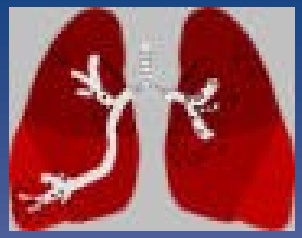
Overview and Basics of Exercise Physiology

Topics to Cover

- Basic Definitions
- Physiologic Responses to Exercise
- Maximal Aerobic Capacity and Exercise Testing
- Energy Systems
- Skeletal Muscle Fiber Types
- Terms and Concepts Associated with Exercise

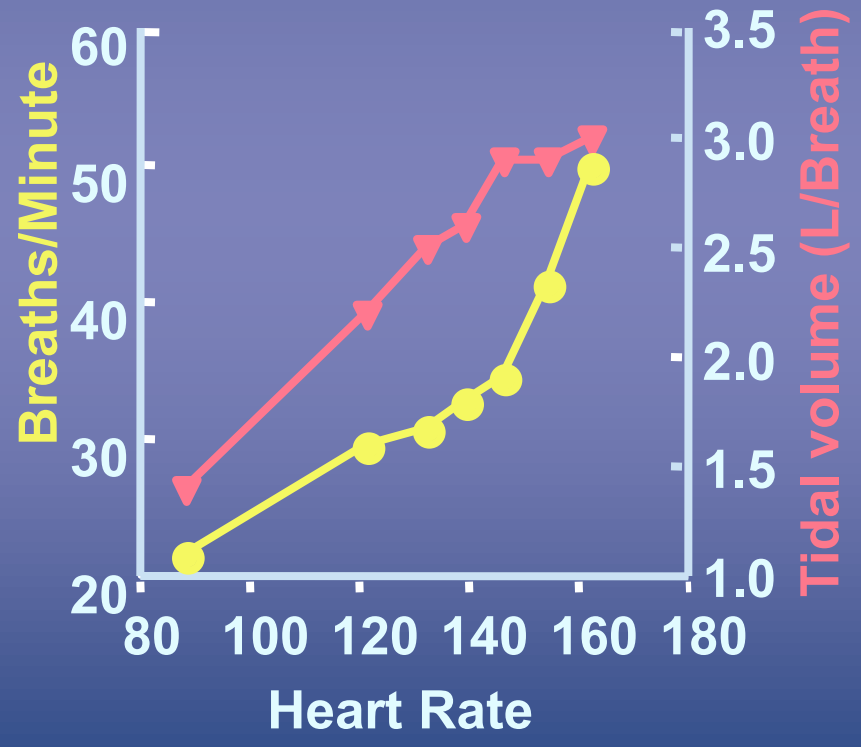
Pulmonary Ventilation

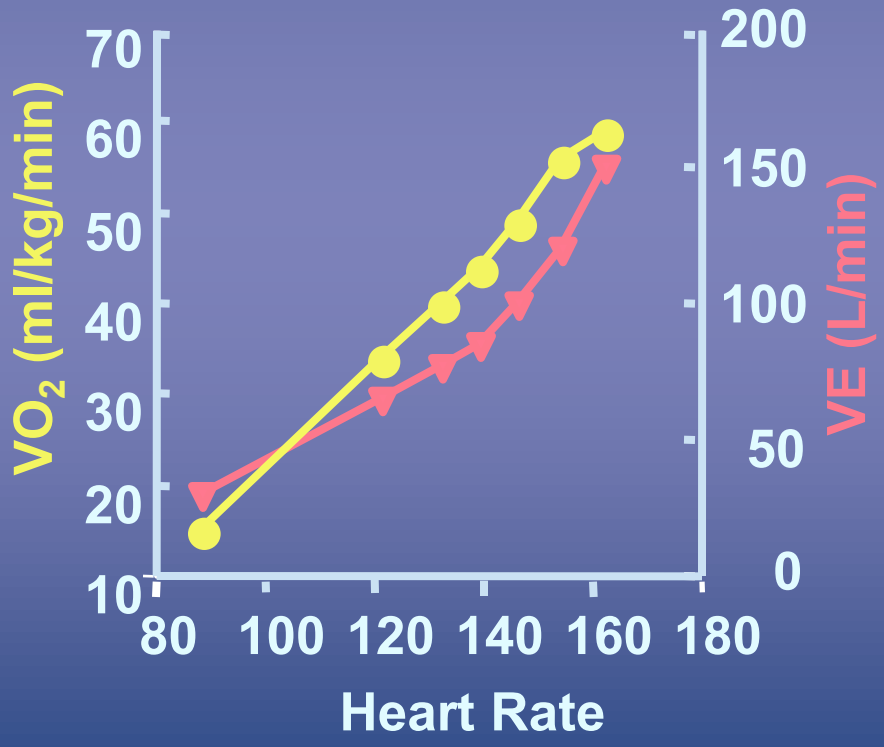


- Minute ventilation or VE (L/min) = Tidal volume (L/breathing) X Breathing rate (Breaths/min)
- Measure of volume of air passing through pulmonary system:air expired/minute

Variables	Tidal Volume (L/breathing)	Breathing Rate (breaths/min)
Rest	10 - 14	10 – 20
Maximal Exercise	100 – 180	40 - 60

Relation Between Breathing and Ventilation





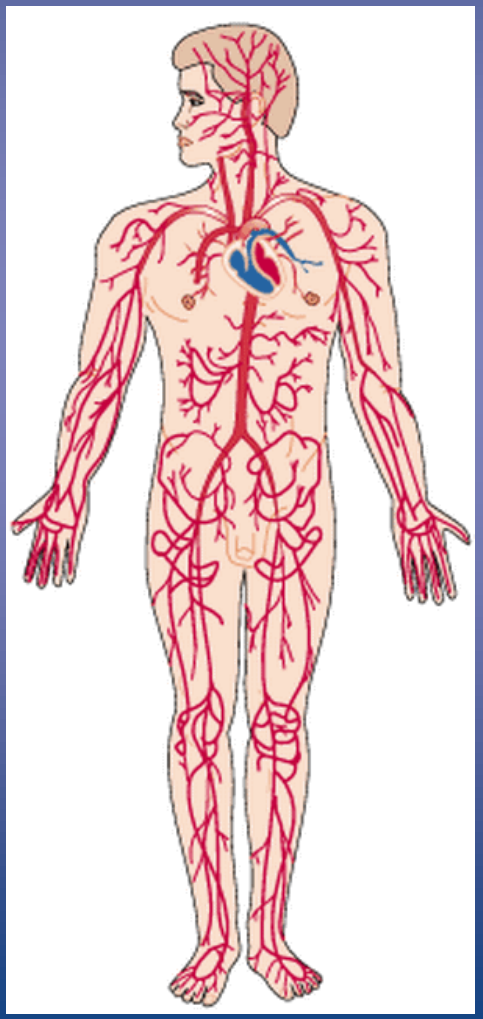
Stroke Volume (SV)

- Amount of blood ejected from heart with each beat (ml/beat).

Rest	Exercise (max)	Max occurs
80 – 90	110 – 200 (Depending on training status)	▪ 40-50% of $VO_{2\ max}$ untrained ▪ Up to 60% $VO_{2\ max}$ in athletes

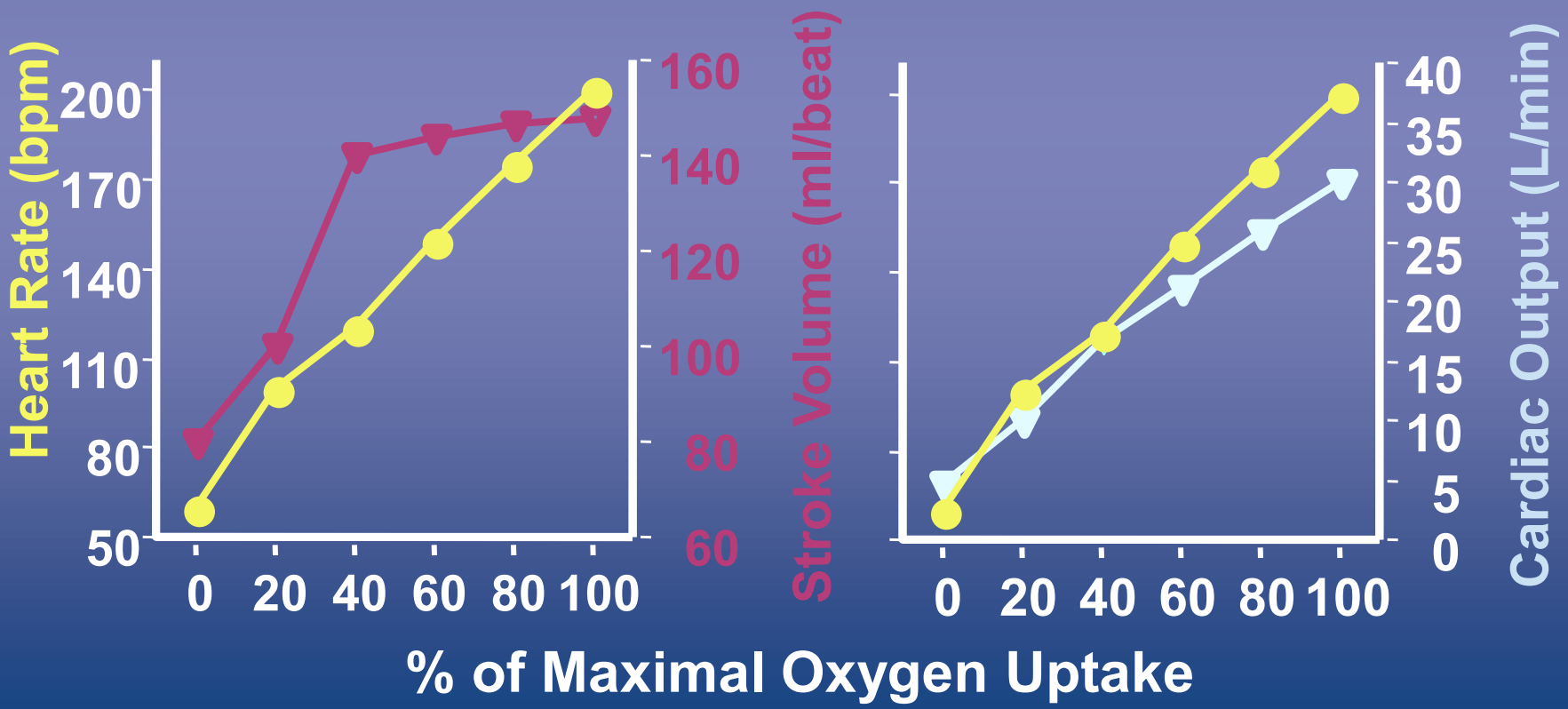
Cardiac Output (CO)

