment and falls are a major issue in COPD
• Requires careful assessment to identify the underlying mechanisms
• Targeted intervention for balance rehabilitation and falls prevention require consideration, particularly in pulmonary rehabilitation programs
Energy expenditure and activity: is it inefficient?

Tom Dolmage MSc
Special Procedures Technologist/Scientist
Respiratory Diagnostic & Evaluation Services
West Park Healthcare Centre
Toronto, ON CANADA M6M2J5
tom.dolmage@westpark.org

Aims
The aim of this presentation is to improve your physiological knowledge of the relationships between energy, exercise and physical activity with specific attention to individuals with COPD and provide an overview of technologies that measure exercise related energy expenditure with examples of how they are used in clinical research.

Summary
Energy is an important unifying concept in exercise physiology because many physical phenomena can be analysed in terms of continuous transformation of energy from one form (food) to another (physical work). An understanding of energy demands of different physical activities explains how some activities can be endured indefinitely while others only for seconds. It also helps explain why an endurance athlete can perform well on a long distance run and have less than normal strength whereas a weight lifter has phenomenal strength but perform poorly in a 10 km run. The attractive approach to exercise training and energy conservation is to understand the energy components of an activity and then improve those systems to facilitate optimal adaptation and performance. Improved energy transfer translates to improved performance of physical tasks. Additionally, it is becoming apparent that increased energy transfer by muscle contraction translates to healthier body organs.

The presentation begins by briefly describing the physical units related to the first law of thermodynamics that ‘energy cannot be created or destroyed; only converted from one form to another’. Energy is defined as the ability to do work. Power is defined as the rate of doing work i.e. the rate of energy use.

Energy transfer within the body is introduced by describing a generalized model, the critical power model and relating exercise performance to human bioenergetics [1]. The model describes energy flow during human exercise that defines the relationship between power and time to exhaustion. When walking, the power is determined by the subject’s speed as long as the weight and efficiency does not change. Endurance time is inversely related to power; activity can be maintained exponentially longer at lower power. Moreover, there is a threshold power, ‘critical power’ that demarcates the maximum power that can be endured indefinitely. The critical power is closely linked to the ability to transfer oxygen from the atmosphere to the working muscle. As long as energy expenditure is within the capacity to deliver and use oxygen the activity can be maintained indefinitely.

Energy is the ‘currency’ of physical activity. It is becoming increasingly apparent that energy expenditure has important influences in health and disease processes. There is a strong relationship between cardiorespiratory health and aerobic fitness [2, 3]. This includes patients with chronic diseases like COPD. Oga et al. [4] demonstrated that 5 year survival of patients with COPD was related to aerobic fitness as measured by peak oxygen uptake. The patient group with the lowest capacity to deliver and use oxygen had much poorer survival than the more fit groups. While most of the health benefits of aerobic exercise are attributed to changes in the cardiovascular system there is increasing evidence that skeletal muscle also plays a more direct role. In response to the increased energy demands of muscle contractions, skeletal muscle fibres express substances termed ‘myokines’ which exert beneficial effects locally within the muscle and, when released into the circulation, in several organs in a hormone-like fashion. It is also becoming clear that our healthy lifestyle messages to patients should include the concept of energy balance that captures the synergy between diet (energy in) and physical activity (energy out). When combined with dietary restriction, exercise has a
synergistic effect and enhances weight loss beyond the effect of diet alone [5]. Sedentary time, time without energy flux, appears to be an independent risk factor for the development of metabolic risk factors. Individuals who spend more time sitting, particularly during prolonged uninterrupted periods, have poorer metabolic profiles, even if they achieve the recommended amount of physical activity per week, compared to those who move frequently throughout the day [6]. The deleterious effects of prolonged sedentary behaviour are independent of the time spent participating in moderate or vigorous physical activity [7] and therefore reducing prolonged bouts of sedentary behaviour, with brief periods of light physical activity, represents a discrete target for physical activity programming.

