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Quizzes
Learning Objectives

- Recognise the role of the kidney in maintaining balance in the body
- Understand the causes and phases of Acute Kidney Injury (AKI)
- Understand the principles of fluid and solute management in Continuous Renal Replacement Therapy (CRRT): diffusion, convection, adsorption, ultrafiltration
- Understand the rationale for using each CRRT modality
  - Slow Continuous Ultrafiltration (SCUF)
  - Continuous Veno-Venous Haemofiltration (CVVH)
  - Continuous Veno-Venous Haemodialysis (CVHD)
  - Continuous Veno-Venous Haemodiafiltration (CVVHDF)
- Discuss the importance of vascular access and anticoagulation in successful CRRT usage
- Understand the rationale for using substitution and dialysate fluids in CRRT
- Recognise all the components needed to perform a successful CRRT treatment
- Recognise advantages, limitations and special requirements when performing CRRT
Lesson 1:
Renal Anatomy and Physiology

NIKKISO
Renal Anatomy and Physiology

Every time the heart beats, 25% of the cardiac output is sent to the kidneys.

THE KIDNEY
- The kidney functions using three principles: ultrafiltration, excretion and reabsorption
- The kidney consists of three parts:

![Kidney Diagram]

Cortex

Medula

Renal Pelvis

Notes
Components of the Kidney

1. The cortex (outer layer) contains 80% of the nephrons. These nephrons filter the blood continuously to maintain balance.
2. The medulla (inner layer) contains 20% of the nephrons. These nephrons also filter the blood, but have the added responsibility to concentrate urine. This becomes an important diagnostic tool.
3. The renal pelvis is the start of the collecting system, containing the collecting tubules and the ureter.

Additionally, ureters carry urine into the bladder where it is stored until it is eliminated from the body through the urethra.

RESIDUAL KIDNEY FUNCTION

- The kidney is capable of maintaining the body’s fluid, electrolyte and acid-base equilibrium until the majority of the nephrons are damaged.
- With progressive loss of kidney function, the body begins to make trade-offs to maintain homeostasis.
- With severe loss of kidney function, some form of renal replacement therapy is necessary to preserve life.

Notes
The Nephron

The functional unit of the kidney is called a nephron. Each kidney has about one million nephrons. Each nephron contains a glomerulus, which functions as an individual filtering unit. It also contains tubules for secretion and absorption of substances.

THE BLOOD PATHWAYS

Blood leaves the heart, enters the abdominal aorta and enters the kidney through the renal artery. The renal artery divides into many branches of arterioles until it becomes the afferent arteriole.

The afferent arteriole carries blood to the glomerulus, where it is filtered. It then leaves the glomerulus through the efferent arteriole, and is returned to the venous system. This system converges into larger vessels until it becomes the renal vein. Blood leaves the kidney via the renal vein, and is returned to the heart via the inferior vena cava.

Notes
GLOMERULUS
The glomerulus consists of a group of cells with selective permeability. It is a semi-permeable membrane. Selective permeability means that certain substances will cross the membrane and others will not be allowed to cross. Through selective permeability, the kidney regulates fluid and electrolyte balance. The tea filter is an example of a membrane with selective permeability.

In an adult, the kidneys produce approximately 180 litres of filtrate per day. Only 1.5 - 2 litres are excreted as urine. The remaining 178 litres are reabsorbed by the kidney.

THE AFFERENT AND EFFERENT ARTERIOLES
The afferent arteriole has a larger lumen than the efferent arteriole. Therefore, blood flows into the glomerulus faster than it flows out, which creates a pooling of blood in the Bowman’s capsule.

Hydrostatic pressure and capillary plasma oncotic pressure on the blood will force fluid to cross the glomerular membrane and enter the tubules. This is ultrafiltration.

As filtrate flows through the tubular network, special cells will respond to the need for reabsorption and secretion.
The end product of this filtrate is urine. The urine color is light to dark yellow depending on volume, and the color is provided by solutes. Substances including urea, creatinine, phosphorus, potassium, acids, etc. are cleaned and filtered to keep the blood values normal.

The goal of the kidney is to maintain a normal balance of fluids, electrolytes, minerals and acid-base. It works continuously to preserve equilibrium and homeostasis.

The kidneys also produce renin, vitamin D and erythropoietin. Renin promotes sodium retention and it also causes vasoconstriction. Vitamin D stimulates calcium and phosphate absorption. Erythropoietin promotes production of red blood cells in the bone marrow.

Notes
In summary:

- With every heartbeat, 25% of the cardiac output goes to the kidneys.
- Blood enters the abdominal aorta and flows into the renal artery.
- The renal artery branches until it becomes the afferent (entering) arteriole.
- The afferent arteriole takes the blood into the glomerulus (the filtering unit located in Bowman's capsule of the nephron).
  - Because blood flows into Bowman's capsule faster than it flows out, a resulting increase in pressure facilitates filtration.
- The efferent (leaving) arteriole takes the blood coming out of the glomerulus and returns it to the venous system. The venous system converges into larger vessels to become the renal vein.
- The renal vein carries blood to the vena cava and returns it to the heart.
- This process is continuous.

