Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 5s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

Arteriovenous Fistula Failure in Hemodialysis: Mechanisms, Risk Factors, and Management Strategies

Abhijeet Arvind Raut[*1], Dr. Rashmi Uddanwadikar[2], Dr. Pramod Padole[3], Dr. S V. Upadhye[4], Dr. G. A. Fiske[5], Dr. B. K. Bhadane[6]

[*1]Research Scholar, Department of Mechanical Engineering, Visvesvaraya National Institute of Technology (VNIT), Nagpur, Maharashtra, India.

[2]Professor, Department of Mechanical Engineering, Visvesvaraya National Institute of Technology (VNIT), Nagpur, Maharashtra, India.

[3]Professor, Department of Mechanical Engineering, Visvesvaraya National Institute of Technology (VNIT), Nagpur, Maharashtra, India.

[4]Dean, Maharashtra Animal and Fishery Sciences University, Nagpur, Maharashtra, India.

[5]Hospital Registrar, Veterinary clinical Complex, Nagpur Veterinary College, MAFSU, Nagpur

[6]Dept. of Surgery & Radiology, Nagpur Veterinary College, Nagpur

***Corresponding Author:**

Email ID: abhijeetraut21@gmail.com

Contributing Author:

Email ID: rashmiu71@gmail.com

Email ID: pmpadole01@gmail.com;

Email ID: shirishupadhye@gmail.com

Email ID: drgauriifiske@gmail.com

Email ID: drbhagyashreebhadane@gmail.com

Cite this paper as: Abhijeet Arvind Raut, Dr. Rashmi Uddanwadikar, Dr. Pramod Padole, Dr. S V. Upadhye, Dr. G. A. Fiske, Dr. B. K. Bhadane, (2025) Arteriovenous Fistula Failure in Hemodialysis: Mechanisms, Risk Factors, and Management Strategies. *Journal of Neonatal Surgery*, 14 (5s), 3-8.

ABSTRACT

Arteriovenous fistula (AVF) is the most used vascular access for hemodialysis treatment due to its great long-term patency, lower infection rates, and cost-effectiveness compared to arteriovenous grafts and central venous catheters. However, Arteriovenous fistula failure remains a critical clinical issue, contributing in increasing morbidity, healthcare costs, and suboptimal dialysis outcomes. AVF failure is broadly categorized into early failure, resulting from inadequate maturation, and late failure, often due to stenosis, thrombosis, or excessive neointimal hyperplasia.

This review explores the pathophysiology, risk factors, and mechanisms underlying AVF failure, including endothelial dysfunction, hemodynamic stress, inflammation, and vascular remodeling. Additionally, we examine current strategies to enhance AVF maturation and long-term functionality, such as preoperative vascular mapping, pharmacological interventions, surgical techniques, and endovascular treatments. Furthermore, emerging therapies including gene therapy, stem cell applications, and computational modeling hold promise for reducing AVF failure rates and improving patient outcomes. A multidisciplinary approach combining clinical expertise, biomedical innovations, and patient-specific treatment strategies is essential for optimizing AVF patency and ensuring effective hemodialysis access.

Keywords: *Arteriovenous fistula, Hemodialysis, Vascular access failure, hyperplasia, Endothelial dysfunction, Stenosis, Thrombosis*

1. NTRODUCTION

Vascular access remains a crucial determinant of hemodialysis outcomes in patients with end-stage renal disease (ESRD). Among the available options, the arteriovenous fistula (AVF) is considered the 'Gold standard' worldwide due to its superior long-term patency, lower infection rates, and reduced need for repeated interventions compared to arteriovenous grafts (AVGs) and central venous catheters (CVCs) [1]. The arteriovenous fistula (AVF) is ranked as the best accessible method for delivering hemodialysis according to the National Kidney Foundation Kidney Disease Outcomes Quality Initiative vascular access criteria [2]. The Fistula First initiative and their guidelines advise AVF formation in the majority of patients because of this. A considerable proportion of fistulae (28–53%), however, do not develop sufficiently to sustain dialysis treatment [3–7].

