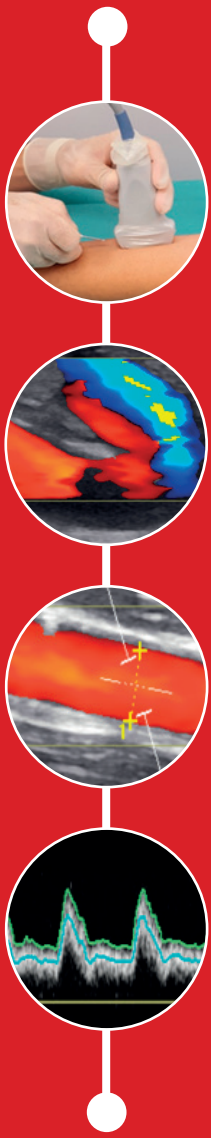
EDTNA/ERCA
Caring Together

HANDBOOK ON ULTRASOUND FOR VASCULAR ACCESS EXAMINATION

From the Specialist to the Nurse



Editors

Rubén Iglesias
Joaquím Vallespín
José Ibeas

HANDBOOK ON ULTRASOUND FOR VASCULAR ACCESS EXAMINATION

From the Specialist to the Nurse

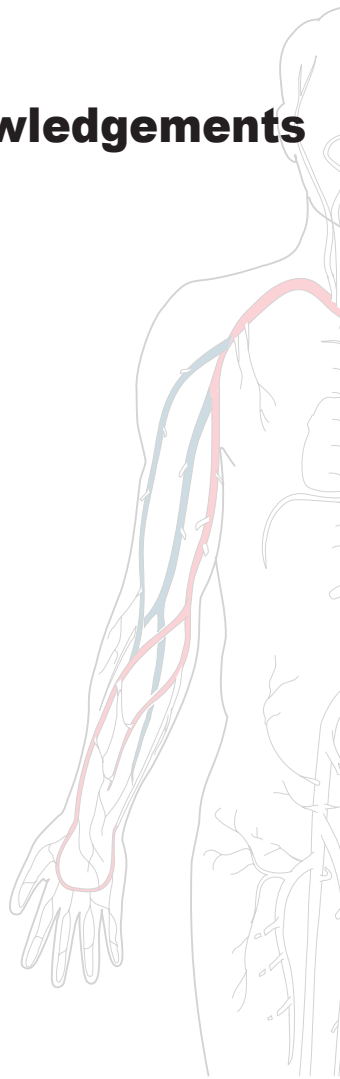
First edition: September 2018

European Dialysis and Transplant Nurses Association/ European Renal Care Association (EDTNA/ERCA)
Seestrasse 91, CH 6052 Hergiswil, Switzerland
www.edtnaerca.org

ISBN: 978-84-09-02800-9
D.L.: M-21331-2018

Layout, Binding and Printing: Imprenta Tomás Hermanos
Río Manzanares, 42-44 · E28970 Humanes de Madrid
Madrid - Spain
www.tomashermanos.com

Acknowledgements



The EDTNA/ERCA Executive Committee acknowledge the Initiative of the EDTNA/ERCA Haemodialysis Consultant Mr. Rubén Iglesias for producing this book. We would also like to thank all the authors and reviewers for their considerable contributions.

The editors and authors acknowledge Parc Taulí Hospital Universitari, Institut d'Investigació i Innovació Parc Taulí I3PT, Universitat Autònoma de Barcelona for the institutional support provided.

Editors

- **Rubén Iglesias**
  Renal Nurse. Vascular Access Program, Parc Tauli University Hospital. Sabadell (Barcelona), *Spain*

- **Joaquim Vallespin**
  M.D. Vascular Surgeon. Vascular Access Program, Parc Tauli University Hospital, Sabadell (Barcelona), *Spain*

- **Jose Ibeas**
  M.D., Ph.D. Nephrologist. Vascular Access Program, Parc Tauli University Hospital. Sabadell (Barcelona), *Spain*

Authors

Jose Ibeas
M.D., Ph.D., Nephrologist. Secretary of the Vascular Access Group of the Spanish Society of Nephrology. Member of the Spanish Multidisciplinary Group on Vascular Access (GEMAV). Member of the Diagnostic and Interventional Nephrology Group of the Spanish Society of Nephrology. International Committee of the American Society of Diagnostic and Interventional Nephrology. President Elect of the Vascular Access Society. Vascular Access Program, Parc Tauli University Hospital, Sabadell (Barcelona), *Spain*.