Notes
Kidney Functions

The kidney has several functions:

1. Fluid balance
   - Through ultrafiltration and reabsorption

2. Electrolyte balance
   - Through reabsorption and excretion

3. Acid-base balance
   - Through reabsorption and excretion

4. Excretion of drugs and by-products of metabolism
   - Nitrogen
   - Urea
   - Creatinine

5. Synthesis of erythropoietin
   - Stimulates the bone marrow to produce healthy red blood cells and helps them mature

6. Regulation of blood pressure
   - Through the renin-angiotensin system

7. Maintenance of calcium-phosphate balance
   - Kidneys produce the active vitamin D₃ and regulate calcium-phosphate balance
   - Kidneys also represent the major route of phosphate excretion
   - In advanced CKD, phosphate excretion is impaired and phosphate may bind with calcium and deposit in blood vessels and soft tissues

Notes
Kidney Facts

- The kidneys are two bean shaped organs, located just below the inferior boundary of the rib cage
- Each kidney can function independently of the other
- Each adult kidney weighs approximately 110 – 170 grams and is about the size of a human fist
- The adult kidneys receive 1200 millilitres of blood (25% of cardiac output) every minute. That is 72 litres per hour or 1728 litres per day.
- Normal kidney function is measured in terms of glomerular filtration rate (GFR). Normal GFR is typically 90-120 millilitres per minute. An Estimation of Glomerular Filtration Rate (eGFR) can be calculated based on age, serum creatinine, gender and race.
- The kidney is divided into three parts: the cortex, the medulla and the renal pelvis.
- The functional unit of the kidney is called a nephron.
- Each kidney contains approximately one million nephrons.
- Each nephron has a glomerulus, which functions as an individual filtering unit. It also contains the tubules which are responsible for reabsorption and secretion.
- The kidney has several roles:
  - Fluid balance
  - Electrolyte balance
  - Acid-base balance
  - Excretion of drugs and by-products of metabolism
  - Synthesis of erythropoietin
  - Regulation of blood pressure
  - Maintenance of calcium-phosphate balance.

Notes
Lesson 2: Acute Kidney Injury
Acute Kidney Injury

Acute Kidney Injury (AKI) results from the sudden loss of kidney function. Acute Kidney Injury in the setting of critical care patients is defined as an abrupt decline in glomerular filtration rate.\(^1\)

- Waste products that are usually excreted by the kidney accumulate in the blood
- AKI may be accompanied by metabolic, acid-base and electrolyte disturbances and fluid overload
- AKI may affect many other organ systems
- AKI may require immediate treatment

---

Acute Kidney Injury Can Be Classified As:²

A. PRE-RENAL
Pre-renal failure typically results from decreased blood flow to the kidneys. The reduction in glomerular filtration enables the solutes in the blood to accumulate but does not cause any structural damage to the kidney itself. Examples of situations leading to pre-renal failure may include dehydration, haemorrhage, congestive heart failure, sepsis, and embolism/thrombosis.

B. RENAL (INTRA-RENAL)
Intra-renal failure typically involves direct injury to the kidney itself. The most common cause is Acute Tubular Necrosis (ATN). Some causes are ischemia, hypertension, nephrotoxins and some systemic vascular diseases such as lupus.

C. POST-RENAL
In post-renal failure, the underlying cause is typically a bilateral obstruction below the level of the renal pelvis and may be due to tumor development, thrombi, calculi or hypertrophic prostate.

Clinical Phases of Acute Kidney Injury

In most cases of Acute Kidney Injury, patients will progress through distinct phases as outlined below. However, in some cases, AKI may have non-oliguric presentation.

<table>
<thead>
<tr>
<th>Oliguric phase</th>
<th>Polyuric phase</th>
<th>Recovery phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low urine output (less than 400 ml/24 hrs)</td>
<td>Begins when urine output begins to rise</td>
<td>May last several months following the onset of the Acute Kidney Injury</td>
</tr>
<tr>
<td>Possibly protein in the urine</td>
<td>Has variable time frames, sometimes occurring as little as 24 hours after the onset of renal failure</td>
<td>During this period, kidney function gradually returns to normal and proper urine concentrations and volumes are achieved</td>
</tr>
<tr>
<td>Electrolyte imbalances</td>
<td>Associated with potassium and sodium loss in the urine</td>
<td></td>
</tr>
<tr>
<td>Metabolic acidosis</td>
<td>Enhanced urine output may not reflect restored kidney function but rather may be the result of accumulating serum urea and creatinine, which have an osmotic diuretic effect</td>
<td></td>
</tr>
</tbody>
</table>

Notes
RIFLE Criteria

The Acute Dialysis Quality Initiative (ADQI) recommends a new classification of AKI based on the RIFLE criteria.

