Surgery for renal replacement therapy

John Asher

Abstract

Access for haemodialysis and peritoneal dialysis is critical to achieving good dialysis outcomes for patients with renal failure. Surgical access is associated both with better patient survival and better quality of dialysis. Both options are at risk of early and late complications, and require active surveillance and maintenance. Peritoneal dialysis is also a good option to consider in patients who place a premium on maintaining personal independence. This article discusses the assessment, surgical operations and management of complications in haemodialysis and peritoneal dialysis.

Keywords Dialysis; fistula; graft; peritoneal; steal

There are three forms of renal replacement therapy (RRT) for patients with end-stage chronic kidney disease: transplantation, haemodialysis and peritoneal dialysis. Although transplantation is the best long-term RRT, in terms of patient survival, quality of life and healthcare costs, many patients require long-term definitive dialysis if unfit for transplantation or difficult to match, and the form of dialysis access is important to patient experience and outcome.

Assessment of the patient

Whatever mode of RRT is planned, the others should be considered initially. A 'transplant first' approach is the ideal, and avoids the need for access surgery as well as the complications of dialysis, but for most patients it is only realistic if they have a suitable living donor. Key to success is early and multimodal assessment. Decline in renal function in chronic kidney disease is usually linear over time, although severe acute illnesses may cause an acute drop in GFR or even a sustained change in the rate of decline in GFR. In most cases though the time for reaching end-stage kidney disease is to an extent predictable. Patients should ideally be assessed around a year before expected to reach need for RRT, so appropriate plans can be made. Assessment for transplantation and assessment of dialysis options should be done in parallel. A minority of patients experience no symptoms from renal disease until they reach end stage and present as an emergency; they will generally start dialysis via a temporary or tunnelled line inserted at the time of presentation, but formal assessment of RRT should take place as soon as possible.

In patients unsuitable for transplant or waiting for transplant, the choice falls between haemodialysis and peritoneal dialysis (see Table 1). Haemodialysis typically requires attendance at hospital for 4–6 hours three times weekly, although home dialysis is an option for patients with an established well-functioning arteriovenous fistula and a competent individual to cannulate. Peritoneal dialysis is usually done at home, does not always need assistance, and is better for maintaining a high degree of independence, especially for patients in full time employment or who live in remote areas.

Both modes of dialysis depend on movement of solutes to be cleared across a semi-permeable membrane. In haemodialysis, there is counter-current exchange of blood and dialysate across a high surface area membrane in the dialyser. Peritoneal dialysis uses the peritoneum itself as a natural semipermeable membrane. Unfortunately, neither is anywhere near as sophisticated or efficient at regulating exchanges as the complex structure of the nephron in a healthy kidney.

The main surgical concerns during assessment are adequacy of vessels for haemodialysis and suitability of the abdomen for peritoneal dialysis, with particular concern if extensive adhesions are likely. Functional bowel symptoms may be incompatible with tolerating the fluid volumes moved in peritoneal dialysis exchanges.

Haemodialysis access

Good haemodialysis requires rapid blood flow from a reliable access which should minimize recirculation: if the blood coming back from the circuit can mix with blood going into the circuit, the effectiveness of dialysis at removing solutes may be inadequate. In the early days of dialysis, peripheral arteries and veins were connected directly to the machine and ligated at the end of the session, so dialysis could only be done for a few sessions in acute renal failure until the native kidneys recovered function; it took the invention of re-usable access for dialysis to be an option in chronic renal failure, which had previously been universally fatal.

The mainstay of high-quality haemodialysis is the arteriovenous fistula. A good fistula provides the high blood flows needed for dialysis, allows placement of needles far enough apart to minimize recirculation and is at low risk of infection. However, a fistula needs a large calibre vein which is either close to the skin or capable of being transposed to a suitable site for cannulation. Where the superficial veins are not suitable but there is a good artery and a good deeper vein, an arteriovenous graft may be used instead; these offer many of the advantages of a fistula but are at much greater risk of infection and are more likely to need further procedures to maintain patency. A double lumen tunnelled central venous catheter (TCVC) is the access of last resort, as they are prone to infection, blockage and recirculation, and can lead to central vein stenosis, but they do have a place in patients without suitable vessels and can be used immediately after insertion, e.g. for 'crash landers' who suddenly need to start dialysis. Multivariate analyses show patients who first start dialysis with a TCVC have inferior survival to those who start with a fistula or graft (Figure 1).