Rubén Iglesias
Renal Nurse. Haemodialysis Consultant EDTNA/ERCA. Vascular Access Program, Parc Tauli University Hospital, Sabadell (Barcelona), *Spain*.

Jana Merino
M.D., Ph.D. Vascular Surgeon. Certification by the Chapter of Vascular Diagnosis of the Spanish Society of Angiology and Vascular Surgery. Vascular Access Program, Parc Tauli University Hospital, Sabadell (Barcelona), *Spain*.

Carolina Rubiella
Renal Nurse. Member of the Spanish Multidisciplinary Group on Vascular Access (GEMAV).Vascular Access Program, Parc Tauli University Hospital, Sabadell (Barcelona), *Spain*.

Joaquím Vallespin
M.D., Vascular Surgeon. Certification by the Chapter of Vascular Diagnosis of the Spanish Society of Angiology and Vascular Surgery. Secretary of the Vascular Access Group of the Spanish Society of Angiology and Vascular Surgery. Member of the Spanish Multidisciplinary Group on Vascular Access (GEMAV).Vascular Access Program, Parc Tauli University Hospital, Sabadell (Barcelona), *Spain*.

Xavier Vinuesa
Renal Nurse. Vascular Access Program, Parc Tauli University Hospital. Sabadell (Barcelona), *Spain*.

Reviewer

Angela Drähne
Renal Nurse. M.A. Health Economics. Registered Professional Carer (Germany). Member of Interdisciplinary Workgroup Dialysis shunt (Germany). Head of Renal Unit, Bielefeld, *Germany*.

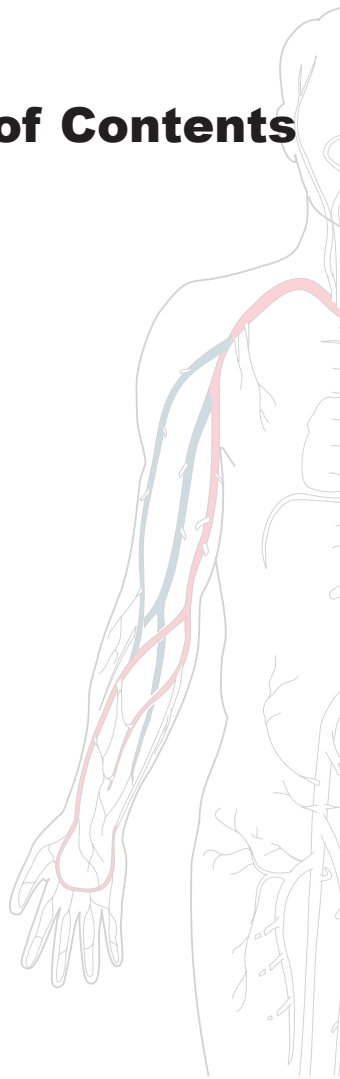
English Proofreading

EDTNA/ERCA acknowledges Mrs. Susan Rogers for her kind cooperation in the proofreading of this publication.

Sponsor

The printing of this book has been sponsored by an unrestricted educational grant from Fresenius Medical Care Deutschland GmbH. A special acknowledgement to Maria Teresa Parisotto for her support with this publication.

Table of Contents



I. Physical Principles of Doppler Ultrasound and its Application in Vascular Access Assessment (Jana Merino) 21

1. B-Mode Sonography 23
   1.1. Probe Choice 23
   1.2. Echo Generation 23
   1.3. Echo Detection: Image Creation 24
      1.3.1. B-Mode Adjustments 25
2. Doppler Sonography 26
   2.1. Colour Doppler 27
      2.1.1. Colour Doppler Adjustments 28
   2.2. Continuous and Pulsed Doppler: Doppler Curves 29
      2.2.1. Doppler Curves Adjustments 30
3. Interpretation of Doppler Curves 31
4. Volume Flow Assessment 33

II. Pre-Surgical Mapping (Joaquím Vallespin | Jose Ibeas) 37

1. Introduction.
   Types of vascular access and best choice 38
2. Clinical history 40
3. Physical examination 41
   3.1. Arterial Examination 41
   3.2. Venous Examination 42
4. Indications for other examination 43

