Haemodialysis

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Abstract

The population undergoing haemodialysis continues to expand, with an increasing prevalence of elderly dependent patients including those aged >80 years. Despite major advances in technology, long-term clinical outcomes are disappointing, even in low-risk patients. Current definitions of adequacy of dialysis, based on urea clearance, need to be broadened to encompass parameters including middle molecule clearance, salt and water balance, and patient symptoms and well-being. Haemodiafiltration provides improved middle molecule clearance over haemodialysis, with some evidence of improved survival. There is a trend towards individualizing the haemodialysis dose to meet the patient's needs. Patients with significant residual kidney function may require less dialysis. For others without residual kidney function, more frequent treatments can be necessary to adequately control uraemia and volume status, and improve survival. Home-based treatment can facilitate more frequent treatments for some patients, although centre-based therapy remains the default for most.

Keywords Adequacy; convection; diffusion; dry weight; haemodiafiltration; haemodialysis; kidney function; middle molecule; MRCP; residual; uraemia

Key points

- The population undergoing haemodialysis continues to increase, with a higher proportion of elderly patients now given this therapy
- Despite major advances in technology, long-term clinical outcomes are disappointing, even in low-risk patients
- Current definitions of adequacy of dialysis, based on urea clearance, need to be broadened to encompass parameters such as middle molecule clearance, salt and water balance, and patient-reported outcome measures
- Haemodiafiltration provides improved middle molecule clearance, and there is increasing evidence of a survival benefit, particularly with high-volume haemodiafiltration
- Individualizing haemodialysis prescriptions to the particular needs of the patient, considering their native kidney function, age, gender, activity, co-morbidity, degree of frailty and likely prognosis, is a logical approach
- Home haemodialysis provides optimum outcomes and facilitates the use of extended dialysis schedules in terms of session length and frequency. Uptake, although increasing, remains low
- Increased involvement of patients in their own care, including in-centre haemodialysis (shared care), can improve outcomes and facilitate psychological adjustment

Introduction

Haemodialysis, together with peritoneal dialysis and kidney transplantation, has revolutionized the outlook for patients with end-stage renal failure (ESRF). Evolution of the technique from experimental studies in dogs (Abel in 1913) to its successful use in humans with acute kidney injury (Kolff in 1945) followed in the wake of technical advances in the development of semipermeable membranes and anticoagulants. Its application to the treatment of ESRF 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 fistula (AVF).

Since then, the number of patients given chronic haemodialysis worldwide for the treatment of ESRF has risen dramatically, and the therapy is widely available in developed countries. As a consequence, the age, co-morbidity and dependency of the haemodialysis population has increased, and the technique has become the default modality for the treatment of ESRF. However, haemodialysis only partially replaces aspects of kidney function, and despite improvements in mortality rates over the last 20 years, the life expectancy of haemodialysis patients remains far below that of the age-matched general population. Three-times-weekly treatment is the standard, but there is emerging evidence of the benefits of increased dialysis frequency on quality of life, phosphate control, blood pressure and regression of left ventricular hypertrophy.[1]

Principles of haemodialysis

Dialysis involves the movement of solutes and water across semipermeable membranes by diffusion and convection.

Diffusion is the movement of solutes across a semipermeable membrane down a concentration gradient. Diffusive clearance of a solute depends on its molecular weight and electrical charge, the blood–dialysis fluid concentration gradient, blood and dialysis flow rates and 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 β_2-microglobulin (11,800 Da) can be improved using

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

Extracorporeal circuit: blood is withdrawn from the patient via the arterial ('A') needle by a peristaltic pump, circulated through the dialyser and returned to the patient through the venous ('V') needle (Figure 1). The circuit is anticoagulated either by unfractionated heparin, which is infused downstream of the blood pump, or by low-molecular-weight heparin (LMWH) administered as a bolus. The arterial pressure monitor protects the fistula by detecting excessive negative pressure. The venous pressure monitor can help to detect venous stenosis in the access and provides some protection against blood loss from the circuit to the environment through leaks arising from dislodgement of the 'V' needle; however, this does not preclude the need for other monitoring to guard against this. 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 set at the time of dialysis and individualized for each patient.