Up to one-third of hospitalizations and a large portion of these patients' medical expenses are related to AVF failure, making it one of the leading causes of morbidity and mortality in renal failure patients [8–9].

In order to improve hemodialysis patient care and outcomes, there has been a surge in research into AVF creation techniques and strategies for AVF failure prevention and treatment in recent decades by various scientific researches advancements related to vascular access and AVF failure. This review paper is to describe in detail about AVF and its failure. It also gives overview and analysis of the associated risk factors which causes AVF failure.

2. METHODS

Maturation, arteriovenous fistula, AVF, non-maturation, prediction, renal failure, end-stage renal disease, hyperplasia and hemodialysate such keywords were used in various combinations to search papers in Pubmed and google scholar. After reading and reviewing each abstract, the retrieved articles were added based on their applicability in paper. While we acknowledge that a thorough evaluation of the caliber of each included study would improve the reviews, we believe this can be handled in a subsequent systematic review because this article is meant to be a narrative review.

3. ARTERIOVENOUS FISTULA

AV Fistula is the connection of artery and vein as shown in Fig. 1. AV Fistula was invented and used in 1966 by Brescia and colleagues [10]. However, there have been few researches and improvement done afterwards. In fact, more than fifty years later, the radiocephalic AV fistula remains the best option for the AV fistula creation process. When compared to other vascular access options such as AV Graft and Catheter, the AV fistula is the most popular type of hemodialysis vascular access because of its low complication rates and good long-term patency [11].

Artery spelling in fig 1

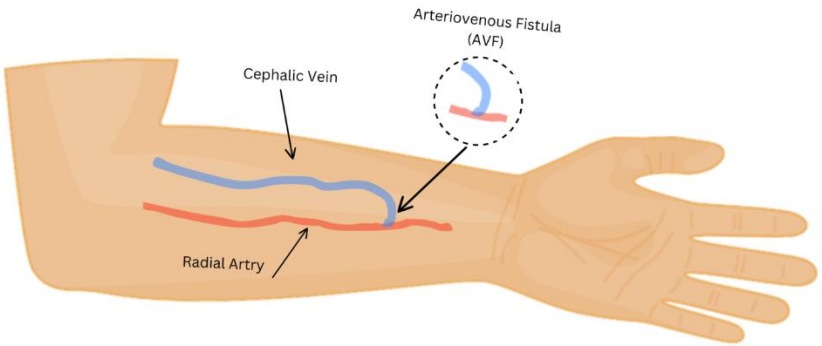

Fig. 1 Arteriovenous Fistula (AVF)

3.1 Arteriovenous Fistula Maturation

Arteriovenous Fistula (AVF) maturation is a complicated process that involves the formation of an arteriovenous anastomosis, which increases arterial and venous diameters and exposes the vein to an environment with more oxygen which causes compensatory vascular outward remodelling, vasodilatation on targeted AVF site [12–13]. The process of fistula maturation typically takes place in 4 to 6 weeks, and an ultrasound (US) study evaluation of the 4th week fistula provides crucial information regarding fistula acceptability and if any potential causes of AVF non-maturing which further may need investigation for solution [14].

As per US Doppler evaluation, a blood flow of < 500 ml/min and an output vein smaller than 4 mm are predictive markers for fistula failure to mature [15]. According to the Kidney Disease Outcomes Quality Initiatives given guidelines, a mature

fistula is said to which targeted cannulation straight segment at least 6 cm, a venous diameter of at least 6 mm and venous blood flow of 600 ml/min, and a depth of skin shall less than 6 mm by 6 weeks. This is called as the "rule of 6." [16].