5. Vascular anatomy of upper limbs 44
5.1. Arterial anatomy 44
5.2. Venous anatomy 46
6. Ultrasound mapping 48
6.1. Pre-surgical Mapping of the Arterial System 49
6.2. Pre-surgical mapping of the Venous System 50
6.3. Criteria of Pre-surgical Mapping 53

III. Arteriovenous Fistula Ultrasound Examination (Jose Ibeas | Joaquím Vallespin) 59

1. General examination 60
2. Maturation assessment 61
3. Flow determination 61
4. Resistivity index 64
5. Stenosis detection 64
6. Thrombosis diagnosis 69
7. Aneurysms and pseudoaneurysms 70
8. Steal Syndrome (Distal Hypoperfusion Syndrome) 71
9. Vascular access and cardiovascular disease 72

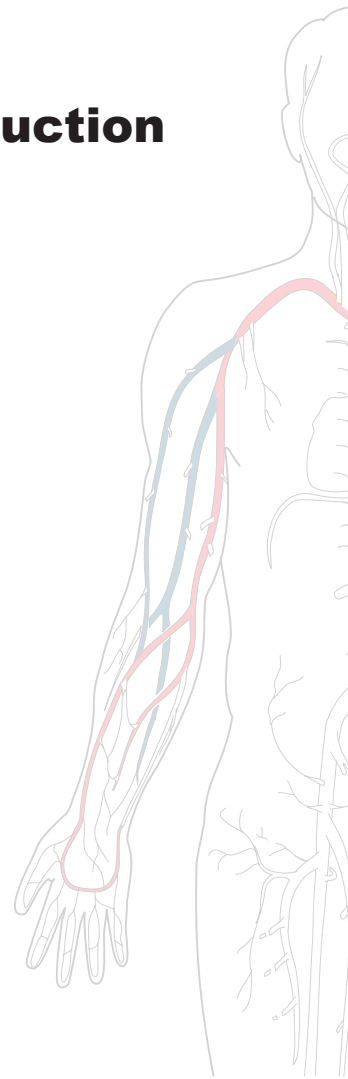
IV. The Role of the Nurse in Vascular Access Ultrasound Examination (Xavier Vinuesa) 79

1. Advantages of using Doppler ultrasound by nurses 80
2. Real time ultrasound-guided cannulation 81
3. First needling 83
4. Cannulation of non-pathological complex nAVF 84
5. Pathological AVF needling 85
6. Spectral wave in the brachial artery 85
7. Resistivity index 86
8. Aliasing 87
9. Individualized AVF approach 88
10. Flow Monitoring 89

V. Routine Examination of Vascular Access (Rubén Iglesias | Carolina Rubiella) 97

1. Arterial examination 99
2. Anastomosis 99
3. Vein examination 100
4. Flow measure 102

Introduction



Introduction

In patients with end stage renal disease (ESRD), the need for vascular access is mandatory to start haemodialysis (HD) as renal replacement therapy. Haemodialysis vascular access is the key point of the therapy. No working vascular access, no therapy.

Vascular access guides recommend native arteriovenous fistula (nAVF) as the ideal vascular access type, mainly for its long durability, higher patency and low rate of complications. In the last few years, the age of patients with ESRD starting haemodialysis as renal replacement therapy has increased significantly, so this means patients with a higher incidence of multi-pathology, including peripheral vascular pathology or diabetes mellitus. These factors impact on the success and associated complications of the vascular access. With all these factors in mind, follow-up of vascular access is a very important issue throughout the therapy. Various tools are available to perform this follow-up.

Doppler ultrasound is one of the surveillance tools. This tool has a considerable number of advantages above others, as it is a non-invasive method, permits the morphological and functional study of the access and with the latest generation of portable devices can be done in the HD unit, at the patient's bedside. Vascular access surveillance using Doppler ultrasound has been shown to reduce vascular access complications and increase long-term patency.

Doppler ultrasound helps to facilitate quick decisions and avoids wasting time referring the patient to other departments. It allows multidisciplinary team decisions on diagnosis of the pathology to be undertaken. Doppler ultrasound has now arrived in the field of nursing. It helps nursing staff make decisions on where to insert the needle, decide if a vascular

access is ready to use during the maturation process and reduces extravasation in difficult types of cannulation. Nurses can play an important role in vascular access surveillance, because they have most contact with the access, so are highly familiar with the access and can detect immediately if something is wrong. In that case, in a multidisciplinary context, nurses can help the team diagnose problems using Doppler ultrasound.