- Amount of blood ejected from heart each min (L/min).
- Stroke Volume x Heart Rate
  - Fick Equation:
    $CO = VO_2/(a - v\ O_2)$
  - Rest: ~ 5 L/min
  - Exercise: ~10 to 25 L/min
- Primary Determinant = Heart rate



Relation Between SV and CO

Cardiac Output = SV x HR
Rest: ~ 5.0 L/min
Maximal Exercise: up to 30 L/min



Maximal Aerobic Power ($VO_{2\ max}$)

- Also known as oxygen consumption, oxygen uptake, and cardiorespiratory fitness.
- Greatest amount of O_2 a person can use during physical exercise.
- Ability to take in, transport and deliver O_2 to skeletal muscle for use by tissue.
- Expressed as liters (L) /min or ml/kg/min.

Assessing VO_2

- Direct Measure: Rearrange Fick Equation: $VO_2 = CO \times (a - v_{O2})$
- Indirect Measure: gas exchange at mouth: $VO_2 = V_E \times (F_{IO2} - F_{EO2})$
  - Rest: 0.20 to 0.35 L/min
  - Maximal Exercise: 2 to 6 L/min

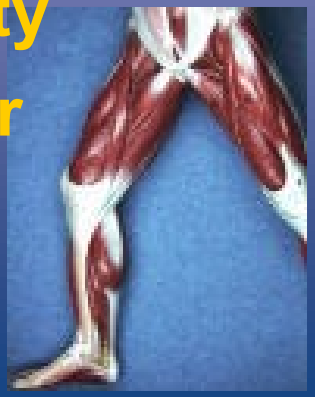
Importance of $VO_{2\ max}$

- An index of maximal cardiovascular and pulmonary function.
- Single most useful measurement to characterize the functional capacity of the oxygen transport system.
- Limiting factor in endurance performance

Determinants of VO_{2max}

Peripheral Factors

- Muscle Blood Flow
- Capillary Density
- O_2 Diffusion
- O_2 Extraction
- Hb-O_2 Affinity
- Muscle Fiber Profiles



Central Factors

- Cardiac Output
- Arterial Pressure
- Hemoglobin
- Ventilation
- O_2 Diffusion
- Hb-O_2 Affinity
- Alveolar Ventilation Perfusion ratio

Factors Affecting VO_{2max}

Intrinsic

- Genetic
- Gender
- Body Composition
- Muscle mass
- Age
- Pathologies

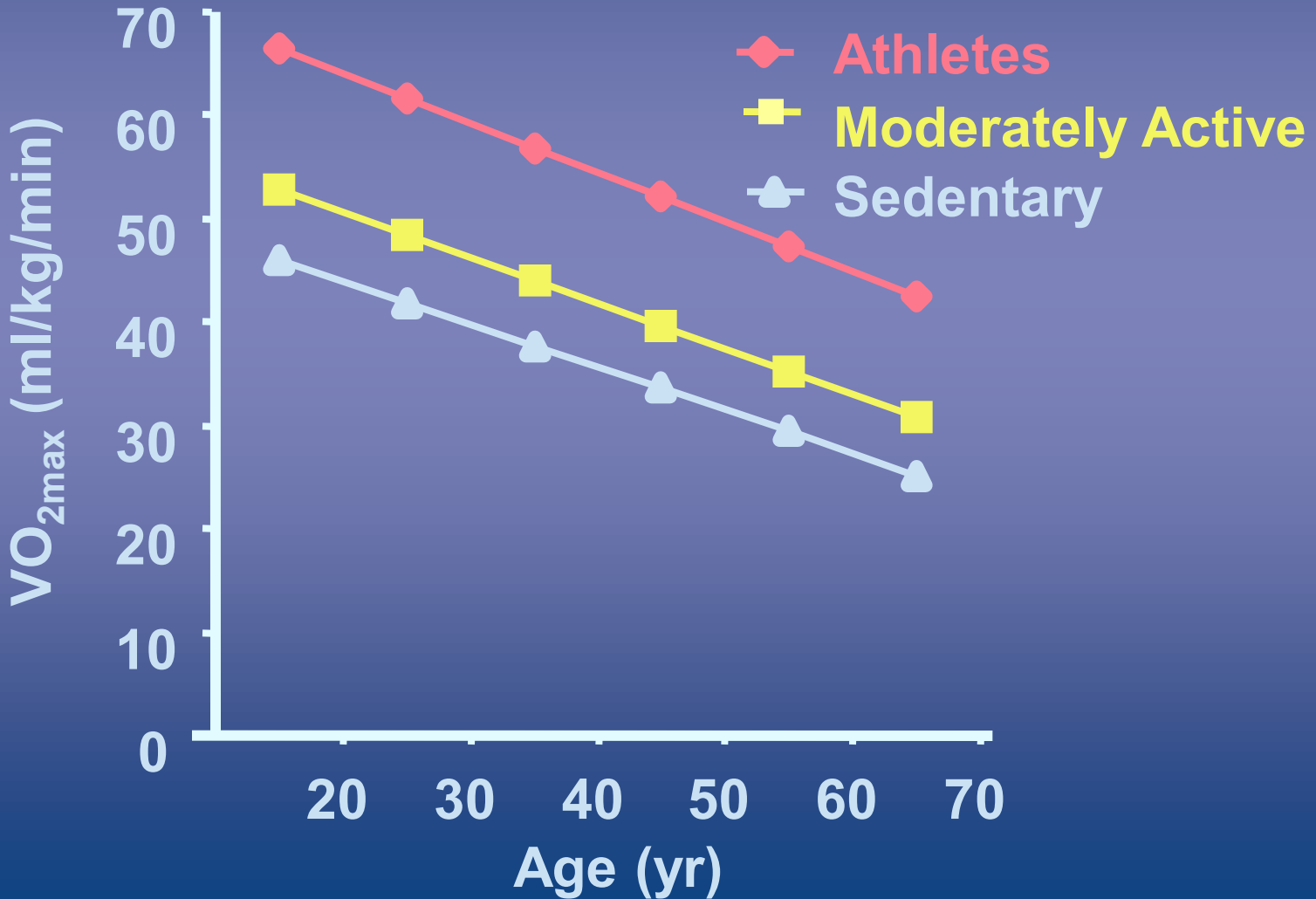
Extrinsic

- Activity Levels
- Time of Day
- Sleep Deprivation
- Dietary Intake
- Nutritional Status
- Environment

