CASE 6

Tight shoes and disturbed nights

CASE AND MCQS

Case introduction

A 60-year-old salesman, Mr J.S., attends your surgery complaining that over the past month or so he has felt breathless when going upstairs. He also notices that his shoes feel tight towards the end of a day. Occasionally he feels light-headed, but after sitting down soon feels better. He does not sleep well and often feels tired during the day.

Increasingly, he needs to pass urine several times at night and when he lies down he feels that his breathing becomes more laboured. He has found that this is relieved if he supports his head and neck with a couple of pillows. He has not taken much exercise for many years.

Examination reveals a thin man with pale skin and clammy hands. His arterial blood pressure is 170/110 mmHg; his pulse rate is 72–75 beats/min. Body temperature is normal and there are no signs of infection. Auscultation of his chest reveals light crackling noises associated with respiration (rales or crepitation) but no murmurs from cardiac valves can be detected.

The abdomen is slightly distended but the liver appears only marginally enlarged. Pitting oedema is detected with the fingers on the legs and ankles. A digital examination of the patient's rectum does not reveal evidence of an enlarged prostate gland.

Q1 **In order to know more about cardiovascular status, you wish to measure central venous pressure. What is the routine clinical technique for this procedure?**

A. an intravenous catheter and blood pressure transducer
B. visual inspection of peripheral superficial veins
C. measuring the height of the jugular venous column above the sternum
D. auscultation with a blood pressure manometer
E. palpation of the venous pulse

Mr S.'s central venous pressure, as measured by this technique, is 9 cm H_2O.

Q2 **List the most important signs detected so far.**

Q3 **Can you draw any preliminary conclusions on the reasons for the symptoms? Do you think that they reflect problems that could be:**

A. cardiac
B. respiratory
C. vascular
D. haematological
E. any of the above

Q4 **Mr S.'s blood pressure has been measured as 170/110 mmHg. What are the normal levels of arterial blood pressure? Does pressure vary during the day? Is blood pressure likely to be affected by the environment?**

You have noted that oedema is present in the legs and feet. Before taking the story further we need to look at some of the physiology that underlies the development of oedema.

Q5 **Oedema is caused by:**

A. subcutaneous proteoglycan deposition
B. increased interstitial fluid
C. enlarged superficial veins and capillaries
D. low haematocrit
E. both A and B above

Q6 **In this patient, which observation is indicative of oedema in his legs and feet?**

A. tight shoes
B. distended veins
C. appearance of superficial pits in skin when pressed
D. pale skin on the legs
E. all of the above

We need to think about the various physiological mechanisms involved in controlling the distribution of extracellular fluid across the wall between the interstitial space and the interior of a capillary. This is achieved through a balance of the Starling forces across the capillary wall: that is, the difference in hydrostatic pressure inside and outside of the capillary wall balanced against the osmotic pressures exerted by plasma protein and the normally small amounts of protein in the interstitial space.

Q7 **Interstitial fluid:**

A. has the same ionic composition as plasma
B. contains more potassium than plasma
C. contains more sodium than plasma
D. contains less sodium than plasma
E. contains less potassium than plasma

Q8 **If the hydrostatic pressure inside the capillary increases:**

A. fluid moves from the interstitial space into the capillary
B. fluid moves from the capillary into the interstitial space
C. fluid moves from the interstitial space into cells
D. fluid moves from cells into the interstitial space
E. there is no fluid movement provided that plasma oncotic pressure remains constant

Q9 **Why does peripheral oedema occur more in the feet and lower legs than in other parts of the body?**

A. capillary hydrostatic pressure is higher in the feet
B. plasma oncotic pressure is lower in the feet
C. arterial blood pressure is higher in the feet
D. peripheral resistance is lower in the feet
E. none of the above

Q10 **Based on the symptoms displayed, oedema in the current case is likely to be caused by:**

A. reduced peripheral resistance
B. reduced hepatic synthesis of plasma protein
C. increased capillary membrane permeability
D. increased peripheral venous pressure
E. a combination of A and B above

Q11 **Under what circumstances could alterations in plasma protein become important? Think about the conditions that might cause this.**

We now need to focus on the problems created by oedema, wherever it occurs. In this case there is evidence for oedema in the peripheral capillaries and in the lungs, as indicated by the patient's orthostatic dyspnoea.

