Management of the circulation on ICU

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Abstract
The management of the circulation of the critically ill surgical patient is a major challenge and is becoming increasingly complex. Prompt recognition and treatment of acute circulatory failure, or shock, is crucial to improve the poor prognosis that most shock states carry. While critical care specialists may be involved in the later stages of the treatment process, the recognition, diagnosis and initial management of the shocked patient will often be the responsibility of the surgical team. This article aims to describe the different types of shock, the principles of diagnosis and basic and advanced haemodynamic monitoring, and finally it provides a basic strategy for the management of circulatory failure in the critically ill.

Keywords acute circulatory failure; haemodynamic assessment; haemodynamic monitoring; shock; shock management

Definition and types of shock
A recent international consensus conference has defined shock, or acute circulatory failure, as a life-threatening, generalized maldistribution of blood flow resulting in failure to deliver and/or utilize adequate amounts of oxygen, leading to tissue dysoxia. It was also recommended that hypotension (systolic blood pressure, SBP <90 mmHg, an SBP decrease of 40 mmHg from baseline, or mean arterial pressure, MAP <65 mmHg), while commonly present, should not be required to diagnose shock. In fact in the early stages of the disease process (“compensatory phase”) the SBP may even be elevated due to peripheral vasoconstriction. The diagnosis of shock does require evidence of inadequate tissue perfusion on physical examination. In the absence of hypotension, when acute circulatory failure is suggested by history and examination, the conference consensus was that a marker of inadequate perfusion be measured (increased blood lactate, decreased venous oxygen saturation — central or mixed, increased base deficit or perfusion-related acidosis).

All types of shock have a common final pathway at the cellular level: anaerobic metabolism leading to depletion of adenosine triphosphate (ATP) and other energy stores and accumulation of lactic acid. Failure of energy-dependent ion pumps in the cell membrane leads to an influx of sodium and water, causing swelling and changes in cellular architecture. Accumulation of intracellular calcium further exacerbates mitochondrial dysfunction. Together these processes can lead to irreversible cell damage and death. On a macroscopic level organ dysfunction and multi-organ failure are the consequences of untreated shock.

The different types of shock are commonly classified according to their aetiology (Table 1). They can occur in isolation or in combination; a good example of the latter being septic shock where hypovolaemia due to third-space losses and cardiac dysfunction commonly coexist.

Diagnosis
Clinical signs
An exemplary clinical examination of the shocked patient is detailed in Table 2. Whereas some signs are usually found in all types of shock (hypotension, tachycardia, tachypnoea, oliguria and altered conscious level — ranging from anxiety, agitation and confusion to unconsciousness), others depend on whether the circulation is hyperdynamic or hypodynamic.

The hyperdynamic patient (classically in septic and anaphylactic shock) has warm peripheries, bounding pulses and appears flushed. In contrast, a hypodynamic patient (hypovolaemic and cardiogenic shock) is usually cold, pale and mottled, displaying signs reflecting reduced blood flow to the skin. The presentation of neurogenic shock can be unusual, because in high spinal injuries there is a loss of sympathetic outflow to the heart that can cause bradycardia. It is also important to consider the normal host response to injury: a patient in haemorrhagic shock for example is usually tachycardic and tachypnoeic. If this is not the case, the compensatory response is inadequate and there is a risk of sudden deterioration. Apart from looking for the signs of shock the clinical examination should be tailored towards possible underlying pathologies (for example the distended neck veins and muffled heart sounds of cardiac tamponade).

Investigations
Investigations will be guided by history and clinical examination and the pathology suspected. Standard tests performed in most cases are full blood count, urea and electrolytes, coagulation screen, cardiac enzymes, inflammatory markers, electrocardiogram and chest x-ray.

More specific tests can help differentiate types of shock or investigate the cause and facilitate treatment. Examples are culture of blood and other fluids to identify the causative organism and source in sepsis, echocardiography in cardiogenic shock and suspected cardiac tamponade, computed tomography...