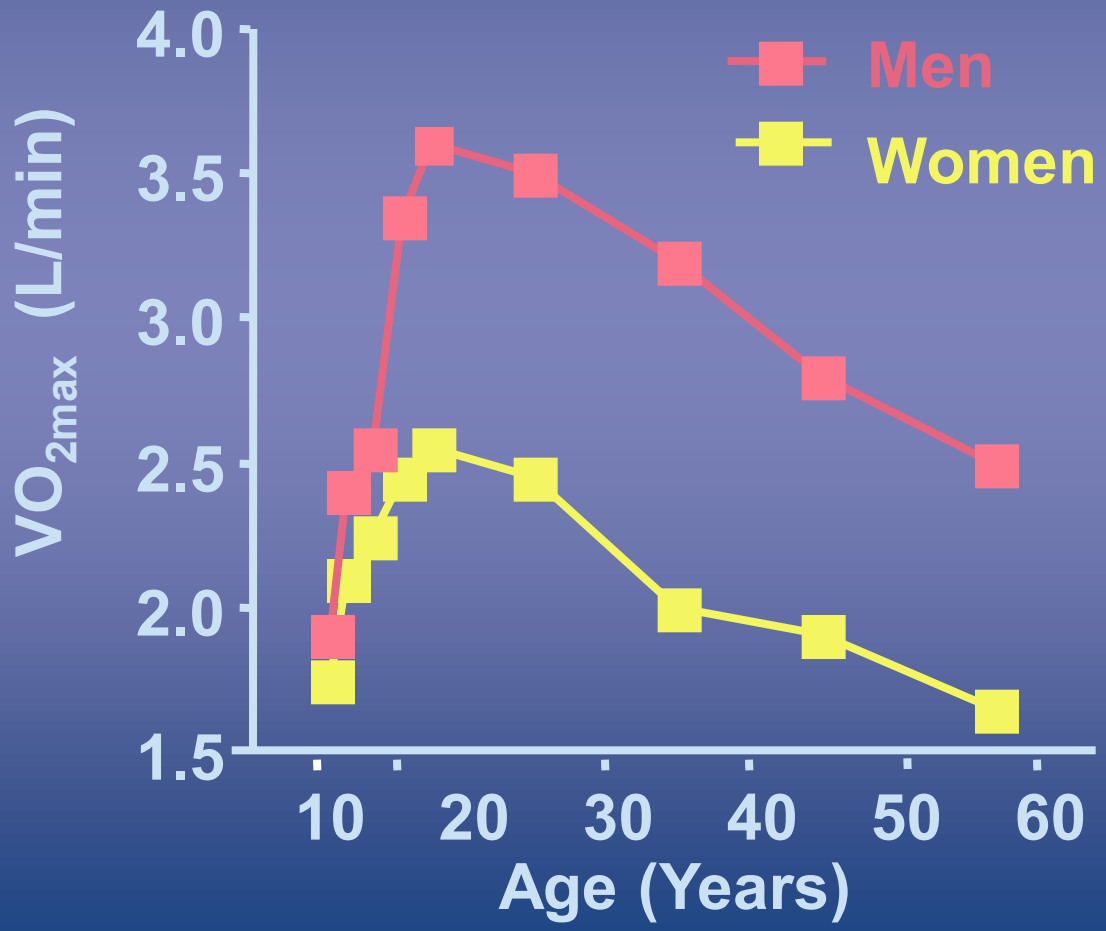
Common Criteria Used to Document $VO_{2\ max}$

- **Primary Criteria**
  - < 2.1 ml/kg/min increase with 2.5% grade increase often seen as a plateau in VO_2
- **Secondary Criteria**
  - Blood lactate ≥ 8 mmol/L
  - RER ≥ 1.10
  - ↑ in HR to 90% of age predicted
  - RPE ≥ 17

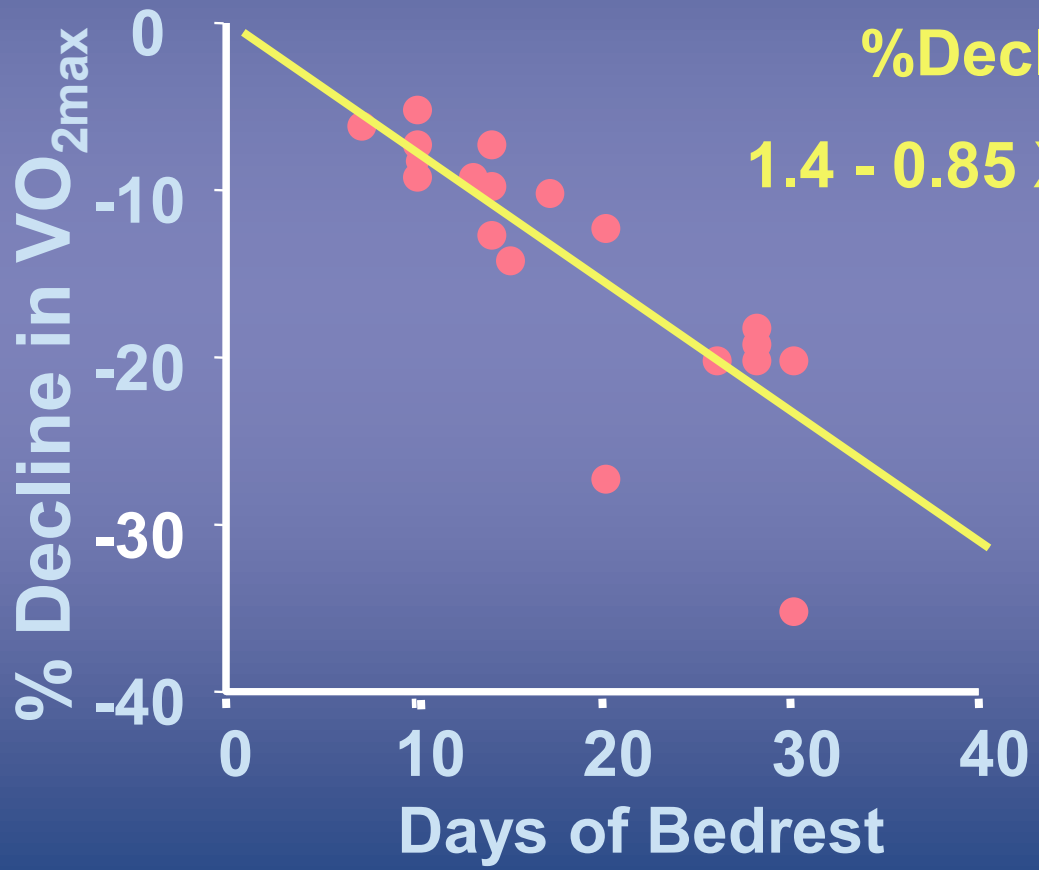
Aging, Training, and VO_{2max}



Gender, Age and VO_{2max}



Effect of Bed rest on VO_{2max}



%Decline in VO_{2max}

1.4 - 0.85 X Days; r = - 0.73

Data from VA Convertino MSSE 1997

VO_{2max} Classification for Men (ml/kg/min)

Age (yrs)	Low	Fair	Average	Good	High
20 - 29	<25	25 - 33	34 - 42	43 - 52	53+
30 - 39	<23	23 - 30	31 - 38	39 - 48	49+
40 - 49	<20	20 - 26	27 - 35	36 - 44	45+
50 - 59	<18	18 - 24	25 - 33	34 - 42	43+
60 - 69	<16	16 - 22	23 - 30	31 - 40	41+

VO_{2max} Classification for Women (ml/kg/min)

Age (yrs)	Low	Fair	Average	Good	High
20 - 29	<24	24 - 30	31 - 37	38 - 48	49+
30 - 39	<20	20 - 27	28 - 33	34 - 44	45+
40 - 49	<17	17 - 23	24 - 30	31 - 41	42+
50 - 59	<15	15 - 20	21 - 27	28 - 37	38+
60 - 69	<13	13 - 17	18 - 23	24 - 34	35+

Respiratory Exchange Ratio/Quotient

- Respiratory Exchange Ratio (RER): ratio of CO_2 expired/O_2 consumed
  - Measured by gases exchanged at the mouth.
- Respiratory Quotient (RQ): ratio of CO_2 produced by cellular metabolism to O_2 used by tissues
  - Measurements are made at cellular level
- Useful indicator of type of substrate (fat vs. carbohydrate) being metabolized:
  - Fat is the first fuel source used during exercise. As RQ/RER increases towards 1.0 the use of CHO as energy increases.
- RER/RQ typically ranges from .70 to 1.0^{+}

Estimating Maximal Heart Rate

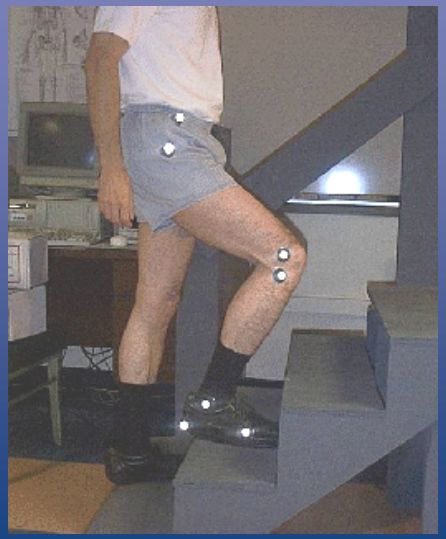
- **OLD FORMULA: 220 – age**
- **NEW FORMULA: 208 - 0.7 X age**
  - New formula may be more accurate for older persons and is independent of gender and habitual physical activity

Age	Old Formula	New Formula
60	160	166
40	180	180
20	200	194

- **Estimated maximal heart rate may be 5 to 10% (10 to 20 bpm) > or < actual value.**

Typical Ways to Measure VO_{2max}

- Treadmill (walking/running)
- Cycle Ergometry
- Arm Ergometry
- Step Tests



Maximal Values Achieved During Various Exercise Tests

Types of Exercise	% of VO_{2max}
Uphill Running	100%
Horizontal Running	95 - 98%
Upright Cycling	93 - 96%
Supine Cycling	82 - 85%
Arm Cranking	65 - 70%
Arms and Legs	100 - 104%
Step Test	97%

