# Haemodialysis

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## Abstract

The haemodialysis population continues to increase and is becoming more elderly and dependent. Despite major advances in technology, long-term clinical outcomes are disappointing, even in low-risk patients. Current definitions of dialysis adequacy, based on urea clearance, need to be broadened to encompass parameters such as $\beta_2$-microglobulin clearance, salt and water balance, and phosphate control. Haemodiafiltration provides improved $\beta_2$-microglobulin clearance over haemodialysis, and may improve survival. There is a trend towards individualizing haemodialysis dose to the needs of the patient. Patients with significant residual kidney function may require less dialysis. For others without residual function, more frequent treatments may be necessary to adequately control uraemia and volume status, and to improve survival. Home-based treatment can facilitate more frequent treatments for a proportion of patients, although centre-based therapy remains the default for the majority.

**Keywords** $\beta_2$-Microglobulin; adequacy; convection; diffusion; dry weight; haemodiafiltration; haemodialysis; residual kidney function; uraemia

## What's New?

- There is increasing evidence of a survival benefit for haemodiafiltration over standard haemodialysis
- More frequent haemodialysis treatments than standard thrice-weekly schedules may improve outcomes for a proportion of patients
- The capacity to adapt the timing and frequency of haemodialysis sessions to suit lifestyle has led to a resurgence of interest in haemodialysis at home. Innovations in dialysis technology to support this move are emerging
- The need to increase patient focus is exemplified by shared-care initiatives and increased emphasis on patient-reported measures as valid indicators of outcome

## Introduction

Haemodialysis (HD), together with peritoneal dialysis and kidney transplantation, has revolutionized the outlook for patients with end-stage kidney disease (ESKD). Evolution of the technique from experimental studies in dogs (Abel, 1913) to its successful use in humans with acute kidney injury (AKI) (Kolff, 1945) followed in the wake of technical advances in the development of semi-permeable membranes and anticoagulants. Its application to the treatment of ESKD required further technical developments in the 1960s to allow reliable and repeated access to the blood circulation — the Scribner shunt and the Cimino—Brescia arteriovenous fistulae. Since then, the number of patients receiving chronic HD worldwide has risen dramatically and it is now widely available in developed countries. As a consequence the age, co-morbidity and dependency of the HD population has increased and the technique has become the default modality for the treatment of ESKD. However, the technique only partially replaces aspects of kidney function, and life expectancy of HD patients remains far below that of the age-matched general population. Thrice-weekly treatment is the standard, but there is emerging evidence of the benefits of increased dialysis frequency.

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## Principles of haemodialysis

Dialysis involves movement of solutes and water across semi-permeable membranes by diffusion and convection. Diffusion is the movement of solutes across a semi-permeable membrane down a concentration gradient. Diffusive clearance of a solute depends on its molecular weight, electrical charge, the blood—dialysis fluid concentration gradient, blood and dialysis flow rates and on membrane characteristics (diffusion coefficient). Smaller molecules such as urea (60 Da) are cleared well, whereas larger molecules such as albumin (60,000 Da) cannot pass through the membrane. The clearance of middle molecules such as $\beta_2$-microglobulin (11,800 Da) can be improved using high-flux membranes, which have pores of sufficient size to allow the passage of such molecules. Convection refers to the movement of solvent and dissolved solutes across a semi-permeable membrane, down a hydrostatic pressure gradient. Convection significantly improves middle molecule clearance. Ultrafiltration is the convective movement of water across the membrane. The ultrafiltration rate depends on the hydrostatic pressure difference across the membrane and on its permeability to water (ultrafiltration coefficient).

### The dialysis system: technical considerations

**Dialysers** consist of semi-permeable membranes arranged to form separate adjacent paths for blood and dialysis fluid, which flow on either side of the membrane, in opposite directions to maximize diffusion gradients. Dialysers are classified by their design geometry, membrane composition, surface area, permeability characteristics (diffusion and ultrafiltration coefficient) and biocompatibility characteristics. Hollow-fibre dialysers are most commonly used.

**Extracorporeal circuit** (Figure 1): blood is withdrawn from the patient via the 'A' needle by a peristaltic pump, circulated through the dialyser and returned to the patient through the 'V' needle. The circuit is anticoagulated by unfractionated heparin, which is infused downstream from the blood pump, or by low-molecular-weight heparin (LMWH). The arterial pressure monitor protects

 

