### 7.1 Human cardiac output
- a. can be calculated from a subject’s O₂ consumption and the O₂ concentrations in the radial artery and antecubital vein. **F**
- b. can be assessed by echocardiography. **T**
- c. can be estimated using pulsed Doppler ultrasound directed at the aorta. **F**
- d. can be calculated from blood temperature in the pulmonary artery following a cold saline injection into the left ventricle. **F**
- e. can be assessed from the pulse pressure and heart rate. **F**

### 7.2 When cardiac output is measured using the Fick principle,
- a. pulmonary blood flow is equated with cardiac output. **F**
- b. cardiac output is calculated as pulmonary O₂ uptake (U) multiplied by the difference between the O₂ content of arterial blood (A) and the mixed venous blood entering the lungs (V); \( CO = U(A - V) \). **T**
- c. cardiac catheterization is necessary. **T**
- d. a six-fold increase in oxygen uptake indicates a six-fold increase in cardiac output. **F**
- e. the subject must be in a steady state. **F**

### 7.3 When cardiac output is measured by the indicator dilution method,
- a. the measured flow is the combined outputs of the right and left ventricles. **F**
- b. the key relation is that indicator concentration = cardiac output × blood volume. **F**
- c. it is essential to know the mass of indicator injected. **F**
- d. the indicator recirculates via the coronary circulation in about 20 seconds. **F**
- e. the indicator should ideally be confined to the circulation. **F**

### 7.4 When cardiac output is estimated from the peripheral arterial pulse,
- a. the pulse pressure is calculated as diastolic pressure plus one-third of systolic pressure. **F**
- b. the pulse pressure serves as an index of the left ventricle stroke volume. **F**
- c. the pulse pressure increases in direct proportion to arterial compliance. **F**
- d. it is necessary to measure the heart rate too. **F**
- e. the output may be underestimated, due to flow out of the arterial system during ventricular ejection. **F**
For a change, here is a different type of question.

### 7.5 The different cardiac outputs of three subjects

In three subjects (two healthy, one with a cardiac disorder), O₂ consumption was measured by collecting expired air in a Douglas bag. Arterial blood oxygen concentration was measured in a sample drawn from the femoral artery. Mixed venous oxygen concentration was measured in a sample obtained from the right ventricle outflow tract by cardiac catheterization. The results were as follows.

<table>
<thead>
<tr>
<th></th>
<th>Subject A</th>
<th>Subject B</th>
<th>Subject C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse rate (min⁻¹)</td>
<td>75</td>
<td>150</td>
<td>75</td>
</tr>
<tr>
<td>Mean arterial blood pressure (mmHg)</td>
<td>90</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td>Arterial pulse pressure (mmHg)</td>
<td>40</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Mean right atrial pressure (mmHg)</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>O₂ uptake from lungs (ml O₂ min⁻¹)</td>
<td>250</td>
<td>1250</td>
<td>260</td>
</tr>
<tr>
<td>Femoral arterial O₂ content (ml O₂/litre)</td>
<td>195</td>
<td>195</td>
<td>195</td>
</tr>
<tr>
<td>Mixed venous O₂ content (ml O₂/litre)</td>
<td>145</td>
<td>95</td>
<td>145</td>
</tr>
<tr>
<td>Arterial compliance (ml/mmHg)</td>
<td>1.67</td>
<td>1.67</td>
<td>1.67</td>
</tr>
</tbody>
</table>

Insert the most appropriate answer from the list below into the following passage.

Cardiac output can be estimated in two different ways from the data table, namely by the ______________ or more approximately by the ______________. Based on the oxygen data, the cardiac output of subject A was ______________, while that of subject B was ______________ and subject C was ______________. The total peripheral resistance of subject B, namely ______________ differed markedly from that of subject A, namely ______________. Based on the above cardiac output values, and the fact that stroke volume is related to cardiac output by the relation stroke volume = ______________, the stroke volumes of the subjects were approximately ______________ for subject A, ______________ for subject B and ______________ for subject C. There is an alternative way, however, to estimate the stroke volume from the data, namely using the relation stroke volume equals (approximately) ______________. When applied to subjects A and B, this second method gave similar results to the first method, but when applied to subject C the stroke volume works out to be ______________. Based on these results, it is likely that subject A fits the description ______________, subject B fits the description ______________ and subject C fits the description ______________.