<table>
<thead>
<tr>
<th>GFR Criteria</th>
<th>Urine Output Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td></td>
</tr>
<tr>
<td>Injury</td>
<td>Increased SCreat x1.5 or GFR decrease &gt; 25%</td>
</tr>
<tr>
<td>Failure</td>
<td>Increased SCreat x2 or GFR decrease &gt; 50%</td>
</tr>
<tr>
<td></td>
<td>Increased SCreat x3 or GFR decrease 75% OR SCreat ≥4 mg/dL</td>
</tr>
<tr>
<td>Loss</td>
<td>Persistent ARF = complete loss of kidney function &gt; 4 weeks</td>
</tr>
<tr>
<td>ESKD</td>
<td>End Stage Kidney Disease (&gt; 3 months)</td>
</tr>
</tbody>
</table>

High Sensitivity

Oliguria

High Specificity

KEY

SCreat = Serum Creatinine
UO = Urine Output
ARF = Acute Renal Failure


Notes
Lesson 3: What is CRRT?
CRRT: Definition

Continuous renal replacement therapy (CRRT) is indicated for continuous solute removal and/or fluid removal in the critically ill patient. It allows for slow and isotonic fluid removal that results in better haemodynamic tolerance even in unstable patients with shock and severe fluid overload.

CRRT can be modified at any time of the day and night to allow adaptation to the rapidly changing haemodynamic situation of critically ill patients.

CRRT therapy indications may be renal, non-renal, or a combination of both. It is the treatment of choice for the critically ill patient needing renal support and/or fluid management.

HISTORY OF CRRT

The sophisticated and advanced CRRT currently employed in the management of Acute Kidney Injury was initially carried out by very simple means. The forerunner to modern machines now has its beginning from a simple set up which was discovered by accident. In March 1977, Dr. Peter Kramer, a nephrologist from Goettingen, Germany, was preparing a patient for haemofiltration. While attempting to insert a catheter into the femoral vein, he inadvertently punctured the femoral artery. This was the first step in CRRT. Over the past thirty years CRRT has continued to develop and has emerged as a front line therapy for treatment of critically ill patients with Acute Kidney Injury.


Notes
AKI Management Goals

- Removal of waste products
- Restoration of acid-base balance
- Correction of electrolyte abnormalities
- Haemodynamic stabilisation

Fluid balance
Nutritional support

CRRT INDICATIONS

Accepted indications are Acute Kidney Injury combined with: 6

- Haemodynamic instability (cardiovascular)
- Severe fluid overload unresponsive to diuretics
- Hypercatabolic states/trauma - rhabdomyolysis
- High fluid requirements (nutrition, blood products) 7

Possible non-renal indications include: 8

- Sepsis, lactic acidosis, acute respiratory distress syndrome (ARDS), multiple organ failure
- Chronic congestive heart failure (CHF), or decompensated CHF
- Pre- and post-cardiovascular surgery/ coronary artery bypass graft (CABG)
- During extracorporeal membrane oxygenation (ECMO) for fluid management

Notes

Principles of CRRT/Solute Management

DIFFUSION
Diffusion is the movement of solutes through a semi-permeable membrane from an area of higher concentration to an area of lower concentration until equilibrium has been established.

- Solute move from a higher concentration to a lower concentration.
- Diffusion occurs when blood flows on one side of the membrane, and dialysate solution flows counter-current on the other side.
- The dialysate does not mix with the blood, but some molecules from the dialysate such as bicarbonate do move from the dialysis compartment to the blood compartment.
- Efficient for removing small and medium molecules but not large molecules.
- Molecular size and membrane type can affect clearances.
- Diffusion is a haemodialysis principle.

The figure above demonstrates the physiologic principles. Not drawn to scale.

Notes
CONVECTION

Convection is the one-way movement of solutes through a semi-permeable membrane with a water flow. Sometimes it is referred to as solvent drag.

- Efficient for small, medium and large molecules
- The faster the substitution flow rate, the higher the clearance
- Pressure difference between the blood and ultrafiltrate causes plasma water to be filtered across the membrane. This causes solvent drag for small, medium and large molecules across the membrane leading to removal from the blood. The ultrafiltrate containing the solute should be replaced by substitution solutions
- Substitution solutions must have near physiological levels of electrolytes and buffer, and be sterile
- Solute molecular size and membrane type can affect clearances
- Convection is a haemofiltration principle

The figure above demonstrates the physiologic principles. Not drawn to scale.

Notes
Principles of CRRT/Solute Management

ULTRAFILTRATION
Ultrafiltration is the movement of fluid through a semi-permeable membrane along a pressure gradient.

- Positive and negative pressures affect ultrafiltration
- Positive pressure is generated on the blood side of the membrane and negative pressure is generated on the fluid side
- This gradient, positive to negative, influences the movement of fluid from the blood side to the fluid side, resulting in a net removal of fluid from the patient
- The ultrafiltration rate depends on the pressure applied to the filter, inside and outside the fibres
- Minimal solute clearance happens by convection during ultrafiltration

The figure above demonstrates the physiologic principles. Not drawn to scale.

Notes
**ADSORPTION**

Adsorption is the adherence of solutes and biological matter to the surface of a membrane.

- High levels of adsorption can cause certain filters to clog and become ineffective
- Membrane type affects adsorptive tendencies/effectiveness
- Adsorption may also cause limited removal of some solutes (e.g., β₂ microglobulins) from the blood

The figure above demonstrates the physiologic principles. Not drawn to scale.

