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Original research article

JVA The Journal of Vascular Access

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The Journal of Vascular Access
2021, Vol. 22(1S) 32–41

DOI: 10.1177/1129729820969314
journals.sagepub.com/home/jva
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Abstract

Chronic kidney disease is associated with increased cardiovascular morbidity and mortality. A well-functioning vascular access is associated with improved survival and among the available types of vascular access the arterio-venous (AV) fistula is the one associated with the best outcomes. However, AV access may affect heart function and, in some patients, could worsen the clinical status. This review article focuses on the specific cardiovascular hemodynamics of dialysis patients and how it is affected by the AV access; the effects of an excessive increase in AV access flow, leading to high-output heart failure; congestive heart failure in CKD patients and the contraindications to AV access; pulmonary hypertension. In severe heart failure, peritoneal dialysis (PD) might be the better choice for cardiac health, but if contraindicated suggestions for vascular access selection are provided based on the individual clinical presentation. Management of the AV access after kidney transplantation is also addressed, considering the cardiovascular benefit of AV access ligation compared to the advantage of having a functioning AVF as backup in case of allograft failure. In PD patients, who need to switch to hemodialysis, vascular access should be created timely. The influence of AV access in patients undergoing cardiac surgery for valvular or ischemic heart disease is also addressed. Cardiovascular implantable electronic devices are increasingly implanted in dialysis patients, but when doing so, the type and location of vascular access should be considered.

Keywords

Chronic kidney disease, hemodialysis, arteriovenous fistula, peritoneal dialysis, heart failure, pulmonary hypertension

Date received: 1 October 2019; accepted: 1 October 2020

Hemodynamics of ESRD patients and the effect of arteriovenous access

Epidemiological studies revealed that chronic kidney disease (CKD) is an independent risk factor for cardiovascular morbidity. Data from the US Renal Data System revealed that risk for death in a dialysis patient with heart failure is 33%, 46%, and 57% at 12, 24, and 36 months, respectively, after dialysis therapy initiation.[1] There are multiple adverse risk factors for this in patients with long-standing and significant renal impairment, including sodium and water retention, chronic anemia, hypertension,

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vascular wall rigidity, and aortic stenosis.[2] A recognized independent risk factor for cardiovascular morbidity and mortality in patients with advanced renal disease is the left ventricular hypertrophy (LVH), which is present in up to 75% of patients at commencement of dialysis. LVH is a normal response to increased pressure and volume loads of any etiology, but is associated with the development of progressive intramyocardial fibrosis, ventricular stiffness, and abnormal diastolic filling and is associated with higher risk of sudden death in patients with advanced CKD.[3]

The increased prevalence of cardiovascular disease in CKD-patients is in part explained by the traditional risk factors such as hypertension, diabetes, dyslipidemia and increased age, but also by specific factors, such as calcium-phosphate disturbances with arterial and heart calcification. Another factor specific for ESRD patients is the arteriovenous (AV) access. It significantly affects the hemodynamic and circulatory parameters of the cardiovascular system. The current literature suggests that the creation of AV access can cause or exacerbate heart failure (HF), LVH, pulmonary hypertension, coronary artery disease, and valvular dysfunction. The connection of a low-pressure vein to the high- pressure arterial system results in cardiovascular remodeling. An increase in the arterial blood flow rate increases wall shear stress (WSS) on endothelial cells that produce dilating mediators (nitric oxide, endothelium-derived hyperpolarizing factor) resulting in enlargement of the vessel lumen and a consequent reduction of WSS to the physiologic range.[4] Further arterial dilatation is enabled by the increased activity of matrix-metalloproteinases that degrade the stroma of the arterial wall. Increased WSS and wall tension are the driving forces modifying vessel diameter and wall structure and WSS values normalize after more than 2 years since access creation.[5]

WSS is defined by Poiseuille's formula: $4\eta Q/\pi r^3$, where η = blood viscosity, Q = flow and r = vessel radius.

An increase in intraluminal pressure regulates wall thickness through its effect on wall tension and smooth muscle cells response to mechanical stimulation. Maladaptive remodeling is inward (negative) growth that leads to a reduction in the lumen diameter, whereas adaptive remodeling is outward (positive) growth that maintains the lumen diameter.[4] The radius of the vessel is the critical determinant of flow as described in Poiseuille law, which states that the blood flow in any vessel, and therefore also the blood flow of an AV access (Qa), is determined by the following relationship:

$$\mathrm{Qa}\ (\mathrm{ml/min}) = \pi \Delta \mathrm{Pr}^4 / 8\eta \mathrm{l}$$

ΔP is the pressure difference between the extremities of the vessel, r radius of the vessel, η viscosity of the fluid, and l length of the vessel. Note that Qa is directly proportional to the fourth power of radius; the brachial artery is utilized for an upper arm AVF and must necessarily have a higher r than the radial artery utilized for a lower arm AVF.

