Physiology week 12 – Respiratory (volumes) VIVAs

2 a). What are the causes of hypoxaemia in a person breathing room air	Hypoventilation, diffusion limitation, shunt, V/Q inequality	Need 3/4
2 b). Explain why ventilation-perfusion inequality causes a reduced arterial P_{O_2} while arterial P_{CO_2} remains relatively normal	Basically due to the differences in their dissociation curves. If one could in isolation cause V/Q inequality then gas exchange would deteriorate with hypoxia and hypercapnia. But the chemoreceptors act to increase ventilation. P_{CO_2}- The **CO_2 dissociation curve is linear** at the working range. The increased ventilation is able to correct the P_{CO_2}.by increased CO_2 output, particularly in units with high V/Q ratios P_{O_2} –the **oxygen dissociation curve is not linear**. So high V/Q areas can only boost their P_{O_2} a little with increased ventilation. Conversely very low V/Q areas have proportionally lower P_{O_2} (close to mixed venous). Overall P_{O_2} is low.	Bold plus demonstrate understanding

1.1 VP inequality (West pp 67-72)	Describe the relationship between ventilation and perfusion of the lung in a person while standing?	• Max ventilation 3-4x greater at apex • PO_2 40mmHg higher at lung apex • Max perfusion basally Q nearly 20x greater at base • Prompt: are there regional variations in either
	What are the effects of V/Q inequality on gas exchange?	• V/Q inequality impairs uptake or elimination of all gases • Majority of blood returns from lung bases where the oxygen saturation is low • Results in blood PO2 being lower than that of mixed alveolar PO2
	What effect does increasing ventilation to the lungs have on arterial PO2 and PCO2	• PCO2 reduces much more than PO2 increases

TOPIC: Ventilation Perfusion Inequality_____

OPENING QUESTION	**What is the effect of ventilation perfusion inequality on gas exchange?**	**COMMENTS**
POINTS	Impedes exchange of oxygen and carbon dioxide	need 2/3
	Hypoxia which cannot be corrected by increased ventilation	
	Hypercapnia can be corrected by increased ventilation	
PROMPTS	**Both gases**	
SECOND QUESTION	**Can increasing ventilation correct these problems?**	expect oxygen explanation Others additional information
POINTS	The oxygen dissociation curve is S shaped which means that increasing ventilation to units with high VQ ratios cannot compensate for the shunt caused by low VQ units	
	The carbon dioxide dissociation curve is more linear so that increasing ventilation will blow off CO2 from lung units with both high and low VQ ratios	
PROMPTS	**Both gases**	
THIRD QUESTION	**How can we determine the effect of VQ mismatch on oxygenation in clinical practice?**	
POINTS	Calculate the AA gradient = PAO2-PaO2	Prefer equation
	PAO2=PIO2-PaCO2/R	
	Give normal values for each	
PROMPTS	**Ask about AA gradient if candidate does not volunteer it**	

TOPIC: Relationship of intrapleural pressure and lung volume and regional differences in ventilation_____ **NUMBER:** _____ 5b

OPENING QUESTION	What is the relationship between intrapleural pressure and lung volume?	**PROMPTS**	**COMMENTS**
POINTS REQUIRED	1 Sigmoid curve of IP pressure vs volume, does not reach 0% lung volume	1	
	2 Shows lung volume is higher during deflation than inflation for any given pressure = Hysteresis	2	Pass if describes relationship, or draws curve with features
	3 Shows that lung contains residual air, without any expanding pressure (due to airway closure)	3	3 OF 4 POINTS
	4 Shows that compliance decreases at higher lung volumes – lung becomes stiffer due to reaching limits of elasticity	4	
	3	3	
SECOND QUESTION (if needed)	**What variables affect pulmonary compliance?**		
POINTS REQUIRED	• Slightly greater during deflation than during inflation as noted above; • Lung volume – at very low and very high volumes compliance is reduced; • Increased when tissue elasticity is reduced, as in emphysema; • Decreased by increased tissue mass - fibrosis or pulmonary congestion; • Decreased by loss of surfactant.	1	2 of 4 to pass
THIRD QUESTION (if needed)	Describe how regional differences in intrapleural pressure affect the ventilation		
POINTS REQUIRED	1 states that the intrapleural pressure is higher at the apex than at the base of the lung – to keep the lung expanded against its own weight	1	Extra mark for correct answer here
	2 Increased compliance at base, hence better ability to ventilate base compared with apex	2	Bonus if gives values 10cm H2O at apex, 2.5cm at base