**In summary:**
- Principles used in all CRRT/blood purification therapies are:
  - Diffusion (haemodialysis)
  - Convection (haemofiltration)
  - Diffusion & convection (haemodiafiltration)
  - Ultrafiltration (all therapies)
  - Adsorption (all therapies)

**Notes**
Treatments

CRRT/ Blood Purification

<table>
<thead>
<tr>
<th>SCUF</th>
<th>CVVHDF</th>
<th>CVVH</th>
<th>CVVHD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HAEMOFILTRATION CONVECTION | HAEMODIALYSIS DIFFUSION

CRRT includes several treatment modalities that use a veno-venous access. The choice will depend on the needs of the patient and on the preference of the physician.

**Slow Continuous Ultrafiltration**⁹ (SCUF)
Removal of ultrafiltrate at low rates without administration of a substitution solution. The purpose is to prevent or treat volume overload when waste product removal or pH correction isn’t necessary.

**Continuous Veno-Venous Haemofiltration**⁹ (CVVH)
Continuous convective removal of waste products (small, medium and large molecules) utilising a substitution solution, pH is affected by the buffer contained in the substitution solution.

**Continuous Veno-Venous Haemodialysis**⁹ (CVVHD)
Continuous diffusive removal of waste products (small and medium molecules) utilising a dialysate solution, pH is affected by the buffer contained in the dialysate.

**Continuous Veno-Venous Haemodiafiltration**⁹ (CVVHDF)
Continuous diffusive and convective removal of waste products (small, medium and large molecules) utilising both dialysate and substitution solution, pH is affected by the buffer contained in the dialysate and substitution solution.

⁹ Aquarius system Operating Manual

Notes
**Primary therapeutic goal:**
- Safe management of fluid removal

**Principle used:**
- Ultrafiltration (water removal)
- Convection (clearance)

**Primary indications:**
- Fluid overload

**Therapy characteristics:**
- No dialysate or substitution solutions
- Fluid removal only

**NOTE:** The figures in this section are taken from the Aquarius system Operating Manual.


**Notes**
CONTINUOUS VENO-VENOUS HAEMOFILTRATION\textsuperscript{\textregistered} (CVVH)

![Diagram of CVVH process]

<table>
<thead>
<tr>
<th>Primary therapeutic goal:</th>
<th>Principle used:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Solute removal and safe management of fluid volume</td>
<td>• Convection</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary indications:</th>
<th>Therapy characteristics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Uremia, acid/base or electrolyte imbalance, fluid overload</td>
<td>• Requires substitution solution to drive convection</td>
</tr>
<tr>
<td></td>
<td>• No dialysate solution</td>
</tr>
<tr>
<td></td>
<td>• Used to achieve solute removal (small, medium and large sized molecules) and fluid balance</td>
</tr>
</tbody>
</table>

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Notes
CONTINUOUS VENO-VENOUS HAEMODIALYSIS^9 (CVVHD)

Primary therapeutic goal:
- Solute removal and safe management of fluid volume

Primary indications:^6
- Uremia, acid/base or electrolyte imbalance, fluid overload

Principle used:
- Diffusion

Therapy characteristics:
- Requires dialysate solution with a buffer to drive diffusion
- No substitution solution
- Used to achieve solute removal (small and medium sized molecules) and fluid balance

Notes

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^9 Aquarius system Operating Manual
CONTINUOUS VENO-VENOUS HAEMODIAFILTRATION® (CVVHDF)

Primary therapeutic goal:
- Solute removal and safe management of fluid volume

Principle used:
- Diffusion and convection

Primary indications:
- Uremia, acid/base or electrolyte imbalance, fluid overload

Therapy characteristics:
- Requires substitution solution with a buffer, to drive diffusion and convection
- Used to achieve solute removal (small, medium and large sized molecules) and fluid balance

Notes
Lesson 4:
Delivery of CRRT

NIKKISO
Components of a CRRT Program

- Vascular access
- Anticoagulation
- CRRT system (machine, haemofilters, line sets, accessories)
- Fluid management
- Team

VASCULAR ACCESS

Vascular access is a basic prerequisite to perform any type of extracorporeal therapy. Access is particularly important in CRRT where catheter performance is tested 24 hours a day. In dialysis therapies, central venous catheters provide rapid and easy access permitting immediate use in critically ill patients. The most common catheter now in use is the large-bore, double-lumen catheter. The primary sites for insertion include the femoral vein, internal jugular vein, and, less commonly, the subclavian vein.

Using a blood pump, the patient’s blood is removed via the red coloured line typically connected to the red port of the catheter and delivered through the haemofilter back to the patient via the blue coloured line typically connected to the blue port.

NOTE: In this training guide, all references are to veno-venous vascular access. When inserting vascular access for CRRT, please follow the manufacturer’s instructions and your hospital’s protocols for insertion of central lines.

To have an effective CRRT treatment, it is absolutely crucial to have properly functioning access. Failure to have good access will result in a less than optimal treatment.