Since access resistance (AR) is expressed by the following ratio:

$$\mathrm{AR} = (\mathrm{MAP} - \mathrm{CVP}) / \mathrm{Qa}$$

where MAP = mean arterial pressure, CVP = central venous pressure, which is sometimes neglected. We can then rewrite this relationship in the following way

$$\mathrm{AR} = \mathrm{MAP} \times 8\eta \mathrm{l} / \pi \Delta \mathrm{Pr}^4$$

The decrease of AR at the limb with AV access significantly decreases also the systemic vascular resistance (SVR) – one of the key factors, which determine systemic blood pressure. Indeed, the creation of an AV access significantly decreases blood pressure in ESRD patients, whereas blood pressure tends to increase after ligation.[6] Circumferential wall stress in the radial artery feeding the AV access rises to levels substantially higher than that in the contralateral radial artery. Interrelation of Qa and cardiac output (CO) exists. It has been demonstrated that he postoperative AV access blood flow is lower in patients with reduced ejection fraction that in patients with normal ejection fraction.[7] However, recent data suggest that the relationship between Qa and CO is not linear; a third-order polynomial regression model best fits this relationship with a curve consisting of an initial plateau of CO followed by a steep slope with CO rising more sharply at greater Qa.[8] The increase in Qa is not accompanied by a significant increase in CO in the Qa range 0.95–2.2 l/min. The mechanisms underlying this phenomenon is unknown. One may hypothesize that very high Qa leads to systemic steal followed by secondary dilatation of the arteries of various arterial beds. Also, some sort of myocardial functional reserve probably plays a role.

Creation of an AV access leads to a suddenly increased demands on cardiac output – by the value of Qa. In patients with patent AV access, measured CO includes also Qa. Therefore, the term "effective CO," which is the difference between measured CO and Qa, has been introduced. Similarly, one can calculate the effective cardiac index. Figure 1 illustrates serial connection of the AV access to the cardiovascular system. The proportion of blood pumped by the heart to the AV access depends on AR and SVR.

Thus, AV access increases CO substantially. Negative effects of too high CO include high-output heart failure and pulmonary hypertension. Congestive HF worsening and organ hypoperfusion (AV access vs. left internal mammary artery coronary bypass, cerebral hypoperfusion) characterize other effects of a high flow AV access.

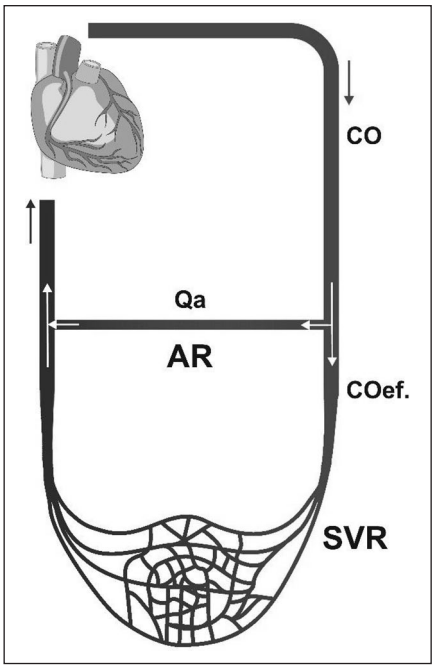

Figure 1. Scheme of the circulation in a subject having arteriovenous access. Only the great circulation is shown. If the patient has an AV access, it acts as a shortcut between the systemic arteries and veins. The total CO is therefore divided into the AV access – as Qa – and to the effective portion dedicated to the organs perfusion – COef. The ratio between Qa and COef depends on the ratio of the access resistance (AR) and systemic vascular resistance (SVR). This figure also explains, why Qa changes together with systemic blood pressure or hydration fluctuations. Moreover, too large anastomosis (with too low AR) leads to high AV access flow, while the body could have inadequate blood supply (low COef.).
Source: Adapted from Basile and Lomonte.[9]

High-output heart failure

There is no standard definition for high output HF probably because it a relatively rare entity. A high-output heart failure is usually defined by symptoms of cardiac failure (dyspnea either at rest or with varying degrees of exertion, orthopnea, paroxysmal dyspnea and edema, either pulmonary and/or peripheral) in the presence of an above-normal cardiac index (CI = CO indexed to the body surface area).[10] The cut-off values of CI[11] used in the recent literature very between 3.5 and 3.9 l/min/m^2.[12] Resolution of HF symptoms and decrease of heart cavities size after access flow-reducing surgery is another typical feature of high-output HF. Long-lasting untreated high-output HF probably leads to further dilatation and systolic dysfunction of the left ventricle followed by a secondary mitral regurgitation.

