



Level III

Exercise Physiology

Special thanks to Doug Stacey

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Outline

- Review of Energy Systems
 - Sources
 - Specific use in body
- Review of Metabolic Responses to Exercise
 - What activities use what energy systems
- Assessing Sport/Work Specific Energy Demands
 - How to train specifically

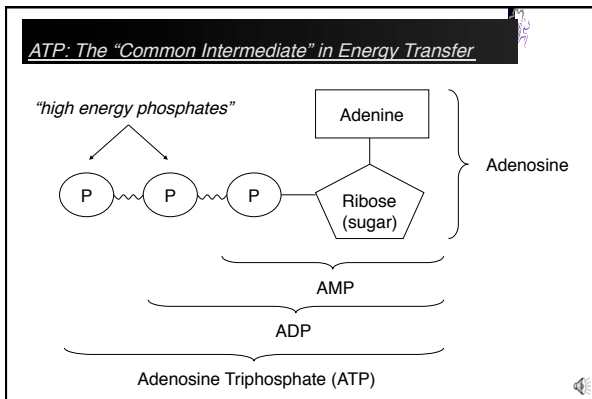


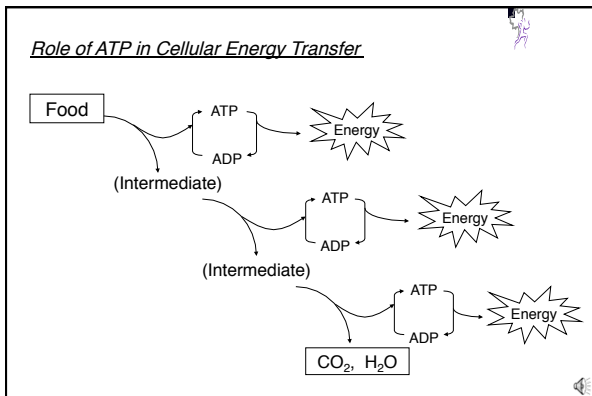


Review of the Energy Systems









Why Don't We Just Store ATP in our Muscles?

ATP use by skeletal muscle at rest $\approx 1 \text{ mmol} / \text{min} / \text{kg}$

For a 70 kg person with 30 kg of skeletal muscle...

ATP requirement = $30 \text{ mmol/min} \times 60 \text{ min} \times 24 \text{ h}$

= 43,200 mmol/day

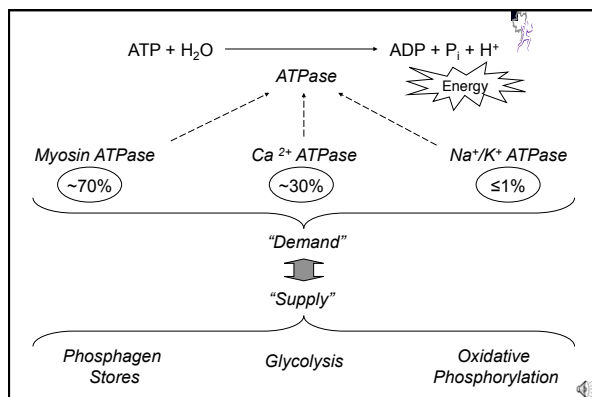
= 43.2 mol/day

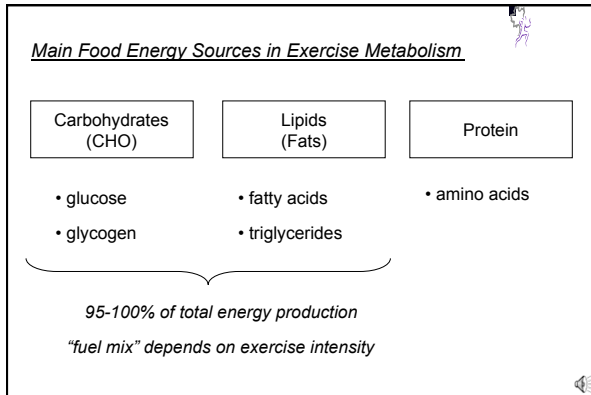
(1 mol of ATP weighs 507 g)

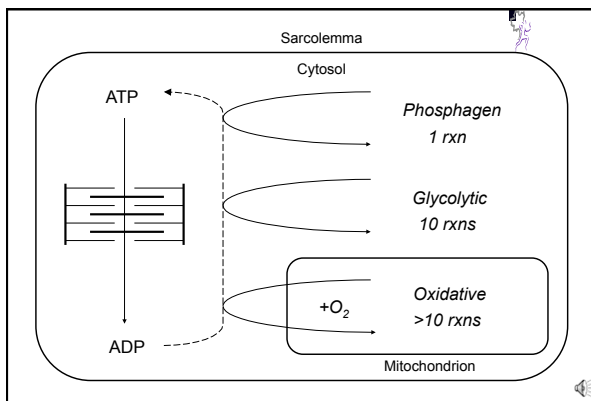
= 21.9 kg of ATP/day!!