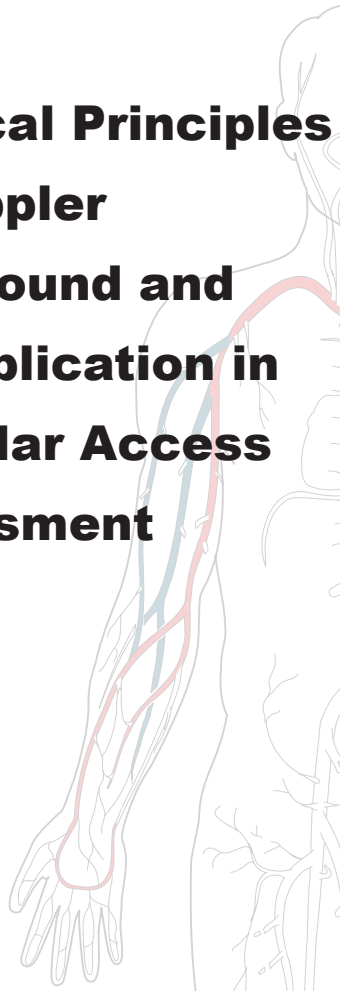
The aim of this handbook is to provide users with a practical guide to vascular access ultrasound use, with basic principles and applications to daily practice.

Who is this addressed to: from physicians to nurses

Aims for this handbook:

- To review the basic principles of ultrasound
- To review how to perform and interpret the mapping prior to arteriovenous fistula creation
- To review how to perform the systematic ultrasound examination in the arteriovenous fistula
- To review how to conduct surveillance of the arteriovenous fistula and diagnose different pathologies
- To help in daily clinical practice for nurses supporting cannulation practice and assisting them to rule out pathology

Physical Principles of Doppler Ultrasound and its Application in Vascular Access Assessment



Jana Merino

Medical ultrasound (US) is based on the use of high-frequency sound and the analysis of the variation that exists when it rebounds off different structures.

A probe or transducer is used to obtain US image on the screen, which emits sound waves with a frequency greater than audible sound. Fequencies from 2 to 20 megahertz are required for medical application. The probe is composed of piezoelectric crystals or ceramics with piezoelectric properties: when electric power is applied, the particles move and waves are produced. These waves propagate through tissues and variable amounts of sound waves are reflected towards the interface through the different tissues with different impedances. Thus, the probe which emits these waves also senses the reflected waves (echoes) and converts them into electrical energy. The transducer converts one type of energy into another (electrical <--> mechanical/sound).

US devices make efficient use computer capabilities to process the received information. Thus, based on the distance travelled by the wave before it is reflected and on the frequency changes experienced by the wave, this information is presented on a two-dimensional screen in grey scale. Finally, this image is assessed and used to make a decision.

There are different types of ultrasound. In this chapter we will explain: B-mode and Doppler sonography, given that these are the most useful in vascular access examination.

1. B-Mode Sonography

1.1. Probe Choice

First of all, there are different kinds of probes with several emission frequencies. The absorption level should be known to choose the best probe for each examination.

Due to the friction of particles, energy turns into heat, thereby increasing the average temperature and decreasing wave energy. This absorption depends on US frequency.

The higher the emission frequencies, the higher the absorption and the lower the penetration. Therefore, when emission frequencies are high, absorption is also high and, as a result, penetration is low. Consequently, the probe should be chosen with a specific frequency according to the depth of the studied area.

A linear probe with high frequency (between 7 and 12 MHz) should be selected to explore superficial structures like arm vessels, such as a vascular access. In contrast, a probe with low frequency (between 3 and 5 MHz) should be selected to explore deep structures like the kidney.

1.2. Echo Generation

Echoes are produced by the interaction of ultrasound with the medium they pass through.

Different tissues present different **impedances**, that is to say, the resistance that each tissue opposes to the passage of ultrasound. The separation surface between two media with different impedances is called the **interface**. When the US beam passes through an interface, part of this beam is reflected and another part continues forward. The relation

between emitted and reflected intensity is **reflection**, and the greater the reflection, the greater the difference between tissue impedances.

In addition, when the US beam reaches the interface obliquely, it is reflected and **refracted**. In the same way as reflection depends on different impedances between tissues, **refraction** depends on different US velocity in these tissues and modifies beam direction.