Q12 **Pulmonary oedema reduces gas transfer in the lungs primarily because it:**

A. reduces respiratory rate and depth
B. increases the diffusion distance between alveolus and capillary
C. reduces alveolar exchange area
D. dilutes alveolar oxygen
E. washes surfactant away from the alveolar epithelial surface

You decide to have the following tests performed.

- Chest X ray: this shows some shadowing in the alveolar lung tissues, thus confirming the possibility of pulmonary oedema. The ventricles are enlarged. No other abnormalities are seen.
- Renal function: 24-hour urine collection and measurements of volume, urinary protein, urea, electrolytes and creatinine clearance show that all these variables are within normal limits.
- Blood: Red and white cell counts, haemoglobin, ESR (erythrocyte sedimentation rate), serum albumin and fasting glucose are all normal.

Q13 **In identifying the underlying cause of oedema, the finding of a normal ESR is useful because it helps to exclude:**

A. hepatic disease
B. infection
C. vascular disease
D. haematological disease
E. all of the above

It may be useful to summarize the most important symptoms we have seen so far:

- dyspnoea on gentle exercise
- signs of peripheral and pulmonary oedema
- raised jugular venous pressure
- high arterial blood pressure
- orthopnoea
- nocturnal diuresis
- but no signs of major cardiac valve problems.

What preliminary conclusions can you reach?

Q14 **Mr S. is *not* likely to be suffering from:**

A. aortic stenosis
B. kidney disease
C. cardiac myopathy
D. diabetes insipidus
E. any of the above

We now need to look at possible reasons for the raised capillary pressures in the pulmonary and systemic circulations – remember the oedema. Mr S. is hypertensive and it is therefore useful to consider the ways in which a high arterial blood pressure might affect the heart and circulation.

Q15 **In the presence of high arterial blood pressure:**

A. end-systolic left ventricular volume is increased
B. end-systolic left ventricular volume is decreased
C. end-diastolic left ventricular volume is decreased
D. systolic ejection fraction is increased
E. none of the above

Initially, the effect of an increased afterload is to increase the force of contraction of the ventricles (Starling's law), but only if the muscle is not stretched too far (look up the relation between diastolic pressure and stroke volume). With moderate elevation of end-diastolic volume stroke volume increases, but it then falls if the fibres are stretched beyond the optimal length of muscle fibre for producing active tension. It should be noted that the pericardium restricts the expansion of the heart and so helps to prevent this passive overstretching.

The reduced outflow from both ventricles will result in an increase in left and right atrial pressures and if these rise sufficiently, there will be elevation of pulmonary and systemic capillary hydrostatic pressures, leading to oedema. So, hypertension alone may be part of the explanation for Mr S.'s symptoms.

Since there are several established pharmacological measures that will reduce the blood pressure effectively and selectively, you decide to use this approach first. Beta-blockers (beta-adrenoreceptor antagonists) reduce the vascular and cardiac effects of circulating catecholamines; diuretic agents will reduce the overall blood volume; selective calcium-channel blockers will reduce the contraction of vascular smooth muscle as will angiotensin-converting enzyme (ACE) inhibitors. All will reduce arterial blood pressure in the appropriate doses.

Q16 **ACE inhibitors:**

A. reduce the production of renin
B. reduce the production of angiotensin II
C. reduce the production of angiotensin I
D. reduce the production of angiotensinogen
E. none of the above

Q17 **ACE inhibitors lower blood pressure by:**

A. increasing renal sodium excretion
B. reducing the plasma concentration of aldosterone
C. increasing water excretion
D. causing vasodilation
E. all of the above

You send Mr S. away with a prescription for a diuretic. But you have in mind that raised arterial blood pressure is unlikely to be the sole cause of the relatively severe oedema seen in this case and that other factors may be operating.

One month later, it is clear that this prescription is not working effectively. When you now re-examine him his blood pressure is normalized (125/85 mmHg) but the major symptoms remain. The next stage is to look at the function of the heart since the remaining symptoms are likely to involve problems within the 'pump' itself. You send Mr S. for further tests at the hospital.

It may be useful to list the various investigations that can be carried out and the specific information that each will provide. Some information is shown below, but you may be able to think of additional factors:

Non-invasive tests

- Electrocardiogram – indicates arrhythmias, infarction, ischaemia, left or right ventricular hypertrophy
- Chest X-ray – indicates size of chambers of the heart, especially ventricles
- Echocardiogram – assesses action of valves and enables identification of possible blockage of the valves or other dysfunction
- Doppler echocardiography – visualizes detail of cardiac chambers, enables calculation of ejection fraction
- Exercise stress testing – tests ability of heart to respond to demands for increased oxygen in active skeletal muscles in a controlled way, identifies ischaemic heart disease.