Many Factors Affect the Functioning of a CRRT Access\textsuperscript{10,11,12}

Type and size of catheter
- Polyurethane or silicone
- French size

Length and placement site of catheter
To ensure proper flow, it is important that the appropriate catheter is placed in the appropriate vessel. The following are suggestions.
- For jugular placement, it’s usually 12.5 cm on the right side and 15 cm on the left side (check each manufacturer’s recommendations)
- For subclavian placement, it’s usually 15 cm on the right side and 20 cm on the left side (check each manufacturer’s recommendations)
- The femoral vein should have an extra long catheter (24 cm) (check each manufacturer’s recommendations)
- Right side is anatomically easier to cannulate for jugular & subclavian
- As a rule, the left side needs the longer catheter

The patient’s disease processes and fluid status
- Caution should also be taken in cases where patients may be at high risk for bleeding
- If the patient is hypercoagulable and/or is dehydrated, it will be more difficult to maintain patency and proper flow


Notes
Components of a CRRT Program

ANTICOAGULATION

Anticoagulants are used to prevent the blood from clotting within the extracorporeal circuit during the CRRT procedure. All types of anticoagulation have risks. It is a constant challenge to find a balance between the risk of filter clotting and the risk of patient bleeding. In many critically ill patients undergoing CRRT, anticoagulation is typically achieved through the use of low dose heparin administered into the blood, before the haemofilter. Some patients may have underlying conditions, which put them at high risk of bleeding, and therefore heparin anticoagulation is not used.

The formation of clots in the blood is primarily the result of coagulation platelet factors and interaction and activation of the coagulation cascade. Therefore the majority of anticoagulation therapies are designed to interfere with the coagulation pathway. Both the patient and the circuit should be monitored to determine the effect of anticoagulation delivered, keeping in mind that preventing patient bleeding takes priority over preventing filter clotting.

HEPARIN

Heparin is the most frequently used anticoagulant. It is commonly used during the priming of the haemofilters and is infused into the CRRT circuit after the blood pump and before the filter. The effects of heparin are systemic and both the patient and the CRRT circuit are anticoagulated. All types of heparin carry the risk of heparin induced thrombocytopenia (HIT) and platelet counts must be monitored. If HIT is suspected, heparin must be discontinued immediately.

Notes
Components of a CRRT Program

HEPARIN DELIVERY

Typical pre-filter heparin
- Approximately 5-10 units/kg/hr\textsuperscript{13}
- Delivered into the CRRT circuit post-pump, pre-filter
- Mildly elevates the activated partial thromboplastin time (aPTT)

LOW-MOLECULAR WEIGHT HEPARIN (LMWH)
- Variable dose based on preparation
- Less likely to cause HIT
- Contra-indicated for patients who have developed HIT
- Difficult to monitor and difficult to reverse
- More expensive

! Precaution should be taken to monitor patient closely for excessive or inadequate anticoagulation.


Notes
OTHER ANTICOAGULANTS\textsuperscript{13,14,15}

Other, less frequently used anticoagulants, (when compared to Heparin) include:

- Trisodium citrate
- Nafamostat mesilate
- Prostacyclin
- Hirudin
- Danaparoid

NO ANTICOAGULATION

In some circumstances, risks to the patient complicates the use of any anticoagulant. These circumstances may include, but are not limited to:

- Active bleeding
- Increased aPTT
- Increased international normalized ratio (INR)
- Liver failure
- Low platelet count

Notes


\textsuperscript{14} Davenport A. Anticoagulation Options for Patients with Heparin-Induced Thrombocytopenia Requiring Renal Support in the Intensive Care Unit. \textit{Contrib Nephrol} 2007; 156:259-266.

The CRRT System

Delivering CRRT requires an integrated system consisting of:

- Machine
- Haemofilter
- Line sets
- Solutions
- Accessories

CRRT MACHINE

The **Aquarius** system is an example of an instrument designed to deliver CRRT. It consists of blood and fluid pumps, user-friendly interface, scales and integrated safeguards (see section “Getting Started with the **Aquarius** system” of the Operating Manual).

Notes
Haemofilter

The haemofilter (often referred to as an artificial kidney) is a requirement of any CRRT system. The haemofilter contains a semi-permeable membrane in a hollow fibre design.

- Blood flows inside of the hollow fibres
- Dialysate flows on the outside of the fibres
- Solute and fluid removal will be determined by the type of membrane and the surface area
- Haemofilters with synthetic membranes are recommended

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Notes
Line Sets

The line set is used to transport blood and fluids through the haemofilter and the CRRT circuit.

ACCESSORIES
Other accessory products may be used in the CRRT settings. They include:

• Filtrate waste bags
• Three-way or four-way adaptor (manifold)
• Syringes
• Anticoagulant
• Priming solution
• Dual-lumen catheters

Notes
Fluid Management

The goals of fluid management in CRRT are typically to achieve two important functions:

- Solute removal
- Fluid removal

Substitution and dialysate solutions are used to facilitate the removal of solutes from the patient’s blood using the principles of convection and/or diffusion. Fluids for this purpose are simultaneously removed by the CRRT machine as delivered, and do not affect the patient’s circulating volumes. Substitution solutions can be infused before the filter (pre-dilution) and after the filter (post-dilution).

To manage the patient’s circulating volume, it is often necessary to remove fluid from the patient. This is Patient Fluid Removal. When calculating Patient Fluid Removal, it is necessary to consider the non-CRRT intakes and outputs of the patient. Fluids removed from the patient (substitution solutions) are collected, as filtrate, in the filtrate waste bag.