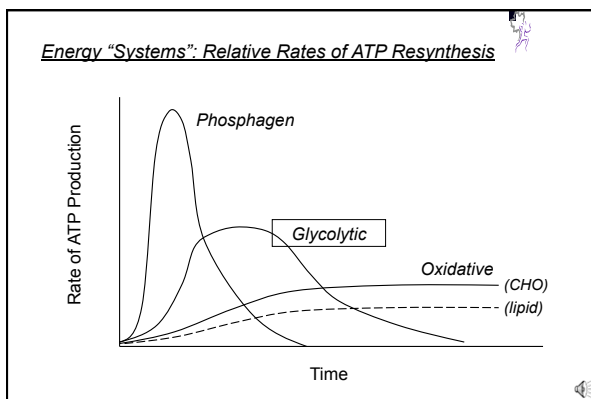
The Importance of ATP for Cell Function

1. ATP functions to *transfer* free energy
2. Very little ATP is stored inside the cell
3. Cells strongly defend against a decrease in [ATP]
4. ATP production is carefully matched to ATP utilization
5. The *resynthesis* of ATP is an extremely rapid process
6. Loss of ATP "homeostasis" is a *critical* problem for cell





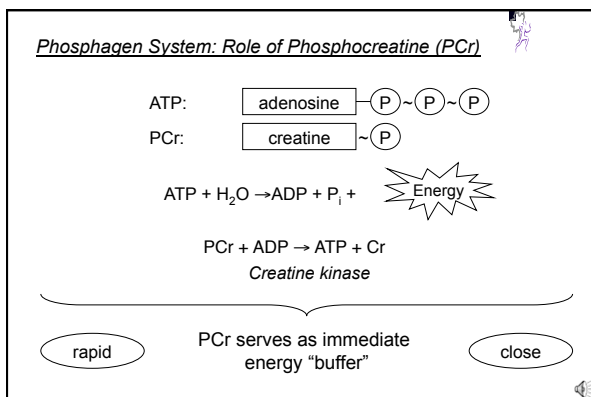




Overview: Energy Systems

System	Location	O ₂ ?	Fuel Storage Form
Phosphagen "Power"	cytosol	no	phosphocreatine (PCr) ATP
Glycolytic "Speed"	cytosol	no	glucose glycogen
Oxidative "Endurance"	mitochondria	yes	glucose glycogen FAs TGs AAs

Phosphagen System



Phosphagen system is very limited...

Muscle concentration (mmol/kg "dry weight"):

ATP:	25	}	total "phosphagens" $\approx$ 100
PCr:	75		

Rate of ATP utilization (mmol/kg/sec):

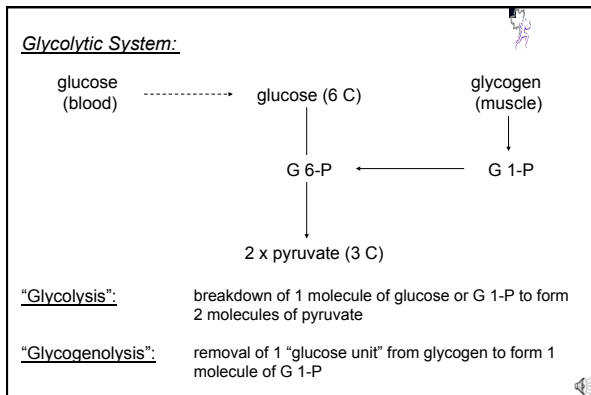
Rest:	~ 0.1	}	100-fold increase!
Intense Exercise:	~ 10		