Invasive tests

- Coronary angiography – identifies partial or full blockage of coronary arteries which will reduce the supply of blood to the active cardiac muscle
- Radionuclide tests – infusions of specific radiolabelled agents enable specific aspects of ventricular physiology and function to be evaluated.

The details of these tests are available in standard cardiology texts.

Back to this case. You ask for a 12-channel ECG to be performed. A portion of the record obtained is shown in Fig. 6.1.

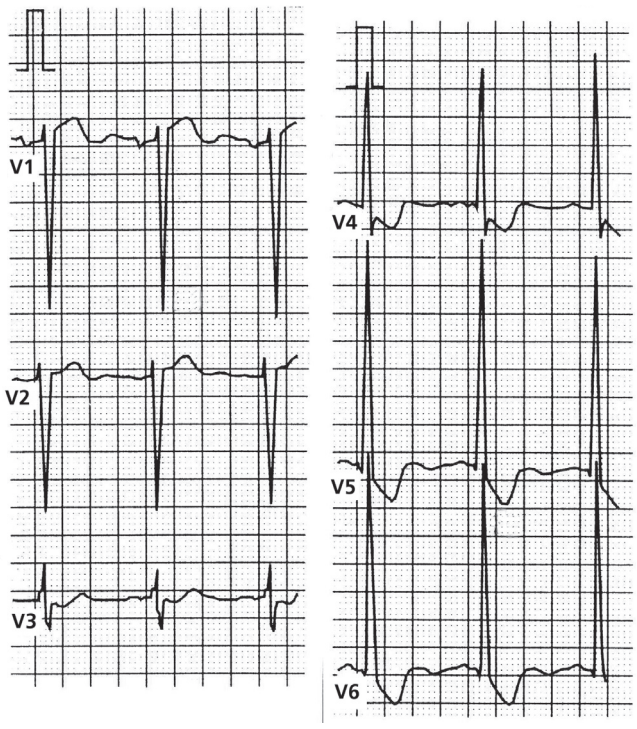

Fig. 6.1 Chest lead ECGs (V1–V6) recorded from J.S.

Q18 **This ECG indicates:**

A. ventricular hypertrophy
B. complete heart block
C. 1 : 2 heart block
D. ventricular hypertrophy and complete heart block
E. a normal heart

Chest X-ray shows enlarged left and right ventricles. A cardiac echocardiogram is also performed. This indicates that all cardiac valves are operating normally and that the ejection fraction is 30%.

Q19 **What is the normal ejection fraction?**

A. 40%
B 60%
C. 80%
D. 100%
E. none of the above

An exercise stress test indicates a significantly reduced exercise tolerance, clear evidence of coronary bed ischaemia. It is not judged necessary to perform an angiographic study of the coronary arteries at this stage.

It is concluded that while the echocardiogram indicates no valve problems, Mr S. is suffering from a failure of his cardiac muscle to contract effectively. His inability to pump the blood through the chambers effectively has resulted in enlargement of the atria and ventricles on both sides: this has in turn led to raised atrial and venous pressures with consequent pulmonary and peripheral venous congestion.

Further treatment should be aimed at reducing the workload of the heart and strengthening the vigour of contraction of the cardiac muscle. Additional investigations will be needed to identify further the reasons for the cardiac muscle dysfunction. These could include metabolic dysfunction, viral myocarditis or an infiltrative disease. Further examination could determine if a previous 'silent' heart attack had resulted in damage to part of the myocardium which had not been detected by electrocardiography. Possible investigations for this purpose would include coronary angiography and/or radionuclide imaging studies.

Other studies would be aimed at showing whether the problem lies in the systolic action of the heart or in some aspect of diastolic function, such as stiffening of the ventricle or the pericardium that limits ventricular filling. For us, further detailed examination at this stage is not helpful as we have identified the main physiological factors that underlie the symptoms.

MCQ ANSWERS AND FEEDBACK

1.C. Jugular venous pressure is the standard index of central venous pressure. It is measured non-invasively with the patient lying on a bed and the head supported on pillow. The height above the sternal angle at which the internal jugular vein collapses marks central venous pressure. Normally, jugular venous pressure (JVP) is approximately 6 cmH_2O.