After a fistula is made, the high pressures and shear forces transform the vein wall from being too thin to tougher fibrotic walls able to tolerate repeated cannulation with large needles. This initial 'maturation' period typically takes around six weeks, but can take longer or fail altogether.

John Asher MD FRCSEd(GenSurg) is a Consultant Transplant & General Surgeon at the Queen Elizabeth University Hospital, Glasgow, UK. Conflicts of interest: none declared.

Comparison of haemodialysis and peritoneal dialysis

Haemodialysis	Peritoneal dialysis
Advantages: • Can be started immediately • Effective at clearing solutes and water • Can be used in anuric patients	Advantages: • Preserves independence • Easier to integrate with working • Infrequent hospital visits, important for those living in remote areas
Disadvantages: • Requires frequent hospital attendance • Risk factor for cardiovascular disease • Dependent on well functioning access • Treatment at home possible but needs a carer who can cannulate access	Disadvantages: • Needs surgical placement of PD catheter at least 2 weeks before start • Not effective at clearing excess water, most useful if patient still passes some urine

Table 1

Assessment

Assessment uses a mixture of clinical examination and imaging, but history of cardiovascular disease and diabetes are both relevant to planning. Key features are:

- transplant suitability status
- hand dominance and/or patient preference to keep a particular arm free
- adequacy of peripheral veins, evidence of scarring from venepuncture or cannulation
- arterial inflow including hand perfusion, capillary refill and Allen's test
- assessment of any pre-existing neurological deficit, especially in patients with diabetes
- Doppler ultrasound vein mapping to assess depth and calibre of cephalic and basilic veins
- venography to assess axillary or femoral veins if a graft is planned

Venepuncture and cannulation will tend to cause scarring or occlusion of veins, and can make them unsuitable for fistula formation. In patients with chronic kidney disease, especially stage IV and V, it is vitally important to avoid using veins in the wrist, forearm and antecubital fossa for blood sampling or cannulation except in emergency scenarios.

Diabetes history is particularly relevant to prevent steal, where the artery is insufficient to supply both the fistula or graft and the arm or leg. The lower resistance to flow in a vein or graft tends to take blood preferentially to the distal arterial tree, and the inflow artery may be unable to compensate if diseased. In patients with diabetes, the risk can be mitigated by using the radial artery rather than brachial artery, thus maintaining flow into the ulnar artery.

Where vessels are suitable on both sides, generally the non-dominant arm is preferred first, to allow the patient to use their dominant arm while on dialysis, but a social history of occupation and hobbies should be taken as sometimes it is better to keep the left arm free even in a right-handed patient, e.g. to allow playing of a musical instrument.

Selected patients may be suitable for home haemodialysis, but this requires a reliable access for haemodialysis and someone else at home able and willing to perform the cannulation. Realistically it is only an option for a few motivated patients with a good arteriovenous fistula as grafts and lines are not suitable to home haemodialysis.