Regional differences in pulmonary blood flow	Describe the distribution of blood flow in the lungs	Linear increase from top to bottom 3 zones explained by hydrostatic pressures
	Explain how V/Q matching varies from apex to base in the normal lung	Slow increase in ventilation from top to bottom but not as much as perfusion. Highest V/Q at apex
	What factors effect pulmonary vascular resistance?	Hypoxia - arteriolar smooth muscle to contract One of low pH, autonomic or passive factors

3.1 Elastic Properties of the Lung West pp 96-106	Define lung compliance?	• Change in volume / change in pressure (Slope of pressure-volume curve) (Lung "stiffness")
	What factors influence lung compliance?	**(3 out of 6)** • Fibrosis • Alveolar oedema • Elastic tissue • Emphysema / age • Volume / Size of lung • Surface tension in alveoli (Surfactant)
	What else does surfactant do?	**(2 of 3)** • Reduces WOB Prevents collapse Keeps alveoli dry

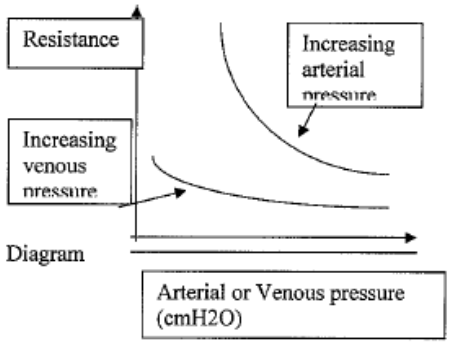
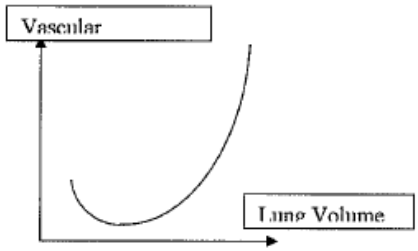
1a). What is Pulmonary Compliance?	a) Compliance =Volume Change/Pressure Change, proportional to slope the pressure volume curve of the lung. Within normal range (-2 to –10 cm H20) of expanding pressures, lung is very compliant. At higher expanding pressures, compliance is smaller. Normal human lung compliance =200 ml /cm H2O) Specific Compliance = "compliance per unit volume of lung"	a) delta V/delta P
b) What are the factors that decrease and increase pulmonary compliance?	c) Reduced = pulm venous hypertension, unventilated lung (espec at low lung volumes i.e. atelectasis), pulm fibrosis and alveolar oedema of any type. Increased = increasing age and emphysema	b) Three factors which decrease Compliance and both the factors which decrease it c)two factors which increase it
c) What are the physiological effects of surfactant on the lung?	d) What are the physiological effects of Surfactant? i) increases lung compliance ii) reduces work of breathing iii) improves stability of alveoli iv) keeps alveoli dry	d) Three of four

TOPIC: Dead space in the lung _____ **NUMBER:** __

OPENING QUESTION	What is the definition of dead space in the lung?	**PROMPTS**	**C**
POINTS REQUIRED	1 Volume of lung not involved in CO^2 elim^n	1 Can you describe anatomical and physiological dead space?	
	2 Anatomical and physiological	2	
	3 Vols nearly same (150 ml or 0.2-0.35 V_t) in health	3	
	4	4	
	5	5	
	6	6	
	7	7	
	8		
SECOND QUESTION (if needed)	How can the physiological dead space be measured?		
POINTS REQUIRED	1 Bohr's method calculates fraction of tidal volume by measurement of mixed expired CO2 and arterial CO2	1 Direct?	
	2 $V_D = V_T \times (Pa_{CO2} - PE_{CO2}) / Pa_{CO2}$	2	
	3	3	
	4		
THIRD QUESTION (if needed)	What will lead to increased physiological dead space?		
POINTS REQUIRED	1 V/Q mismatch= Non-perfused alveoli and Alveoli with excessive ventilation	1 Can you give clinical examples	
	2	2	
	3	3	