Notes
Solution

**SUBSTITUTION SOLUTION**
- Sometimes referred to as “replacement fluid”
- Removal of solutes via **convection** (small, medium, large)
- Aids in volume management
- Must be physiological from an electrolyte standpoint and sterile
- Can be commercially available or pharmacy-prepared
- Infused into the patient’s blood pre-dilution, post-dilution or both
- Formulation, volume, and infusion method (pre- or post-dilution) are prescribed by a physician
- The volume of substitution solutions infused is automatically removed by the machine based on prescription

**DIALYSATE SOLUTION**
- Removal of solutes via **diffusion** (small and medium)
- Must be physiological from an electrolyte standpoint and should be sterile
- Commercially available
- Prescribed by a physician
- Solution enters the external dialysate port of the haemofilter counter-current to the blood flow
- Buffers include lactate or bicarbonate
- Formulation is usually calcium-free when used with citrate anticoagulation

Notes
Fluid Removal

PATIENT FLUID REMOVAL
• Fluid removed directly from the patient’s intravascular compartment
• Hourly rate of removal is prescribed by the physician
• Non-CRRT intakes and outputs must be calculated and considered
• Fluid removal occurs by ultrafiltration
• Fluid removed contains components of plasma

FILTRATE
• Filtrate is a combination of the substitution fluid, dialysate fluid and fluid removed from the patient
• Components of filtrate include water, electrolytes, waste products, inflammatory mediators, drugs, vitamins and amino acids
• Filtrate is removed from the filtrate port of the haemofilter into a filtrate waste bag
• Filtrate is a biological waste substance, hospital protocols should be followed

Notes
In summary:
In summary, the main goals of CRRT are removal of waste products, restoration of acid/base balance, and correction of fluid and electrolyte abnormalities, while maintaining haemodynamic stability. The goal of any continuous renal replacement therapy is to replace, as best as possible, the lost function of the native kidney. While CRRT provides a good option for a patient with AKI, nothing will replace the complete function of a healthy kidney. The illustration below demonstrates how the CRRT system attempts to mimic the function of the native kidney.

Notes
Though several studies have shown similar outcomes between CRRT and Intermittent Haemodialysis (IHD), CRRT has physiologic advantages in critically ill patients. It can provide haemodynamic stability, volume control and improved blood pressure support.17,18,19,20 When normal kidney function can be restored, freedom from the need for chronic dialysis can provide the patient with a better quality of life. The following illustration depicts kidney function from a healthy kidney, to failure, to treatment, to recovery.


Notes
ADVANTAGES

- Compared to standard haemodialysis applied for a short period of time, CRRT provides improved haemodynamic stability (slow, gentle and continuous)
- Provides continuous fluid and electrolyte management (avoidance of rapid fluid and electrolyte shifts)
- May facilitate removal of cytokines and mediators
- Adapted to the needs of the critically ill

LIMITATIONS

- Requires a large-bore central vascular access
- Typically requires continuous anticoagulation
- Requires immobilisation of the patient for prolonged periods


Notes
Special Considerations

CRRT is used to treat critically ill patients, typically suffering from Acute Kidney Injury accompanied by haemodynamic instability. While CRRT offers some advantages, certain parameters may require special monitoring.

DRUG MANAGEMENT

Drug removal in CRRT techniques is dependent upon the molecular weight of the drug, the sieving coefficient and the degree of protein binding. Drugs with significant protein binding are removed minimally. Additionally, some drugs may be removed by adsorption to the membrane. Most of the commonly used drugs require adjustments in dose to reflect the continuous removal during CRRT.22

ACID/BASE AND ELECTROLYTE BALANCES

During CRRT, acid/base and electrolyte balances are continually modified, and should be watched closely.

BLEEDING

Patients receiving continuous anticoagulation may be at risk of bleeding. The patient should be monitored for bleeding. Patient’s clotting parameters and access site should be closely monitored.


Notes
CRRT patients are prone to hypothermia due to the significant volume of blood that is circulated outside of the body, and the significant volumes of the substitution solutions used. During CRRT thermal energy is lost. There is little published on thermal energy exchange during CRRT, but some potential effects of cooling could be:

- May improve cardiovascular stability
- May affect nutritional requirements
- May affect immune function
- May increase risk of circuit clotting

The Aquarius has an integrated heating management system to reduce thermal energy losses.


**Notes**
Quiz for Module 1: Continuous Renal Replacement Therapy Overview
Lesson 1: Renal Anatomy and Physiology

Score: _______________________

Name: _______________________

Date: _______________________

Instructor: ___________________

Location: ____________________

Please circle the most appropriate answers:

1. What percentage of cardiac output goes to the kidney?
   A. 15%    
   B. 25%    
   C. 20%    
   D. 10%

2. Which of the following are NOT structural components of the kidney?
   A. Cortex and medulla
   B. Nephrons and glomerulus
   C. Renal pelvis and tubules
   D. Bladder and urethra

3. Which of the following can be described as the functional unit of the kidney?
   A. Renal artery
   B. Efferent arteriole
   C. Nephron
   D. Glomerulus

4. Approximately, how much filtrate is produced by the kidney each day?
   A. 100 litres
   B. 180 litres
   C. 200 litres
   D. 50 litres

