

An Overview of Arteriovenous Fistula and Graft Failure: Causes, Interventions and Risks

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Abstract

Arteriovenous Fistulas (AVFs) and grafts are crucial components in hemodialysis for patients suffering from end-stage renal disease. However, their high failure rate remains a considerable challenge in medical practice, often resulting in substantial morbidity and compromised quality of life. This comprehensive review provides an in-depth examination of the potential causes behind AVF and graft failure. This includes, but is not limited to, neointimal hyperplasia, venous hypertension, compromised flow dynamics and infection. It additionally outlines the crucial role of patient demographics and comorbidities.

Recognizing the need for efficient and effective intervention in cases of failure, this paper also reviews and compares the techniques and outcomes of balloon angioplasty and mechanical thrombectomy. These procedures are often necessitated by thrombosis and stenosis, significant complications leading to AVF and graft failure. Balloon angioplasty, a standard first-line therapy, is considered for its technical simplicity and relatively low invasiveness. In contrast, mechanical thrombectomy devices, which physically remove thrombi, are typically reserved for balloon angioplasty failure or larger, complex thrombi.

Our review then delves into the associated risks and potential complications of these interventions. Notably, rethrombosis and embolization are among the significant risks, which, if not handled promptly and effectively, could lead to more severe complications and poorer patient outcomes. We present the latest statistics and analyze the risk factors contributing to rethrombosis and embolization following balloon angioplasty and mechanical thrombectomy.

This review will be beneficial to medical professionals dealing with AVF and graft management, offering a concise, evidence-based examination of failure etiology, therapeutic interventions and their associated risks. We aim to provide a nuanced understanding of these procedures, facilitating informed decision-making in clinical practice and opening avenues for future research to improve patient outcomes and longevity of AVF and grafts.

Keywords: AVF; Thrombectomy; Graft; Inflammation; Surveillance

Introduction

Arteriovenous Fistulas (AVFs) and grafts are essential conduits facilitating effective hemodialysis in patients with End-Stage Renal Disease (ESRD). These vascular access points allow for efficient blood flow during the hemodialysis process, serving as a lifeline for individuals with compromised kidney function [1].

Despite their critical role in managing ESRD, AVF and grafts are not without complications, with failure representing a significant hurdle in optimal patient care. Often, these failures stem from the development of thrombosis-the formation of blood clots within the blood vessels. Thrombosis can obstruct the necessary high-volume blood flow, rendering the AVF or graft unusable for hemodialysis and requiring immediate medical intervention [2].

The implications of AVF and graft failure extend beyond just the affected individuals. It is a matter of public health concern given its high incidence rates, the emergency nature of required interventions and its role as a leading cause of hospitalization among dialysis patients. Moreover, it also adds substantial economic burden on the healthcare system, with costs associated with the diagnosis, management and follow-up of these complications escalating rapidly [3].

Addressing these challenges necessitates a comprehensive understanding of the mechanisms and risk factors underlying AVF and graft failure, alongside exploring effective preventative strategies and efficient therapeutic interventions. With this insight, healthcare professionals can better manage ESRD patients' dialysis needs, improving patient outcomes and optimizing the use of healthcare resources.

Creation of AVF and Grafts

The creation of Arteriovenous (AV) fistulas is a crucial procedure for patients requiring regular hemodialysis. The surgical technique involves the anastomosis, or direct

connection, of an artery and a vein. This process diverts some of the higher-pressure arterial blood into the vein. The increased blood flow and pressure result in structural changes in the vein, including dilation and thickening, a process known as maturation [4].

Maturation of the vein is critical for it to function as a durable and reliable access point for hemodialysis. Typically, the vein needs several weeks to months to mature after the surgery before it can be used for dialysis. During this period, it's crucial to monitor the fistula to ensure adequate blood flow and to detect any complications such as clotting or stenosis early on.

The choice of vessels for creating the fistula depends on various factors such as the patient's anatomy, health conditions and previous vascular access procedures. In most cases, surgeons start with vessels in the non-dominant arm and move up the arm (forearm to upper arm) or to the other arm in subsequent procedures if needed. The radial artery and cephalic vein in the forearm are often used for the first AV fistula, as they are easily accessible and the procedure in this location has a good success rate.

Throughout the procedure, surgeons also need to consider other factors, such as minimizing trauma to the vessels to reduce the risk of complications and planning for potential future vascular access needs. The patient's comfort and personal preferences should also be taken into account.

Radiocephalic fistulas

The radiocephalic fistula, commonly referred to as a Brescia-Cimino fistula, is the primary choice for initial Arteriovenous (AV) fistula creation in patients requiring hemodialysis. This preference is primarily due to its lower complication rate and greater longevity compared to other types of AV fistulas [5].