3.2 Hemodynamics of an Arteriovenous Fistula (AVF)

In order to create an AVF, a high pressure artery must be surgically anastomosed to a low pressure vein, increasing tension and wall shear stress (WSS). Venous arterialization is defined as medial thickening, which is caused by an increase in pressure in the venous outflow tract. WSS is the parallel force, while pressure is the perpendicular force applied in a vessel [17]. Typically, an effort is made to lower the WSS back to pre-AVF levels by increasing the luminal diameter. The end result is a thickened media and dilated vein, which is ideal for a hemodialysis-useful fistula[18]. Researchers highlighted this phenomenon in a study that used an ultrasound Doppler device to show hemodynamic changes in six patients with a lower arm AVF. In the first week following the formation of the fistula, the vein's blood flow and WSS significantly increased. A venous luminal diameter increase—a prerequisite for cannulation was the outcome of the increased flow. The WSS progressively stabilized by the 12-week mark.

When a bend or curve occurs, which is often the case, particularly when an AVF is being constructed, issues in vasculature physics arise. A straight vessel typically has laminar, smooth flow [19]. This example shows that the endothelial cells are in a steady state with low permeability, low cell turnover, low levels of oxidative stress, and anti-inflammatory genes. There is not much of an abnormal WSS (red) area. Laminar flow turns turbulent, though, when a bend or curve appears [19]. High endothelial cell turnover, poor alignment, activation of inflammatory genes, and increased oxidative stress are all associated with turbulent flow. There is a far greater area of abnormal WSS. Low WSS, the death of endothelial cells, and the stimulation of pathways that ultimately result in NH are all caused by abnormal turbulent flow [20]. Jia and others. have demonstrated recently in research on the development of AVF in dogs that NH is associated with flow patterns and has a strong inverse relationship with WSS levels [21].

4. ARTERIOVENOUS FISTULA FAILURE

Despite being the preferred vascular access for hemodialysis, arteriovenous fistula (AVF) failure remains a significant challenge, affecting patient outcomes and healthcare costs. AVF failure can be classified into early failure, occurring within 6 to 12 weeks post-surgery due to failure to mature, and late failure, which happens after successful maturation due to thrombosis or stenosis [22].

4.1 Classification of AVF Failure

AVF failure is can be categorized into:

4.1.1 Early AVF Failure (Failure to Mature)

An AVF that does not develop adequate blood flow for hemodialysis within 6–12 weeks of creation causes early failure include poor vessel selection, inadequate blood flow, vascular injury, and excessive neointimal hyperplasia (NIH). Factors responsible like old age, diabetes, female gender, small vein diameter, and pre-existing vascular disease [22-23].

4.2.1 Late AVF Failure (Post-Maturation Failure)

Late AVF failure occurs after the AVF has matured and is being used for dialysis but develops complications like stenosis, thrombosis, or aneurysm formation and in this type risk Factors involved like repeated cannulation, excessive shear stress, endothelial dysfunction, and chronic inflammation [24-25]. Pathophysiology of AVF Failure, the underlying mechanisms of AVF failure involve hemodynamic changes, cellular proliferation, and inflammation leading to vascular dysfunction.

4.2 Mechanisms of AVF Failure

4.2.1 Endothelial Dysfunction

Endothelial dysfunction plays a critical role in AVF failure. The surgical creation of an AVF exposes the vessel to abnormal hemodynamic forces, including increased shear stress and turbulent flow, which can damage the endothelium. Studies have shown that endothelial injury triggers a cascade of inflammatory responses, leading to neointimal hyperplasia and stenosis. In one study author Lee et al. demonstrated that endothelial nitric oxide synthase (eNOS) dysfunction is a key contributor to AVF failure by promoting oxidative stress and inflammation [26][27].

4.2.2 Neointimal Hyperplasia

AVF failure is caused by neointimal hyperplasia as the main pathological process. Luminal narrowing results from the proliferation of fibroblasts and smooth muscle cells in the intimal layer. One of the main causes of neointimal hyperplasia is hemodynamic alterations, such as oscillatory flow and elevated wall shear stress. One of the Misra et al. studies. made clear how platelet-derived growth factor (PDGF) and transforming growth factor-beta (TGF-β) support the migration and proliferation of smooth muscle cells [28].