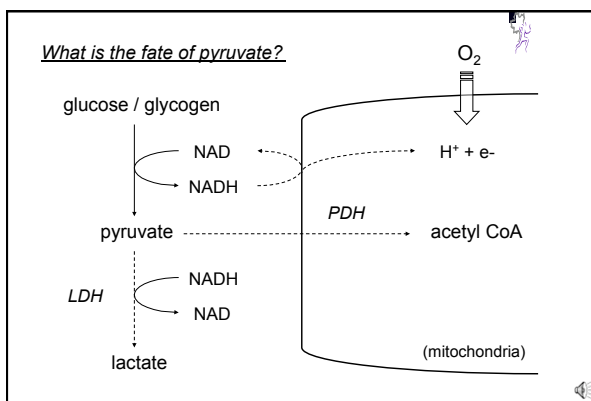
System depleted within ~ 10 sec of hard exercise!

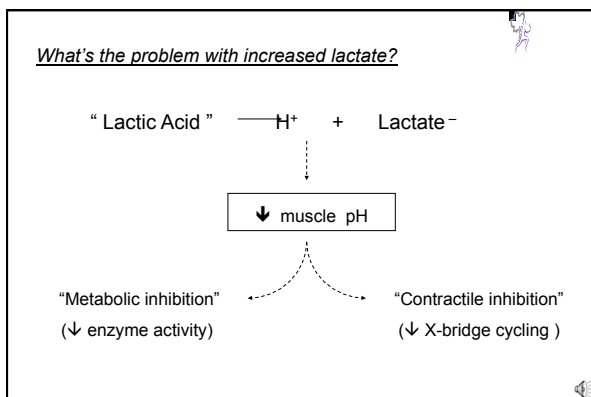
When do we rely on phosphagen system?

- "Rest-to-work" transition
- Transitions in workload during exercise
- Anytime very high rates of ATP production are required
- Predominates during intense exercise lasting < 10 s
 - sprinting, throwing, jumping, weightlifting

Glycolytic System







When do we rely on "glycolytic system"?

- ≈ "anaerobic glycolysis"
- ≈ glycogen-to-lactate
- ≈ "lactic acid system"

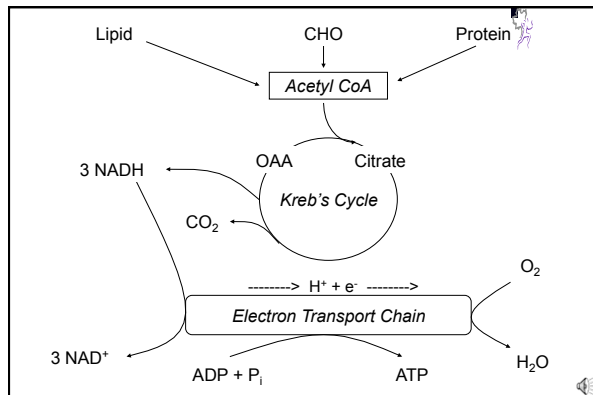
- Required for high rates of ATP production
- Predominates during heavy exercise lasting ~10-120 sec
- 400m race, hockey shifts, interval work

Oxidative System

Oxidative System

- occurs inside mitochondria
 - requires adequate O_2 supply
 - allows further breakdown of CHO
 - permits breakdown of fat and AAs
- } much higher yield of ATP

- 3 stages:
1. Formation of acetyl CoA (CHO, fat, AA)
 2. Oxidation of acetyl CoA in Krebs's cycle
 3. ATP formation via electron transport chain



When do we rely on "oxidative system"?

- Predominates during exercise lasting > ~2 min
- Permits "moderate" rates of ATP provision
- Higher yield of ATP per unit of "substrate"
 - e.g., CHO: 1 molecule of glucose (6C):
 - 2 ATP from glycolytic system
 - 36 ATP from oxidative system!
 - e.g. FAT: 1 molecule of palmitate (16 C):
 - 129 ATP from oxidative system!