In the creation of a radiocephalic fistula, the procedure typically takes place in the forearm, usually at the wrist, although higher locations may be used if necessary. The surgeon first exposes the radial artery and the cephalic vein, two vessels conveniently located in close proximity. To ensure a smooth and efficient blood flow, it is critical to dissect and fully expose both vessels, verifying their suitability before creating the anastomosis.

The anastomosis in a radiocephalic fistula is typically performed in a side-to-end manner. In this technique, an incision is made on the side of the artery and the end of the vein is then connected to this opening. This configuration promotes arterial blood flow directly into the vein, which leads to its dilation and maturation over time.

When securing the anastomosis with sutures, the surgeon needs to ensure the vein does not twist or kink. Any misalignment can compromise the blood flow, potentially leading to early fistula failure or thrombosis. Furthermore, a meticulous suture technique is necessary to prevent leakage and to encourage optimal blood flow through the newly created fistula.

Following the procedure, the surgical site is thoroughly inspected to ensure there are no complications such as bleeding

or hematoma. Postoperatively, the maturation process is closely monitored over weeks to months, with regular assessment of the fistula's patency, the patient's symptoms and potential complications.

Brachiocephalic fistulas

Brachiocephalic fistulas represent another valuable Arteriovenous (AV) fistula option for patients requiring hemodialysis access. Created by anastomosing the brachial artery and cephalic vein at the elbow, these fistulas are typically considered when the creation of a radiocephalic fistula isn't possible due to factors such as inadequate vein or artery size, or previous unsuccessful fistula placements in the forearm [6].

The brachiocephalic fistula creation procedure begins with a detailed vascular mapping to ensure the chosen vessels-the brachial artery and cephalic vein-are of appropriate size, patency and condition. This is essential because the health of these vessels significantly impacts the success rate of the fistula.

In the surgical process, the brachial artery and cephalic vein, located in the antecubital fossa (the bend of the elbow), are dissected and exposed. Similar to the radiocephalic fistula creation, a side-to-end anastomosis is usually performed. The end of the cephalic vein is connected to a lateral incision in the brachial artery. This arrangement allows arterial blood to flow directly into the cephalic vein, prompting the vein to dilate and thicken, a process known as maturation.

Brachiobasilic fistulas

Brachiobasilic fistulas provide yet another option for vascular access in hemodialysis patients when other fistula types aren't feasible. These fistulas involve connecting the brachial artery to the basilic vein at the elbow, usually through a two-stage procedure due to the anatomical position of the basilic vein.

The first stage of creating a brachiobasilic fistula involves a careful vascular assessment to verify the suitability of the brachial artery and basilic vein. These vessels, located at the antecubital fossa, are then dissected and exposed. A side-to-end anastomosis is typically performed, connecting the end of the basilic vein to a lateral incision in the brachial artery. This allows arterial blood to flow directly into the basilic vein, promoting its dilation and thickening for maturation.

A critical point of difference in the brachiobasilic fistula creation process is that the basilic vein is typically situated deeply under the skin and muscles, making it less accessible for regular hemodialysis needle access. Therefore, it usually necessitates a second stage, known as vein transposition.

In vein transposition, performed after allowing the fistula to mature for several weeks or months, the basilic vein is surgically relocated to a more superficial position under the skin. This makes it easier to access for regular dialysis. In the procedure, the vein is dissected along its length, preserving its branches and tributaries and then tunneled subcutaneously to the new position.

Postoperatively, the brachio basilic fistula is monitored closely to ensure successful maturation and to detect any potential complications such as thrombosis, infection, or stenosis. Regular patency checks and patient education on fistula care play crucial roles in ensuring the longevity and functionality of the fistula.

Physiology and Mechanics of Fistulas

The creation of an Arteriovenous (AV) fistula instigates a series of physiological and mechanical changes in the vasculature that allows the fistula to serve as a robust access point for hemodialysis. The arterialization process, which is initiated once the anastomosis between the artery and vein is made, sets off a complex series of events leading to maturation of the fistula.

Arterial blood flow into the vein causes an immediate increase in pressure and blood flow within the vein. This hemodynamic alteration triggers endothelial cells to release nitric oxide, a potent vasodilator, which promotes the dilation and thickening of the venous wall, leading to the maturation of the fistula. The matured fistula is capable of withstanding the routine punctures required for hemodialysis and the high flow rate prevents stasis and consequent clot formation within the fistula.