Dialysis machine: this supplies dialysis fluid at the prescribed flow rate, temperature and chemical composition. It 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 can 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. Haemodialysis patients are exposed to >300 litres of water each week. Contamination of water with chemical impurities and microorganisms carries 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 bacteraemia caused by bacteria and endotoxins are very rare with modern water purification systems. These involve a combination of techniques including softening and deionization, 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/ml and endotoxin content <0.03 endotoxin units/ml).[2] Use of ultrapure dialysate has been associated with improved clinical outcomes.

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 can result in clotting in the circuit. Anticoagulation — most commonly using LMWH — prevents this. For patients with contraindications to systemic anticoagulation, options include heparin-free haemodialysis (regular sodium chloride flushing of the circuit), regional citrate anticoagulation or use of dialysers with heparin-coated membranes.

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 loop D of the dialysis fluid flow path. Fluid removal from the loop results 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 ultrafiltration of 20–50 litres per session. Dissolved solutes are also removed. High-volume replacement is required with substitution fluid, delivered either on the arterial side of the filter (pre-dilution) or into the venous bubble trap (post-dilution). Middle molecule clearance is excellent, but small molecule clearance is poor. For this reason, intermittent haemofiltration has not been a successful long-term treatment for ESRF. However, the technique is very successfully used in continuous mode for the treatment of acute kidney injury in critical care settings. Continuous veno-venous haemofiltration, which requires a pumped venous supply, is the most common technique. Continuous veno-venous haemodiafiltration (HDF) is a variant. Both techniques are well tolerated haemodynamically, avoiding the 'peaks and troughs' in metabolic, electrolyte, acid–base and volume control that are a feature of intermittent treatments.

High-flux haemodialysis uses highly permeable, usually biocompatible, membranes. These membranes provide good diffusive clearance of small solutes, combined with much better diffusive removal of middle molecules than conventional dialysis. This is augmented by a convective contribution to

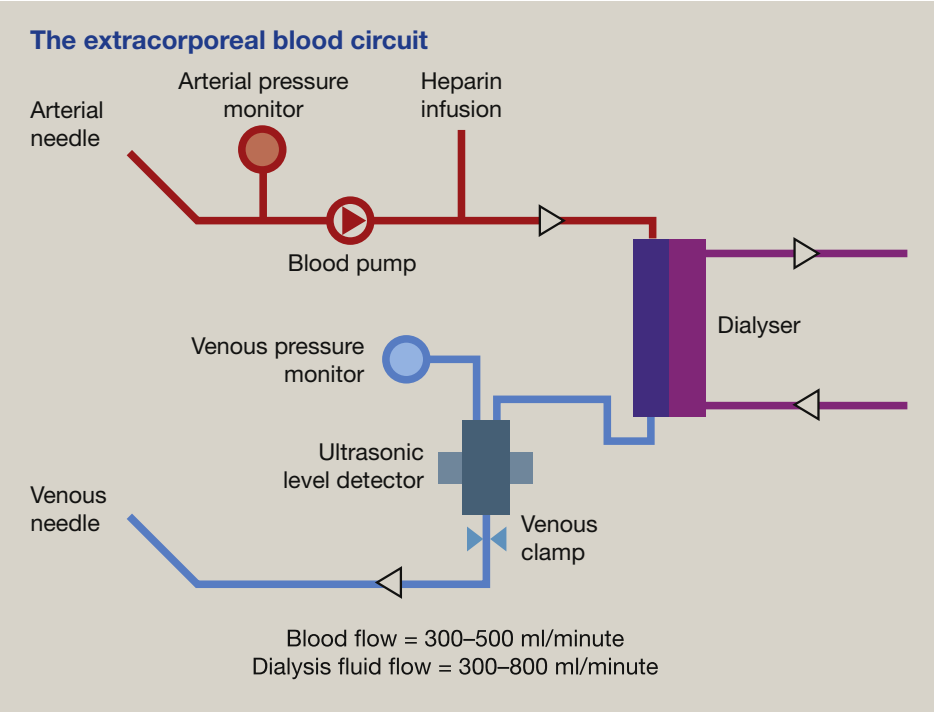

Figure 1

middle molecule clearance resulting from a degree of obligate back-filtration within the dialyser. Evidence from the HEMO and the Membrane Permeability Outcome studies suggests that high-flux haemodialysis can confer survival benefits for long-surviving dialysis patients and high-risk groups.