What is the better fuel?: CHO vs lipid

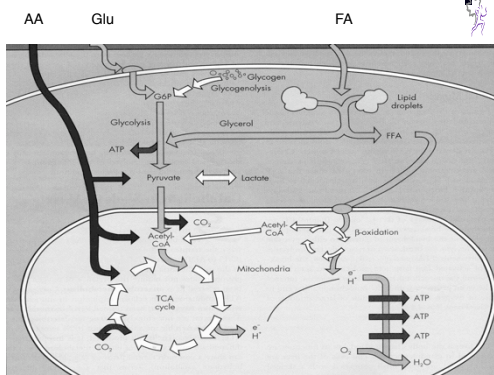
- e.g., glucose (6 C) vs palmitate (16 C)

	CHO	FAT
kcal / g	4	9
capacity (kcal)	~1800	unlimited
ATP / carbon	38 / 6 = 6.3	129 / 16 = 8.1
ATP / O ₂	6.3	5.7

- CHO ~10% more "O₂ efficient"
- permits exercise at higher pace

Summary of Energy Systems

System	Summary of Overall Reaction	Rate of ATP yield	ATP / "unit" substrate (i.e., 1 mol)	"Usable" storage capacity
Phosphagen	$\text{PCr} \rightarrow \text{Cr}$	~ 10	1	≤ 10 sec
Glycolytic	$\text{Glu} / \text{Glyc} \rightarrow \text{Lactate}$	~ 5	2 / 3	≤ 90 sec
Oxidative (CHO)	$\text{Glu} / \text{Glyc} \rightarrow \text{CO}_2, \text{H}_2\text{O}$	~ 2.5	36 / 38	~ 90 min
Oxidative (FAT)	$\text{FA} / \text{TG} \rightarrow \text{CO}_2, \text{H}_2\text{O}$	~ 1.5	~ 129	days

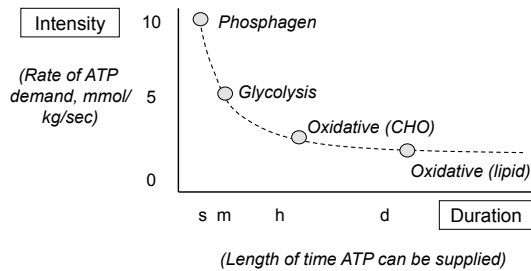


Take Home Points: Energy Systems			
Energy Systems Names	Phosphagen: Anaerobic Alactic	Glycolytic: Anaerobic Lactic	Oxidative: Aerobic

Take Home Points: Energy Systems (cont'd)			
Energy Systems Names	Anaerobic Alactic	Anaerobic Lactic	Aerobic

Metabolic Response to Exercise

ATP Resynthesis: The "Intensity – Duration Trade-off"



Energy Systems: Relative Contribution at Maximal Exercise

%	seconds			minutes					
	10	30	60	2	5	10	30	60+	
Non-Oxid.	90	80	70	50	20	10	5	1	
Oxidative	10	20	30	50	80	90	95	99	

%	seconds						
	2	5	10	30	60	120	
Phosphagen	80	55	40	10	5	<1	
Glycolytic	20	40	50	70	60	50	
Oxidative	<1	5	10	20	30	50	

Elite Running Performance*: Relative Energy Contribution

Distance	Duration (min:s)	% Aerobic	% Anaerobic
100 m	9.79	10	90
400 m	43.18	30	70
800 m	1:41:11	60	40
1500 m	3:26:00	80	20
5000 m	12:39.36	95	5
10000 m	26:22.75	97	3
42.2 km	2:05:42	99	1

* men's outdoor world records as of 21-Sept-00

How to Train Based on Duration of Activity

Energy system	Anaerobic (aerobic independent)			Aerobic (aerobic dependent)				
	Alactic	Lactic acid	Aerobic					
Duration	0	10 s	40 s	70 s	2 min	6 min	25 min	1-2 h >6 h
Type of strength training needed	MxS	MxS	MxS	MxS	MxS	MxS (<80%)	MxS (<80%)	
	P	P, P-E	P, P-E, M-ES	P, P-E, M-EM	P-E, M-EM, ME-L	M-EL	P-E, M-EL	

Legend: MxS = maximum strength
P = power
P-E = power-endurance
M-ES = muscle-endurance of short duration
M-EM = muscle-endurance of medium duration
M-EL = muscle-endurance of long duration