Simultaneously, these changes induce structural remodeling in the vein known as neointimal hyperplasia. The increased pressure and shear stress incite smooth muscle cells in the venous wall to proliferate and migrate inward, leading to thickening of the wall and potential narrowing of the lumen. Though this phenomenon supports the resilience of the fistula, excessive neointimal hyperplasia can contribute to stenosis and compromise fistula patency, underscoring the importance of regular monitoring.

While a functioning AV fistula significantly enhances hemodialysis efficiency, long-term changes in systemic hemodynamics warrant close attention. The increased blood flow can put additional strain on the heart, causing it to work harder to maintain the expanded circulatory volume. Over time, this can result in high-output cardiac failure in susceptible patients. Further, a phenomenon known as 'steal syndrome' can occur, where the high flow through the fistula "steals" blood flow from the distal extremity, causing ischemia and related symptoms.

Understanding the multifaceted physiological and mechanical aspects of AV fistulas is integral to their successful implementation and maintenance. Surgeons need to adopt precise techniques during fistula creation to optimize the maturation process. Additionally, rigorous postoperative care and monitoring can preemptively identify and address potential complications, ensuring the longevity of the fistula and thereby improving the quality of life for patients with end-stage renal disease. This comprehensive approach, alongside ongoing research to mitigate the adverse systemic implications, will continue to refine the effectiveness of AV fistulas as vital lifelines for hemodialysis patients.

Causes of AVF and Graft Failure

Arteriovenous Fistula (AVF) and graft failure can result from a multitude of factors, broadly categorized as mechanical, patient-related or disease-related. Understanding these factors is crucial as it can help identify at-risk patients and guide clinical decisions regarding fistula or graft placement.

Mechanical factors often account for a significant proportion of AVF and graft failure. Primarily, venous stenosis, often resulting from neointimal hyperplasia, is a leading cause of failure. The turbulent flow and shear stress at the anastomosis, as well as vascular injury during the fistula or graft creation, can trigger this process, causing the smooth muscle cells in the vessel wall to proliferate and thicken which in turn can narrow the lumen and impede blood flow.

Another mechanical factor involves inadequate vein or artery size, which can impede blood flow, affect fistula maturation and increase the risk of thrombosis. Poor surgical technique can also contribute to complications such as pseudoaneurysms, where a false aneurysm forms due to a leak in the arterial wall, or hematomas, which can compress the fistula or graft and hinder blood flow.

Patient-related factors also play a significant role in AVF and graft failure. Diabetes is a well-recognized risk factor, given its association with microvascular and macrovascular complications. Peripheral vascular disease can also compromise the vascular access due to its impact on the vessels' integrity. Hypercoagulable states, whether inherited or acquired, increase the risk of thrombosis in the fistula or graft.

Certain demographic factors have also been associated with higher failure rates. Aging may affect vessel health and the healing process post-surgery, while female gender has been associated with higher rates of failure, potentially due to smaller vessel size and other gender-specific vascular changes.

Lastly, disease-related factors, particularly the pro-inflammatory state associated with uremia in end-stage renal disease, can affect the vessel wall and promote neointimal hyperplasia, contributing to stenosis. Other systemic diseases like hypertension and atherosclerosis can also impact the fistula's or graft's function and longevity.

Thrombectomy Procedures

Thrombectomy procedures are integral in the management of Arteriovenous Fistula (AVF) and graft thrombosis, aiming to restore the patency of the vascular access. Depending on the specifics of the case, either surgical or endovascular techniques may be employed. Among endovascular interventions, balloon angioplasty and mechanical thrombectomy devices are two common methods.

Balloon angioplasty

Balloon angioplasty is an endovascular technique widely used for restoring patency to occluded or stenotic fistulas and grafts. The procedure involves the use of a balloon catheter to dilate the occluded or narrowed segment of the fistula or graft.

The procedure is performed under local anesthesia, usually with the aid of ultrasound or fluoroscopic guidance. A puncture is made in the vein and a guide wire is introduced and navigated through the occlusion. Over this guide wire, a balloon catheter is then advanced. Once the balloon is positioned across the stenosis or thrombus, it's inflated to compress the blockage against the vessel wall, thereby reestablishing blood flow.

Balloons used for angioplasty come in different sizes, typically ranging from 2 mm to 10 mm in diameter and lengths up to 80 mm. The choice of balloon size depends on the size of the vessel being treated. It's crucial to choose a balloon that's a similar size to the vessel to achieve optimal dilation while minimizing the risk of vessel rupture.