TOPIC: Factors that determine the work of breathing. **NUMBER:** _____5a

OPENING QUESTION	**What factors determine the work of breathing.**	**PROMPTS**	**COMMEN**
POINTS REQUIRED	1 elastic forces of the lungs and chest wall		Must pass
	2 viscous resistance of the airways and tissues		Must pass
	3		
SECOND QUESTION	**What variables affect elastic workload?**		
POINTS REQUIRED	1 Larger tidal volumes	1	Must pass
	2 Reduced compliance due to: • lung volume - a person with only one lung has halved compliance; • slightly less during inflation than during deflation; • increased by increased tissue mass - fibrosis or pulmonary congestion or chest wall restriction; • loss of surfactant	2	2 of 4 to pass
	3	3	
THIRD QUESTION (optional)	**What variables affect viscous resistance?**		
POINTS REQUIRED	1 Higher respiratory rates increasing flow rates	1	
	2 Decreased airway radius due to: Lower lung volumes; Bronchoconstriction;	2	
	3 Increased air density (eg SCUBA diving)	3	
	4 Increased air viscosity	4	

Question	Required response [Key items marked with*]	To Pass
Please describe the relationship between pulmonary vascular resistance and pulmonary vascular pressure? PROMPTS: What mechanisms are involved in the vascular response to rising pulmonary vascular pressure?	A low resistance system Capacity for resistance to DECREASE with INCREASE pressure* (both INCREASED pulmonary art & INCREASED pulm venous) Mechanisms: vascular 'recruitment' (with rises in pressure from low levels); vascular 'distension' (with rises in pressure at higher levels) *  Diagram	* to pass Drawing diagram not essential
How does lung volume influence pulmonary vascular resistance?	Vascular resistance initially decreases as lung volume increases, then rises (see diagram below) * At very low lung volumes (eg. lung collapse) must reach a 'critical opening pressure'(several cm H2O above downstream pressure) to enable any flow * Very high lung volumes, when alveolar pressure exceeds pulmonary capillary pressure, pulmonary vascular resistance will increase (pulm capillaries squashed).  	* to pass Drawing diagram not essential
What factors influence the distribution of pulmonary arterial blood?	1. **Alveolar Hypoxia** * 2 **Gravity** * :3 main zones Z1 (apical) PA>Pa>Pv Z2 (middle) Pa>PA.>Pv Z3 (basal) Pa>Pv>PA 3 vascular resistance pulmonary HT / PE 4 pulmonary disease : asthma /COAD / infection/ infarction/ cancer / fibrosis / pneumothorax / chest trauma 5 vasoactive substances * (NO, endothelin, prostaglandin) 6 low blood pH leads to pulm vasoconstriction 7 Sympathetic stimulation leads to stiff pulmonary arteries leads to vasoconstriction.	* To pass, p others
What **EXTRA-PULMONARY** factors influence pulmonary blood flow ?	1 blood volume 2 cardiac output 3 atmospheric pressure 4 temperature 5 pathology eg, anaemia, cancer, infection 6 exercise 7 posture	4 of 7

TOPIC: Distribution of Blood Flow in the Lung NUMBER:

OPENING QUESTION	**Describe the distribution of blood flow in the lung of an upright subject at rest.**	**COMMENTS**
POINTS REQUIRED	1. **Decreases linearly from base to apex**	Must identify 1, 2 ,3 and 5 to pass
	2. **Due to hydrostatic pressure,**	
	3. **Under normal conditions, flow almost ceases at apex**	
	4. Distribution more uniform with exercise	
	5. **Explanation of West's zones 1 – 3 +/- zone 4** 6. Zone 4 only at very low lung volumes	
PROMPTS	What are the zones of the lung described by West ?	
SECOND QUESTION (if needed)	**What are the main determinants of flow in these three zones ?**	
POINTS REQUIRED	1. **Zone 1 PA>Pa>Pv(not under normal conditions and is alv. dead space)** 2. **Zone 2 Pa>PA>Pv (recruitment)** 3. **Zone 3 Pa>Pv>PA (distension + recruitment)**	Must identify 3 pressures and their relationship to pass
PROMPTS	What pressure gradients determine flow in zones 1-3	
THIRD QUESTION (if needed)	**How does the distribution of blood change when the subject becomes supine?**	
POINTS REQUIRED	1. Blood flow from base to apex is almost uniform but flow in posterior segments exceeds that in anterior segments	