Energy Systems for Exercise

Energy Systems	Mole of ATP/min	Time to Fatigue
Immediate: Phosphagen (Phosphocreatine and ATP)	4	5 to 10 sec
Short Term: Glycolytic (Glycogen-Lactic Acid)	2.5	1.0 to 1.6 min
Long Term: Aerobic	1	Unlimited time

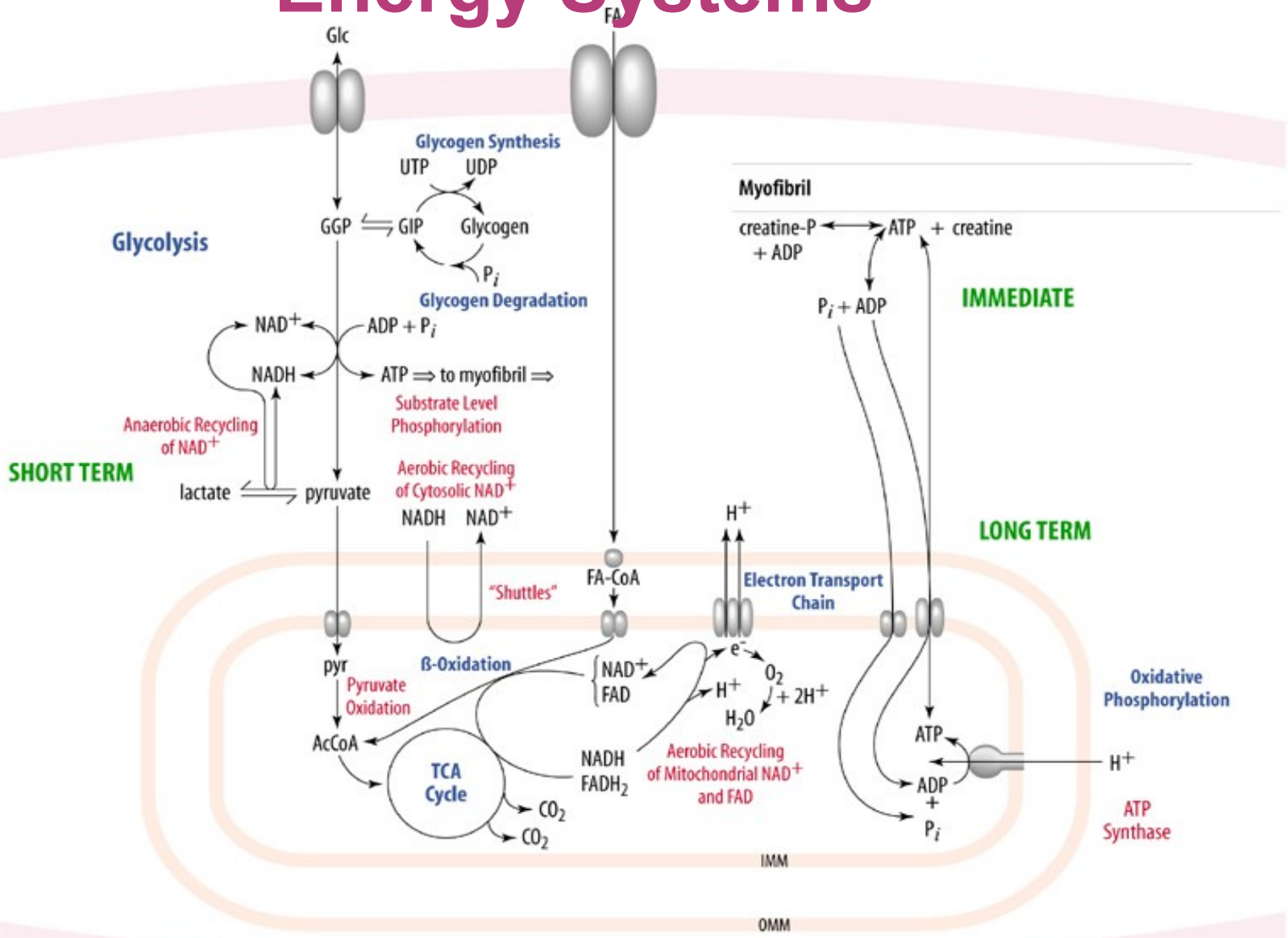
Anaerobic vs. Aerobic Energy Systems

- **Anaerobic**
  - ATP-CP : ≤ 10 sec.
  - Glycolysis: A few minutes

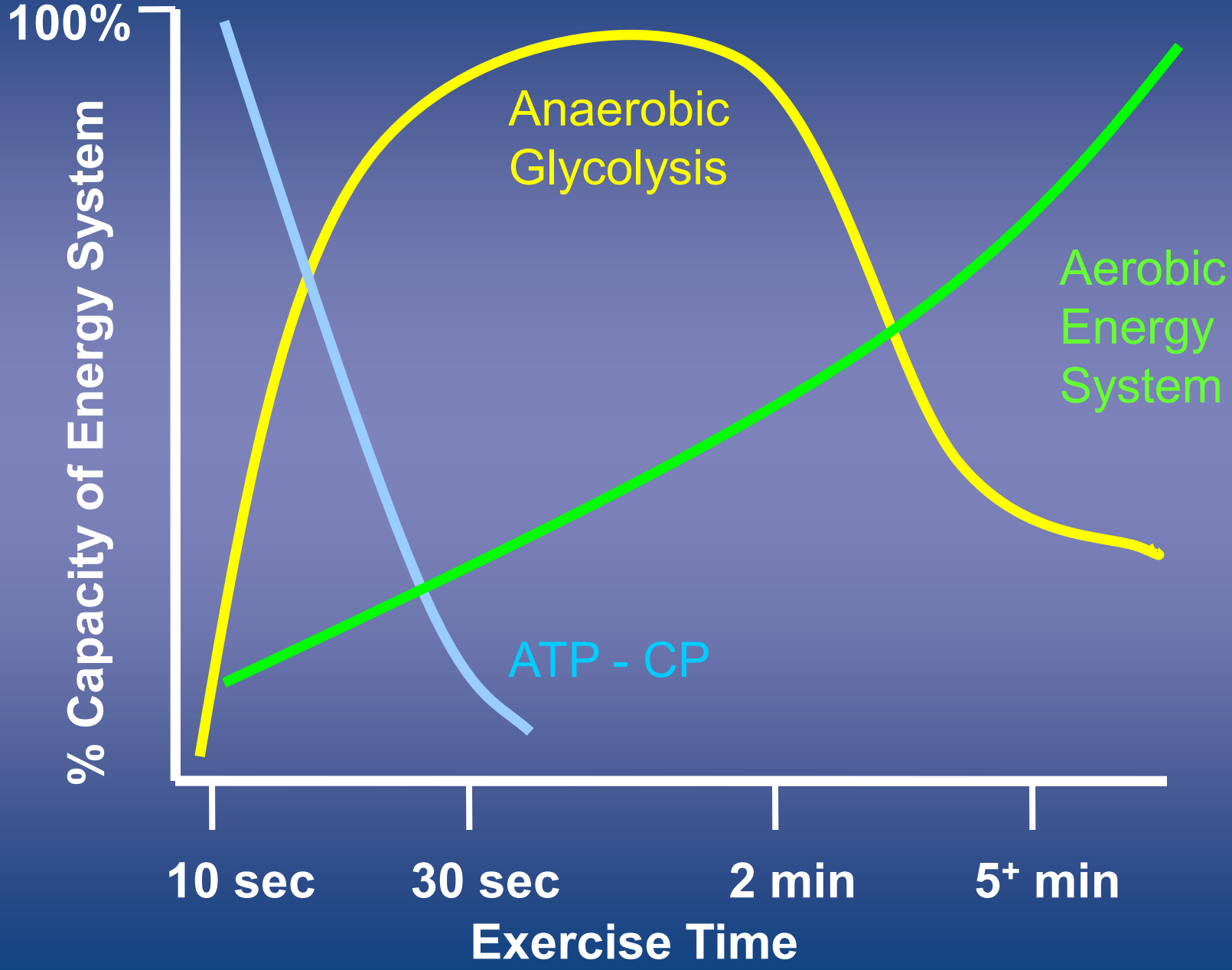
- **Aerobic**
  - Krebs cycle
  - Electron Transport Chain