5. Which kidney structure can best be defined as a semi-permeable membrane?
   A. Nephron
   B. Medulla
   C. Afferent and efferent arterioles
   D. Glomerulus

6. Which of the following pressures forces fluid to cross the glomerular membrane?
   A. Capillary plasma oncotic pressure
   B. Hydrostatic pressure
   C. Osmotic pressure
   D. A and B

7. Which blood vessel carries blood INTO the glomerulus?
   A. Afferent arteriole
   B. Efferent arteriole
   C. Renal vein
   D. Renal artery

8. Normal kidney function is measured in terms of glomerular filtration rate (GFR). What is the normal GFR?
   A. 120-150 ml/min
   B. 90-120 ml/min
   C. 60-90 ml/min
   D. 30-60 ml/min

9. List seven functions of the kidney
   1. _______________________
   2. _______________________
   3. _______________________
   4. _______________________
   5. _______________________
   6. _______________________
   7. _______________________

Answers:

1-B, 2-D, 3-C, 4-B, 5-D, 6-D, 7-A, 8-B

Fluid balance, electrolyte balance, acid-base balance, excretion of drugs and by-products of metabolism, synthesis of erythropoietin, regulation of blood pressure, maintenance of calcium-phosphate balance.
Quiz for Module 1: Continuous Renal Replacement Therapy Overview

Lesson 2: Acute Kidney Injury

Score: ____________________________

Name: ____________________________  Instructor: ____________________________
Date: ____________________________  Location: ____________________________

Please circle the most appropriate answers:

1. Select the statement(s) that represent Acute Kidney Injury:
   A. May be accompanied by metabolic disturbances
   B. May require immediate treatment
   C. Is defined as an abrupt decline in glomerular filtration rate
   D. All of the above

2. Select the answer that best describes “pre-renal” failure:
   A. Direct injury to the kidney
   B. Decreased blood flow to the kidney
   C. Increased blood flow to the kidney
   D. An obstruction below the kidney

3. Some examples of “post-renal” failure may include:
   A. Venous thrombi
   B. Urinary tract obstruction
   C. Tumors
   D. B & C correct

4. Select the answer that BEST describes the clinical phase(s) of Acute Kidney Injury:
   A. Polyuric phase
   B. Recovery phase
   C. Oliguric phase
   D. All of the above

5. Which of the following statements is NOT true when referring to the oliguric phase of Acute Kidney Injury?
   A. Only lasts 5 days
   B. Protein may be present in the urine
   C. Urine output less than 400 ml/24 hours
   D. There may be electrolytes and acid-base imbalances
Quiz for Module 1: Continuous Renal Replacement Therapy Overview

Lesson 3: What is CRRT?

Score: ____________________________

Name: ____________________________  Instructor: ____________________________
Date: ____________________________  Location: ____________________________

Please circle the most appropriate answers:

1. Select the answer that BEST defines Continuous Renal Replacement Therapy (CRRT):
   A. A fluid removal therapy
   B. A kind of dialysis
   C. A therapy indicated for continuous solute and/or fluid removal in critically ill patients
   D. A therapy indicated for intermittent solute and/or fluid removal in critically ill patients

2. Which of the conditions listed below might be used as a non-renal indication to start therapy?
   A. Severe fluid overload unresponsive to diuretics
   B. Rhabdomyolysis
   C. Sepsis
   D. All of the above

3. Diffusion is the movement of solutes through a semi-permeable membrane from an area of higher concentration to an area of lower concentration. Select the answer that is NOT true of diffusion in CRRT:
   A. Blood flows on one side of the membrane and dialysate flows counter-current on the other side
   B. Dialysate does not mix with blood
   C. Occurs during haemofiltration
   D. Efficient for removing small and medium molecules

4. Convection is the one-way movement of solutes through a semi-permeable membrane with a water flow. Select the answer that is true of convection in CRRT:
   A. Substitution fluids should be clean
   B. Molecular size of solutes does not affect clearance
   C. Occurs during haemofiltration
   D. Only efficient for removing large molecules
Quiz for Module 1: Continuous Renal Replacement Therapy Overview
Lesson 3: What is CRRT?

5. Ultrafiltration is the movement of fluid through a semi-permeable membrane along a pressure gradient. Select the answer(s) below that also represent ultrafiltration in CRRT:
   A. Positive and negative pressures affect ultrafiltration
   B. Positive pressure is generated on the blood side of the membrane
   C. Minimal convective solute clearance occurs
   D. All of the above

6. Adsorption is the adherence of solutes and biological matter to the surface of a membrane. Select the answer below that is true of adsorption in CRRT:
   A. High levels of adsorption may cause haemofilters to clog and become less efficient
   B. The type of membrane does not affect adsorption
   C. Adsorption happens only in convective therapies
   D. Adsorption has no impact on treatment

7. Select the correct answer(s). In Slow Continuous Ultrafiltration (SCUF):
   A. The principle used is ultrafiltration
   B. Substitution and dialysate fluids are not used
   C. Primary indication is fluid overload
   D. All of the above