TOPIC: Elastic properties of the lung _____ **NUMBER:** _____

OPENING QUESTION	What is thoracic compliance?	**PROMPTS**	**COMMENTS**
POINTS REQUIRED	1 Change in lung volume per unit change in airway pressure (DV/DP)		Essential
	2 Measure of elastic recoil of lungs and chest wall	What is it a measure of?	
	3 Normally 200 mL/mmHg in intact thorax		
SECOND QUESTION	What are the main determinants of compliance of the thorax?		2 to pass
POINTS REQUIRED	1 Surface tension of the alveoli (2/3rds)		
	2 Elastin/collagen fibres (1/3rd)		Allow tissue properties
	3 Alveolar surface tension depends on alveolar pressure, alveolar radius, surfactant (Law of Laplace – P=2(or4) x T/R)		
THIRD QUESTION (if needed)	How does compliance vary throughout the upright lung?		Must say that base > apex
POINTS REQUIRED	1 Higher at base than apex because apex is already more distended		

2.1 Airway Resistance West pp 106-112	What factors impact on resistance in airways?	• Size of airway: R highest in medium sized bronchi, low in very small airways. • Lung volume: R decreases with expansion as airways pulled open • Bronchial smooth muscle tone: controlled by B sympathetics • Gas density: eg heliox -> low R • Forced expiration: intrathoracic pressure compresses airways = 'dynamic compression'
	What factors cause turbulent flow in airways	Expressed by Reynold's number; **(3 out of 4)** Where: ρ is the fluid density; D is the diameter of the tube; V is the velocity of flow; η is the viscosity of the fluid. $Re = \frac{\rho DV}{\eta}$ Laminar flow only in small airways, transitional most areas, turbulent in trachea (rapid breathing)

Question 2:a) Score:	**What are the major factors that effect pulmonary vascular resistance in the normal lung?**	1) ↑Art or 2) Ven Pressure 3) Lung volume (U/J shaped curve) 4) Alveolar hypoxia > increased PVR via hypoxic vasoconstriction 5) Vascular Smooth Muscle Tone - response to endogenous/ exogenous factors 6)Area of lung (apex partic < base) 7) Position change 1	(A > V) (recruit – low P) (distension (high P) Low vol- collapsed ex-alveolar vessels Intermed Vol – vessels open High Vol – compressed alveol vessels (pulled open v normal elastic -cap 1st) (complex: Ipleural P < CO, alveolar P > capillary + caps squashed in alveoli) **Pass/Fail 3 of 6 , extra marks for detail in** eg nitrates, Ach, Isoprenaline, NO, decrease PVR; Increased sympathetic tone, serotonin, histamine and norepinephrine increase PVR, endothelin, thromboxane A2
b)	**Why is pulmonary flow so sensitive to pulmonary vascular pressures?**	) V low Pressure system – few resistance vessels 2) Easily distensible vessels 3) Recruitment 4) Only just enough P for normal gravity/ position to get apical flow 2/4 to pass	P just enough to reach only standing but (dependent lung may collapse) -due to < art pressure in low pressure system- partic if poor output V thin walls Vasc bed expands + geometry with alveolar expansion Surrounding IP/ alv P v significant effect on output Additional info 1/10th syst P (5-15 A-V diff) (low vol smooth muscle/high P and higher lung vol) (geometry-low P) (distension/ effects on cap) (due to v low P in system)