### Classification of shock

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypovolaemic</td>
<td>Haemorrhage, fluid loss from gastro-intestinal tract or skin (burns), third-space losses</td>
</tr>
<tr>
<td>Cardiogenic</td>
<td>Myocardial infarction, acute left ventricular failure</td>
</tr>
<tr>
<td>Septic</td>
<td>Infection (bacterial, viral, fungal); common in Gram-negative sepsis</td>
</tr>
<tr>
<td>Anaphylactic</td>
<td>Histamine release from mast cells in response to allergen exposure</td>
</tr>
<tr>
<td>Neurogenic</td>
<td>Loss of vasomotor tone in spinal cord injury or spinal/epidural anaesthesia</td>
</tr>
<tr>
<td>Obstructive</td>
<td>Pulmonary embolus, cardiac tamponade, tension pneumothorax</td>
</tr>
</tbody>
</table>

### The role of haemodynamic monitoring

Haemodynamic monitoring is used for several reasons: firstly to diagnose cardiovascular dysfunction and identify a possible cause, and, secondly to guide a coherent treatment strategy based on the pathophysiological perturbation and, thirdly, to monitor changes in the patient’s condition in response to therapy. The types of monitoring used will obviously differ markedly between these aims. Examples illustrating the spectrum of choices are: pulmonary artery catheterization to detect a low cardiac output state or intracardiac shunt and continuous ECG monitoring to detect arrhythmias. The monitoring requirement also depends on the severity of illness and on patient location, which should be appropriate for the clinical condition. Whereas basic monitoring can be provided on a normal ward, more advanced methods make high-dependency or intensive care necessary.

### ECG

Continuous three- or five-lead ECG monitoring is typically used in critically ill patients to monitor heart rate and rhythm. As this approach monitors only one precordial lead its usefulness for ST segment monitoring is limited, but it allows rhythm identification and detection of arrhythmias. A 12-lead ECG can detect cardiac ischaemia with higher accuracy.

### Pulse oximetry

The saturation of haemoglobin with oxygen in arterial blood ($\text{SaO}_2$) can be measured with reference to the differential absorption of infrared light between oxygenated and deoxygenated blood at two wavelengths. This non-invasive monitor provides continuous information about $\text{SaO}_2$, heart rate and, in some cases, the concentration of haemoglobin. Modern pulse oximeters also display the plethysmograph trace, which can be used as an indicator for the status of peripheral perfusion and fluid responsiveness.

### Non-invasive arterial blood pressure (NIBP)

Non-invasive intermittent measurements of arterial blood pressure can be performed using an automated sphygmomanometer. Non-invasive readings can be inaccurate in low cardiac output states, tachyarrhythmias, or if the size or positioning of the cuff is incorrect. Automated devices are useful to demonstrate trends in blood pressure and are reliable in most stable patients.

### Invasive monitoring of arterial blood pressure

Real-time arterial pressure data and more reliable readings can be gained with invasive monitoring, where an arterial cannula is connected to an electronic pressure transducer via a fluid filled tube. Invasive monitoring is principally indicated in the following situations: in patients who are unstable or at risk of instability, patients in need of inotropic or vasoactive therapy, patients in need of tight BP monitoring and where there is a need for regular blood gas analysis. The radial artery is most commonly used but the femoral, dorsalis pedis, ulnar, brachial and axillary arteries are all alternatives. Complications include distal ischaemia, haematoma formation, infection, formation of a pseudoaneurysm, blood loss from accidental disconnection and accidental drug injection, so careful monitoring and care of the system are necessary.

In addition to providing real-time information about the blood pressure and heart rate, the arterial pressure waveform can be used

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**Table 1**

(CT) pulmonary angiogram in pulmonary embolism and neuro-axial imaging in suspected neurogenic shock. In traumatic hypovolaemic shock, imaging in the form of fast-access abdominal ultrasound followed by formal CT imaging of the chest, abdomen and pelvis has replaced diagnostic peritoneal lavage as the investigation of choice.

Arterial blood gas analysis allows assessment of oxygenation, ventilation and the severity of the expected metabolic acidosis. Blood lactate levels are frequently elevated; the degree of this is an indicator of the extent of tissue hypoxia and severity of the shock state. Reduced central- or mixed-venous haemoglobin oxygen saturations also point towards reduced tissue perfusion, since the latter leads to high oxygen extraction rates and correspondingly low venous oxygenation values.