2. Dyspnoea on slight exercise; high arterial blood pressure; some signs of peripheral and pulmonary oedema; raised JVP; orthopnoea; nocturnal diuresis; no signs of major cardiac valve problems.

3.E. At this preliminary stage, none could be sensibly excluded.

4. Normal arterial blood pressure is usually stated to be 120/80 mmHg. However, it varies greatly during the day with activity and mood and is particularly low during sleep. Generally a resting systolic pressure over 140 mmHg or a diastolic pressure over 90 mmHg is now regarded as being one that requires attention in some way, with selective elevation of systolic pressure being especially common in elderly people. In many individuals the fact of taking their blood pressure is sufficient to raise it significantly (the 'white coat' effect). How would you ensure that this error was minimized when measuring a patient's blood pressure?

5.B. By definition, oedema is an increase in interstitial fluid volume.

6.C. 'Pitting' of the skin in the lower limbs and feet is diagnostic. Tight shoes, venous distension and pallor could all have several explanations.

7.A. Interstitial fluid is an ultra-filtrate of plasma; plasma protein is the only constituent that cannot pass across the capillary wall. Hence the ionic compositions of the two compartments are identical.

8.B. The plasma protein exerts an oncotic (= colloid osmotic) pressure tending to draw fluid back into the capillary, which is substantially larger than the pressure exerted by the small amount of free protein in the interstitial space. If intracapillary pressure becomes greater than interstitial pressure and oncotic pressures remain the same, water movement must be from plasma to interstitium. Fluid movement between these compartments has no effect on intracellular fluid unless the composition of the interstitial fluid changes.

9.A. When standing, capillary pressure in the legs and feet is higher than in the upper limbs, because there is a continuous column of blood between the heart and the feet. Thus, in the feet, there is a gravitational pressure of around 150 cmH_2O in the capillaries on top of the normal hydrostatic pressure of around 40 mmHg.

You can estimate the gravitational effect on intracapillary pressure in mmHg using the fact that the density of mercury is 13.6 times that of water. The gravitational force means that arterial pressure is also higher in the feet than at heart level in a standing person but, since there can be no water movement across the arterial wall, it is the intracapillary pressure that is important in determining whether oedema occurs.

10.D. You know that central venous pressure is elevated and this will be reflected in a rise in peripheral venous and capillary pressure. The other alternatives could also lead to oedema but there is no evidence that they are likely to be involved in

this patient. In particular, his high blood pressure indicates that his peripheral resistance is if anything elevated above normal.

11. Reduced plasma protein concentration and reduced oncotic pressure can occur during severe famine and starvation or as a result of liver or kidney disease. Also, a small amount of protein does leak out of the circulation and is recycled back into the venous system via the lymphatics. Widespread damage to the lymphatics will impair this recycling.

12.B. Any increase in the diffusion distance between the alveoli and plasma has a dramatic effect on transfer of respiratory gases, especially oxygen from alveoli to plasma. If pulmonary oedema is sufficient to cause movement of fluid into the alveoli this will further impair respiratory efficiency by diluting surfactant and making it harder to inflate the lungs. The effects of oedema on gas transfer are the same at the peripheral capillary/tissue interface and can profoundly affect the unloading and uploading of gases, especially oxygen, at the tissue level.

13.B. Elevated erythrocyte sedimentation rate is useful as a non-specific indicator of infection.

14.E. None of the alternatives is compatible with the combination of symptoms shown by this patient. Aortic stenosis and cardiac myopathy would be associated with reduced blood pressure and his normal renal function data exclude kidney disease or diabetes insipidus.

15.A. The high arterial blood pressure represents an additional load against which the heart has to eject blood (= increased afterload) and so it has to generate higher intraventricular pressures to eject the same amount of blood and/or eject less blood. Since venous return continues at the same rate as before, reduced ventricular emptying (stroke volume) will increase the end-diastolic volume of the heart. Therefore, ejection fraction (end-systolic volume/end-diastolic volume) will also fall.

16.B. Inhibition of angiotensin-converting enzyme (ACE) will reduce the production of angiotensin II from angiotensin I, which is in turn derived by the action of renin on the plasma alpha-globulin, angiotensinogen. Renin comes from the juxtaglomerular cells of the renal afferent arteriole.