} 2 minutes +

Energy Systems



Energy Transfer Systems and Exercise



Skeletal Muscle Fiber Types

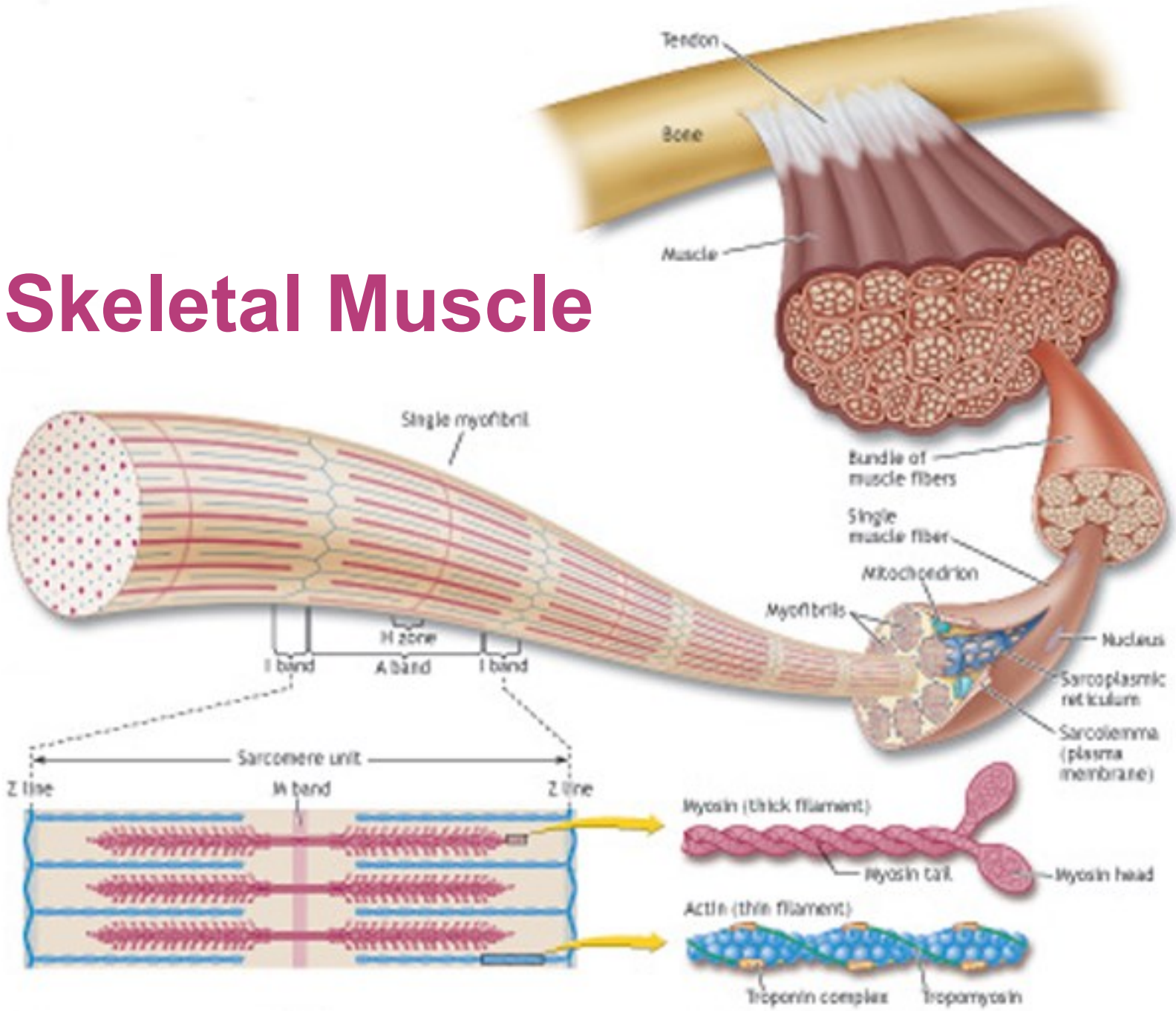
- **Fast-Twitch**
  Type IIa
  Type IId(x)

- **Slow-Twitch**
  Type I

Skeletal Muscle Fiber Types

- Characterized by differences in morphology, histochemistry, enzyme activity, surface characteristics, and functional capacity.
- Distribution shows adaptive potential in response to neuronal activity, hormones, training/functional demands, and aging.
- Change in a sequential manner from either slow to fast or fast to slow.

Skeletal Muscle



Characteristics of Human Muscle Fiber Types

Other Terminology	Slow Twitch	Fast Twitch	
	Type Ia	Type IIa	Type IId(x)
Aerobic Capacity	HIGH	MED/HIGH	MED
Myoglobin Content	HIGH	MED	LOW
Color	RED	RED	PINK/WHITE
Fatigue Resistance	HIGH	MED/HIGH	MED
Glycolytic Capacity	LOW	MED	MED/HIGH
Glycogen Content	LOW	MED	HIGH
Triglyceride Content	HIGH	MED	MED/LOW
Myosin Heavy Chain (MHC)	MHCIb	MHCIIa	MHCIId(x)

Terms and Concepts Associated with Exercise

- Rating of Perceived Exertion
- Training Heart Rate
- Energy Expenditure
- Thresholds and Exercise Domains
- O_2 Deficit and Excess Post-Exercise O_2 Consumption

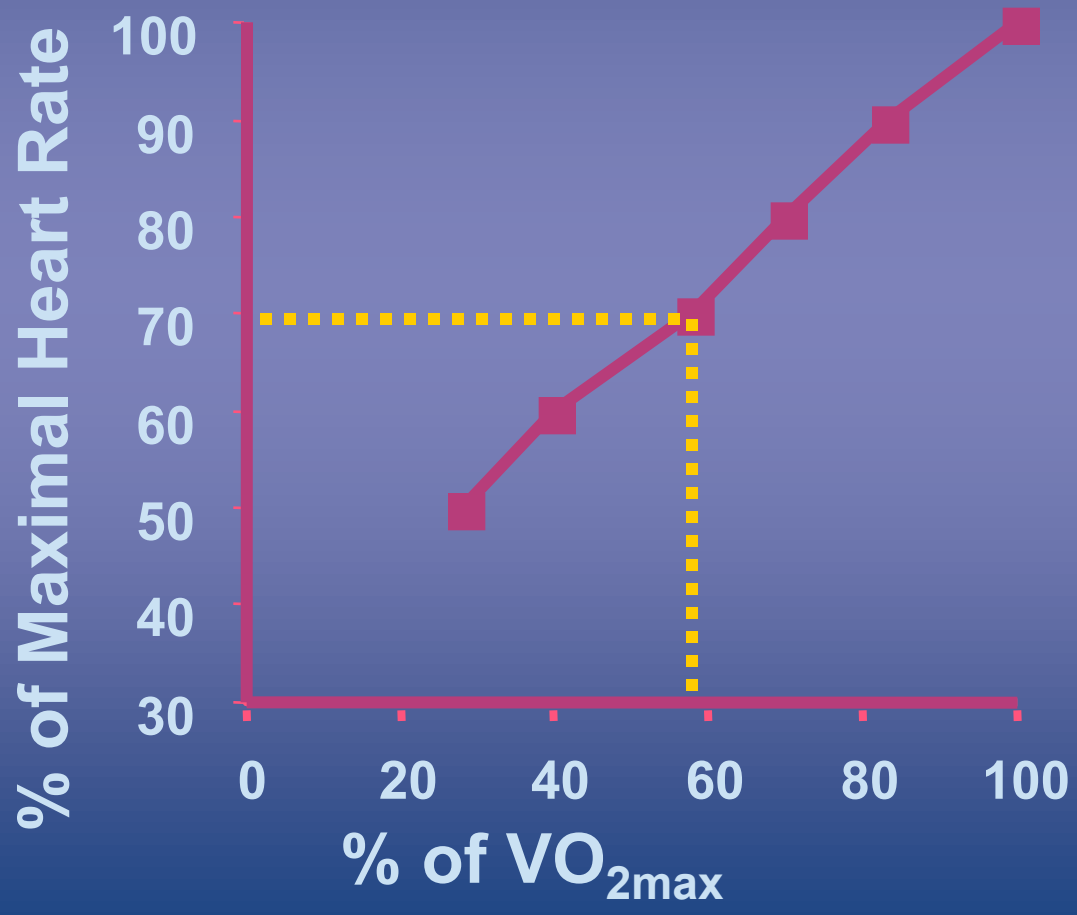
Rating of Perceived Exertion: RPE/Borg Scale

6 7 8	Very, very light	
9 10	Very light	
11 12	Fairly light	Lactate Threshold
13 14	Somewhat hard	2.0 mM Lactate
15 16	Hard	2.5 mM Lactate
17 18	Very hard	4.0 mM Lactate
19	Very, very hard	

Approaches to Determining Training Heart Rate

- 60 to 90% of Maximal HR
  - Max HR = 180
  - 60% = 108 and 90% = 162
- 50 to 85% of Heart Rate Reserve
  - Max HR = 180 and Resting HR = 70
  - HRR = 180 - 70 = 110
  - 50% = 70 + 65 = 135; 85% = 94 + 70 = 164
- Plot HR vs. O_2 Uptake or Exercise Intensity

Heart Rate and VO_{2max}



Energy Expenditure

- **MET: Energy cost as a multiple of resting metabolic rate**
  - 1 MET = energy cost at rest ~3.5 ml of O_2/kg/min
  - 3 MET = 10.5 ml of O_2 /kg/min
  - 6 MET = 21.0 ml of O_2 /kg/min
- **1 L/min of O_2 is ~ 5 kcal/L**
  - VO_2 (L/min) ~ 5 kcal/L = kcal/min
- **1 MET = 0.0175 kcal/kg/min**