Haemodiafiltration is the addition of a prescribed convective component (haemofiltration) to the technique of high-flux haemodialysis. During each high-flux session, 12—30 litres of ultrafiltrate are removed and replaced by substitution fluid. The cheap on-line production by the dialysis machine of ultrapure substitution fluid from dialysis fluid has allowed HDF to become established as a viable routine therapy for ESRF (Figure 4). Fluid is removed from the constant-volume loop D by an HDF pump (HDF), passed through an ultrafilter (F2) and infused in to the 'V' line (post-dilution) or the 'A' line (pre-dilution; not shown). To

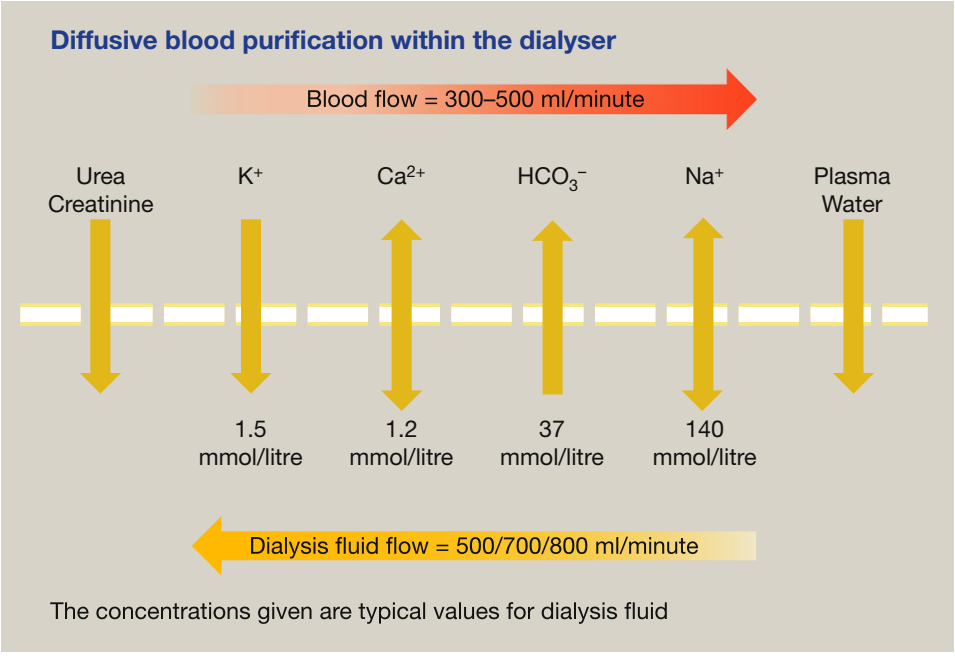

Figure 2

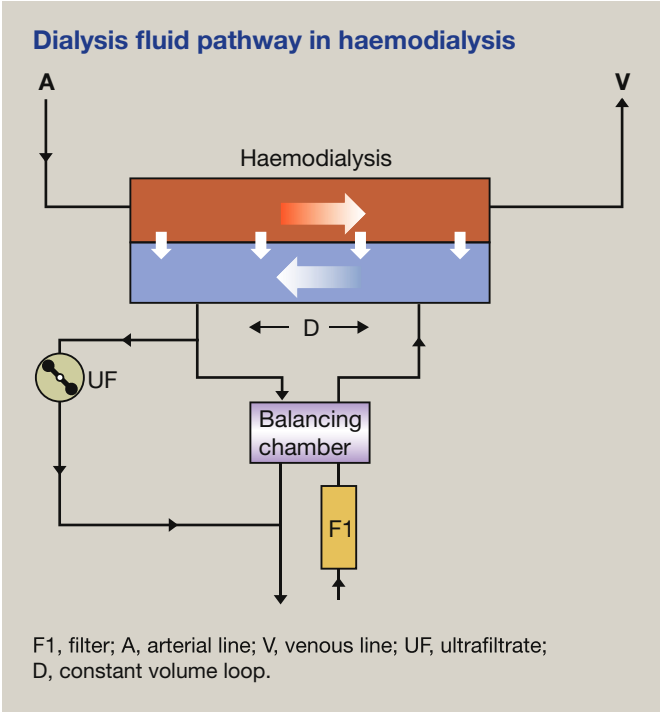

Figure 3

maintain the volume in loop D, an equal volume of fluid is drawn from the blood across the dialysis membrane.