4.2.3 Hemodynamic Changes

The creation of an AVF significantly alters blood flow dynamics, leading to increased flow rates and pressure gradients. These changes can cause vascular remodeling, but excessive hemodynamic stress can also lead to endothelial injury and neointimal hyperplasia. A study by Ene-Iordache et al. used computational fluid dynamics to demonstrate that regions of low and oscillatory shear stress are prone to stenosis[28].

4.3 Risk Factors for Arteriovenous Fistula Failure

As was indicated in the section above, arteriovenous fistula failures can also be caused by other parameters and factors, which can occasionally impact AVF maturation and result in dysfunctions as shown in Fig. 2.

4.3.1 Patient-Specific Factors

Age: Because of their higher frequency of comorbidities and worse vascular compliance, older patients are more likely to experience AVF failure. According to a 2017 study by Al-Jaishi et al., patients over 65 were 30% more likely than younger patients to experience AVF failure [29].

Diabetes: Diabetes is linked to increased atherosclerosis and endothelial dysfunction, both of which are factors in the failure of AVF. According to a 2019 study by Lok et al., patients with diabetes were 40% more likely to experience early AVF failure [30].

Obesity: Due to greater incidence of venous hypertension and more technical difficulties during surgery, obesity is associated with poor AVF results.

4.3.2 Anatomical Factors

Vessel Diameter: One known risk factor for AVF failure is a smaller vessel diameter. Veins with a diameter less than 2.5 mm were linked to a 50% increased chance of not maturing, according to a study by Allon et al. (2018) [31].

Artery Calcification: AVF patency can be decreased and surgical results can be negatively impacted by artery wall calcification.

4.3.3 Surgical Factors

Surgical approach: AVF results are greatly influenced by the surgeon's experience and the anastomosis approach (end-to-side vs. side-to-side). Better patency rates were linked to end-to-side anastomosis, according to a Huber et al. (2020) study [32].

AVF location: While brachiocephalic and brachiobasilic AVFs are frequently employed in patients with insufficient vasculature, radiocephalic AVFs have lower failure rates.

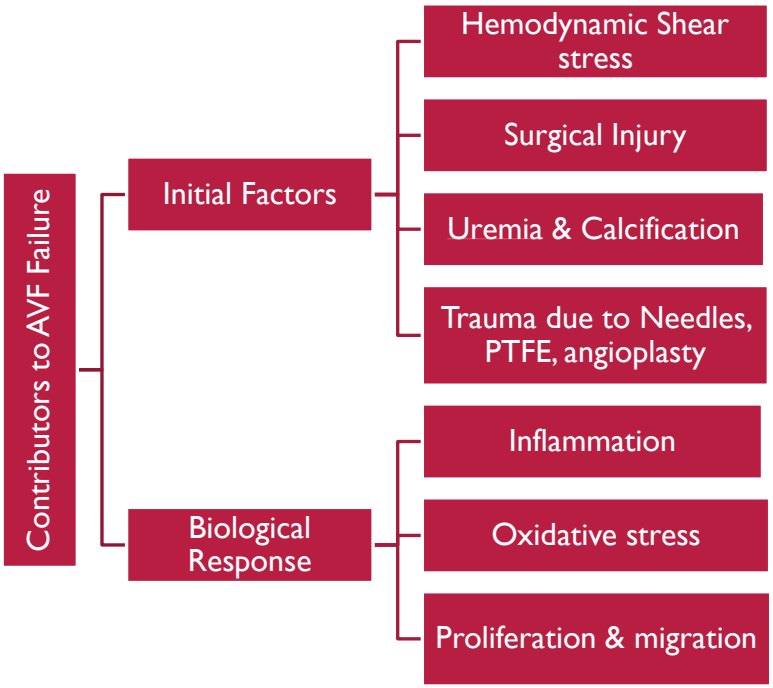

Fig. 2. Risk factors associated with AVF dysfunction.