However, balloon angioplasty is associated with several risks. Balloon overinflation can lead to vessel rupture, while underinflation might result in suboptimal dilation. There's also a risk of rethrombosis or restenosis due to vessel injury during the procedure, which can induce neointimal hyperplasia. Additionally, there is a risk of distal embolization where fragments of the thrombus dislodge and travel downstream, potentially causing occlusions in smaller vessels.

Mechanical thrombectomy

Mechanical thrombectomy provides an alternative to balloon angioplasty. Devices like the Cleaner rotational system have been developed to mechanically remove thrombus from the occluded fistula or graft.

The cleaner device utilizes a rotating, flexible, sinusoidal wire to macerate the thrombus at 4000 rpm, facilitating its removal. The procedure begins similarly to balloon angioplasty, with the device being introduced through a vascular sheath. Once in place, the device's wire is activated to rotate at high speed, breaking down the thrombus. The debris can then be aspirated or may pass harmlessly into the systemic circulation due to its small size.

Mechanical thrombectomy has the potential advantage of causing less vessel injury compared to balloon angioplasty, potentially reducing the risk of restenosis. However, the procedure still carries risks such as vessel perforation, distal embolization and incomplete removal of the thrombus.

Both balloon angioplasty and mechanical thrombectomy have their respective advantages and risks and the choice of procedure often depends on the specifics of the case, including the location and size of the thrombus, the vessel's anatomy and the patient's overall health status.

Balloon angioplasty: One of the most common complications of balloon angioplasty is the risk of recurrence. This is often due to the formation of intimal hyperplasia, where there is proliferation of smooth muscle cells within the vessel wall. This can occur as a reaction to the vascular injury caused by the angioplasty, leading to restenosis or reocclusion.

In order to mitigate the risk of restenosis, drug-eluting balloons, which release a medication to inhibit cell proliferation, have been introduced. These have been found to be particularly

effective in reducing the incidence of restenosis and prolonging the patency of the fistula or graft.

Another approach to decrease the risk of restenosis is stent placement, which can be particularly beneficial for recalcitrant stenosis or dissection. However, stent placement in a fistula or graft has its own challenges, including potential mechanical problems due to repetitive needle puncture for dialysis and the possibility of stent migration.

Mechanical thrombectomy: In comparison to balloon angioplasty, mechanical thrombectomy may cause less trauma to the vessel wall and therefore potentially reduce the risk of neointimal hyperplasia and restenosis. Devices like the Cleaner rotational thrombectomy system also offer the advantage of reducing procedure time, as the thrombus maceration and removal can be more efficient than balloon angioplasty.

However, a potential downside to mechanical thrombectomy is the risk of distal embolization of thrombotic debris, despite the fragmented pieces usually being small enough to pass through the circulation without causing issues. Thrombectomy devices do not address vascular stenosis which still requires dilation of the vessel.

Risk of Rethrombosis and Embolization

The risks of rethrombosis and embolization following a thrombectomy procedure are considerable and can have significant implications on patient outcomes.

Rethrombosis

Rethrombosis refers to the recurrence of a blood clot at the same location following successful thrombectomy. It is a common issue following these procedures, with studies showing that up to 60% of patients can experience rethrombosis within one year following an intervention, though the exact rates can vary depending on patient characteristics and surgical techniques used [7].

Several risk factors contribute to the likelihood of rethrombosis. Persistent stenosis, or narrowing of the vessel, following the procedure can impede blood flow, increasing the chance of clot formation. Similarly, inadequate blood flow during dialysis, which might be due to factors such as suboptimal pump settings or vascular access issues, can also increase the risk of rethrombosis.

Hypercoagulability, a state in which the blood has an increased tendency to clot, is another significant risk factor. This can be due to inherited conditions, such as Factor V Leiden, or acquired conditions like antiphospholipid syndrome, cancer or nephrotic syndrome. In the setting of end-stage renal disease, the balance of coagulation and anticoagulation factors can be further disrupted, contributing to a hypercoagulable state.

Embolization

Embolization refers to the migration of a part or the whole clot to a different location in the vascular system. While it is less

common than rethrombosis, embolization can lead to severe complications.

If a part of the clot travels to the lungs, it can cause a pulmonary embolism, a potentially life-threatening condition. It is estimated that symptomatic pulmonary embolism occurs in less than 1% of thrombectomy procedures. However, the rate of asymptomatic pulmonary embolism, detected incidentally on imaging, may be higher.

Distal arterial embolization, where the clot travels to the arteries supplying the limbs or organs, is another serious complication. It can cause acute ischemia, necessitating urgent intervention. The risk of distal embolization varies depending on the specifics of the case but is generally considered to be low.