The added convective component in HDF produces a small improvement in small solute clearance over that seen in high-flux dialysis, but a significant improvement in middle molecule clearance. Serum β_2-microglobulin concentration is reduced, and dialysis-related amyloidosis can be delayed. Evidence from a number of studies has suggested a survival benefit particularly for patients subjected to high-volume HDF.[3] HDF also provides better haemodynamic stability with less intradialytic hypotension, possibly mediated by cooling.

There are newer medium cut-off membranes, which allow the removal of a wider spectrum of uraemic toxins without the need for the high convection rates associated with haemodialysis. There are limited data on the clinical use of this modality (known as HDx).

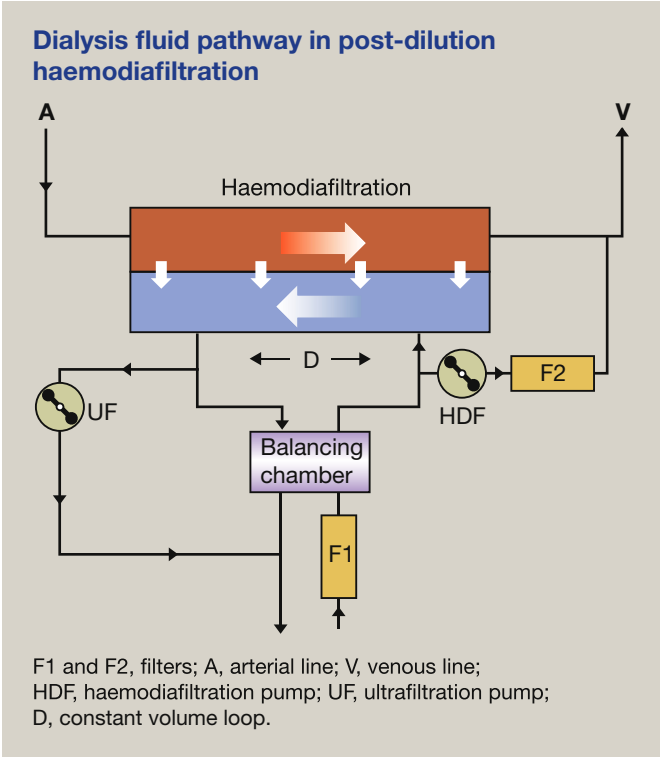

Figure 4

Home haemodialysis has been subject to resurgent interest since the demonstration of benefits of frequent haemodialysis, which is difficult to provide in–centre. Home haemodialysis allows adaptation of schedules to suit patients' lifestyles, including options for overnight (nocturnal) and/or more frequent treatments; this can improve quality of life and enhance survival, although the evidence is largely observational. Haemodialysis machines adapted for the home setting are becoming available, and at least one model is transportable. Wearable haemodialysis devices using sorbent technology are in development.

Managing dialysis

Timing initiation of dialysis

In the setting of chronic kidney disease, planned early initiation of dialysis based on estimated glomerular filtration rate (eGFR) alone has not been shown to improve survival. Dialysis should be started, if indicated, in patients with advanced renal impairment (usually at an eGFR <15 ml/minute//1.73 m^2) who have one or more of the following: a) symptoms of uraemia that affect daily living, b) uncontrollable fluid overload, c) life-threatening electrolyte abnormalities (most commonly hyperkalaemia), or d) an eGFR of 5–7 ml/minute/1.73 m^2 even if there are no symptoms.[4] The mean eGFR at initiation of dialysis in the UK is around 8 ml/minute/1.73 m^2. A significant proportion of patients, around 20%, present late with advanced kidney failure. Some of these require initiation of dialysis as an emergency. The indications for emergency initiation are severe hyperkalaemia, severe metabolic acidosis, pulmonary oedema and uraemic encephalopathy or uraemic pericarditis.

Adequacy of dialysis

The assessment of how much dialysis is required to maintain health is still controversial. Blood concentrations of urea and creatinine can be misleading as indicators of adequacy of dialysis. Low concentrations are just as likely to indicate malnutrition and muscle wasting as good dialysis. Instead, dialysis dose is normally defined in relation to small-solute clearance, either by the urea reduction ratio (percentage reduction in blood urea during dialysis) or, more commonly, by urea kinetic modelling expressed in terms of normalized urea clearance (Kt/V, where K is the dialyser urea clearance in ml/minute, t is the duration of dialysis in minutes and V is the urea distribution volume, estimated as total body water in ml from anthropomorphic data). Dialyser clearance depends on membrane characteristics (permeability, area), and blood and dialysis fluid flow rates.