Direct calorimetry measures total heat loss. The subject is placed in an insulated chamber and change in temperature associated with the heat released is measured. Early investigations demonstrated that direct calorimetry could account for nearly all of the heat produced and substrates metabolized. These metabolic chambers were and remain important tools in our present framework because they can determine the accuracy of indirect calorimetry. However, in the context of this presentation, direct calorimetry is of theoretical interest but practically it is limited due to its inaccessibility, expense, technical difficulty, and the limitations placed on a subject’s mobility.

The doubly labelled water method provides information on the total energy expenditure of a ‘free-living’ individual for a period of days (4 to 20). The metabolism of doubly labeled water (DLW) provides a very accurate method for determining carbon dioxide output, and it is often used as the gold standard criterion when validating physical activity questionnaires and accelerometers. The individual swallows a dose of water containing a known amount of stable isotopes of hydrogen and water. Carbon dioxide and water are produced as energy is converted from stored chemical energy (metabolism) to useful forms (e.g. mechanical energy). Total energy expenditure can be calculated by the loss of the isotopes from the body. Because the interval between the initial and final sampling, days, it is only possible to examine relatively long-term averages of accumulated physical activity.

The quantification of energy expenditure will be presented with a focus on indirect calorimetry because of its accessibility and recent technological advances in its portability. Indirect calorimetry provides a proxy of measuring heat. It is a well-established method assisting the diagnosis of cardiorespiratory disease and measuring fitness, respiratory gas exchange kinetics and nutritional needs. Indirect calorimetry requires that oxygen uptake and carbon dioxide output are measured. It is assumed oxygen is used to oxidize degradable fuels and that all the carbon dioxide evolved is recovered. The total amount of energy can then be calculated by knowing the energy equivalent of oxygen (approximately 20.9 kJ/LO₂ or 5 kcal/LO₂). The most accurate estimation of energy expenditure from oxygen uptake requires knowledge of the respiratory quotient and urinary nitrogen excretion to apply the appropriate oxygen equivalent for carbohydrates, fats and proteins. Often non-protein respiratory quotients provide reasonably precise estimates as the contribution from protein is minimal except in prolonged relatively intense endurance activity. A second fundamental requirement of indirect calorimetry is the assurance that the subject has reached a steady state of respiratory gas exchange. At the start of exercise and during intense non-steady state exercise energy is supplied by anaerobic processes that will not be captured by the immediate measurement of oxygen uptake.

For practical reasons we often rely on manufacturers reported specifications for their system and devices, and that they have calibrated and validated the delivered product. A biological validation, quality control, procedure allows a check on the stability (repeatability) of a system over time and comparisons with other systems (reproducibility). The same method can be used to test the validity of surrogate measures (agreement).

Portable indirect calorimetry systems are often evaluated by their agreement with stationary laboratory systems [8, 9]. Surrogate measures of indirect calorimetry are often validated with portable indirect calorimetry systems. For example, validation of a multi-sensor armband ability to monitor energy expenditure in patients with COPD was assessed by its agreement with indirect calorimetry [10].

Finally, applications and examples, with a focus on indirect calorimetry, are given. Indirect calorimetry has been used to assess economy of movement in patients with COPD. First the lack of consistent definitions of
economy and efficiency is recognized [11]. Economy is defined as energy expended to perform a task of given intensity. Early studies [12, 13] suggested that patients with COPD presented with reduced mechanical efficiency, work per unit of oxygen uptake, whereas this has not been substantiated in more recent studies [14, 15]. Conclusions may depend on the modality of the exercise and the methods used [13, 15]. A second application is presented in which wearable monitors are validated against indirect calorimetry and used to assess ‘free-living’ daily energy expenditure [16] and activities of daily living [17, 18]. These studies generally show that patients with COPD are less active and more sedentary. Typical daily activities, undemanding for healthy individuals, are relatively intense when the energy expenditure to do the task is compared to the capacity of the patient’s capacity of energy expenditure by oxidative metabolism.

In summary, energy is presented as a unifying concept between physical activity and health. We should help our patients adopt a lifestyle which 1) includes habitual periods of high energy flow (exercise training), 2) balances intake with output, 3) avoids prolonged periods without raising energy expenditure above resting levels and 4) helps with economical movement to make tasks feel easier. Success is increasingly challenged with the progression of COPD.