TOPIC: Distribution of blood flow in the lung_____ **NUMBER:** _____

OPENING QUESTION	What factors affect the distribution of blood flow in normal lungs?	**PROMPTS**	**COMMENTS**
POINTS REQUIRED	1. Passive: a. Posture (lung zones, see below) b. Exercise (this will increase blood flow throughout the lung) c. Other: eg decreased blood flow through the periphery of the acinus	How do you divide up the factors?	Need both active & passive.
	2. Active: vasoconstriction occurs with… (3) a. Decreased pO2 (hypoxic pulmonary vasoC) = the **opposite** of systemic circulation, to prevent VQ mismatch b. Decreased pH c. Increased sympathetic stimulation (a weak effect)		
SECOND QUESTION	What do you understand by the term 'zones in the lung'?		
POINTS REQUIRED	1. Describe the concept a. blood **flow** decreases towards the apex. b. The lung is a column of blood, whose **pressure** increases towards the base c. But **alveolar** pressure stays constant. d. **(MCQ)** 23mm Hg pressure difference between apex & base		

TOPIC: Airway resistance NUMBER: 2

OPENING QUESTION	Discuss the factors that determine airway resistance.	**PROMPTS**	**COMMENTS**
POINTS REQUIRED	1. Flow resistance R = 8 X viscosity X length / pieX r^4		Need to say that radius is the most important determining factor, 2/3 to pass.
	2. Directly proportional to viscosity & length. Inversely proportional to radius to the power of 4 (ie: half the radius increases resistance 16 fold).		
SECOND QUESTION (if needed)	What factors affect the radius of the airway?		Need 2 to pass.
POINTS REQUIRED	1. Bronchial smooth muscle tone: sympathetic and parasympathetic activity		
	2. Lung volume		

TOPIC: Perfusion and diffusion limited gas exchange ____ NUMBER: _____ 5c

OPENING QUESTION	Describe the difference between diffusion limited and perfusion limited gas exchange in the lung.	**PROMPTS**	**COMMENTS**
POINTS REQUIRED	1 Blood in pulmonary capillary has 0.75 seconds for gas exchange	1	
	2 Ability to reach partial pressure equilibrium depends on reaction with substances in the blood.	2	Pass if describes both adequately
	3 No reaction with substances in blood – gas dissolves only on plasma – rapid equilibrium reached, gas uptake limited by perfusion	3	
	4 Example of N2O as perfusion limited	4	
	5 Describes reaction of CO with Hb, such great affinity that PCO in capillary falls rapidly – slow equilibrium, diffusion limited		
SECOND QUESTION (if needed)	Explain how oxygen exchange is limited across the pulmonary capillary?		
POINTS REQUIRED	1 Perfusion limited	1	Must pass
	2 Describes O2 and Hb combination, and time frame of combination (0.3 sec)	2	Extra mark for correct answer here
	3	3	
THIRD QUESTION (if needed)	What would you expect to be the effect of heavy exercise on oxygen uptake in the pulmonary capillary?		
POINTS REQUIRED	1 Describes reduced time for combination with Hb (0.25 seconds), possible reduced O2Hb saturation	1	Bonus Points
	2 Describes possible effect of altitude	2	Bonus Points
	3		

2.1 Alveolar surface tension and surfactant	Describe the relationship of pressure and wall tension in connected bubbles.	Law of Laplace: **P = 4T/r.** Two bubbles connected (same surface tension), the smaller with higher pressure will blow up the larger with lower pressure. Smaller bubble will collapse.
	What are the effects of surfactant in alveoli?	**Surfactant reduces surface tension.** Alveolar bubbles are stable because of very low surface tension when small (on expiration). Hysteresis curve demonstrates very low pressures on expiration to small volumes = bubble stability. Increased **compliance** = ease of expansion. **Also keeps alveoli dry** = opposes transudation fluid into bubble.
	How does surfactant achieve this?	**Bipolar molecules oppose the normal increasing attracting forces as molecules get closer in a smaller surface.** The ends of surfactant molecules repel each other and oppose collapse.

3.2 Flow, pressure, resistance, blood flow	What factors cause turbulence in blood flow?	'Critical velocity'; smaller diameter, reduced viscosity.
	Why is blood flow slower in capillaries?	Velocity relates to total cross sectional area => capillaries, 1000x area aorta, low velocity same flow.
	What is the relationship between pressure and wall tension in blood vessels of different sizes;	P = T/r. Smaller = less tension in the wall for the same distending pressure. Eg aorta : vena cava : capillaries = 170,000 : 21,000 : 16 dynes/cm. Small vessels unlikely to rupture.
	What is the relationship between pressure and wall tension in the heart?	Ventricular dilation means more tension required to generate same pressure = more work.