Lower *Kt/V* doses are associated with increased short-term morbidity and mortality, and observational data suggest improved outcomes with higher doses. However, the HEMO study, a randomized controlled trial, showed no additional benefit of high compared with standard doses except perhaps in women.[5] UK and US guidelines recommend a minimum *Kt/V* of 1.2. However, urea clearance is just one measure of the adequacy of dialysis; broader concepts of adequacy are required that encompass other factors impacting on, and reflecting, the patient's overall well-being.

Optimizing the haemodialysis prescription – frequency and duration

The conventional practice of three times weekly haemodialysis may not be appropriate for all patients. There are proponents of both more frequent and less frequent haemodialysis regimens. For instance, residual kidney function (RKF) can provide significant solute clearance, especially for those who have recently been started on haemodialysis. Hence haemodialysis prescriptions can be individualized to take RKF into account in meeting *Kt/V* targets, enabling the haemodialysis dose to be gradually increased as native kidney function diminishes. This is known as incremental haemodialysis. There is some evidence that such an approach may help preserve RKF. On the other hand, anuric patients can benefit from longer or more frequent treatments. Trials have suggested that more frequent treatments can improve general well-being, medication burden and survival. Patients with poor cardiac function who cannot tolerate high ultrafiltration rates can benefit from slower, longer or more frequent treatment schedules.

Dry weight and hypertension

The removal of the excess fluid accumulated between sessions is a vital function of dialysis. The 'dry weight' concept assumes that there are two components of body weight: a dry or target weight, at which body fluid compartments are normal; and excess weight, resulting from accumulated fluid that expands fluid compartments, elevates blood pressure and contributes to excess cardiovascular morbidity and mortality. Dry weight is the weight at which the patient is euvolaemic and below which hypotension occurs on further fluid removal.

The concept is difficult to apply rigorously to the increasing proportion of the dialysis population who are elderly and have cardiac dysfunction or autonomic disturbances. Compromise is frequently necessary. Shorter treatment times and less rigorous salt restriction have increased these difficulties. Dry weight changes over time, falling during periods of intercurrent illness and poor nutrition, and increasing during recovery from such episodes. It is set by clinical evaluation, supplemented by bioimpedance measurements, and requires regular review. Trials to evaluate the effect of routine bioimpedance measurements on volume management and RKF decline are currently under way.

Vascular access

Securing and maintaining reliable access to the circulation is vital for the continued well-being of patients on chronic haemodialysis. The options include AVFs, arteriovenous polytetrafluoroethylene (PTFE) grafts and cuffed, tunnelled haemodialysis catheters (THCs). AVFs are preferred over THCs because of a reduced risk of complications (e.g. infection, central venous stenosis) and increased adequacy of dialysis (from increased blood flow and reliability). Current guidance dictates that most ESRF patients requiring planned haemodialysis should be given this treatment via a functioning AVF or arteriovenous graft, although in patients with severe cardiac dysfunction a THC may be preferable.

AVFs are created by end-to-side or side-to-side anastomosis, preferably of the radial artery and cephalic vein in the non-dominant forearm; however, use of other sites, including the brachial artery and cephalic vein, is common. Preservation of these vessels in pre-dialysis patients is important if primary non-function of the access is to be avoided. After anastomosis, venous distension and arterialization occur, and needling is usually possible after about 6 weeks.

Distal steal can occur with large brachiocephalic fistulae. Stenosis and thrombosis can occur, predisposing to premature fistula loss and access recirculation. Recirculation occurs when, as a result of poor access flow rates, the blood pump speed exceeds the access flow, and dialysed blood returning to the fistula through the venous needle is drawn by the blood pump directly to the arterial needle, resulting in underdelivery of the prescribed dialysis dose. Access monitoring can help to avoid such problems, facilitating early diagnosis and pre-emptive radiological or surgical intervention. Fistula flow assessment by ultrasound dilution is probably the monitoring mode of choice. THCs have a significant risk of infection, are prone to clotting and provide lower blood flow rates than AVFs.

Initiatives such as Fistula First in the USA and remuneration incentives in the UK have encouraged the adoption of fistulae for primary vascular access. The wisdom of applying this approach indiscriminately to frail, elderly individuals is less certain. Elderly patients have poorer vasculature, making fistula creation more difficult, and complications, such as stenosis, thrombosis and peripheral steal, more likely.