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**Table 2**

<table>
<thead>
<tr>
<th>General</th>
<th>Injuries, haematomas, obvious blood loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiovascular</td>
<td>Pulse (rate, volume, rhythm)</td>
</tr>
<tr>
<td>Respiratory</td>
<td>Respiratory rate/effort</td>
</tr>
<tr>
<td>Gastro-intestinal</td>
<td>Abdominal tenderness/localizing signs</td>
</tr>
<tr>
<td>Renal</td>
<td>Urine output, fluid balance</td>
</tr>
<tr>
<td>Nervous system</td>
<td>Conscious level</td>
</tr>
<tr>
<td></td>
<td>Peripheral signs (i.e. of spinal cord injury)</td>
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</table>
to derive other useful indices. Modern computer algorithms can transform changes in pressure into changes in stroke volume or cardiac output. Often these devices need to be calibrated by an independent mechanism in order to compensate for the different levels of vascular compliance seen between and within patients (see below). The morphology of the individual waveform can also give information with regards to the systemic vascular resistance and cardiac contractility in both normal and pathological conditions.

The changes in the arterial pressure trace with the fluctuations in intra-thoracic pressure during artificial mechanical ventilation can be used to identify patients who will respond to a fluid challenge with an increase in stroke volume. These changes can be characterized either by the systolic pressure variation, the pulse pressure variation or nowadays, when combined with a cardiac output monitor, the stroke volume variation.

Central venous pressure (CVP)

A central venous catheter allows the monitoring of CVP, administration of drugs and assessment of central venous oxygen saturation. The catheter is typically inserted into the superior vena cava via either the internal jugular or subclavian vein. Early complications include pneumo- and haemothorax, damage to local structures including arteries and nerves, air embolism and dysrhythmias. Late complications are infection (line-related sepsis), thrombosis and erosion of the superior vena cava.

The CVP is commonly measured in order to give information about a patient’s preload or intravascular volume status. The pressure in the superior vena cava equates to the pressure in the right atrium, however, as the main determinant of cardiac output is the left ventricular preload and left-sided filling pressures do not equate to right-sided pressures in numerous conditions in critically ill patients, these assumptions may be flawed. This has been demonstrated in a recently published meta-analysis of all the studies that have used the CVP as a guide to volume status.

Monitoring of cardiac output (CO)

In shock states, the delivery of oxygen to the tissues is at least as important as the level of systemic arterial pressure. Global oxygen delivery is characterized by the equation:

\[
\text{oxygen delivery} = \text{cardiac output} \times \text{arterial oxygen content}
\]

The cardiac output is a pivotal variable to understand and manipulate in shocked patients, and the above equation forms the basis of virtually every resuscitation manoeuvre.

An understanding of the concept of cardiac output allows an estimate of systemic vascular resistance to be made. The following equation details the relationship between driving pressure and resistance in determining cardiac output:

\[
\text{cardiac output} = \frac{\text{driving pressure} \ (\text{i.e. MAP–CVP})}{\text{systemic vascular resistance}}
\]

The combination of these variables, flow (cardiac output), pressure and resistance, as well as volume (preload), enables clinicians to make rational and logical choices about volume resuscitation and vasoactive therapies.

The pulmonary artery catheter (PAC or Swan-Ganz catheter) allows the most comprehensive overview of the circulation. Information can be gained on preload, cardiac contractility and afterload. This is achieved by direct measurement of pressures, flow (cardiac output) and oxygen saturations and the calculation of a variety of other parameters (Table 3).

The pulmonary artery occlusion pressure (PAOP or ‘wedge’) is measured by temporarily inflating the balloon at the tip of the catheter, thus occluding the pulmonary artery branch. The pressure distal to the balloon now reflects left atrial pressure because a static column of blood links the two points across the pulmonary capillary bed. Assuming that left atrial pressure correlates to left ventricular end-diastolic pressure, which in turn is governed by left ventricular end-diastolic volume, PAOP can be used as an indicator of left ventricular preload. In a variety of disease states, including critical illness, these assumptions do not hold true and PAOP is of limited use as an indicator of left ventricular filling.

Indicator dilution and pulse pressure analysis: Continuous measurements of cardiac output and stroke volume can be acquired from the arterial pressure waveform by analysing the changes in the pulse pressure trace. Most technologies require this to be calibrated by an independent measurement. Instead of measuring temperature changes in the pulmonary artery, which requires a PAC, these calibrations can be performed with a thermistor placed in the systemic arterial circulation. This so-called transpulmonary thermodilution requires only a central venous injection port and a thermistor in a proximal (femoral, axillary or brachial) arterial catheter. Other techniques that can provide similar information include using lithium as the indicator, rather than the thermo-bolus. Apart from cardiac output other variables can also be determined. For example, extravascular lung water as a therapeutic goal could help to avoid excessive fluid administration and global end-diastolic volume represents the volume of blood in the four chambers at end-diastole, therefore being an indicator of preload.