Patient survival from start of dialysis by type of access

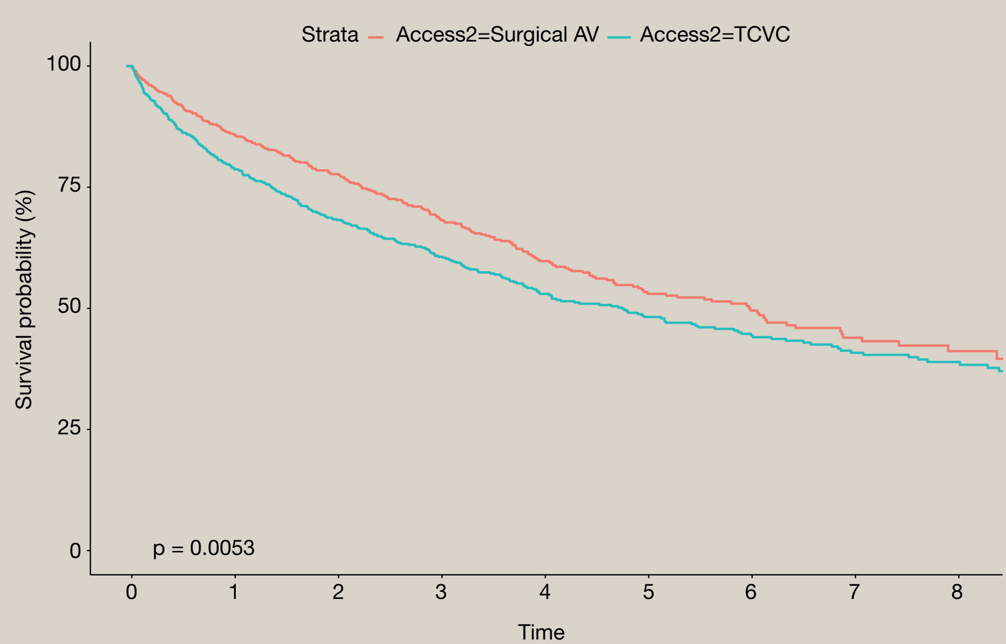

Figure 1

Transplant status plays a key role in work-up. Young patients with high levels of HLA antibody sensitivity are likely to require a long term dialysis and need first access planned in a way to make subsequent access procedures successful. Generally it is possible to perform a brachial fistula in a patient with a previous radial fistula, but the reverse does not apply: a failed brachiocephalic fistula will usually mean no adequate outflow for a later radiocephalic.

Arteriovenous fistula

The most common operations are formation of radiocephalic, brachiocephalic or brachiobasilic fistula.

The operations can generally be done under local anaesthetic, regional blocks or general anaesthetic. Regional blocks are associated with the highest chance of success as systemic blood pressure is maintained and concurrent sympathetic anesthesia of the upper limb leads to vasodilatation and better initial flow.

The first stage after skin incision is to identify, mobilize and assess the vein. A healthy vein which has not been subjected to venepuncture will be tethered by loose connective tissue which can be peeled off the vein with little difficulty. If there has been repeated venepuncture, the loose tissue will be replaced with denser scar tissue which may need careful sharp dissection.

Once the vein is mobile, it should be assessed for suitability based on calibre, any signs of scarring of the vein wall or visible clots in the lumen. If it appears suitable initially, the artery should then be dissected and inspected – often it is best to leave the artery untouched if the vein is unsuitable, so that it is easier to dissect if an arteriovenous graft is to be used in future.

Once both vein and artery appear suitable, the vein can be divided and distal stump ligated. After division the vein should be observed to assess back bleeding and then flushed with heparinized saline and temporarily clamped with a soft venous Bulldog clamp. A good vein will flush and distend with almost no resistance.

The artery is controlled with fine vascular clamps and an arteriotomy made. The length of the arteriotomy will determine the flow through the fistula but also therefore the risk of steal, and typically 5–7 mm is the optimum length. The anastomosis is usually end-to-side, but side-to-side can be preferred in some situations. For the end-to-side anastomosis there are three common techniques, all using a double-ended fine 6/0 or 7/0 non-absorbable suture:

- Conventional continuous suture (Figure 2): first suture placed in-to-out on each of artery and vein at the heel of the anastomosis, tied and then continued around the anastomosis in-to-out on the artery (to minimize risk of forming an intimal flap). The suture at each end of the anastomosis is placed at a 0° angle, then each side of this at 45° and the side sutures at 90°. This technique is simple, but with small vessels it is tricky to get the 45° sutures right at the heel of the anastomosis.
- Parachute anastomosis (Figure 3): similar to the conventional suture but the first suture is not tied, and the first sutures placed loosely before tightening using a push–pull movement to evenly pull the sutures tight. This allows good view of the heel of the anastomosis for accurate placement of the 45° sutures, but care must be taken to pull the sutures evenly and not leave any loose loops of redundant suture.
- Interrupted anastomosis: three separate in-to-out sutures placed at 0° and 45° at the heel of the anastomosis then each tied and continued as for the conventional technique. This allows good visualization of the heel and is a good technique for very small vessels.