Cardiac output increases greatly and immediately after opening an AV access in experimental models.[1] This increase in CO is achieved by means of a reduction in SVR, an increase in sympathetic nervous system activity (increasing contractility) and an increase in stroke volume and heart rate. The overall effect, beside of an increase in CO, is the expansion of blood volume.[1] The effects on myocardium are mainly due to the volume overload, which subsequently translate into a remodeling of the cardiac muscle characterized by the four chambers enlargement and by addition of new sarcomeres in series. Thus, the AV access increase CO and lead to significant increases in both left ventricular wall mass and diameter with predominately eccentric LVH. This must be distinguished from the concentric LVH in which the addition of the new sarcomeres is parallel and the pathogenetic mechanism is a pressure overload. The circulatory and hemodynamic effects of an AVF are listed in Table 1.

Table 1. Hemodynamic and unwanted effects of AV access creation.

Immediate/days
Increase in cardiac output[8]
Decrease in systemic vascular resistance[8]
Increase in sympathetic nervous system activity with increased contractility, heart rate, and stroke volume[8]
Increase in pulmonary arterial flow and pressure[12]
Increased natriuretic peptides (ANP and BNP)
Weeks/months (side effects in some patients especially with higher AV access flow)
Increase in left ventricular end-diastolic volume[12]
Increase in left ventricular mass and size[12]
Increase in atrial chamber size[12]
Diastolic and systolic left ventricular dysfunction[12]
Pulmonary hypertension[12]
Long-term effects (side effects in some patients)
High-output cardiac failure[11] (rare)
Coronary steal[13] (rare – in patients after coronary artery bypass grafting
Central vein stenosis[14] (frequent – after dialysis catheters)

ANP: atrial natriuretic peptide; BNP: brain- natriuretic peptide.

Patients bearing a high-flow rate AV access and having a greater increase in left ventricular end diastolic volume (LVEDV) are clearly more likely to develop heart failure (HF).[4] A strong relationship exists between blood flow rate (Qa) and CO; furthermore, AV access contributes to the LVH. In fact, the incidence of LVH is reported to increase from 67% to 83% and 90% at 1 and 3 months, respectively, after AV access creation, suggesting that hemodynamic changes from the AV access contribute to the left ventricular mass progression.[6]

The ratio of Qa to CO can also be used to predict the risk of worsening HF. Some authors have stressed that when the cardio-pulmonary recirculation (CPR) exceeds 30%, the onset of high-output HF is possible independently of the absolute value of Qa.[10] What causes the transformation of an eccentric LVH in HF is not known. Specific characteristics of either the patients or the AV access, or both, may predispose to the development of HF,

such as male gender, upper arm AVFs and previous access surgery.[15] Qa cut-off values > 2.0 l/min together with HF symptoms have a high predictive power for high-output HF. The recent ESVS Guidelines recommend to regularly monitor the dialysis patients with an access flow above 1500ml/min by means of flow measurements, echocardiography and evaluating the clinical signs of heart failure.[16] On the other hand, the Spanish Guidelines suggest an AVF flow reduction when Qa is > 2000 mL/min or CPR >30% to reduce the risk of high-output HF.[17]

Congestive heart failure

By definition, congestive HF ensues, when the heart is not able to fulfill adequate organ perfusion by blood at rest or during exercise, or is able to do so only at the cost of increased filling pressure. Inadequate organ perfusion is sometimes called forward HF and is clinically manifested by dizziness, confusion, cool extremities, systemic hypotension or even cardiogenic shock. "Increased filling pressures" represent the backward HF, implying that a higher blood pressure is needed for the filling of the left or right ventricle due to their lower compliance or prolonged relaxation time. This higher pressure is transferred to the left and right atrium. Increased left atrial pressure is freely transmitted to the pulmonary veins and capillaries and pulmonary congestions develops. Increased right atrial pressure is freely transmitted to the central veins and also to the renal veins, which is one mechanism of glomerular filtration decrease in non-ESRD patients. Moreover, increased central venous pressure leads to blood stagnation in the liver and in the portal system. Liver congestion leads to inadequate synthesis of proteins or even to the so-called cardiac cirrhosis. Portal hypertension is associated with impaired absorption of nutrients, vitamins etc. from the gut content.