Oesophageal Doppler: An ultrasound probe is placed in the oesophagus via the mouth or nose is used to measure the velocity of red cells in the descending aorta using the Doppler principle. Integrating blood flow velocity over time integral yields the stroke distance from which cardiac output can be calculated; cardiac output = stroke distance, aortic cross-sectional area (derived from a nomogram) and heart rate. Other parameters measured can be used as preload indicators, so assessment of

### Pulmonary artery catheter assessment of the circulation: measured and calculated parameters

**Measured parameters:**
- Pulmonary artery pressures (systolic and diastolic)
- Pulmonary artery occlusion (wedge) pressure
- Cardiac output
- Right heart pressures (atrial and ventricular)
- Mixed venous oxygen saturation

**Calculated or derived parameters:**
- Systemic vascular resistance
- Pulmonary vascular resistance
- Stroke volume
- Left and right ventricular stroke work indices
- Oxygen delivery and consumption

Table 3
preload and cardiac output is possible. With input of blood pressure data, systemic vascular resistance can be calculated. Probes are poorly tolerated in conscious patients; at present the main use of oesophageal Doppler is as a guide for intra-operative fluid therapy.

**Transthoracic and transoesophageal echocardiography**

Bedside echocardiography is becoming increasingly available since the hardware required is getting smaller and more affordable. In the context of intensive care, assessment of preload and cardiac contractility before and after interventions and diagnosis of major abnormalities (pericardial tamponade, severe valvular and regional wall motion abnormalities) play the main role (Table 4).

**Stepwise management of shock**

Circulatory failure is an emergency therefore rapid initial assessment and resuscitation must take place without delay. Initial treatment should have two aims; rectification of any underlying cause (for example stopping the bleeding in haemorrhagic hypovolaemia, prompt relief of a tension pneumothorax) and correction of the physiological disturbance. In the following we outline a stepwise approach which, with modifications in detail, applies to all types of shock.

**Step 1: initial assessment**

Any assessment of a critically ill patient should follow the airway, breathing, circulation (ABC) approach. Identifying the cause of shock allows definitive treatment in some cases (for example tension pneumothorax, cardiac tamponade). In any other case, two simple questions are to be answered:

- Is the blood adequately oxygenated?
- Is there sufficient blood flow to the organs?

Supplemental oxygen in high concentrations should be given to any patient in shock, a patent airway and adequate breathing will have been assured in the first two steps of ABC. The circulation can be rapidly assessed (Table 5).

**Step 2: fluid challenge**

Hypovolaemia (and hypovolaemic shock) are common and fluid therapy is a cornerstone of management. Hypovolaemia must be avoided in all types of circulatory failure; therefore optimizing preload and cardiac stroke volume by fluid challenges is almost always the first intervention. Even cardiogenic shock is no absolute contraindication, but here judicious fluid boluses and more advanced monitoring are required. In other scenarios and certainly in most surgical patients, an initial fluid bolus, for example 250 ml of colloid, given rapidly in order to detect physiological changes, is appropriate.

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### Advantages and disadvantages of various types of haemodynamic monitoring