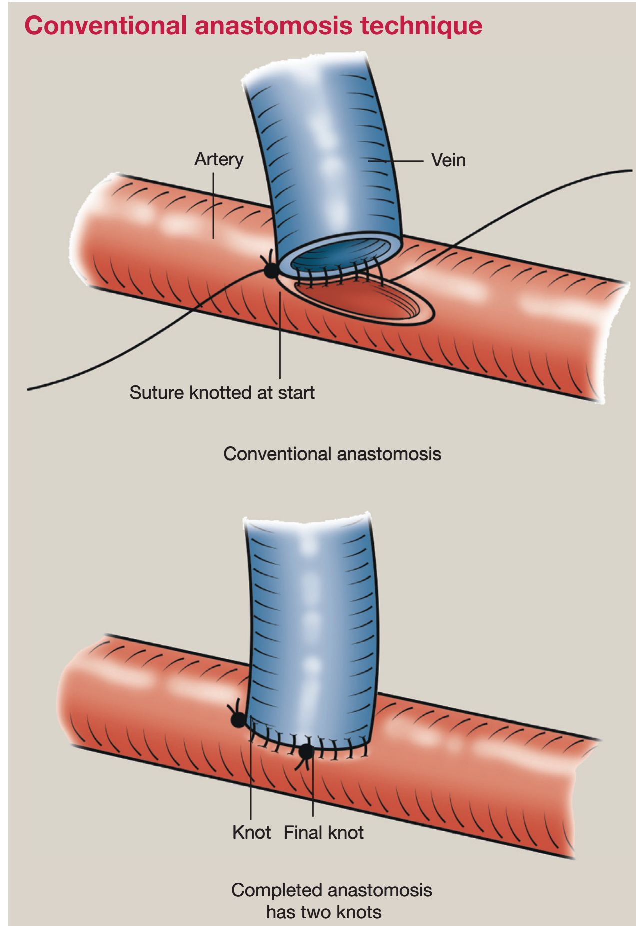

Figure 2

On release of clamps, there should be good flow into the vein, with a continuous buzzing sensation on palpation called a 'thrill'. If the flow is poor, consider inflow issues like the anastomosis or arterial spasm. Applying papaverine topically to the artery may help reduce spasm. If the flow is pulsatile, it implies resistance in the venous outflow; exploring the vein more proximally and dividing any tissue bridges or tributaries producing a sharp angulation can improve this rapidly.

If all is well at the end of the operation, the fistula should be regularly observed for strength of thrill and bruit for the first few hours postoperatively on the ward, and be re-explored if there is cessation of previously good thrill or bruit.

Brachiobasilic fistula

In the case of the brachiobasilic fistula, the basilic vein runs an anatomical course below the deep fascia and along the edge of the arm which makes cannulation difficult, so the vein needs to be transposed to a more superficial course along the anterior aspect of the arm. This can either be done at one operation, if the vein has