Another classification differentiates left-sided, right-sided and biventricular HF. Left-sided HF is the most common as the result of the left ventricular systolic and diastolic dysfunction, LVH, aortic and mitral valvular diseases. The left-sided HF usually progresses into the right-sided and becomes biventricular. Many mechanisms are involved in the development of HF[2] – see Table 2.

Congestive HF is much more common than high-output HF and is associated with a significantly increased morbidity (shortness of breath, tiredness, edemas, cachexia, accelerated cognitive impairment) and mortality, namely sudden cardiac death.[18]

Since the heart is affected by many complications (see Table 2) and is unable to increase CO adequately – congestive HF develops. Asymptomatic HF occurs frequently before AV access creation.

The diagnosis of HF is challenging in ESRD patients especially because of two reasons: (1) patients are frequently frail with limited exercise capacity; and (2) HF symptoms are very similar to the symptoms of overhydration. Moreover, abnormal hydration affects not only symptoms, but also the echocardiographic findings, such as size of the cavities, significance of valvular regurgitations or left ventricular ejection fraction. Recently, the Acute Dialysis Quality Initiative XI workgroup proposed a new classification of heart failure in ESRD patients.[19] They specifically excluded patients with simple water overload and a normal heart and focuses on those having specific echocardiographic changes. These include three elements: (1) echocardiographic evidence of structural or functional heart abnormalities; (2) shortness of breath occurring in the absence of pulmonary disease and (3) response of congestive symptoms to ultrafiltration. However, the echocardiographic findings are also significantly load-dependent, but also Qa-dependent. Therefore, echocardiography report should always contain information about the time delay since the last hemodialysis (ideally >24 h since the last dialysis), estimation of the current central venous pressure (based on inferior vena cava diameter and collapsibility), should estimate CO and take into account the actual Qa.[20] According to the clinical experience of the authors, a surprisingly high proportion of dialysis patients are chronically over- or underhydrated. Especially in cases with inadequate dry weight setting, an echocardiographic re-examination should be performed to understand the volume-dependency of various findings. Regular use of bio-impedentiometry could help. The actual echocardiographic finding and hemodynamic assessment is the net result of many involved mechanisms and its understanding could be best achieved by a close cooperation of nephrologists and cardiologists.

Cardiac output is a complex variable including various particular mechanisms affecting heart action. Commonly, it is indexed to the body surface area (in m^2) getting cardiac index (CI). Nephrologists working in dialysis units have frequently devices for the measurement of Qa and CO and these

Table 2. Heart failure mechanisms and associated structural heart changes in ESRD patients.

Mechanisms
- Arterial hypertension
- Hyperkinetic circulation due to water retention, anemia and arteriovenous dialysis access
- Arterial changes – increased stiffness, endothelial dysfunction
- ESRD endocrine and metabolic changes

Associated functional and structural heart changes
- Coronary artery disease
- Left ventricular dilatation, systolic and/or diastolic dysfunction, hypertrophy
- Left atrial dilatation, impaired compliance and systolic dysfunction
- Valvular heart disease – aortic stenosis/regurgitation, mitral stenosis/regurgitation
- Right ventricular dilatation, systolic dysfunction
- Arrhythmias
- Pericardial disease – effusion, calcifications, constrictive pericarditis
- Pulmonary hypertension