<table>
<thead>
<tr>
<th>Monitoring method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECG</td>
<td>Simple; readily available in most hospitals in the UK; easy to interpret</td>
<td>Artefacts may prevent interpretation; lacks sensitivity in some conditions (e.g. myocardial ischaemia)</td>
</tr>
<tr>
<td>Pulse oximetry</td>
<td>Easy to use and interpret; readily available</td>
<td>Inaccurate in shock states (due to peripheral vasoconstriction), carbon monoxide poisoning, and in patients wearing false fingernails or nail varnish</td>
</tr>
<tr>
<td>NIBP (Non-invasive blood pressure)</td>
<td>Rapid and simple; readily available</td>
<td>Inaccurate in shock states; does not reflect cardiac output, regional blood flow nor perfusion of tissues</td>
</tr>
<tr>
<td>Invasive monitoring of arterial pressure</td>
<td>More reliable blood pressure data; enables repeated analysis of blood gases</td>
<td>Kinking of the catheter may cause damped trace; requires skilled nursing</td>
</tr>
<tr>
<td>Invasive monitoring of central venous pressure (CVP)</td>
<td>Simple; guides administration of i.v. fluid; reliable access for administration of drugs</td>
<td>Complications related to insertion; requires skilled nursing</td>
</tr>
<tr>
<td>Pulmonary artery catheter (PAC)</td>
<td>Provides widest range of haemodynamic data</td>
<td>Most invasive cardiac output monitor; potentially serious complications</td>
</tr>
<tr>
<td>Transpulmonary thermodilution and pulse contour analysis</td>
<td>Continuous cardiac output data; suitable for conscious and unconscious patients</td>
<td>Errors from damped arterial trace; unsuitable for radial arterial lines</td>
</tr>
<tr>
<td>Lithium indicator dilution and pulse contour analysis</td>
<td>Continuous cardiac output data; suitable for conscious and unconscious patients</td>
<td>Errors from damped arterial trace; lithium may be contraindicated</td>
</tr>
<tr>
<td>Oesophageal Doppler</td>
<td>Easy to use; range of data provided to guide fluid management</td>
<td>Unsuitable for conscious patients; assumptions of aortic cross-sectional area needed for cardiac output calculations</td>
</tr>
<tr>
<td>Transthoracic/transoesophageal echocardiography</td>
<td>Qualitative and quantitative assessment of left and right ventricular function and preload; detection of valvular and regional wall motion abnormalities</td>
<td>Requires high operator skill level; oesophageal pathology is contraindication for transoesophageal probe</td>
</tr>
</tbody>
</table>

**Table 4**
Step 3: reassessment
The most useful variables for assessing the effect of the fluid administration are heart rate, blood pressure and trends in other perfusion indices (Table 5). An improvement should prompt a repeat bolus if indices are still deranged and other clinical signs point to a persisting fluid deficit. The first target is the restoration of an adequate perfusion pressure (that is MAP >65 mmHg), achievement of which should lead to quantification of markers of tissue dysoxia (that is lactate, acid-base balance). Pulmonary oedema is unlikely to be the consequence of fluid overload alone, more commonly it is the complication of coexisting cardiac dysfunction. Failure to respond and coexisting cardiac pathology should prompt early referral to a critical care specialist. Another important point to be considered is the timing of surgical interventions. Resuscitation might be the more immediate priority but on the other hand, reversal of hypovolaemic shock may not be achievable without haemorrhage-controlling surgery.

Step 4: invasive monitoring
In cases where there is no improvement with initial fluid resuscitation, invasive monitoring is likely to be required to ensure adequate volume replacement without fluid overload. Initially this will involve central venous and peripheral arterial pressure monitoring. Further fluid challenges can then be given with particular attention to changes in CVP. Limitations of right-heart pressures as indicators of preload have been highlighted above and absolute CVP values, although helpful, can be misleading. Dynamic changes in response to fluid administration carry more relevance. A small and transient rise in CVP (that is <3 mmHg) after a fluid bolus indicates persisting hypovolaemia and should prompt a repeat bolus. When adequate filling is achieved, a fluid challenge results in a more marked and, importantly, sustained rise in CVP (>7 mmHg), this should lead to discontinuation of fluid resuscitation. The risk of volume overload is minimized when only small boluses are given each time.

Step 5: advanced interventions
Because of the limitations of CVP-directed management it has now become common practice to establish cardiac output

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### Table 5

**Indirect indices of abnormal global perfusion**

- Tachycardia
- Reduced systolic blood pressure (SBP) or mean arterial pressure (MAP)
- Cold extremities
- Capillary refill time > 2 s
- Urine output < 0.5 ml/kg/h
- High lactate level
- Metabolic acidosis
- Central venous oxygen saturation (ScvO₂) < 70%

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**The principles of haemodynamic management in shock states**

1. **Initial assessment**
2. **Fluid challenge**
   - Responding?
     - **YES**: Maintenance fluid, further management. Continue to reassess
     - **NO**: Invasive monitoring, seek critical care advice
       - Fluid challenge against invasive pressures until well filled
       - Further management of underlying illness
       - Consider transfer to critical care area
       - Monitoring of cardiac output
       - Inotropes and vasopressors as indicated