5. CONCLUSION

AVFs are still the preferred vascular access for hemodialysis because of their long-term patency, lower infection rates, and overall cost-effectiveness. However, AVF failure is still a major problem that affects patient outcomes and increases healthcare burdens. The two main types of AVF failure early failure due to inadequate maturation and late failure resulting from stenosis or thrombosis need a thorough understanding of the underlying mechanisms to improve outcomes. Vascular remodeling, hemodynamic stress, endothelial dysfunction, and chronic inflammation are some of the factors that contribute to AVF failure. Early detection and intervention are essential for preventing complications and extending AVF function. Strategies like preoperative vein mapping, cautious surgical techniques, pharmacological therapy, and endovascular interventions have shown promise in improving AVF patency rates.

Future developments in stem cell applications, gene therapy, and computer modeling could improve the longevity of vascular access and lower the failure rates of AVFs. Developing novel solutions that maximize AVF results requires ongoing research and cooperation between researchers, biomedical engineers, and healthcare practitioners. It is feasible to raise AVF success rates, lower complications, and improve hemodialysis patients' quality of life by combining cutting-edge technologies with current clinical procedures.

REFERENCES

[1] Lawson, J. H., Niklason, L. E., & Roy-Chaudhury, P. (2020). Challenges and novel therapies for vascular access in haemodialysis. Nature Reviews Nephrology. DOI: 10.1038/s41581-020-0333-2

[2] NKF-K/DOQI clinical practice guidelines for vascular ac- cess: Update 2000. Am J Kidney Dis 37[Suppl 1]: S137–S181, 2001

[3] Palder SB, Kirkman RL, Whittemore AD, Hakim RM, Laza- rus JM, Tilney NL: Vascular access for hemodialysis. Pa- tency rates and results of revision. Ann Surg 202: 235–239, 1985

[4] Miller PE, Tolwani A, Luscy CP, Deierhoi MH, Bailey R, Redden DT, Allon M: Predictors of adequacy of arterio- venous fistulas in hemodialysis patients. Kidney Int 56: 275–280, 1999

[5] Allon M, Lockhart ME, Lilly RZ, Gallichio MH, Young CJ, Barker J, Deierhoi MH, Robbin ML: Effect of preoperative sonographic mapping on vascular access outcomes in he- modialysis patients. Kidney Int 60: 2013–2020, 2001

[6] Asif A, Cherla G, Merrill D, Cipleu CD, Briones P, Pennell P: Conversion of tunneled hemodialysis catheter consigned patients to arteriovenous fistula. Kidney Int 67: 2399–2407, 2005

[7] Won T, Jang JW, Lee S, Han JJ, Park YS, Ahn JH: Effects of intraoperative blood flow on the early patency of radiocephalic fistulas. Ann Vasc Surg 14: 468–472, 2000

[8] Ravani P, Palmer SC, Oliver MJ, et al. Associations between hemodialysis access type and clinical outcomes: a systematic review. J Am Soc Nephrol 2013; 24(3): 465– 473.

[9] Lok CE and Foley R. Vascular access morbidity and mortality: trends of the last decade. Clin J Am Soc Nephrol 2013; 8(7): 1213–1219.

[10] Brescia, M. J., Cimino, J. E., Appel, K. & Hurwich, B. J. Chronic hemodialysis using venipuncture and a surgically created arteriovenous fistula. N. Engl. J. Med. 275, 1089–1092 (1966).

[11] Enzler, M. A., Rajmon, T., Lachat, M. & Largiader, F. Long-term function of vascular access for hemodialysis. Clin. Transplant. 10, 511–515 (1996).

[12] Lu DY, Chen EY, Wong DJ, et al. Vein graft adaptation and fistula maturation in the arterial environment. J Surg Res 2014; 188(1): 162–173.

[13] Rothuizen TC, Wong C, Quax PHA, et al. Arteriovenous access failure: more than just intimal hyperplasia. Nephrol Dial Transplant 2013; 28(5): 1085–1092.