References


Evaluation

1. In general terms, the law of conservation of energy states:
   a. Patients with COPD should not expend too much energy in their daily lives
   b. The total amount of energy in an isolated system remains constant over time Patients with COPD should not expend too much energy in their daily lives
   c. Gasoline prices will decline if we walk instead of driving
   d. None of the above

2. Which of the following statements are true:
   a. Energy is defined as the ability to do work
   b. Power is defined as the rate of work
   c. Energy and work are expressed as the same unit of measurement
   d. All of the above

3. Measuring energy expenditure with indirect calorimetry:
   a. Indirect calorimetry requires that oxygen uptake is measured by knowing the energy equivalent of oxygen
   b. Immediately reveals energy expenditure due to anaerobic processes
   c. Is used as a gold standard to validate direct calorimetry
   d. Does not require the subject to wear a breathing interface such as mask

4. Economy of movement:
   a. Does not affect a patient with COPD’s ability to perform work
   b. Is defined as energy expended to perform a task of given intensity
   c. Refers to the balance between energy intake with output
   d. Refers to the total energy patients with COPD have available for the day

5. Wearable monitors used to assess ‘free-living’ daily energy expenditure generally show that patients with moderate to severe COPD are:
   a. very anxious and intense
   b. inefficient in their movement
   c. less active and more sedentary
   d. have an energy imbalance

Please find all correct answers at the back of your handout materials
INTRODUCTION

• Energy: exercise physiology’s unifying concept
• Explains how some activities can be endured indefinitely while others seconds
• Explains endurance and strength performance
• Understand training and energy conservation
• Energy transfer and health

AIMS

• Improve physiological knowledge of the relationships between energy, exercise and physical activity
• Focus on COPD
• Provide overview of technologies
• Provide examples from clinical research.
Contents

1. Physical terms and the law
2. Model of energy transfer – ‘critical power’
3. Health benefits of energy transfer - exercise
4. Quantification of energy transfer
   - Direct calorimetry
   - Doubly labelled water
   - Indirect calorimetry – portability
   - Wearable monitors
5. Applications and examples

ENERGY is a unifying concept

- Many phenomena can be analyzed in terms of continuous transformation of energy from one form to another
- Principle of Conservation of Energy generalization that only a limited amount of work can be done by an engine (person) for a given amount of fuel (food)
- Entropy – all potential energy in a system is ‘degraded’ to kinetic energy or heat
Words of wisdom

Karl Friedrich Mohr: …there is in the physical world one agent only, and this is called Kraft [energy or work]

Physics Laws to Physically Live By…

1st Law: conservation of energy
2nd Law: everything progresses from order (low entropy) to a disordered state (high entropy)

The ability of human beings to adapt relies on the capacity of cells to transform energy into work.

PRINCIPLES OF CALORIMETRY

- Work: total energy transferred from one system to another
- Energy: the ability to do work
  joule: energy expended (work done) applying a force of 1 newton through a distance of 1 meter
  \[ J = N \cdot m = \frac{kg \cdot m^2}{s^2} \]
- Power: rate of work; rate of energy use; metabolic rate
Energy value of food by heat released

SECTION

Energy Transfer in the Body
Metabolism – flow of energy

Energy from food → ADP + P → ATP


Morton: Modeling power and endurance

AEROBIC

Oxygen → P → Glycogen

ANAEROBIC

High energy phosphates → R1

Power (speed)

Below critical speed – within oxidative capacity

Critical speed

Above critical speed – metabolism with fatiguing consequences

Above critical speed

Above critical speed
di Prampero Model: resistance to oxygen flow & cascade of pressure

The O₂ transport system

Cascade of oxygen pressure decline


A familiar application to assess oxygen flow through systems - CPET

Modified from Wasserman et al. 2005 Fig 10.1.1 (N)

SECTION

Energy Transfer in the Body

Does it matter?
The primary outcomes

Does it matter?