It is important to note that these risks can be mitigated by careful procedural technique, appropriate patient selection and meticulous post-procedure care and follow-up. The use of anticoagulants or antiplatelet agents following the procedure may also reduce the risk of rethrombosis and embolization, though this must be balanced against the risk of bleeding. Ultimately, the goal is to maintain the patency of the AV fistula or graft while minimizing complications, to ensure the patient has reliable access for dialysis [8].

Arteriovenous Fistula (AVF) and graft thrombosis are significant complications in patients undergoing hemodialysis. Detecting these conditions early is crucial for maintaining vascular access patency and preventing more serious complications. Here are the key signs and symptoms that may indicate thrombosis:

- **Decreased or absent thrill or pulse:** A properly functioning AVF or graft should have a palpable thrill (vibration) and a strong, pulsatile flow. The absence or decrease in thrill or pulse could indicate a clot.
- **Prolonged bleeding after dialysis:** If the access site continues to bleed for a long time after dialysis, this could suggest a clot blocking the normal flow of blood.
- **Swelling and pain:** Swelling, redness, or pain over the AVF or graft site might indicate a clot or infection.
- **Poor dialysis efficiency:** Inadequate clearance of waste during dialysis sessions could be a sign of diminished blood flow due to a clot.
- **Changes in venous pressure:** During dialysis, an increase in venous line pressure or a need to decrease the blood pump speed to maintain acceptable pressures could suggest an obstruction in the AVF or graft.
- **Coldness, numbness, or weakness in the hand or arm:** These symptoms might indicate a more severe situation where blood flow to the extremities is compromised due to a clot, known as "steal syndrome."
- **Changes in appearance:** Visible changes, such as bulging or distention of veins in the chest, neck, or face, or a new kink in the graft or fistula, could indicate a blockage.
- **Difficulty placing needles for dialysis:** If the needles cannot be easily inserted or if there is poor blood flow once the needle is inserted, this might suggest a problem with the AVF or graft.
- **Pale or blue-tinged skin (cyanosis):** This could be a sign of severe ischemia due to a clot and requires urgent attention.

- **Altered sensation:** Unusual sensations such as pins and needles or tingling might suggest impaired blood flow.
- **Slowing of blood flow:** Observed during dialysis, a slowing blood flow could suggest a developing clot.
- **Bruits:** While a soft, low-pitched bruit is normal over a functioning AVF or graft, changes in the pitch or loudness of the bruit could indicate a problem.

Remember, it's critical for patients with an AVF or graft to be aware of these signs and symptoms and to seek medical attention promptly if they suspect a problem with their access. Regular check-ups and vigilant follow-ups can prevent more serious complications.

Conclusion

In conclusion, Arteriovenous Fistula (AVF) and graft failure, chiefly driven by thrombosis, represent substantial obstacles in the care of patients necessitating hemodialysis. The durability and performance of AVFs and grafts are critical, as they directly impact the quality of dialysis, patient outcomes and healthcare costs.

Balloon angioplasty and mechanical thrombectomy are two key techniques employed to restore patency when thrombosis does occur. Balloon angioplasty, with its minimal invasiveness and high success rates, has been a long-standing option. Innovations such as drug-eluting balloons have emerged to address challenges like restenosis following angioplasty. However, balloon angioplasty isn't without its disadvantages, including the possibility of vessel trauma leading to neointimal hyperplasia and restenosis.

On the other hand, mechanical thrombectomy offers another avenue for managing thrombotic occlusions. Devices such as the Cleaner rotational system offer promising results with potentially less vessel wall trauma and more efficient thrombus removal. Yet, considerations such as the risk of distal embolization of thrombotic debris and device availability can influence the choice of this procedure.

Regardless of the intervention used, risks of rethrombosis and embolization remain significant. Patient-related factors, such as hypercoagulable states and comorbid conditions, alongside procedure-related factors like persistent stenosis, influence these risks. Education of patients to recognize early signs of AVF and graft thrombosis, such as changes in thrill or prolonged bleeding post-dialysis, is vital for early detection and intervention.

Moving forward, more comprehensive and comparative research is needed to fully understand the relative merits and drawbacks of balloon angioplasty and mechanical thrombectomy. Innovations in both techniques continue to emerge and determining the best application of each based on individual patient and procedural factors is a critical area of future study.

Moreover, research efforts should also focus on risk mitigation strategies for rethrombosis and embolization and on better understanding the pathophysiology of AVF and graft failure to develop preventive strategies. Achieving these goals

can significantly improve the quality of life for patients with end-stage renal disease, providing them with a reliable, long-lasting vascular access for life-sustaining hemodialysis.

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