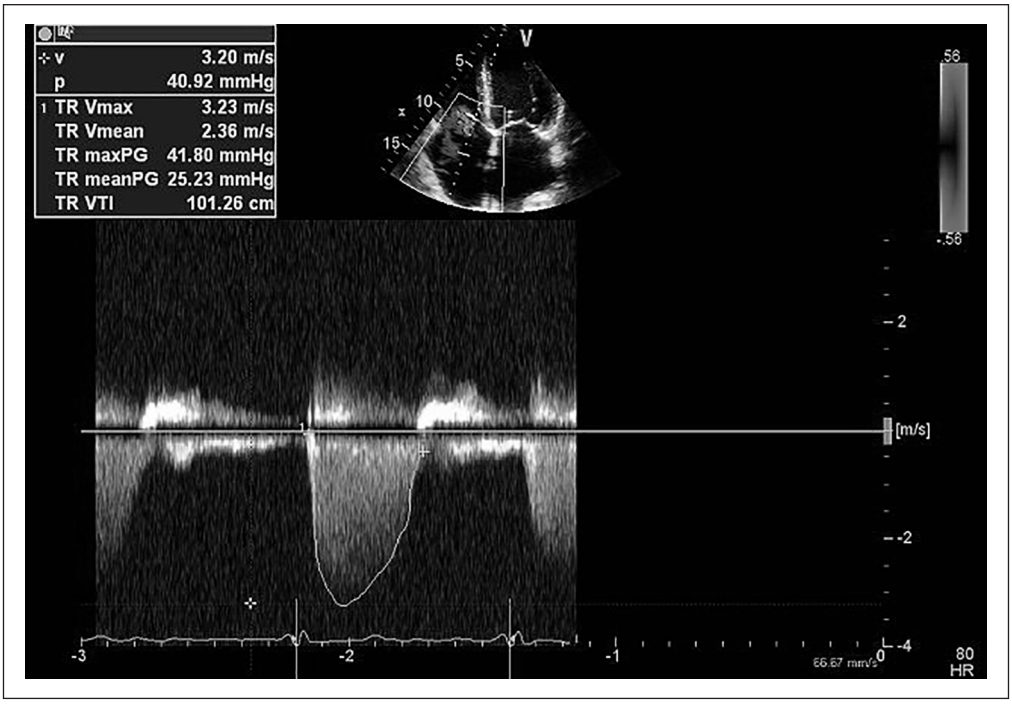

Figure 2. Estimation of the systolic pulmonary arterial pressure. Systolic pulmonary artery pressure can be estimated in patients having at least mild tricuspid regurgitation. The pressure gradient (difference) between the right ventricle and right atrium is a function of the regurgitation velocity (Bernoulli equation). If we add the value of the central venous pressure (measured in patients on central catheter or estimated from the size and collapsibility of the inferior vena cava by ultrasound) we get the systolic pulmonary artery pressure.
TR: tricuspid regurgitation.

two variables can be used for the basic hemodynamic analysis. We advise to measure CO, CI and Qa regularly. For the diagnosis of congestive HF, it is more precise to calculate the effective cardiac output and cardiac index (see Figure 1 for explanation).[21] The effective CI could be calculated as follows: $CI_{ef.}=(CO-Qa)/BSA$. Usual values of CI vary between 2.5 and 3.5 l/min. The values of $CI_{ef.}$ below 2.0–2.2 l/min/m^2 in dialysis patients with a patent AVF are suspicious of HF, However, one of the common reasons is an excessively low setting of the dry weight, leading to inadequate ventricular filling. Again, echocardiography and close cooperation with a cardiologist is recommended.

Pulmonary hypertension

By definition, pulmonary hypertension is characterized by the mean pulmonary artery pressure higher than 25 mmHg at rest or during exercise. Pulmonary artery pressure could be measured either invasively (Swan-Ganz catheter) or it could be estimated non-invasively by echocardiography (Figure 2). Symptoms of pulmonary hypertension include shortness of breath, dizziness, fainting, leg swelling etc. However, the vast majority of ESRD patients with pulmonary hypertension is asymptomatic and its prevalence is very high and reach up to 56%.[22]

Many factors contribute to pulmonary hypertension development. They include a postcapillary component (arterial hypertension, left ventricular disease, aortic and mitral valvular disease), a precapillary component (volume overload, pulmonary embolism – also from the thrombosed vascular access) and a hyperkinetic component (AVF, anemia, inflammation, but also volume overload per se).[22] During a single hemodialysis session, the systolic pulmonary artery pressure decreased by 6 mmHg in our study.[23]

High-flow AVF is a frequent cause of pulmonary hypertension in ESRD patients. Flow-reducing surgery leads to substantial lowering of pulmonary artery pressure. One can speculate that such procedure could improve the life prognosis of these patients, but no such evidence exists.