- For movement the currency is ‘energy’
- Moreover, energy is becoming recognized as the currency in health and disease processes

Aerobic training:
fitness and all cause mortality

Everett, MD et al. (2007) Med Sci Sport Exerc 39
Poor survival with decreased aerobic fitness (Peak Oxygen Uptake) in patients with COPD

Oga, T et al. (2003) Am J Respir Crit Care Med

Contraction-Induced Benefits?
Myokines: protect against disease


Sedentary time – prolonged periods without increasing energy flow

Energy Balance – intake and expenditure

teach patients about energy balance, the inclusive concept that captures the synergy between diet and physical activity – facilitated by measurement?

Relationship Between Capacity and Performance

SECTION

Energy Transfer QUANTIFICATION
Summary of Energy Flow

O₂ uptake → Metabolic energy → CO₂ output

- Maintenance heat
- Isometric work against gravity
- Mechanical energy ([Muscle Tension])
- Net increase in body energy
- Heat of contraction
- Loss due to co-contraction or absorption by antagonist

Body segment energy → External work

Measuring energy expenditure

Direct calorimetry

- Measures total heat loss
- Participant is placed in a thermally-isolated chamber
- Limited practical interest
  - Expense, technical difficulty, and the limitations placed on a subject’s mobility

Winter DA 1979
Doubly Labelled Water

- Indirect free-living total energy expenditure
- Individual for a period of 4 to 20 days
- Oral dose of water containing a known amount of stable (non-radioactive) isotopes of both hydrogen and oxygen
- All groups
- Validation of other methods
Measuring energy expenditure

Indirect calorimetry

- Proxy of measuring heat loss
- Diagnosing cardiorespiratory disease, fitness, respiratory gas exchange kinetics
- Oxygen uptake and carbon dioxide output measured
- Assumed oxygen is used to oxidize fuels
- Assumed all the CO2 evolved is recovered
- Calculate the total energy conversion

Raw measurements of ventilation and gas concentrations are used

- Minute Ventilation ($\dot{V}_E$) - adjusted for environmental conditions (STPD)
- $F_{E O_2}$ - fraction of oxygen
- $F_{E CO_2}$ - fraction of carbon dioxide
- Calculate oxygen uptake ($\dot{V}O_2$) and carbon dioxide output ($\dot{V}CO_2$)
- RQ ($\dot{V}O_2/\dot{V}CO_2$); respiratory exchange ratio (RER)
The total amount of energy can then be calculated by knowing…

- energy equivalent of oxygen
  - (approximately 20.9 kJ/LO₂ or 5 kcal/LO₂).
- More accurate estimation of energy expenditure requires respiratory quotient and urinary nitrogen excretion to apply appropriate oxygen equivalent (carbohydrates, fats and proteins).

Indirect calorimetry

- well-established method
  - assist diagnosis of cardiorespiratory disease
  - measuring fitness
  - respiratory gas exchange kinetics
  - nutritional needs

A familiar application of indirect calorimetry - CPET

![Diagram](modified from Wasserman et al. 2005 Fig 10.1.1 (N))
Indirect calorimetry – energy equivalents

Open-circuit method
- Early manual Douglas bag and Tissot-spirometer methods with separate chemical analyses
- Semi- and full-automated systems (metabolic carts)
  - fast and efficient
  - ventilation, \( F_{2}O_2 \) and \( F_{2}CO_2 \) determined instantaneously and continuously

Validity and reliability of selected commercially available metabolic analyzer systems

Purchase = $12,000
Site visit = $1500

Quality control of metabolic measurements


Case study of biological control...
cycling at constant (steady state) power

Biological control... a second subject
Biological control...
Net (loaded – unloaded)

Energy Expenditure above steady state – high intensity & accumulated oxygen deficit

High-Intensity Exercise Tolerance: An Update on Bioenergetics and Assessment

Steady state energy expenditure and above
Measuring energy expenditure

- Technical advances >>>> research and quality control studies
- Understanding to assess equipment and reports

Indirect Calorimetry Systems Portable
- Battery powered, self-contained, ‘light weight’, telemetric
- Same capabilities as laboratory station
- Gas exchange, heart rate and ventilatory measures
- Reasonably accurate
- Reasonably dependable
- Limited ‘free-living’ use (swimming?)
- Examples: Metamax, Cosmed, Oxycon …
Validation of metabolic measurements

Case study of validation...