8. Select the correct answer(s) regarding Continuous Veno-Venous Haemofiltration (CVVH):
   A. Requires use of a substitution fluid
   B. Used to achieve solute removal (small, medium and large sized molecules) and fluid balance
   C. The principle used is convection
   D. All of the above

9. Select the statement that is NOT true regarding Continuous Veno-Venous Haemodialysis (CVVHD):
   A. The principle used is diffusion
   B. Uses a combination of substitution and dialysate fluids
   C. Used to achieve solute removal (small and medium sized molecules) and fluid balance
   D. Primary therapeutic goals are solute and fluid management

10. Select the statement that BEST describes Continuous Veno-Venous Haemodiafiltration (CVVHDF):
    A. The principle used is convection
    B. The principle used is diffusion
    C. Requires only a dialysate fluid
    D. Uses the principles of diffusion and convection

Answers:
1-C, 2-C, 3-C, 4-C, 5-D, 6-A, 7-D, 8-D, 9-B, 10-D
Quiz for Module 1: Continuous Renal Replacement Therapy Overview
Lesson 4: Delivery of CRRT

Score: ________________________________

Name: ________________________________  Instructor: ________________________________
Date: ________________________________  Location: ________________________________

Please circle the most appropriate answers:

1. Select the statement(s) that correctly identifies the importance of vascular access in CRRT:
   A. Central venous catheters provide rapid and easy access permitting immediate use in critically ill patients
   B. Vascular access is a basic prerequisite to any form of extracorporeal therapy
   C. To have a good CRRT treatment it is essential to have a good vascular access
   D. All of the above

2. Under certain conditions administering continuous anticoagulants may pose a risk to patients. Select the answer(s) that include some of these conditions:
   A. Active bleeding
   B. Increased aPTT and INR
   C. Liver failure and low platelet count
   D. All of the above

3. List five components of a CRRT system needed to deliver a CRRT treatment:
   A. ________________________________
   B. ________________________________
   C. ________________________________
   D. ________________________________
   E. ________________________________

4. Haemofilters are often referred to as artificial kidneys. In reference to a hollow fibres haemofilter, which one of these statements is correct?
   A. Dialysate flows on the inside of the hollow fibres
   B. Membranes are semi-permeable and usually cellulose based
   C. Blood flows on the inside of the hollow fibres
   D. The type of membrane will not affect solute clearance

5. The goals of fluid management in CRRT are typically to achieve two important functions. What are these functions?
   A. ________________________________
   B. ________________________________
Quiz for Module 1: Continuous Renal Replacement Therapy Overview
Lesson 4: Delivery of CRRT

6. When calculating patient fluid removal during CRRT, which parameter is NOT controlled by the CRRT system?
   A. Substitution and dialysate fluids
   B. Non-CRRT intake such as IV antibiotics
   C. Programmed patient net fluid loss
   D. All of the above

7. What is the primary function of substitution fluid?
   A. Volume replacement
   B. Convective clearance
   C. Electrolyte replacement
   D. All of the above

8. What is the primary function of dialysate fluid?
   A. Diffusive clearance
   B. Volume replacement
   C. Convective clearance
   D. Electrolyte replacement

9. Filtrate is a combination of substitution fluid, dialysate fluid and fluid removed from the patient. Which of the following components would you expect the filtrate to contain?
   A. Water and electrolytes
   B. Drugs, water soluble vitamins and amino acids
   C. Waste products and immune mediators
   D. All of the above
Quiz for Module 1: Continuous Renal Replacement Therapy Overview
Lesson 5: CRRT Considerations

Score: _______________________

Name: _______________________
Instructor: ___________________
Date: _______________________
Location: ___________________ 

Please circle the most appropriate answers:

1. Select the answer(s) that may be considered advantages of CRRT:
   A. Slow, gentle, continuous delivery provides improved haemodynamic stability
   B. Avoids rapid fluid and electrolyte shifts
   C. Can be adapted to the needs of the critically ill patient
   D. All of the above

2. Select the answer(s) that may be considered limitations of CRRT:
   A. Requires a large-bore central venous access
   B. Typically requires anticoagulation
   C. Limits mobility of the patient
   D. All of the above

3. Patients receiving CRRT may be at risk of bleeding. Select the answer that describes how you would monitor the patient for signs of bleeding:
   A. Monitor access site closely
   B. Check patient’s clotting parameters
   C. Check patient’s hemoglobin value
   D. All of the above

4. Drug removal in CRRT is dependent on many factors. Select the answer that is LEAST likely to impact the removal of drugs in CRRT:
   A. Molecular weight of the drug
   B. Type of anticoagulation used
   C. Slope coefficient and degree of protein binding
   D. Adsorption to the membrane

5. In CRRT patients prone to hypothermia, which of the following statements is NOT correct?
   A. Has no impact on circuit clotting
   B. May affect nutritional requirements
   C. May affect immune function
   D. May improve cardiovascular stability
Answers:
1-D, 2-D, 3-D, 4-B, 5-A
Advancing Critical Care Education

Advancing Critical Care Education (AdvancCCE) is a comprehensive education program offered by Nikkiso consisting of interactive workshops and support materials for critical care nurses using Nikkiso Continuous Renal Replacement Therapy (CRRT) products.

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