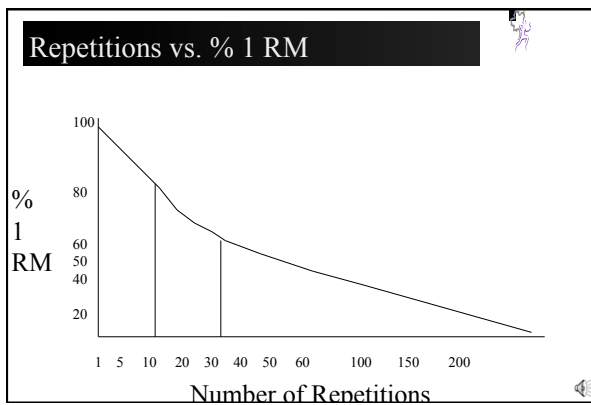
Bompa, 2005

Theory on Specificity of Training Based on Duration

- Developed in Eastern Europe in the 1950s
- Tested in European and North American labs (McMaster)
- Uses physiological characteristics to define training zones

Bompa, 2005

Work:Rest Ratios Bompa, 2005			



Assessing Specific Energy Demands

Assessing Specific Demands: Task Analysis

- 1) Physical Requirements
- 2) Time Motion Analysis
- 3) Physiological Analysis

Assessing Specific Demands: Task Analysis

Physical Requirements

- Strength
 - Hypertrophy
 - Strength
 - Power
 - Endurance



Assessing Specific Demands: Task Analysis

Physical Requirements

- Flexibility
 - Static
 - Dynamic



Assessing Specific Demands: Task Analysis

Physical Requirements

- Neuromuscular Control
- Dynamic Stability



Assessing Specific Demands: Task Analysis

2) Time Motion Analysis

Temporal analysis of energy systems

- A) Cyclical or continuous activities:
 - Performance time indicates energy system (s) involved
 - Track, rowing, cycling, speed skating, typing
- B) Acyclical and/or intermittent exercise
 - Analysis of intermittent schedules
 - calculations/interpretations (E:R ratio)
 - Velocity, number of reps, total distances
 - Team sports, racquet sports, factory line

Assessing Sport Specific Demands: Sport Analysis

3) Physiological Analysis

- Clinic/Lab
 - Strength
 - Flexibility
 - Heart rate
 - Anaerobic Power - Wingate – peak/mean power
 - Max blood lactate

Assessing Sport Specific Demands: Sport Analysis



4. Physiological Analysis

Field Tests

- Aerobic Power – “Beep/Leger Test”
- Anaerobic Power
 - Alactic - “jump and reach”
 - “40 m dash”
 - Lactic - “400m run”
 - “30s activity”
- Strength
- Flexibility



Take Home Points: Task Analysis



- *Know your energy systems: What are their relative contributions at maximal exercise?*
- What is the “weakest link” or limiting factor for the sport/ exercise?
- What are the activity specific demands?
 1. Physical Requirements – strength, flexibility, neuromuscular control
 2. Time Motion Analysis – intermittent schedules, reps, intensity
 3. Physiological Analysis – Clinic/Lab and field testing for aerobic/ anaerobic power



Take Home Points: Activity Analysis



- Training Plan
 - Develop an individual toward elite status or RTW- identify the weak link
 - Stress the appropriate energy system(s)
 - Monitoring - physiological/field testing – evaluate how effective the training has been
 - Is the intensity of game/work vs. practice/training similar



Case #1

- Squash Player:
 - MCL tear Gr II
 - 6 weeks post injury – has maintained cardio base and strength training for legs and is ready to return to sport specific training
- Based on the energy demands of the sport:
 - Design an injury specific gym program
 - Design a sport specific drill

Squash

- a) Analysis
- intermittent exercise
 - time/motion analysis (from Gilliam et al., in 7 male 6 female elite- 103 games)
 - E:P of 3:1
 - Lat: 15, For: 9, Back: 6, Lunge: 1
 - physiological profiles
 - $VO_2^{\max}$ – 84%, MHR – 91%, La: 2.9

Squash

- b) Training
- aerobic $VO_2^{\max}$ and “maintenance of peak power” - i.e. sustained highest “aerobic” = anaerobic threshold
 - fast twitch fibre
 - Peripheral muscle specificity
 - not anaerobic glycolysis

Squash

- Zone 4 Training
 - Squash court suicides x 3 mins at 70% max speed
 - Rest 3 mins
 - 4 sets, 3 times a week
 - In 2nd week- decrease rest to 150 s

Squash

- Gym program
 - Circuit with squat, lunge (45, forward and back)
 - g/s raises, h/s curls, leg extension
 - core (side bridge, 4 pt kneeling leg extension)
- 3 x week, 40% 1RM, 90s of each exercise with a 30 s rest between exercises
- 2 min rest between circuits, 3 sets

Thank you