TOPIC: Diffusion across the alveolar-capillary membrane **NUMBER: 2**

OPENING QUESTION	What factors affect the diffusion of gases across the alveolar capillary membrane?	**PROMPTS**	**COMMENTS**
POINTS REQUIRED	Ficks law diffusion is proportional to tissue area and concentration gradient of gas and inversely proportional to the tissue thickness x R R = diffusion constant and relates to gas and tissue solubility		Need to mention diffusion, concentration gradient & thickness.

Question 2: Alveolar gas equation and its use in a clinical setting West pp 58, pp170	i) What is the alveolar gas equation? ii) How do you calculate the alveolar-arterial gradient? iii) What is the physiological significance of the A-a gradient?	i) **(4 out of 4)** $$PAO2 = PIO2 - \frac{PACO2}{R}$$ Where: • PAO2 is the alveolar oxygen partial pressure • PIO2 is the oxygen partial pressure of inspired air • PACO2 is the alveolar CO2 partial pressure. • R is the respiratory quotient; CO2 production/O2 consumption, typically 0.8 Note that a small correction factor F of 2mmHg has been omitted from the equation. ii) **Difference between PAO2** (alveolar) and **PaO2** (arterial). iii) **V/Q mismatch** (eg: shunting or dead space)

TOPIC: Physiological shunt in the lung_____ **NUMBER:** _____

OPENING QUESTION	Explain the difference between alveolar and arterial oxygen concentrations in the healthy adult.	**PROMPTS**	**COMMENTS**
POINTS REQUIRED	1 Physiological shunt of lung ($P_AO_2 > P_aO_2$)		Essential plus 1 reason.
	2 Blood enters arterial system without passing through a ventilated area of lung		
	3 Bronchial arterial blood flows to pulmonary veins		
	4 Coronary arterial blood flows to coronary veins then thebesian veins in left ventricle		
	5 Atelectasis in lung		

TOPIC: Physiological shunt in the lung_____ **NUMBER:** _____

OPENING QUESTION	Explain the difference between alveolar and arterial oxygen concentrations in the healthy adult.	**PROMPTS**	**COMMENTS**
POINTS REQUIRED	Overview: this is the **physiological shunt** of lung (P_AO_2>P_aO_2). Reasons are as follows:		Essential plus 1 reason.
	1. Blood enters arterial system without passing through a ventilated area of lung ie perfusion without ventilation. **Put another way:** the best perfused region of the lung is the most poorly oxygenated therefore overall pO2 will never reach alveolar pO2.		
	2 . **Bronchial** arterial blood flows directly to pulmonary veins without being oxygenated, then goes on to systemic circulation.		
	3. Similarly, **coronary** arterial blood flows to coronary veins then thebesian veins in left ventricle, ie going on to systemic circulation without 1[st] being oxygenated.		
	4. Age: as we age, the shunt increases because it simply gets harder for the O2 to diffuse from alveolus to capillary.		

	Describe the zones a. **Zone 1:** PA (alveolar pressure) > Pa > Pv. At the apex: not present in healthy people: 'alveolar deadspace'. Pulmonary pressure is so low that alveolar pressure squashes the capillaries! Hence, **ventilated but not perfused.** b. **Zone 2:** Pa > PA > Pv. The 'rubber tube' of the capillaries collapses at the venous end. This is called a 'Starling resistor'. This has ***intermittent*** **blood flow**, mainly in systole. **(MCQ)** Zone 2 is usually from 7-10cm above the heart to the apices c. **Zone 3:** Pv > PA… finally! Here, blood flow is determined by the arterial- venous difference, as usual in the systemic circulation. d. **Zone 4:** right at the base, where blood flow actually decreases because lung tissue poorly ventilated & squashed! **(MCQ)** Zone 4 is only present at low lung volumes. e. **(MCQ)** Zones 1-3 are due to the capillaries, but zone 4 is due to extra-alveolar vessels (which like to tighten at low volumes)		