Other hemodynamic consequences of AV access

High-flow AV access seems to influence also distant organs by flow competition. One such example is the competition between left internal mammary aortocoronary bypass and ipsilateral upper extremity AV access – discussed below. Similarly, the brain arteries flow may compete with AVA. White matter brain abnormalities and cognitive impairment are known to take place in ESRD

patients. Non-invasively measured cerebral oxygenation is considerably lower in ESRD patients that in healthy controls and it is even more apparent in patients suffering also from heart failure.[24] Lower values of cerebral oxygenation were observed in patients with more advanced cognitive impairment.[25]

Access selection according to the cardiac status

Choosing the adequate vascular access for HF patients is a real challenge. The decision between AV access or catheter placement in these patients should be individualized according to the degree of cardiac involvement.[26]

When planning the best vascular access for each incident HF patient, the risk of HF worsening after AV access creation must be evaluated carefully together with the risk of catheter-related complications, but avoiding a non-selective 'catheter first' approach for all HF patients. On the one hand, the AV access creation can trigger a sudden de-compensation in a previously stable HF patient with ESRD, but, on the other hand, starting HD through a catheter is also associated with significantly higher cardiovascular mortality risk compared to AV access use.[14]

This risk of HF worsening is higher during the maturation period of the AV access due to the great increase in blood flow (Qa) that occurs during this time period.[26] In fact, the clinical impact of AV access creation depends on the balance between the cardiac status (myocardial reserve) and the AV access function (Qa value). For instance, a Qa value of the AV access in the normal range, between 600 and 1200 ml/min can be excessive if there is an impaired myocardial contractility with low cardiac output (low myocardial reserve) because it's not possible to satisfy the extra demand of cardiac output imposed by the AVA creation.[27]

Due to the difference in access resistance and flow volume, the cardiac load will be higher in patients with a proximal fistula than with a distal fistula, and therefore, the likelihood of developing or worsening heart failure will be higher in the former. The general rule for AV access creation, that is, the most distal as possible, can be a life-saving approach for the HF patients.

The cardiac function of each ESRD patient with or without HF should be one of the major criteria for selecting the appropriate access type at the pre-dialysis stage. It is therefore necessary to perform a complete cardiac evaluation, including echocardiography, for assessing the current cardiac situation of each ESRD patient before choosing the access type (including peritoneal access) to start dialysis. Each incident patient with HF should be classified according to the severity of their symptoms in one of four categories (Class I to IV) by the New York Heart Association (NYHA) Functional Classification and also according to the assessment by the American College of Cardiology/American Heart Association (ACC/AHA) in another four categories (Stage A to D)[28] as a clinical tool to choose the best access to start HD. Both classifications have been previously used in ESRD patients[29] and they can help us in deciding, which is the most appropriate access for a given degree of HF. For instance, ESRD patients with HF classified in Class IV from the NYHA or Stage D from the ACC/AHA have the highest risk of clinical worsening and fatal outcome after AVF creation.

Table 3. Proposed selection of the vascular access type according to the cardiac status in patients with contraindications to peritoneal dialysis (modified from Roca-Tey[26]).

Clinical presentation	Type of vascular access proposed
Life-threatening heart failure	Catheter
Left ventricular ejection fraction <30%	Catheter
NYHA class IV and ACC/AHA stage D	Catheter
Most NYHA class III and ACC/AHA stage C	Catheter
ACC/AHA stage A, B and certain C	Distal arm AVF
NYHA class I, II and certain III	Distal arm AVF

NYHA: New York Heart Association heart failure classification; ACC/AHA: American College of Cardiology/American Heart Association heart failure classification; AVF: arteriovenous fistula.

A proposed selection of the vascular access according to the cardiac status is in Table 3.[26] In ESRD patients presenting with life-threatening pulmonary edema, performing the first HD session after a non-tunneled catheter placement in the emergency room is the life-saving resource. HF patients with significant reduction in systolic function (ejection fraction lower than 30%) or classified within the NYHA Class IV and the ACC/AHA Stage D, are candidates for peritoneal dialysis or to tunneled catheter placement to start HD treatment. HF patients classified within the NYHA Class I–II and the ACC/AHA Stage A–B can initiate HD through a distal arm AVF, ideally a wrist or snuff-box radiocephalic AVF. The decision for AV access creation or tunneled catheter placement in HF patients classified within the NYHA Class III and the ACC/AHA Stage C, who cannot be treated by peritoneal dialysis, must be individualized according the degree of systolic and/or diastolic dysfunction. After 2–3 months of progressive ultrafiltration during the HD sessions through a catheter, the cardiac function must be re-evaluated by means of a new echocardiography exam to identify those HF patients showing an improvement in cardiac performance, who will benefit from an AV access creation and catheter removal.