1.3. Echo Detection: Image Creation

Different intensity of received echoes is reflected on the screen using a grey-scale image, where tissues with low impedances (like liquid, blood and cyst) are shown towards the black scale (hypo-echogenic) and tissues with high impedances (like bones or catheter) are shown in the white scale (hyper-echogenic). Different grades of grey are used to differentiate soft tissues.

US is **attenuated** when it passes through a medium. **Attenuation** is energy loss due to absorption, reflection, refraction and diffusion, and it is higher for deep areas, so the echo intensity received from deep fields is lower than superficial field echoes. (Fig. 1)

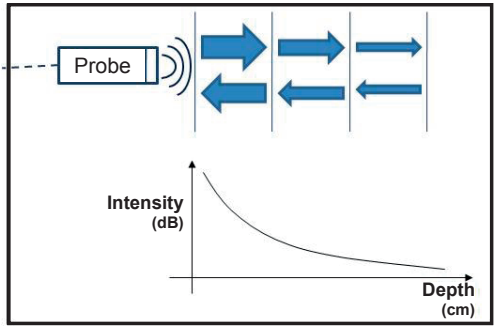


Figure 1. Ultrasound attenuation

Since the signal received from deep areas is lower, the intensity of these deep echoes should be increased, and this is possible using gain (see B-mode adjustments).

A US device calculates the distance to the different surfaces (interfaces) using the time between wave emission and reception to locate each object on the screen. Since emitted waves travel through tissues and are reflected back to the probe, the distance to this interface will be: d=1/2 x c x t, where c is US velocity (in soft tissues it is considered 1.54mm/s) and t is the time taken by the wave to rebound back.

Regarding image temporal resolution, US devices allow real time image when they can process 15 images/second. Current devices can do this, but when using colour Doppler and Doppler curves, temporal resolution may decrease because more process capability is required. Thus, to assess structures, B-mode is the best option to obtain the best resolution as possible and structures have to be insonated perpendicularly to allow the probe to capture most of the reflected echoes.

1.3.1. B-Mode Adjustments

To optimize B-mode image:

- The most appropriate probe should be chosen (*see 1.1.*)
- **Depth** must be modified to see the object of interest in the centre of the screen.
- **Focus**: The best resolution occurs where waves concur. This point is called the focus and is shown by a triangle on the side of the screen. Depth can be modified.
- **Gain**: As previously commented, because of attenuation, echo intensity received from deep fields

is lower than superficial field echoes. Since the signal received from deep areas is lower, gain can increase the intensity of these deep echoes and helps to compensate for any loss of intensity.

Gain should not be confused with **grey scale**, which modifies brightness intensity. Gain is usually modified by sliding buttons representing the different depth zones, and should be increased for deep areas to balance the processed signal. In addition, brightness intensity can be modified by turning the corresponding knob.

2. Doppler Sonography

It is important to know what the Doppler effect is in order to understand Doppler adjustments and optimization.

Doppler effect is the change in frequency of a wave perceived by an observer when the wave and the observer move towards or away from each other. In echography, US changes its frequency when it rebounds off a moving object (or reflector). Frequency varies according to reflector speed, so frequency changes depend on emitted frequency, reflector velocity, US velocity in the medium and cosine of the incidence angle (that is, the angle between the US beam and reflector movement). Reflector velocity is deduced using the following equation. (Fig. 2)

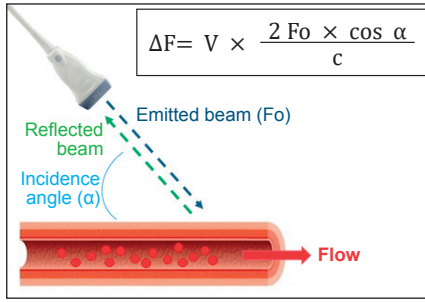


Figure 2: The Doppler effect / Equation for reflector velocity

Therefore, an incorrect incidence angle could distort results:

- If the incidence angle is too high, the cosine approaches zero, and obtained velocities are lower than real.
- If the incidence angle is too low, the US beam cannot penetrate into the vessel.

So, the insonation angle should be between 30 to 60º, and never higher than 60º.

If the reflector is moving towards or away from the source of the waves, frequency increases or decreases, and flow becomes red or blue on the screen. However, current devices allow us to invert these colours.