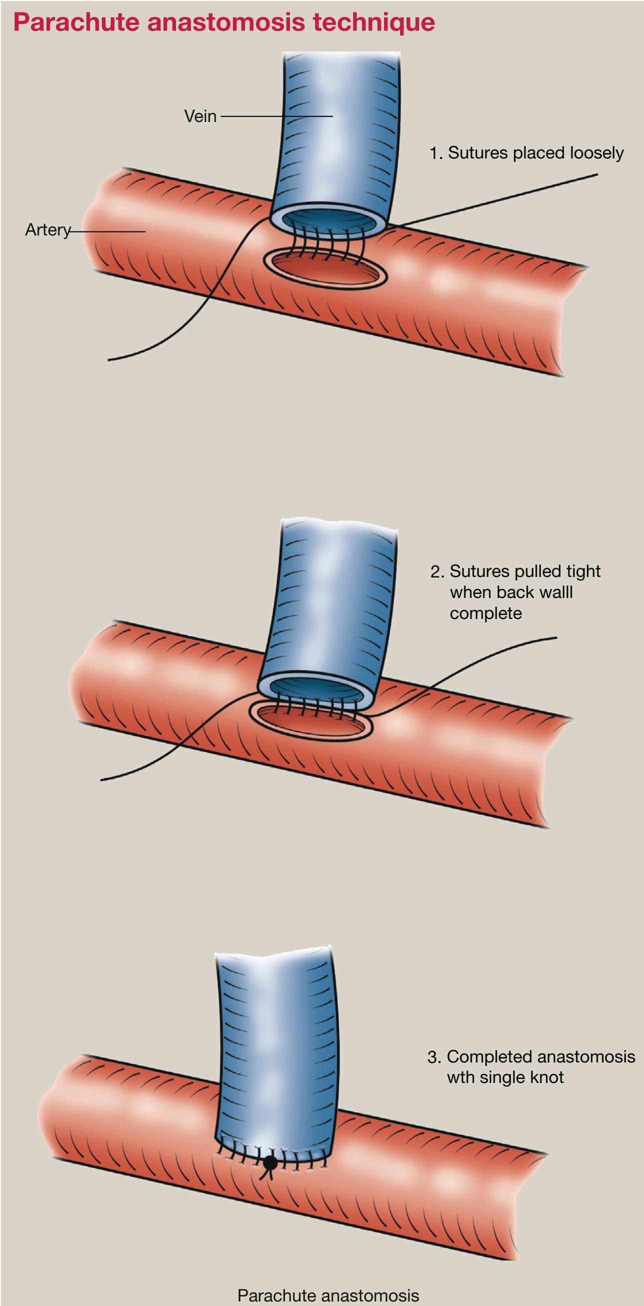

Figure 3

good calibre and is likely to mature well, or around six weeks (two stage) after the fistula formation to allow the vein to mature first.

To superficialize the vein, it is explored along its course up the arm, with division of the fascia and ligation and division of its feeding tributaries until the vein is fully mobile. The medial cutaneous nerve of the forearm usually crosses in front of the basilic vein in the upper arm and should be preserved. Once mobilized, the vein is divided and transposed to a more superficial course in the median of the arm either by using a tunnelling device or by forming a subcutaneous flap and re-anastomosed. When using a tunneller, it is important to make sure the vein is not twisted or kinked — marking the anterior surface of the vein can help to reduce this. Twisting of the vein is less of a risk when using the flap technique, but very meticulous haemostasis is needed with flaps to avoid seromas.

The choice of single-stage brachiobasilic fistula and superficialization versus two-stage procedure largely depends on the likelihood of the fistula working well. If the fistula fails in the single-stage procedure, the patient has undergone extensive dissection of the arm without success, while there is much less morbidity from a failed first stage operation. Another disadvantage of the single stage procedure is that supraclavicular blocks do not always adequately cover the territory at the upper end of the basilic vein, so general anaesthetic is usually required; on a two-stage procedure the first stage can be done under regional block, good flow established in the vein and then a general anaesthetic for second stage is less likely to affect the chances of success.

Management of complications of AV fistula

Common complications include thrombosis, failure to mature, steal and ischaemic monomelic neuropathy.

Thrombosis

Early thrombosis of an arteriovenous fistula occurs in around 10%—25%, and is more common with radial than brachial fistulae as the flow rates are lower and vessels narrower. The peak reversible risk is while flow is limited by arterial spasm, and overnight heparin can be helpful in reducing the risk; six weeks of aspirin can also be helpful in preventing thrombosis while the fistula is developing. Early thrombosis of a fistula with good initial flows can often be salvaged by re-exploration and thrombectomy.

Late thrombosis is much more difficult to treat successfully, and consideration of cause must be made — venous outflow obstruction from cephalic arch stenosis is a common reason, and prolonged bleeding at cannulation sites after dialysis or rising venous pressures on dialysis can be warning signs, which should be investigated with a fistulogram. Balloon angioplasty or stenting of stenoses are effective at improving outflow and preventing thrombosis. Most dialysis units employ some form of proactive surveillance of access flow to avoid the need for “rescue” procedures.

Failure to mature

Failure to mature is usually due to inadequate flow through the fistula. This can be from a narrow anastomosis, stenosis or diversion of blood flow into a large tributary.

Stenosis can be diagnosed with colour Doppler ultrasound: high velocity flow is indicative of stenosis, and first line treatment is by balloon angioplasty or stent unless close to the anastomosis, when surgical revision may be needed. Long stenoses may be treatable by interposition graft, but care must be taken by the dialysis nurses not to cannulate either of the vein-to-graft anastomoses.