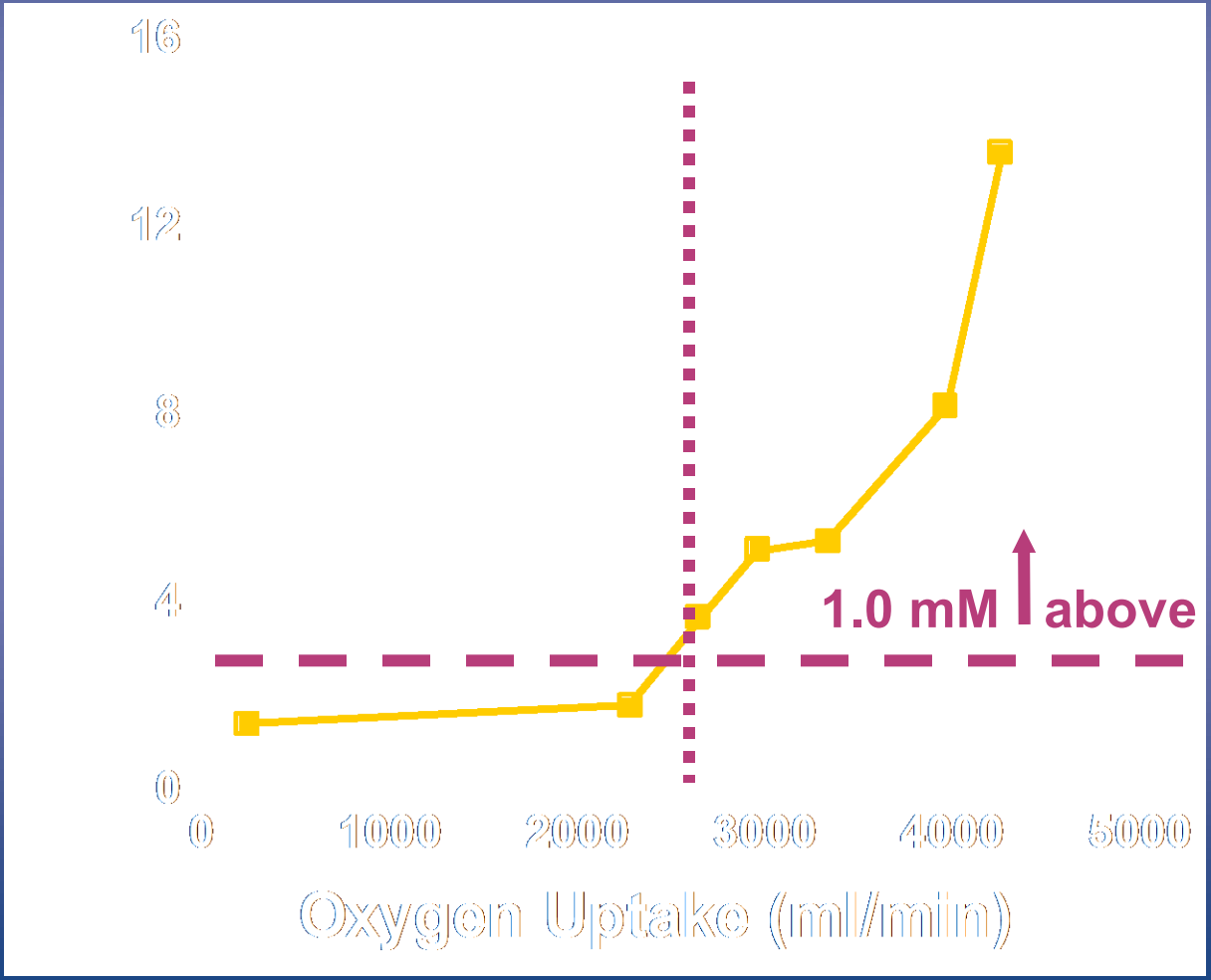
Lactate/Lactic Acid

- A product of glycolysis formed from reduction of pyruvate in recycling of NAD or when insufficient O_2 is available for pyruvate to enter the TCA cycle.
- Extent of lactate formation depends on availability of both pyruvate and NADH.
- Blood lactate at rest is about 0.8 to 1.5 mM, but during intense exercise can be in excess of 18 mM.

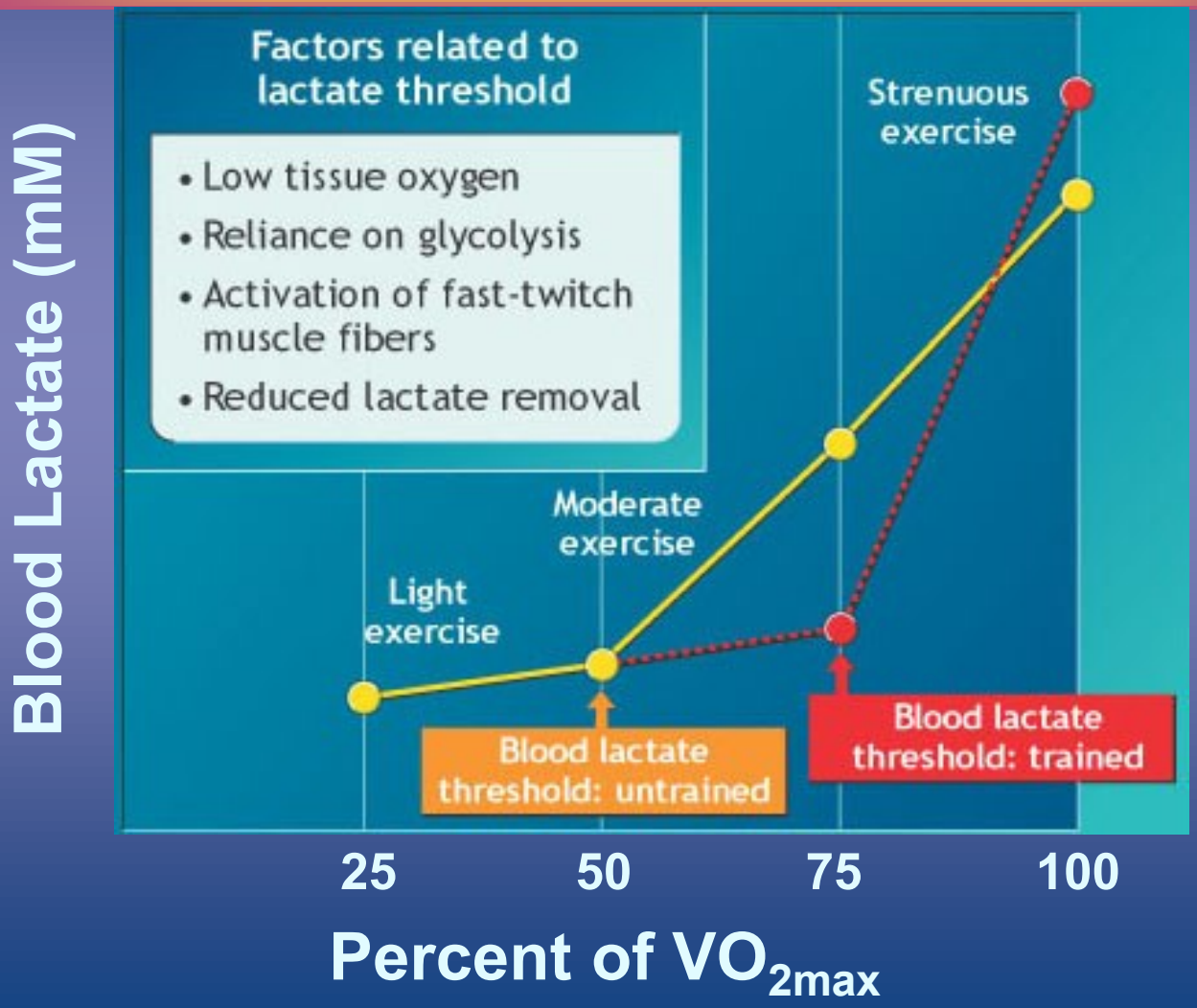
Lactate Threshold

- Intensity of exercise at which blood lactate concentration is 1 mM above baseline.
- Expressed as a function of $VO_{2max,}$ i.e., 65% of VO_{2max}.
- Expressed as a function of velocity or power output, i.e., 150 W or 7.5 mph.