Carrying the device can effect energy expenditure

- Portable gas analysis systems increase energy expenditure when running at submaximal levels
- $\dot{V}O_2$ peak is unaffected
- Using portable systems in field-based situations must consider effects of prolonged use on energy expenditure
Measuring energy expenditure

Motion Sensors
- pick up motion or acceleration
- several types range in complexity and cost...
  - pedometer to the triaxial accelerometer
- Physiological sensors added to Motion Sensors

Validation of metabolic measurements

Apply individualized calibration


SECTION

APPLIED SCIENCE

Practical application – economy

Diverse overlapping and, at times, confusing terminology

Terms "muscular efficiency," "muscle efficiency," "economy," and "effectiveness" should be used in their respective contexts

Economy: oxygen uptake for a given task

Summary of Energy Flow

Decreased mechanical efficiency in clinically stable patients with COPD

- many patients with severe COPD have decreased mechanical efficiency
- based on the results of this study it is hypothesised that an increased oxygen cost of breathing during exercise contributes to the decreased mechanical efficiency


Bioenergetics is not compromised in moderately severe COPD

Bioenergetics is not compromised in moderately severe COPD

Patients with COPD show mechanical inefficiency when walking

Unaccustomed speed explains poor economy?
The concept of "effectiveness"  

![Diagram showing energy expenditure vs mechanical power and oxygen uptake.]

Economy with ambulatory aid?  

![Diagram comparing energy expenditure with and without a rollator.]


Practical application – energy expenditure to show intensity of daily activities…
Intensity of exercise

<table>
<thead>
<tr>
<th>Intensity Level</th>
<th>Energy Consumption (kcal/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>3.0 ± 0.5</td>
</tr>
<tr>
<td>Moderate</td>
<td>5.6 ± 1.0</td>
</tr>
<tr>
<td>Heavy</td>
<td>8.2 ± 1.6</td>
</tr>
<tr>
<td>Very Heavy</td>
<td>10.8 ± 2.2</td>
</tr>
</tbody>
</table>


Patients with COPD spend very little time doing vigorous activity

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time in bed, minutes</td>
<td>32 ± 17</td>
<td>83-195</td>
</tr>
<tr>
<td>Time in moderate activity, minute</td>
<td>5.8 ± 2.9</td>
<td>1.0-24.4</td>
</tr>
<tr>
<td>Time in vigorous activity, minute</td>
<td>1.5 ± 0.7</td>
<td>0.7-2.7</td>
</tr>
<tr>
<td>Total energy expenditure, kcal</td>
<td>1,230 ± 345</td>
<td>787-1,381</td>
</tr>
<tr>
<td>Daily number of steps</td>
<td>4,275 ± 3,345</td>
<td>1,300-5,000</td>
</tr>
</tbody>
</table>

Hill K et al. Chest 2012; 141:406-412

Assessing physical activities

Faculty Disclosures

Dr. Andrea Aliverti is one of the inventors of Opto-Electronic Plethysmography; the patents are owned by the Politecnico di Milano (米兰, 意大利), and licensed to BTS Spa Company.
Faculty

**Dr. Andrea Aliverti**  
Dip. di Elettronica, Informazione E Bioi  
Politecnico di Milano  
via G. Colombo, 40  
20133  
MILANO  
ITALY  
andrea.aliverti@polimi.it

**Dr. Tom Dolmage**  
Respiratory Diagnostic & Evaluation Serv  
West Park Healthcare Centre  
82 Buttonwood Ave  
M6M 2J5  
Toronto  
CANADA  
tom.dolmage@westpark.org

**Dr. Paul W. Hodges**  
School of Health & Rehabilitation Scienc  
The University of Queensland  
CCRE SPINE  
4072  
Brisbane  
AUSTRALIA  
p.hodges@uq.edu.au

**Prof. Thierry Troosters**  
U.Z Gasthuisberg  
Labo Ademspieren Pneumologie  
Herestraat 49  
3000  
LEUVEN  
BELGIUM  
thierry.troosters@med.kuleuven.be