<table>
<thead>
<tr>
<th></th>
<th>5 litre min⁻¹</th>
<th>15.2 litre min⁻¹</th>
<th>5.2 litre min⁻¹</th>
<th>12.5 litre min⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler flow</td>
<td>Pulse pressure method</td>
<td>Echocardiography</td>
<td>Fick principle</td>
<td></td>
</tr>
<tr>
<td>17.8 mmHg/(litre/min)</td>
<td>7.9 mmHg/(litre/min)</td>
<td>pulse pressure × arterial compliance</td>
<td>cardiac output/heart rate</td>
<td></td>
</tr>
<tr>
<td>167 ml</td>
<td>83 ml</td>
<td>69 ml</td>
<td>67 ml</td>
<td></td>
</tr>
<tr>
<td>aortic valve stenosis</td>
<td>aortic valve incompetence</td>
<td>normal, exercising</td>
<td>normal, resting</td>
<td></td>
</tr>
</tbody>
</table>
Answers

7.1  a. F – A mixed venous sample must be taken from the right ventricle to calculate cardiac output by the Fick method. The antecubital venous O$_2$ concentration does not represent the average venous O$_2$ concentration for the whole body, i.e. pulmonary artery O$_2$ concentration.

b. T – Echocardiography records the separation of the ventricle walls in diastole and systole (Figure 6.10). This is converted into stroke volume, using assumptions about chamber shape. Then stroke volume $\times$ heart rate = cardiac output.

c. T – The altered frequency of ultrasound reflected by red cells in the aorta is used to calculate aortic blood velocity (Figure 7.1). Aortic diameter too can be measured by ultrasound. Proximal aorta flow ($\text{cm}^3 \text{s}^{-1}$) = velocity ($\text{cm} \text{s}^{-1}$) $\times$ cross-sectional area ($\text{cm}^2$) = cardiac output $-$ coronary blood flow. Coronary blood is drawn from the root of the aorta, at the sinuses of Valsalva (Figure 2.1).

d. F – In the thermal dilution method cold saline is injected into the right ventricle or base of the pulmonary trunk.

e. T – The pulse pressure depends on stroke volume (Figure 7.2). This is the basis of automated cardiac output monitoring in intensive care units.

7.2  a. T – The entire output of the right ventricle passes through the lungs.

b. F – The Fick principle states that $U = \text{CO} (A - V)$. So $\text{CO} = U/(A - V)$ (Figure 7.3).

c. F – During exercise the O$_2$ uptake increases much more than the cardiac output, because the venous O$_2$ concentration (V) decreases (Figure 6.22).

d. F – It takes several minutes to measure O$_2$ consumption, so the cardiac output has to remain steady over this time.

e. T – In the thermal dilution method cold saline is injected into the right ventricle or base of the pulmonary trunk.

7.3  a. F – Cardiac output is always the output of a single ventricle.

b. F – The key relation is that the arterial concentration of indicator, C, equals the mass of indicator injected, $m$, divided by the volume of blood in which it is distributed $V_1$. $C = m/V_1$. The time that the indicator volume takes to flow past a given point is recorded (Figure 7.4a).

c. T – The cardiac output (CO) is calculated as injected mass $m$ divided by area under the arterial concentration versus time plot, $\text{CO} = m/\text{area}$ (Figure 7.4b).

d. T – This causes a hump in the arterial concentration time course beyond 20s (Figure 7.4c). This limitation of the dye dilution method is circumvented in the thermal dilution method, due to thermal equilibration of the blood in the tissues.

e. T – If the indicator escapes from the bloodstream between the injection point and the sampling point, the true intravascular mass of indicator is smaller than the known, injected mass, $m$.

7.4  a. F – Pulse pressure is systolic pressure minus diastolic pressure (Figure 7.2a).

b. T – The rise in arterial pressure is caused by the temporary accommodation of most of the stroke volume in the elastic arteries (Figure 7.2b).

c. F – The bigger the arterial compliance (distensibility), the smaller the pulse pressure generated by a given stroke volume. Pulse pressure is inversely proportional to compliance. Compliance is change in volume per unit change in pressure.

d. T – Cardiac output = heart rate $\times$ stroke volume.

e. T – A volume of blood equal to 20–30% of the stroke volume flows out of the distal arteries during the time taken for ventricular ejection.
Cardiac output can be estimated in two different ways from the data table, namely by the Fick principle or more approximately by the pulse pressure method. Based on the oxygen data, the cardiac output of subject A was 5 litre min⁻¹, while that of subject B was 12.5 litre min⁻¹ and subject C was 5.2 litre min⁻¹. The total peripheral resistance of subject B, namely 7.9 mmHg/litre/min, differed markedly from that of subject A, namely 17.8 mmHg/litre/min. Based on the above cardiac output values, and the fact that stroke volume is related to cardiac output by the relation stroke volume = cardiac output/heart rate, the stroke volumes of the subjects were approximately 67 ml for subject A, 83 ml for subject B and 69 ml for subject C. There is an alternative way, however, to estimate the stroke volume from the data, namely using the relation stroke volume equals (approximately) pulse pressure × arterial compliance. When applied to subjects A and B, this second method gave similar results to the first method; but when applied to subject C the stroke volume works out to be 167 ml. Based on these results, it is likely that subject A fits the description normal, resting, subject B fits the description normal, exercising and subject C fits the description aortic valve incompetence.