Finally, we must always bear in mind that the wrong access choice in the HF patients can endanger their life. For this reason, it would be better to apply validated predictive models to estimate the flow rate that will have the fistula after its creation or, directly, its cardiac effects.[30] These models can help us to choose with more accuracy the best vascular access for each HF patient.

Management of AV access after kidney transplantation

Although arteriovenous fistulas are the preferred vascular access for patients on chronic HD, it is important to recognize that it results in an additional cardiac burden for these vulnerable patients. LVH and pulmonary hypertension are strong and independent predictors for all-cause mortality and congestive heart failure in both hemodialysis patients and renal transplant patients.[31–34]

While on HD, the benefits of an adequately functioning AV access usually outweigh these detrimental cardiac effects of AV accesses. However, this balance of pros and cons of AV accesses might change after successful kidney transplantation. There is no consensus on the optimal approach regarding AV access management after kidney transplantation.[35] and recommendations in guidelines on this topic are lacking.

Small observational studies suggest that left ventricular mass could improve after AVF ligation in kidney transplantation recipients.[36,37] Recently, a randomized clinical trial on the cardiac effects of AVA ligations was performed in Australia. This study included 63 adult patients who underwent successful kidney transplantation at least 12 months prior to the intervention. Cardiac dimensions were assessed by MRI, at baseline and 6 months later.[38] The primary outcome was left ventricular (LV) mass reduction at 6 months, which decreased with 22.1 g in the group with AVF ligation while an increase of 1.2 g of LV mass was observed in the control group ($p < 0.001$). The cardiac output decreased from 6.8 l/min at baseline to 4.8 l/min at 6 months ($p < 0.05$) upon AVF ligation. Significant decreases in LV end-diastolic volumes, LV end-systolic volumes, atrial volumes and NT pro-BNP were also seen in the AVF closure group ($p < 0.01$). The results of this trial indicate that ligation of the AVF in stable post-renal transplant patients improves LV remodeling.

Although AVF ligation may improve cardiac function, studies on the effect of a functional AVF on kidney function revealed conflicting results, suggesting that kidney allograft function might improve or deteriorate after ligation.[39,40]

With the improving long-term outcomes of kidney transplantation, the proportion of patients returning to hemodialysis decreases substantially. Currently, the 10-year death-censored renal allograft survival after kidney transplantation from brain-death donors is almost 80% in a recent cohort study from Europe.[41] Thus, once patients have a stable allograft function at 1 year after transplantation, the long-term prognosis of the kidney is rather good. In addition, the vascular access that was patent at time of transplantation can only be used in 55% to 70% of cases[42,43] at time of transplant failure and return to hemodialysis due to spontaneous occlusion or ligation of the AV access because of relevant symptoms.

Whether or not to ligate an AV access after kidney transplantation should be a process of shared decision making by the patient and the physician. To properly counsel patients on this topic, a better understanding of the pathophysiology of so-called AV access cardiotoxicity and the risks and benefits of ligation are mandatory. Future studies are warranted to identify patients in whom the cardiovascular benefit of AV access ligation does outweigh the advantage of having a functioning AV access as backup in case of allograft failure.

Heart failure and AV access in peritoneal dialysis patients

Peritoneal dialysis (PD) is the modality of choice in HF patients and it is used even in patients in CKD stage 3–4 with severe, chronic, treatment refractory HF in the peritoneal ultrafiltration mode.[44,45] In several case series, a significant improvement in NYHA functional class and number of hospitalizations reduction were observed in patients treated with peritoneal ultrafiltration.[44] Another issue regrading peritoneal dialysis is whether to place a "back up" AV access in PD patients.[55] Each year, about 10% of PD patients shift to hemodialysis, requiring a vascular access. Thus, in this set of patients it would be useful to have an AV access ready to use. Most of these patients will have a history of recurrent peritonitis, ultrafiltration failure, non-infectious complications such as recurrent hernias or hydrothorax due to dialysate leak. It is not advised placing an AV access in all PD patients, because only a small number of them will be ever used.[56]

Vascular access and ESRD specifics at cardiac surgery

The presence of CKD or even ESRD increases the risk of cardiac surgery procedures.