Diversion of flow into a tributary is usually apparent on clinical examination and can be confirmed with colour Doppler. The clinical sign is a maturing fistula with a good thrill up to the confluence of tributary and vein, then reduced flow in the main vein but a thrill in the distended tributary; if the strength of the thrill in the main vein improves on digital occlusion of the tributary, diverted flow can be confirmed. The problem will usually resolve if the tributary is ligated, which can typically be done under local anaesthetic.

Steal

Steal is an uncommon ischaemic complication of arteriovenous fistula, but will cause significant morbidity if not treated. Distal ischaemia occurs when the blood flow in the artery beyond the fistula is insufficient to meet oxygen demand. Steal is more common with brachial than radial fistulae and also more common in patients with diabetes.

As with peripheral vascular disease, steal can be divided into stages of severity, with slightly cool fingers at the mildest stage, through pain on exertion or dialysis to rest pain and ultimately tissue loss. Intervention should be considered with pain on exertion or dialysis, and is essential if there is rest pain or altered sensation.

Investigation of steal is primarily by colour Doppler ultrasound. For brachial fistulae, reversed flow in the artery beyond the anastomosis confirms steal. The position is more difficult with radial fistulae, as around a third of the flow into a radiocephalic fistula comes retrogradely from the palmar arches. Angiography to identify treatable arterial lesions should also be considered.

Other than treating arterial lesions, the treatment options for steal are ligation, restriction or diversion. Ligation will definitively treat steal but requires an alternative access procedure. A variety of restrictive procedures such as plication and banding are intended to reduce flow through the fistula, but preserve the function of the fistula. The challenge with restrictive procedures is to achieve adequate reduction of flow while still maintaining enough flow into the fistula.

Diversion procedures are intended to maintain the fistula with more reliable reduction of steal. These include proximalization of arterial inflow (PAI), revision using distal inflow (RUDI) and distal revascularization with interval ligation (DRIL).

PAI uses a prosthetic graft onto the artery more proximally, where there is greater arterial flow but the limited calibre of the graft prevents excess flow into the fistula. RUDI is a good option for brachial fistulae and uses vein or interposition graft to move the inflow onto the proximal radial artery so ulnar artery flow is not compromised. The DRIL procedure (Figure 4) uses saphenous vein to bypass the brachial anastomosis then ligates the brachial artery just below the anastomosis. The saphenous vein conduit offers lower resistance than the brachial artery, diverting blood away from the anastomosis and into the downstream brachial artery, although there is a not insignificant risk of graft thrombosis precipitating an acutely ischaemic forearm. These are technically difficult procedures which should be done by experts.

Ischaemic monomelic neuropathy

Ischaemic monomelic neuropathy arises from ischaemic axonal injury to the distal sensory and motor nerves and can occur after fistula formation. It presents with hand or forearm pain and weakness, sometimes within hours of the fistula operation. If detected early, ligation of the fistula can lead to full recovery of neurological function, but if picked up late the nerve injury may be irreversible and require rehabilitation with therapists.

Arteriovenous grafts

Prosthetic grafts are a reasonable alternative to arteriovenous fistulae, especially if there is no suitable vein or if dialysis is