Lactate Threshold



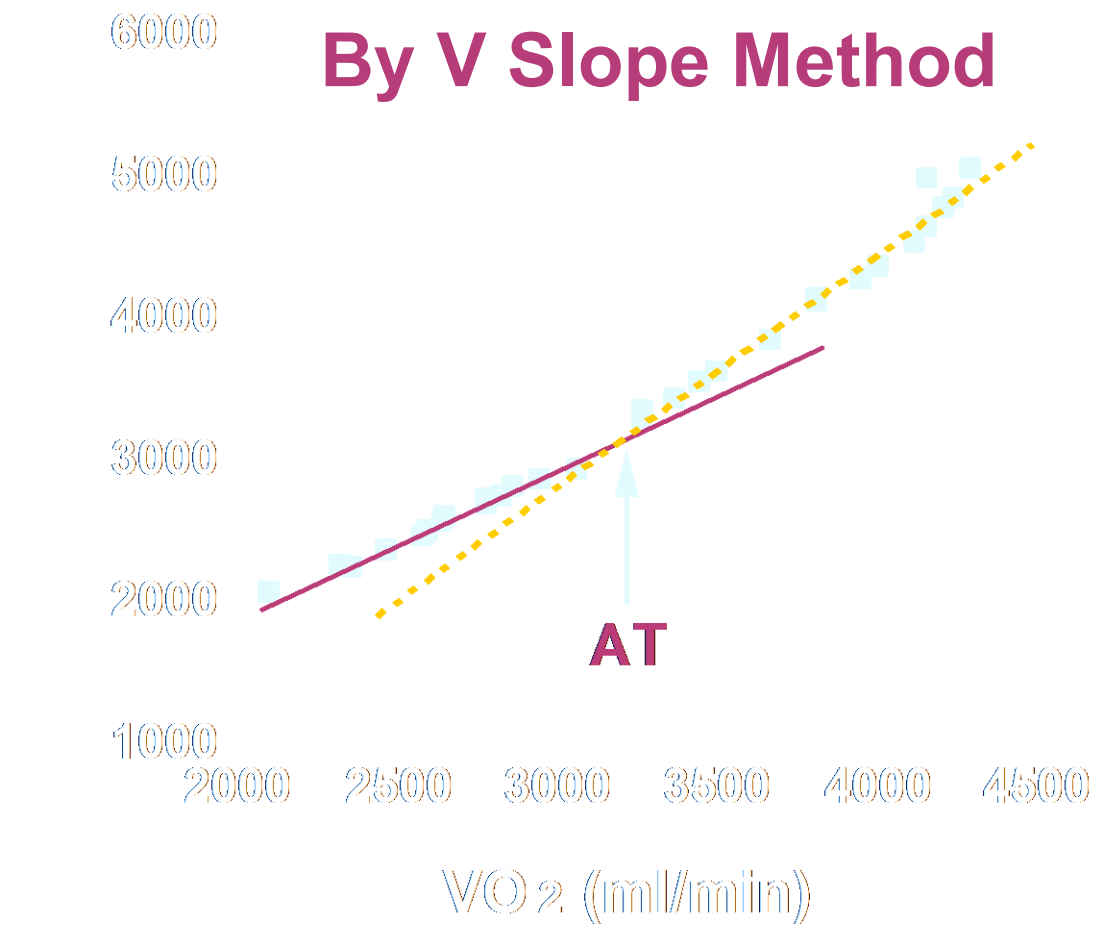
Blood Lactate as a Function of Training



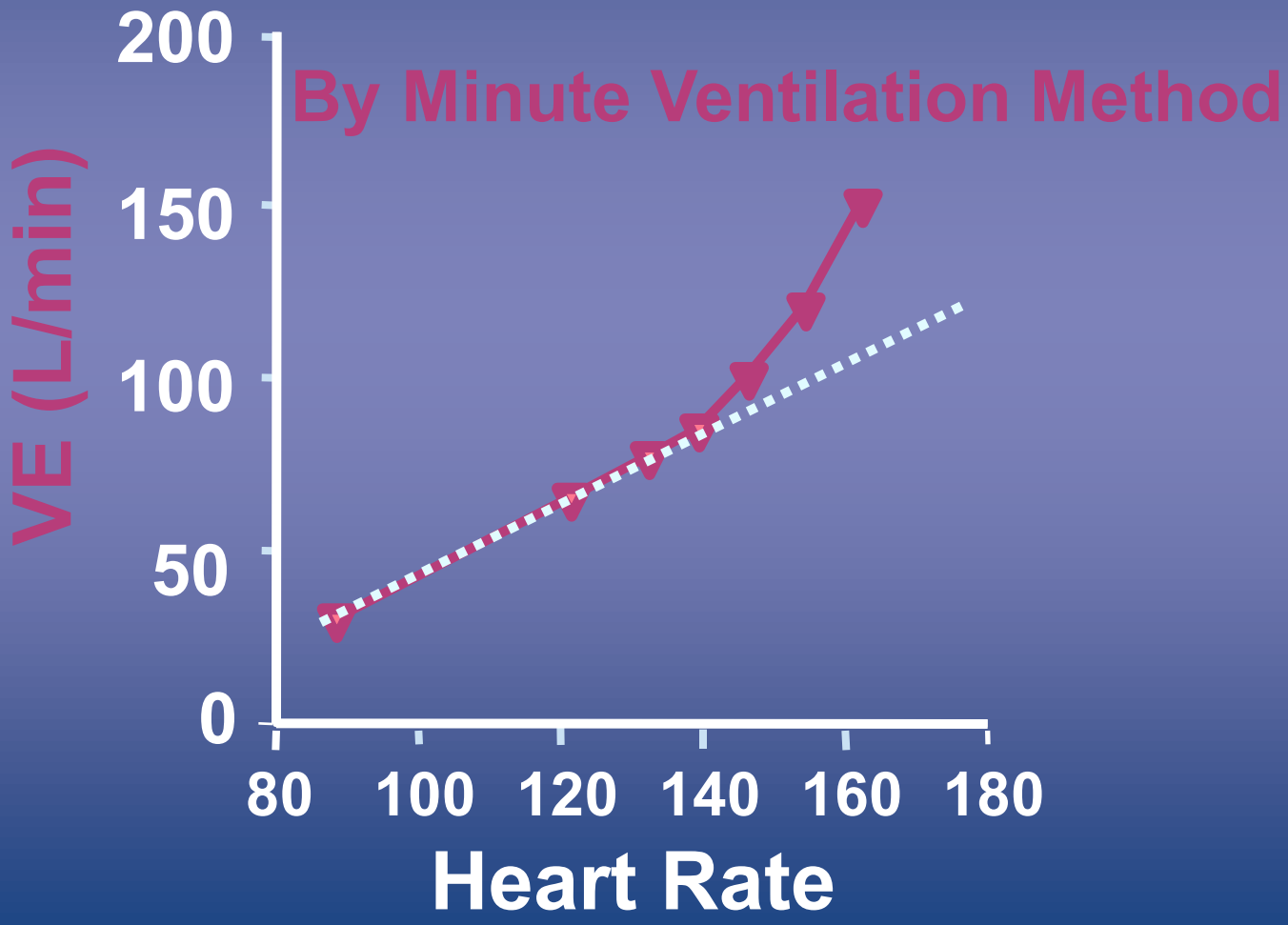
Ventilatory Threshold

- Describes the point at which pulmonary ventilation increases disproportionately with oxygen consumption during graded exercise.
- At this exercise intensity, pulmonary ventilation no longer links tightly to oxygen demand at the cellular level.