**Prof. Enrico Maria Clini**  
Universita di Modena  
Divisione di Pneumologia  
Villa Pineta di Gaiato  
Via Gaiato, 252  
41020  
Modena  
ITALY  
enrico.clini@unimore.it

**Dr. Luis Puente Maestu**  
S. Neumologia  
Hospital Gregorio Maranon  
Dr Esquero 46  
28007  
Madrid  
SPAIN  
lpuente@separ.es
Answers to submitted MCQ’s

Please find all correct answers in bold below

Respiratory and movement biomechanics: laboratory assessment – Dr. Andrea Aliverti

1. Kinematics
   a. describes movements with respect to time and space
   b. describes movements with respect to force
   c. is a synonymous of the term ‘biomechanics’
   d. cannot be applied to respiratory system

2. Ground reaction forces are measured by
   a. optical systems
   b. accelerometers
   c. piezoelectric platforms
   d. magnetic system

3. Inverse Dynamics
   a. allows to obtain joint kinematics
   b. allows to estimate joint torques
   c. allows to estimate ground reaction forces
   d. does not consider kinematics

4. Optical plethysmography
   a. measures chest wall kinematics
   b. measures chest wall kinetics
   c. measures chest wall mechanics
   d. measures respiratory muscle activity

Equilibrium, balance and increased risk of falls related to COPD – Prof. Paul W. Hodges

1. Balance ability is dependent of which of the following systems/components:
   a. Sensory system
   b. Musculoskeletal system
   c. Cognitive control
   d. Motor strategies
   e. All of the above

2. Which of the following is not a clinical test of balance:
   a. Berg Balance Scale (BBS)
   b. Short Physical Performance Battery (SPPB)
   c. Physical Activity Scale for the Elderly (PASE)
   d. Balance Evaluation Systems Test (BESTest)
   e. Sensory Organization Test (SOT)

3. Balance may be compromised in the mediolateral direction (frontal plane) by:
   a. Ankle muscle weakness
   b. Reduced moments/movement at the hip and spine in the frontal plane
   c. Non-steroidal anti-inflammatory drug use
   d. Ankle joint stiffness
   e. None of the above
4. Compromised balance has not been related to which of the following manifestations of COPD:
   a. Lower limb muscle weakness
   b. Dyspnoea
   c. Medication use
   d. Reduced FEV1
   e. Reduced physical activity levels

5. Which of the following statements about balance impairment in COPD is not true:
   a. Amongst chronic diseases, incidence of falls in COPD is second only to knee osteoarthritis
   b. Falls are a debilitating sequela of COPD
   c. Balance rehabilitation and falls prevention are a standard component of current pulmonary rehabilitation programs for COPD
   d. Multiple tests of balance have been used to study balance which makes comparison of studies difficult.

Energy expenditure and activity: is it inefficient? – Dr. Tom Dolmage
1. In general terms, the law of conservation of energy states:
   a. Patients with COPD should not expend too much energy in their daily lives
   b. The total amount of energy in an isolated system remains constant over time Patients with COPD should not expend too much energy in their daily lives
   c. Gasoline prices will decline if we walk instead of driving
   d. None of the above

2. Which of the following statements are true:
   a. Energy is defined as the ability to do work
   b. Power is defined as the rate of work
   c. Energy and work are expressed as the same unit of measurement
   d. All of the above

3. Measuring energy expenditure with indirect calorimetry:
   a. Indirect calorimetry requires that oxygen uptake is measured by knowing the energy equivalent of oxygen.
   b. Immediately reveals energy expenditure due to anaerobic processes
   c. Is used as a gold standard to validate direct calorimetry
   d. Does not require the subject to wear a breathing interface such as mask

4. Economy of movement:
   a. Does not affect a patient with COPD’s ability to perform work
   b. Is defined as energy expended to perform a task of given intensity
   c. Refers to the balance between energy intake with output
   d. Refers to the total energy patients with COPD have available for the day

5. Wearable monitors used to assess ‘free-living’ daily energy expenditure generally show that patients with moderate to severe COPD are:
   a. very anxious and intense
   b. inefficient in their movement
   c. less active and more sedentary
   d. have an energy imbalance