[14] Beathard GA. An algorithm for the physical examination of early fistula failure. Semin Dial 2005; 18(4): 331–335.

[15] Robbin ML, Chamberlain NE, Lockhart ME, et al. Hemodialysis arteriovenous fistula maturity: US evaluation. Radiology 2002; 225: 59–64.

[16] Vascular Access 2006 Work Group. Clinical practice guidelines for vascular access. Am J Kidney Dis 2006; 48(Suppl. 1): S176–S247.

[17] C. Hahn and M. A. Schwartz, “Mechanotransduction in vas- cular physiology and atherogenesis,” Nature Reviews Molecular Cell Biology,vol.10, no.1,pp. 53–62, 2009.

[18] J. M. Corpataux, E. Haesler, P. Silacci, H. B. Ris, and D. Hayoz, “Low-pressure environment and remodelling of the forearm vein in Brescia-Cimino haemodialysis access,” Nephrology Dial- ysis Transplantation,vol.17,

no.6,pp. 1057–1062, 2002.

[19] C. Hahn and M. A. Schwartz, “Mechanotransduction in vas- cular physiology and atherogenesis,” Nature Reviews Molecular Cell Biology,vol.10, no.1,pp. 53–62, 2009.

[20] G. E. Smith, R. Gohil, and I. C. Chetter, “Factors affecting the patency of arteriovenous fistulas for dialysis access,” Journal of Vascular Surgery,vol.55, no.3,pp. 849–855,2012.

[21] L. Jia, L.Wang, F.Wei et al., “Effects ofwall shear stress in venous neointimal hyperplasia of arteriovenous fistulae,” Nephrology, vol. 20, no. 5, pp. 335–342, 2015.

[22] Asif, A., Roy-Chaudhury, P., & Beathard, G. A. (2006). Early arteriovenous fistula failure: A logical proposal for when and how to intervene. *Clinical Journal of the American Society of Nephrology, 1*(2), 332–339. DOI: 10.2215/CJN.00850805

[23] Gameiro, J., & Ibeas, J. (2020). Factors affecting arteriovenous fistula dysfunction: A narrative reviernal of Vascular Access. DOI: 10.1177/1129729819845562

[24] Lawson, J. H., Niklason, L. E., & Roy-Chaudhury, P. (2020). Challenges and novel therapies for vascular haemodialysis. *Nature Reviews Nephrology*. DOI: 10.1038/s41581-020-0333-2

[25] Zhang, Y., et al. (2022). "Risk factors for arteriovenous fistula dysfunction in hemodialysis patients: A retrospective cohort study." *Scientific Reports*. DOI: 10.1038/s41598-023-48691-4.

[26] Lee, T., et al. (2020). Endothelial dysfunction in arteriovenous fistula failure: Role of oxidative stress and inflammation. Journal of Vascular Surgery, 71(3), 789-797

[27] Misra, S., et al. (2019). Mechanisms of neointimal hyperplasia in arteriovenous fistulas. Kidney International, 95(4), 782-790.

[28] Ene-Iordache, B., et al. (2018). Hemodynamic changes and vascular remodeling in arteriovenous fistulas: A computational fluid dynamics study. Journal of Biomechanics, 67, 1-8.

[29] Al-Jaishi, A., et al. (2017). Risk factors for arteriovenous fistula failure: A systematic review and meta-analysis. American Journal of Kidney Diseases, 69(4), 497-506.

[30] Lok, C. E., et al. (2019). Diabetes and arteriovenous fistula outcomes: A multicenter cohort study. Clinical Journal of the American Society of Nephrology, 14(5), 704-711.

[31] Allon, M., et al. (2018). Preoperative vascular mapping and arteriovenous fistula outcomes. Journal of the American Society of Nephrology, 29(3), 987-995.

[32] Huber, T. S., et al. (2020). Surgical techniques and arteriovenous fistula patency: A comparative study. Annals of Vascular Surgery, 62, 45-52.