Intradialytic complications

Dialysis disequilibrium syndrome is a rare complication that occurs in severely uraemic patients, often those presenting late, who have been subjected to aggressive initiation of dialysis. Rapid reductions in serum osmolality and paradoxical cerebrospinal fluid acidosis result in cerebral oedema. Symptoms include restlessness, headache, tremors and, occasionally, fits and coma occurring during or after dialysis. Short initial treatment using dialysers with small surface areas and low blood pump settings prevent this problem.

Hypotension is common during dialysis and is associated with cramps, nausea, vomiting, dizziness and syncope. Ultrafiltration depletes the blood volume, which is replenished by refilling from extracellular and intracellular compartments. An over-rapid ultrafiltration rate, particularly in those with excessive interdialytic fluid gains, heart failure, autonomic dysfunction and antihypertensive medications, results in hypotension. Accurate dry weight assessment, sodium restriction to limit interdialytic fluid gain, restricted use of antihypertensive drugs, low ultrafiltration rates, cooling of the dialysate and longer treatment duration are useful strategies to reduce hypotensive episodes.

Cardiac arrhythmias are common especially in patients with left ventricular hypertrophy and coronary artery disease. Rapid intradialytic electrolyte fluxes, especially changes in serum potassium and acid–base balance, predispose to this.

Dialyser reactions are rare with the use of biocompatible membranes. Ethylene oxide, a sterilant, and other leachable materials have been implicated. Type A reactions are anaphylactoid. They are rare but life-threatening. Symptoms usually begin in the first few minutes of dialysis but can be delayed for 20 minutes or more. Dialysis must be stopped, the lines clamped and discarded, and corticosteroids and antihistamines (with adrenaline (epinephrine) in very severe cases) administered. Type B reactions are less severe but more common. They are seen 30–60 minutes after starting dialysis, and dialysis can be continued and patients managed with supportive treatment.

Pyrexial reactions occasionally occur during dialysis. With the increasing use of ultrapure water, pyrexial reactions are much more likely to be caused by infection related to the use of tunnelled lines for access than to contaminated dialysis fluid.

Circuit clotting, caused by under-anticoagulation, and prolonged bleeding from the fistula after needle removal, caused by over-anticoagulation or venous stenosis, can occur. More serious problems with anticoagulation are rare. Other complications such as air embolism and circuit disconnection are very rare with modern fail-safe machines.

Many patients experience a prolonged period of fatigue, lethargy and other symptoms after a dialysis session. The duration of post-dialysis recovery is emerging as an important patient-reported outcome measure and quality indicator.

Chronic complications

Renal bone disease and renal anaemia are major complications and are discussed elsewhere (see Renal bone disease on pages 580–584 and Anaemia and chronic kidney disease on pages 591–595, respectively of this issue).

Cardiovascular disease is common in patients on haemodialysis and plays a major role in the high mortality. Its pathogenesis is complex, involving both traditional and non-traditional renal-specific risk factors (inflammation, disturbed mineral metabolism, anaemia, oxidative stress). Pathologies include accelerated atheroma, left ventricular hypertrophy, myocardial fibrosis and vascular calcification.

Depression is also common, with >30% of haemodialysis patients screening positive, and 15–20% having the diagnosis on formal psychiatric examination. Diagnosis and management are complex because there is a major overlap between symptoms of depression and those of uraemia. Cognitive behavioural therapy has been shown to be beneficial, but the role of pharmacological therapy is less certain.

Dialysis-related amyloidosis is a disabling complication in patients on long-term haemodialysis. Amyloid deposits contain β_2-microglobulin, a normal component of the human class 1 human leucocyte antigen complex. It has a molecular weight of 11.8 kDa and is renally excreted but not cleared by low-flux dialysis. Hence it accumulates and is deposited in many tissues as amyloid fibrils. Patients present with carpal tunnel syndrome and destructive arthropathy. High-flux haemodialysis and HDF greatly improve the clearance of β_2-microglobulin and can delay the onset of amyloidosis, as can the use of ultrapure water.

Improving patient experience and outcomes on haemodialysis

Age, co-morbidity and dependency are strong predictors of survival, and risk can be stratified using these factors. However, it is apparent that even in patients aged <50 years, mortality is 25–55 times greater than in age-matched controls without renal failure. This relates to the failure of current three-times-weekly treatment to control uraemia adequately in all its facets (solute removal, blood pressure control, mineral metabolism, anaemia). Cardiovascular disease is the major cause of death.