17.E. Angiotensin II increases arterial blood pressure via vasoconstriction and the ACE inhibitor will induce a fall though this mechanism. Angiotensin II also stimulates sodium reabsorption in the renal tubule; chloride and water follow passively. It also stimulates aldosterone secretion from the adrenal cortex which will in turn affect sodium reabsorption in the kidney and secretion of antidiuretic hormone from the posterior pituitary gland. Inhibition of all of these actions will tend to reduce arterial blood pressure and increase urine flow.

18.A. With a normal amount of ventricular muscle tissue, the R wave is never greater than 2.5 mV in any lead. The R waves in this recording of up to 3 mV or more indicate a substantial degree of ventricular hypertrophy. Each QRS complex is preceded by a P wave and the frequency of ventricular activation is normal at around 70 beats/min (remember that each square on the ECG record represents 200 ms), so every atrial impulse is reaching the ventricle – that is, there is no atrioventricular block.

19.B. Typically, the end-diastolic ventricular volume is around 120 ml and stroke volume is around 70 ml.

CASE REVIEW

This case study has discussed three possible malfunctions of physiological mechanisms that can underlie heart failure. These are not the only examples of disturbed physiology that could have been described. Essentially, cardiac failure is present when the output of the left ventricle fails to match the metabolic demands of the body or does so only when the cardiac filling pressure is high. Think about the factors that affect flow of blood through the heart and consider how cardiac failure might result from other physiological disturbances.

Many patients suffering from heart failure remain asymptomatic for long periods, either because the impairment is mild or because the cardiac dysfunction is balanced by compensatory mechanisms elsewhere. Such patients are regarded as being adequately 'compensated'. Often the clinical features of failure only appear as a result of precipitating factors that increase cardiac workload and tip the balance into their being 'decompensated'.

The natural physiological compensating mechanisms include Starling's law, progressive hypertrophy of the cardiac muscle and neurohormonal activation. The latter includes the actions of the adrenergic nervous system, renin–angiotensin system, antidiuretic hormone (ADH, vasopressin) and atrial natriuretic peptide (ANP). Each or all can operate to have positive and negative effects under different circumstances.

These compensating processes can be disturbed by other precipitating factors including alterations in circulating blood volume (causing increased preload), increased blood pressure (causing increased afterload), impaired contractility (causing

reduced stroke volume) and increased metabolic demand (causing reduced peripheral resistance). So, heart failure can be the result of altered physiology in several different systems. But the contribution of each can be isolated and the results used to form the basis of a rational scientific approach to the treatment of symptoms.

It may be useful if you were to make up a flow diagram that summarizes the factors involved during cardiac failure in the transition between compensation and decompensation.

In relation to oedema, we have been explaining it in relation to current and well-established hypotheses. Like most areas of physiology these do evolve and the two short papers in the reading list below illustrate that new ideas, based on new evidence, on how the processes work arise constantly.

Dyspnoea is one of the early symptoms of heart failure, although of course there can be causes of dyspnoea other than heart failure and these need to be excluded. In heart failure, dyspnoea can result from several processes and the relative contributions of these may vary at different phases:

1. Inability to supply adequate cardiac output for the muscular metabolic demands being imposed will lead to hypercapnia.
2. Pulmonary venous congestion will result in transudation of plasma into the pulmonary interstitium. As well as reducing gas exchange directly, this would reduce pulmonary compliance and elevate airways resistance as a result of the compressing the airways and alveoli.

These changes would both increase the work of breathing since the patient would need to generate a greater negative intrathoracic pressure to move the same amount of air.

3. Finally, pulmonary oedema could stimulate juxtacapillary receptors (J-receptors) and result in reflex production of rapid, shallow breathing.

Dyspnoea sometimes occurs in patients without overt pulmonary oedema, probably because there is failure of the cardiac muscle to generate an adequate blood flow to the respiratory muscles. Inevitably, dyspnoea is likely to become progressively greater as the cardiac failure (pumping action) becomes more severe: eventually, even gentle walking becomes difficult.

KEY POINTS

- Cardiac failure represents a mismatch between cardiac output and the metabolic demands of the body.
- It may be due to a primary defect in the myocardium or be secondary to a mismatch between the functional limits of the heart and the volume it is required to pump.
- Regardless of the cause, cardiac failure is characterized by dyspnoea and by peripheral oedema.
- Effective treatment depends on logical analysis of the potential sites of malfunction of the heart.

ADDITIONAL READING

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