Ventilatory Threshold



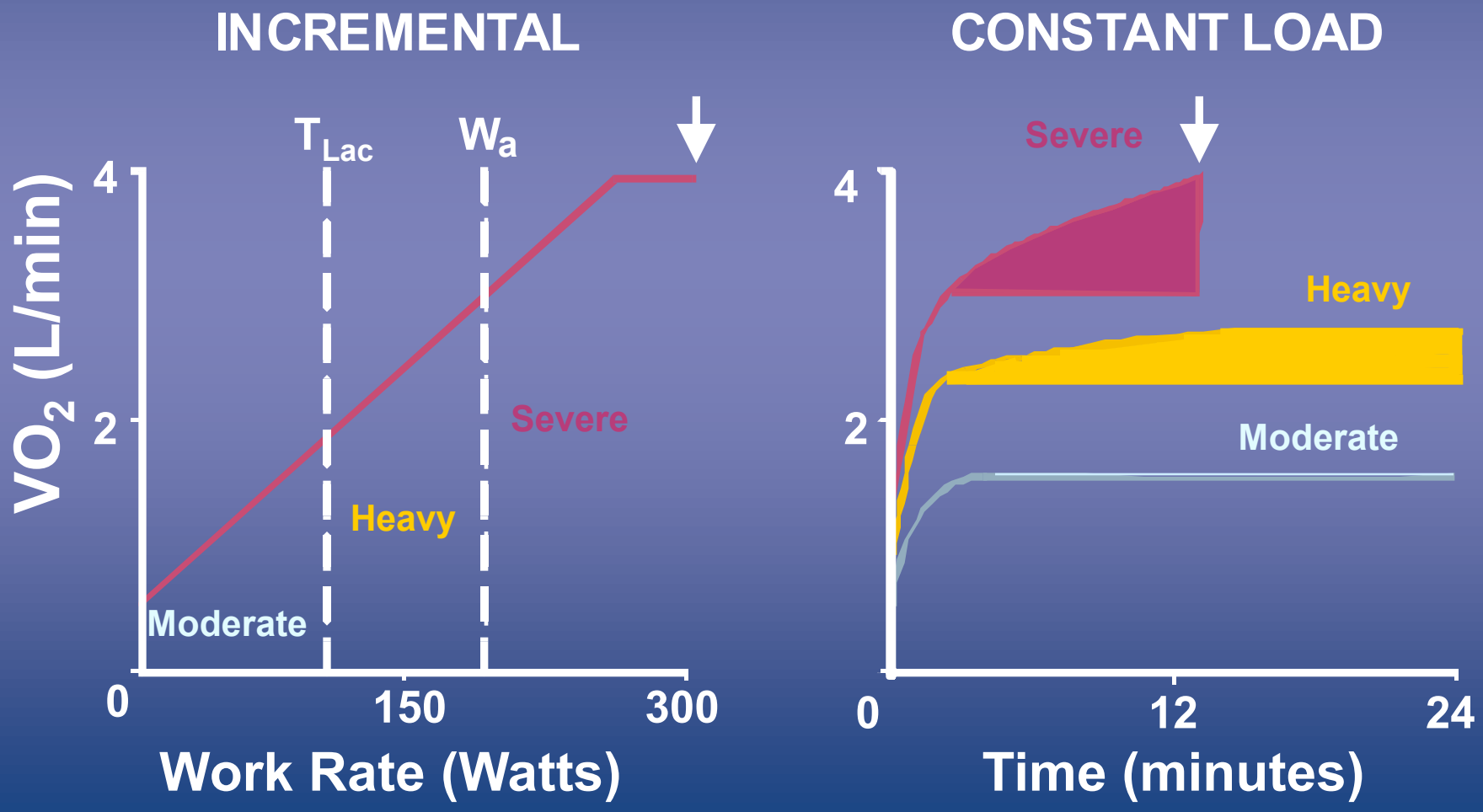
Ventilatory Threshold



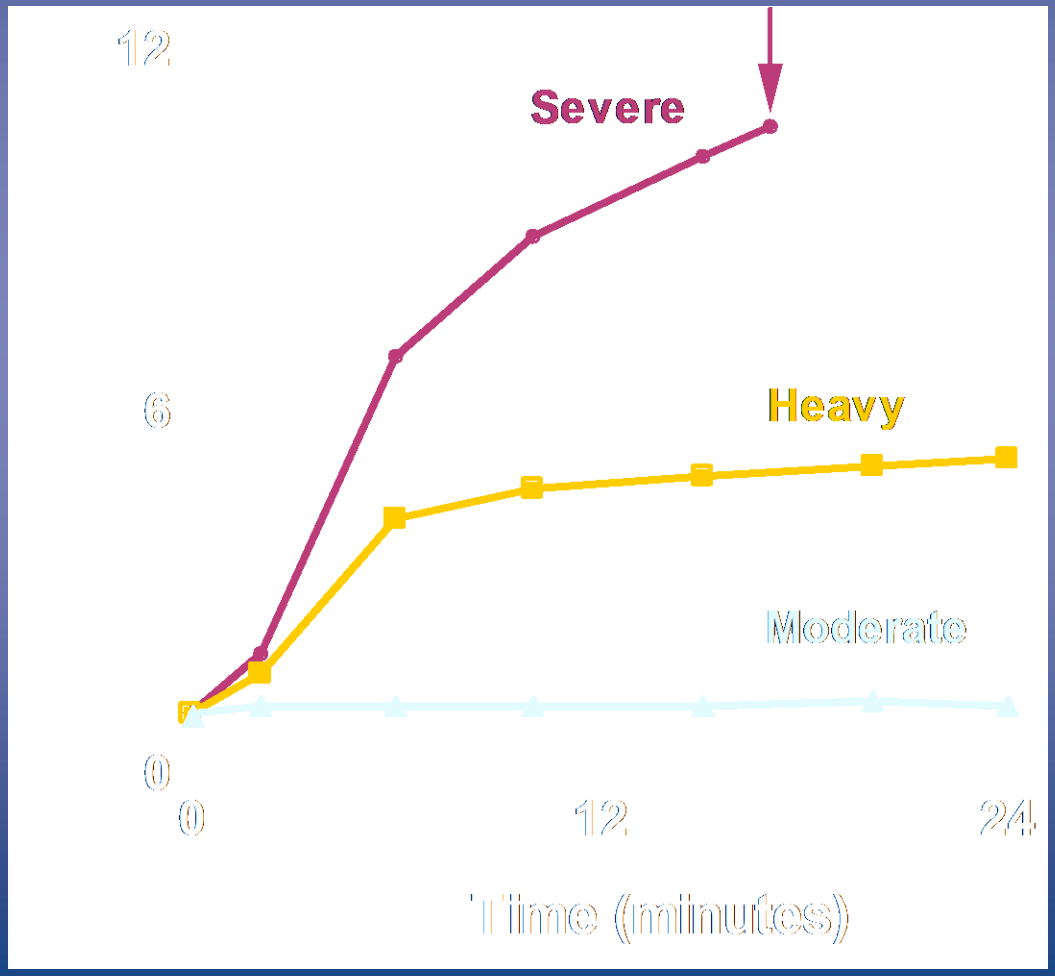
Exercise Intensity Domains

- **Moderate Exercise**
  - All work rates below LT
- **Heavy Exercise:**
  - Lower boundary: Work rate at LT
  - Upper boundary: highest work rate at which blood lactate can be stabilized (Maximum lactate steady state)
- **Severe Exercise:**
  - Neither O_2 or lactate can be stabilized

Oxygen Uptake and Exercise Domains



Lactate and Exercise Domains

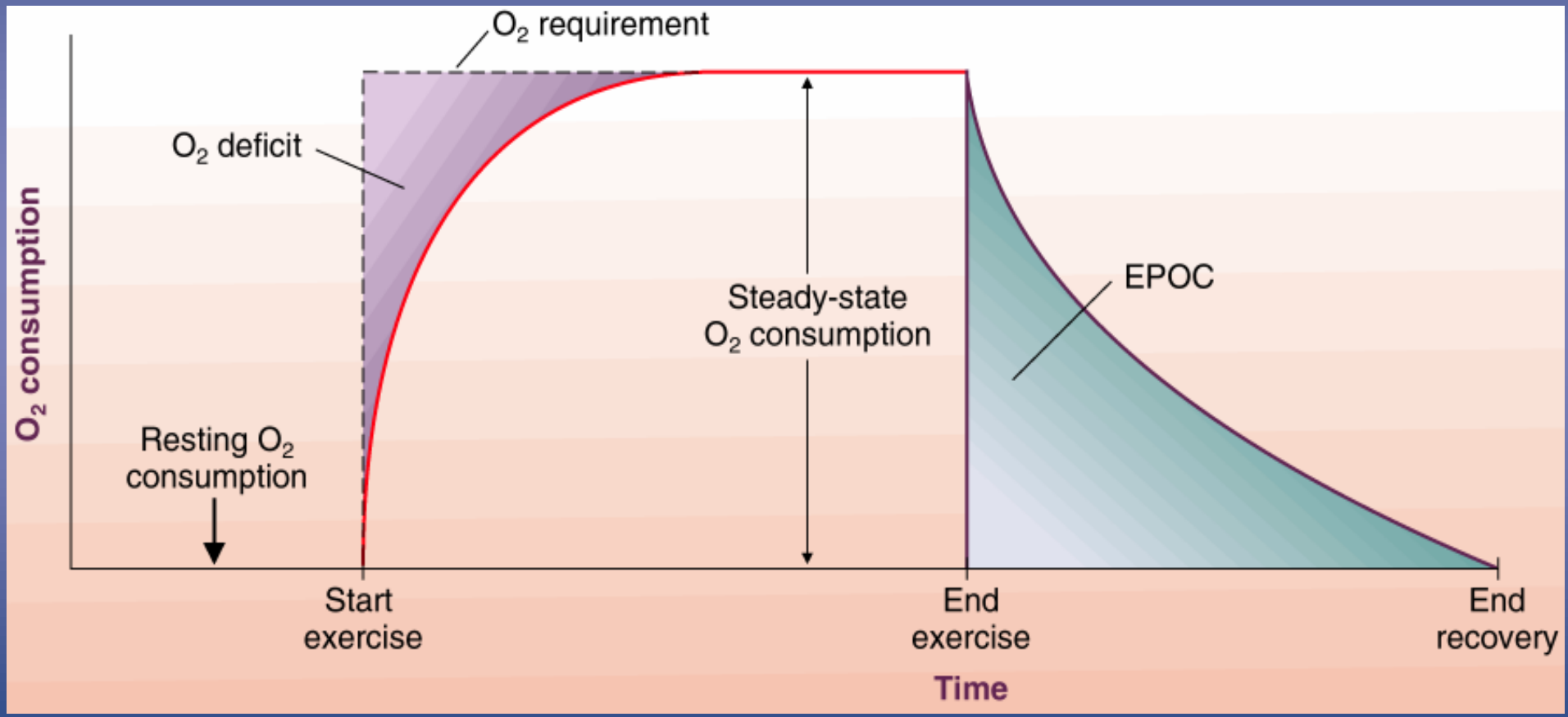


Oxygen Deficit and Debt/EPOC

- O_2 Deficit = difference between total O_2 used during exercise and total that would have been used if steady state had been achieved immediately

- Excess Post-Exercise O_2 Consumption (EPOC) or O_2 debt = increased rate of O_2 used during recovery period. The extra oxygen is used in the processes that restore the body to a resting state and adapt it to the exercise just performed.

Oxygen Deficit and Debt



EPOC or Recovery VO_2

- Fast component (Alactacid debt??) = when prior exercise was primarily aerobic; repaid within 30 to 90 sec; restoration of ATP and CP depleted during exercise.

- Slow component (Lactacid debt) = reflects strenuous exercise; may take up to several hours to repay; may represent re-conversion of lactate to glycogen.

Things to remember:

- Know the basic definitions & normal values
- Understand $VO_{2\ max}$
- Recognize differences in terms often used interchangeably
- Review energy systems for exercise
- Be familiar w/ terms & concepts associated w/ exercise

Questions???