There are increasing moves to individualize haemodialysis. Home haemodialysis provides the best outcomes and use is slowly increasing. For centre-based therapy, RKF and patient factors (age, gender, activity) can be accounted for in the haemodialysis prescription. In anuric patients, increasing dialysis frequency is effective at increasing solute clearance and reducing per-session fluid removal requirements. This can be achieved using daily short hours or nocturnal haemodialysis, although such treatments are more practical in home settings. For patients unable to undertake home-based therapy, promoting shared care, empowering patients and carers to participate with their own dialysis care in-centre or in minimal care units, can help them to achieve more control and independence.

A more individualized approach to monitoring of therapy is also gaining ground. Rigorous attempts to achieve targets for adequacy, haemoglobin, mineral metabolism and blood pressure control sit better when applied to younger, fitter patients, in whom longevity is a major aim, than for older patients with other co-morbidities in whom symptom management and maintenance of other aspects of quality of life may take precedence. Monitoring these patient-reported outcome measures may be of benefit for all patients on haemodialysis.

For very frail individuals, dialysis may achieve little more than prolonging the process of dying. De-escalation to palliative dialysis can be appropriate, to provide a balance between relief of symptoms and reduced exposure to the rigours of haemodialysis. Palliative dialysis can be useful when patients and carers are understandably ambivalent on the decision to withdraw from dialysis in the terminal phases of their illness. Withdrawal of dialysis accounts for almost 20% of the mortality among dialysis patients in the USA. Conservative management of ESRF, i.e. the decision to forego dialysis before initiation, is becoming more widely accepted as an alternative option for frail, highly dependent patients with multiple co-morbidities. ◆

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TEST YOURSELF

To test your knowledge based on the article you have just read, please complete the questions below. The answers can be found at the end of the issue or online here.

Question 1

A 46-year-old man presented for review. He had chronic kidney disease stage 5 secondary to membranous nephropathy. He had no uraemic symptoms. On clinical examination, the chest was clear to auscultation and there was mild peripheral oedema. The patient expressed a preference for either pre-emptive transplantation or home haemodialysis therapy.

Investigations

- Sodium 141 mmol/litre (137–144)
- Potassium 5.1 mmol/litre (3.5–4.9)
- Urea 27.8 mmol/litre (2.5–7.0)
- Creatinine 389 micromol/litre (60–110)
- Estimated glomerular filtration rate (using the MDR equation) 16 ml/minute/1.73 m^2 (1 year previously, 20)

What is the most appropriate next step in management?

A. Create an arteriovenous fistula
B. Insert a tunnelled haemodialysis catheter
C. Refer for discussion of conservative management
D. Review again in clinic in 3 months
E. Start work-up for renal transplantation

Question 2

A 77-year-old man presented with confusion, drowsiness and lethargy. On clinical examination, he was euvolaemic. His Glasgow Coma Scale score was 14/15. A temporary right femoral haemodialysis catheter had been placed and he was about to start haemodialysis therapy.

Investigations

- Sodium 133 mmol/litre (137–144)
- Potassium 7.0 mmol/litre (3.5–4.9)
- Urea 75 mmol/litre (2.5–7.0)
- Creatinine 1404 micromol/litre (60–110)
- Serum bicarbonate 13 mmol/litre (20–28)
- Ultrasonography scan of the abdomen showed bilateral small kidneys

What is the most appropriate next step in management?

A. Administer intravenous glucose and insulin
B. Prescribe a blood pump speed of 400 ml/minute
C. Prescribe a high surface area dialyser
D. Prescribe a short dialysis treatment time of 2 hours
E. Refer to intensive care for intubation and continuous veno-venous haemofiltration

Question 3

A 54-year-old woman developed rigors on dialysis. She had end-stage renal failure secondary to diabetic nephropathy and was receiving regular, in-centre, three-times-weekly haemodialysis therapy via a tunnelled haemodialysis catheter. On clinical examination, her temperature was 38.7°C.

What is the most appropriate immediate step in management?

A. Blood cultures
B. Catheter removal
C. Empirical intravenous antibiotics
D. Intravenous paracetamol
E. Stop dialysis and change the dialyser