Coronary artery disease is very frequent in ESRD patients. There is ongoing debate about the preferable method of revascularization – whether percutaneous or surgical. Surgical revascularization has a better long-term efficacy, but at the cost of higher complications rate. The latter include higher incidence of cerebrovascular accidents, infections,[48] bleeding and other heart related complications including long-term mechanical ventilation, all of which is directly connected to a longer stay in the hospital compared to the general population.[48,49]

Numerous studies show that in patients with ESRD on dialysis the hospitalization mortality is between 6.9% to 12.5% after CABG and between 1.6% to 9.5% after PCI.[46,47] However, 2 years after the procedure, the mortality is lower in patients treated surgically (22.6%–43.6% after CABG and 48.1%–59.6% after PCI).[46,47] Moreover, patients treated surgically had lower restenosis rate. Given the higher morbidity and early mortality with CABG the optimal surgical technique for patients with ESRD is currently discussed,

even though both the quality of life and the proven survival rate have improved. We recommend using arterial grafts and mainly providing the operation off-pump – on the beating heart.

Possible flow competition between the left internal mammary artery (LIMA) used for CABG and ipsilateral upper extremity AVF especially during hemodialysis has been discussed – Gaudino et al.[50] studied five patients who needed hemodialysis through the AV fistula in the left upper limb and who had the bypass LIMA on the left anterior descending artery. During hemodialysis, there was a higher flow through the fistula and considerably lower flow in the LIMA bypass, together with hypokinesis of the anterior wall. Conversely, off hemodialysis, both the flow and the kinetics went back to normal. Although the significance of phenomenon was reduced by the finding that only 12% of LIMA bypass patients develop a coronary steal in another study,[51] creation of an AVF on the left upper extremity is not recommended in patients after LIMA-CABG.

Valvular heart disease is also more frequent in the ESRD patients than in the general population. Both valvular stenosis and regurgitation could occur. The stenotic process is accelerated because of changes in the calcium-phosphate metabolism, but also because of hyperkinetic circulation, to which AVF significantly contributes. The regurgitation develops especially on the atrio-ventricular valves. It could be primary (mechanisms similar to stenoses) or secondary – due to the ventricular dysfunction and dilatation. The latter is typical for high-flow AVF and for inadequately high dry weight – both these factors should be corrected prior to considering more invasive valvular surgery. Moreover, infectious endocarditis is also more frequent in dialysis patients and dialysis access-related bacteremia is one of the reasons. Permanent hemodialysis catheters bring higher risk than AVFs.[13] The selection of an appropriate valve substitute remains a controversial topic. Since the 1970s it is believed that the biological valve replacements are prone to quicker degeneration on the basis of calcification in this group of patients, which leads to early reoperation with all the side effects. Many surgeons therefore choose the mechanical replacement in this group of patients, but at the price of higher risk of bleeding and warfarin-induced extraosseous calcifications. The selection of the substitute type should be therefore strictly individualized and nowadays biological valves are indicated more frequently in the majority of ESRD patients.[52]

Cardiac devices and dialysis access

The number of cardiovascular implantable electronic devices (CIEDs) procedures has progressively increased in all CKD patients in the last 30 years mainly because cardiovascular disease including severe arrhythmia and HF is the first cause of mortality in CKD patients, and especially of ESRD patients.[53] CIEDs might interfere with hemodialysis access.[54]

For arrhythmia treatment or sudden cardiac death prevention (primary or secondary), cardiologists offer placement of pacemaker (including biventricular) and implantable cardioverter defibrillator. The most common method of CIED insertion is transvenous placement of the electrical leads plus implantation of an impulse generator in subcutaneous pocket. Other alternatives include epicardial placement of the electrodes, wireless and subcutaneous CIEDs.

The highest risk of complications (mainly superior vena cava syndrome, bloodstream infections with infectious endocarditis) is observed in HD patient with is coexistence of CIED and central hemodialysis catheter.

In general, CVC is in patients with transvenous CIED not recommended. If it is necessary, the suggested site of CVC implantation is contralateral to CIED. Tunellization must be performed with respecting distance to CIED pocket. While implanting (or explanting) central hemodialysis catheter with tip located next to CIED wire one must take in mind that the electrodes could be displaced, which is dangerous especially in pacemaker-dependent patients. A close cooperation with a cardiologist is recommended.

Epicardial leads bypass this collision trajectory with central venous catheters. However, their placement is much more invasive and dedicated to cardio-surgeons. They are usually indicated in patients with also other indication to cardiac surgery. Currently, the use of subcutaneous cardioverter-defibrillators is recommended in patients with advanced CKD (and indication for cardiac sudden death prevention) to leave the venous tree untouched.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: JM is supported by the grant of the Agency of Health Research of the Czech Republic [17-31796A].

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