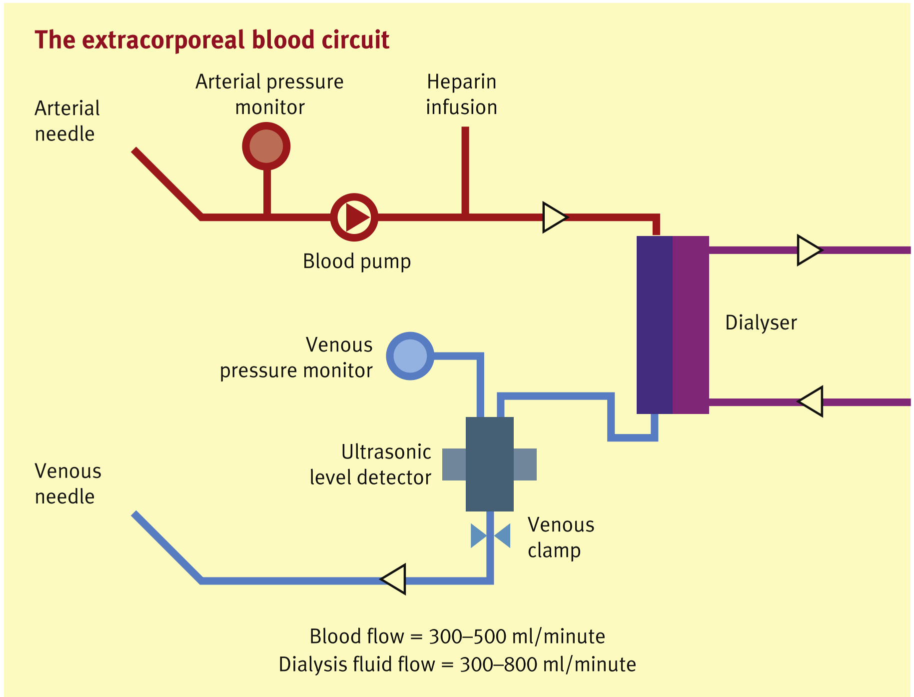


**Figure 1**

the fistula by detecting excessive negative pressure. The venous pressure monitor provides some protection against blood loss from the circuit to the environment though leaks arising from dislodgement of the 'V' needle. The bubble trap level detector protects against air embolism. The blood flow rate, dialysate flow rate, fluid removal rate (ultrafiltration rate) and duration of dialysis are all set at the time of dialysis and individualized for each patient.

**Dialysis machine**: The dialysis machine supplies dialysis fluid at the prescribed flow rate, temperature and chemical composition. The machine also monitors the extracorporeal circuit and, in fail-safe mode, activates the venous clamp and switches off the blood pump. Modern machines use volumetric methods to allow precise control of ultrafiltration volumes. Other technical advances include blood temperature monitors, which allow control of thermal balance during dialysis to improve haemodynamic stability and may also be used to measure vascular access blood recirculation using thermodilution techniques (see 'Vascular Access' below). Blood volume monitors are used to detect changes in blood viscosity in response to ultrafiltration during dialysis and are potentially useful in predicting hypotensive episodes. Facilities for on-line clearance monitoring are now available and their use is increasing.

**Water and dialysis fluid**: The dialysis machine mixes prepared concentrates of electrolytes with treated water to produce dialysate. Typical dialysate electrolyte concentrations are shown in Figure 2. HD patients are exposed to over 300 L of water each week. Contamination of water with chemical impurities and microorganisms carry significant health risks. In the past, aluminium contamination was a significant problem and caused adynamic bone disease, fatal encephalopathy and anaemia. Contamination with chloramines is still, not infrequently, reported as a cause of haemolytic anaemia. Febrile reactions and septicaemia due to bacteria and endotoxins are very rare with modern water purification systems. These involve a combination of techniques including softening and de-ionization, carbon adsorption, reverse osmosis and ultraviolet irradiation. Most clinical practice guidelines recommend the use of ultrapure dialysis fluid (defined as $<0.1$ colony-forming units (CFU)/ml and endotoxin content $<0.03$ endotoxin units (EU)/ml). Use of ultrapure dialysate has been associated with improved clinical outcomes.[1]

**Anticoagulation**: Exposing blood to the extracorporeal circuit results in activation of leucocytes and platelets leading to thrombin and platelet microthrombi deposition in the dialyser; this reduces the effective dialyser surface area, reducing solute clearance and may result in clotting of the circuit. Anticoagulation – most commonly using LMWH – prevents this. For patients with contraindications to systemic anticoagulation, options include heparin-free HD (regular saline flushing of the circuit), regional citrate anticoagulation[2] or use of dialysers with heparin-coated membranes.[3]

### Haemodialysis techniques

**Conventional haemodialysis** uses low-flux (low ultrafiltration coefficient) membranes, which allow diffusive but little convective solute removal. Smaller molecules such as urea are cleared efficiently, but middle molecule clearance is poor. The prescribed fluid is volumetrically removed by means of an ultrafiltration pump (UF in Figure 3) placed in a loop D of the dialysis fluid flow path. Fluid removal from the loop will result in an equal volume being removed from the blood across the dialysis membrane.

**Haemofiltration** is a purely convective treatment. Highly permeable membranes are used, permitting high-volume

 