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**Figure 1**
monitoring earlier if fluid resuscitation does not prove straightforward. Moreover, if a patient remains hypotensive after adequate fluid resuscitation vasoactive or inotropic drugs may be required. The choice of drugs will be guided mainly by cardiac output and invasive pressure monitoring (see below). As mentioned earlier, blood pressure is not a marker of perfusion or blood flow. Although several organ systems (brain, kidneys, heart) autoregulate blood flow over a wide range of blood pressures, they still require a minimum pressure to maintain perfusion. Haemodynamic targets will therefore be a mixture of cardiac output and blood pressure together with other markers of tissue perfusion such as blood lactate levels, base deficit and mixed or central venous oxygen saturation. Certainly at this stage, but probably earlier, high-dependency care is a necessity.

**Step 6: reduction of oxygen consumption**

It is important to remember that shock is the result of an imbalance between oxygen delivery and consumption. When all efforts have been made to optimize cardiovascular performance and oxygen delivery, reducing the oxygen consumption can help to decrease this imbalance. In recent years non-invasive ventilation has gained popularity and its indications are expanding (here the reduction of work of breathing). Pyrexia is another cause of increased oxygen demand that can easily be corrected. Figure 1 summarizes the principles of the management of shock.

**Inotropes and vasoactive drugs**

The choice of vasoactive and inotropic drugs is largely dictated by the clinical picture, local practice and personal experience. In order to explain underlying principles a simplified approach is described here. Blood pressure and cardiac output are the two main determinants: for example, a low BP in combination with a high cardiac output suggests a hyperdynamic circulation with systemic vasodilatation — the classic picture of septic shock. A vasoconstrictor such as norepinephrine (noradrenaline) is the treatment of choice. In cardiogenic shock the expected scenario would be low BP and low cardiac output in the presence of high systemic vascular resistance. A positive inotropic drug with vasodilator properties (an inodilator) is the logical option; dobutamine and milrinone are examples. Pure hypovolaemic shock should be treated with fluid replacement rather than vasoactive drugs. If hypotension is so severe as to imperil organ perfusion, a vasoconstrictor might be used as a bridging agent until control of haemorrhage and complete fluid resuscitation are achieved. In most clinical scenarios there is insufficient published evidence to clearly favour a particular drug or drug combination. This explains the coexistence of different approaches and protocols in different centres. Table 6 gives an overview of commonly used vasoactive and inotropic agents.

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**Pharmacology of common vasoactive/inotropic drugs**

<table>
<thead>
<tr>
<th>Drug</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epinephrine/adrenaline</td>
<td>Potent α- and β-adrenergic agonist (inopressor)</td>
<td>α effects predominate at higher doses</td>
</tr>
<tr>
<td>Norepinephrine/noradrenaline</td>
<td>Almost exclusive α-agonist (vasopressor)</td>
<td>Little β1-agonism; cardiac output not changed significantly</td>
</tr>
<tr>
<td>Dopamine</td>
<td>DA1- and β1-agonist, α effects at higher dose</td>
<td>No proven beneficial effect on renal function; common agent in paediatric ICU-practice</td>
</tr>
<tr>
<td>Dobutamine</td>
<td>β1- and β2-agonist (inodilator)</td>
<td>β1: increased contractility and heart rate; β2: vasodilatation and therefore fall in afterload</td>
</tr>
<tr>
<td>Dopexamine</td>
<td>β2- and DA1-agonist</td>
<td>May increase splanchnic and renal perfusion</td>
</tr>
<tr>
<td>Milrinone</td>
<td>Phosphodiesterase III inhibitor (inodilator)</td>
<td>Less increase of myocardial oxygen consumption; strong vasodilating effect may necessitate co-administration of a vasopressor</td>
</tr>
<tr>
<td>Levosimendan</td>
<td>Sensitizes troponin C to calcium (inodilator)</td>
<td>Little effect on myocardial oxygen consumption; used in low-output heart failure</td>
</tr>
<tr>
<td>Vasopressin</td>
<td>Vasoconstriction not mediated by adrenergic pathways</td>
<td>Co-administration with norepinephrine in severe vasodilated shock</td>
</tr>
</tbody>
</table>

DA: dopamine receptors.

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**Table 6**

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**FURTHER READING**


**CROSS REFERENCES**