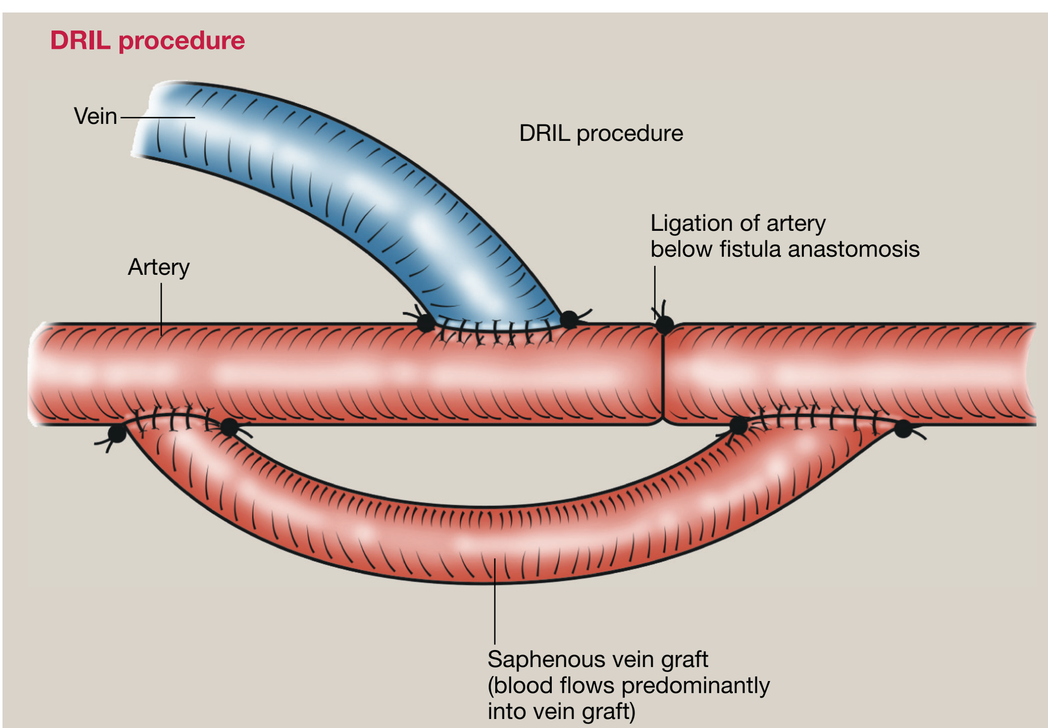

Figure 4

needed to start before a vein would have matured. Traditional dialysis grafts are made from PTFE and can be used around two weeks from insertion. Newer self-sealing immediate cannulation grafts, such as Accuseal, can be used within minutes of insertion.

Grafts can be looped or straight depending on the sites of arterial inflow and venous outflow. Upper limb grafts are preferred by patients, and include brachio-axillary (straight) and brachio-basilic forearm loop grafts. Loop grafts from superficial femoral artery to femoral vein are also common — there are even makers of trousers with zips along the thigh to provide access for cannulating the graft without the patient needing to remove clothing.

The arterial anastomosis is similar to that for fistula, but a venous anastomosis is also needed, and can either be done directly to a vein or using a cuff of saphenous vein like the Miller cuff used for arterial bypass grafts to reduce intimal hyperplasia. Using a cuff helps with venous closure if the graft is later removed.

Compared with fistulae, grafts are prone to thrombosis and infection. Thrombosis can usually be treated if the underlying cause is also addressed, and a combined approach with interventional radiology is the ideal for managing thromboses — stenosis at the venous outflow is common and can be treated with endovascular stents. As with fistulae, prevention is better than cure, and regular imaging for graft surveillance is needed for good long-term results.

Infection is a difficult and unfortunately common issue: by necessity the dialysis graft will have two needles put into it percutaneously three times weekly for as long as it is in use. When infection occurs, it is key to determine whether the graft itself is infected, or just an infected haematoma around the graft: the latter can be treated by antibiotics or surgical drainage, but an infection of the graft itself will usually need excision unless rapidly responding to antibiotics, and will always need excision if there is bleeding secondary to infection. Infection does not necessarily require excision of the whole graft, which would require establishment of alternative dialysis access, but instead the infected part of the graft can be removed and a segment of new graft placed through a different subcutaneous tunnel.

Options for failing access

Patients with long-term haemodialysis can run out of access sites. This is particularly likely if there have been prolonged periods of dialysis via tunnelled vascular catheters leading to central vein stenosis, but can also occur after the usual autologous venous options for fistula have been exhausted.

A variety of extra-anatomic grafts are possible, such as the 'necklace graft' running from subclavian artery on one side to the subclavian vein on the other, or 'seatbelt graft' running from either subclavian artery or superficial femoral artery to the contralateral superficial femoral vein. These are awkward both for patients and dialysis nurses and remain a last resort.

A less drastic option for failing access in the context of central vein stenosis are the HeRO ('Hemodialysis Reliable Outflow') and SuperHeRO Grafts. HeRO is a proprietary hybrid of an arterial graft component placed surgically and a venous outflow component inserted by an interventional radiologist to recanalize the stenosed central vein. SuperHeRO is the same but with a graft suitable for immediate cannulation.

Peritoneal dialysis

Peritoneal dialysis (PD) is a good option for those starting dialysis, but also has a role to play in managing the patient running out of haemodialysis access options. The biggest advantage over haemodialysis is preservation of independence, as it is usually done by the patient at home. Success depends on a large effective peritoneal surface area; abdominal adhesions reduce this and also make placement of the PD catheter and flow of PD fluids more difficult. A preserved native urine output also helps, as PD is less effective at removing fluid than haemodialysis.

The peritoneal dialysis catheter most commonly used is the Tenckhoff catheter, which has two Dacron cuffs and a coiled end. The catheter coil is placed intraperitoneally either laparoscopically or by mini-laparotomy into the pelvis, then the catheter brought through the linea alba and tunnelled subcutaneously to an exit site. The two cuffs should sit extraperitoneally at the linea alba and in the subcutaneous tunnel, to ensure an effective seal. The operation is usually performed under general anaesthetic, but during the COVID-19 pandemic a number of units placed them by mini-laparotomy under spinal anaesthesia and found it was well tolerated by patients.

Complications of PD

The common complications of PD include herniae, fluid leaks, displacement of the catheter and peritoneal dialysis—associated peritonitis. In the longer term, encapsulating peritoneal sclerosis is an uncommon but devastating complication.

Fluid leaks are best managed by resting the peritoneum for two weeks, with temporary haemodialysis, as the peritoneum reconstitutes rapidly and can self seal if rested. Incisional hernia generally cannot be treated easily until the patient no longer requires PD, but obviously should still be treated if strangulated or obstructed. Inguinal herniae are common and usually due to PD fluid passing through a patent processus vaginalis rather than true novel herniation. Surgical ligation of the patent processus via a similar approach to open repair of inguinal hernia is usually effective.

A displaced PD catheter presents with poor fluid flows, either into or out of the abdomen, and can be due to blockage of the catheter with omentum rather than displacement itself. A plain abdominal radiograph will show the position of the PD catheter, and if displaced it can be fairly easily repositioned laparoscopically. Laparotomy and omentectomy is occasionally needed for recurrent blockages.

PD peritonitis presents with abdominal pain and turbid PD fluid effluent, and peritoneal signs are usually fairly mild. It is treated initially with intra-peritoneal antibiotics such as tobramycin, but surgical removal will be needed if symptoms worsen despite treatment, if cultures grow fungi or biofilm-forming organisms like *S. aureus* or *Pseudomonas* are isolated. The surgical treatment for refractory PD peritonitis is laparotomy, washout and removal of the PD catheter. A later return to PD will be possible if there is no peritoneal sclerosis.

Encapsulating peritoneal sclerosis is a rare complication of peritoneal dialysis, and usually occurs after a long duration of treatment. The exact aetiology is unknown but may be related to chronic inflammation arising from chemical irritation of the peritoneum by PD fluid. There is thickening and fibrosis of the visceral peritoneum forming cocoons of encapsulated loops of small bowel and chronic small bowel obstruction. The exact aetiology is unknown, but it can be triggered in a patient at risk by peritonitis or renal transplantation. Medical treatment in less severe cases is based on steroids or tamoxifen, which has anti-fibrotic properties, but more severe cases need surgical excision of the whole visceral peritoneum, a high-risk specialist operation with mortality risk around 20%. ◆

Practice points

- Good access is critical to outcomes in dialysis patients
- 'Transplant first' is the optimal strategy but only feasible if there is a living donor
- Haemodialysis is most effective with an arteriovenous fistula, followed by arteriovenous graft, with tunnelled lines an option of last resort
- A good fistula may last many years and give very effective dialysis, whereas grafts have a shorter lifespan limited by infection and outflow stenosis. Tunnelled lines have even shorter lifespans than grafts, and may cause central vein stenosis severely limiting future access options
- Home haemodialysis is a possible option for selected patients with a good fistula
- Arteriovenous fistula is more likely to be successful if the suitable veins have been protected from venepuncture and cannulation
- Peritoneal dialysis is a good option for patients who still have some urine output, as it is done at home and is particularly good if still working or living in a remote area