Thus, Doppler sonography allows us to detect flow velocities, and can show them on the screen through a colour scale or Doppler curves.

2.1. Colour Doppler

Colour Doppler shows a semi-quantitative velocity image. The colour scale gives us an idea of high or low velocity.

Bright colours represent high velocities and dark colours, low velocities, but it is not an exact value in units.

Since blood flows according to **Poiseuille**'s law, due to viscosity, velocity is lower near the vessel wall and higher in the vessel centre. This means that colours detected in the vessel centre are brighter than the periphery.

2.1.1. Colour Doppler Adjustments

- The **window shape** and **size** must be adjusted to the target vessel. If the box is too big, the processing capacity required increases, and the number of images processed in a time unit decreases, so the optimal real-time image cannot be obtained.
- **The colour box** should be placed over the vessel to be insonated at 60º (never >60º) to obtain correct velocity values. It is essential to remember that velocity assessment is influenced by the insonation angle. Care must thus be taken; otherwise, an incorrectly guided box might not show flow and be interpreted as vessel thrombosis.
- **Colour gain** must be increased to colour the entire vessel (from wall to wall) without causing speckling beyond the vessel. If gain is not suitable, we might not see an existing flow.
- The appropriate **colour scale** must be used. The colours shown in the colour scale correspond to specific values. The ends of the scale, which are brighter, represent the highest velocities. These values can be modified by making the scale more or less compressed. If high velocities are expected in a flow, the maximum values for the scale must be increased. If the values are not high enough, an image with colour

mosaic and glitter excess is obtained, although there is no turbulent flow. However, if values are too high, less colour will fill the vessel and it is possible to make a mistake and consider that there is no flow.

- **Aliasing** is a phenomenon produced when the capacity to measure the blood velocity of the equipment (speed scale) is lower than the speed of the blood in the examined vessel. The maximum speed of the scale is limited by the number of pulses per second that can be emitted and received by the transducer. The colour image will show an area of turbulence without a defined colour.

2.2. Continuous and Pulsed Doppler: Doppler Curves

US devices provide us with a velocity-time graph by analyzing the change in frequency of the emitted echo when it rebounds off a moving receptor. This is possible using continuous Doppler or pulsed Doppler.

In **continuous Doppler**, the probe is composed of a US issuer and an echo receiver. As it can issue, receive and analyse frequency changes continuously, and can give us a time-velocity graph. However, this method cannot give an image on the screen, because it is not able to analyze the time taken by the wave to leave and return.

In **pulsed Doppler**, the issuer itself is the object that receives echoes and analyzes them. Wave pulses are emitted and the probe analyzes not only the frequency changes but the time each pulse takes to return. So, it not only gives us velocity information but image information. With this mode, B-mode image and flow velocity are obtained at a specific point.

2.2.1. Doppler Curves Adjustments

- The US beam must be placed to insonate flow at ≤60º to avoid underestimation of velocities.
- **Sample Volume** must be adapted to vessel size. If velocity is to be measured, sample volume must be narrow and located in the centre of the vessel since the arteriovenous fistula usually has a very turbulent flow, sample volume must be narrow and located in the centre of the vessel. Nevertheless, if flow volume is to be measured, the sample should cover most of the vessel section as velocity differs in the centre and periphery of the vessel. The vessel wall should be excluded since its pulsatility could influence velocity assessment. The ideal way to do this would be to use a sample volume covering two thirds of the vessel section.
- **Gain** can also be modified to avoid speckling or to intensify obtained signal.
- The **base line** can be moved to visualize the whole curve.
- **PRF,** the *Pulses Repetition Frequency*, is an important issue that needs to be known. Since the emitted pulse must be received before emitting another, PRF will have to be adjusted to the depth studied; otherwise, the analysis would be incorrect.

In addition, since waveform needs at least two sample points per cycle, PRF must be modified depending on the suspected velocity. In other words, the wave's frequency must not be above half the sampling frequency. This limit is called the Nyquist limit of a given sampling frequency. If the Doppler change is greater than the Nyquist limit, "aliasing" occurs. In

the pulsed Doppler, aliasing is manifested by decapitating the maximum velocity peak at the high limit of the scale.

Therefore, if high speed flow is being measured by ultrasound waves, PRF must be increased, and in the case of low velocity flows, PRF must be decreased. PRF is the scale we use to assess specific flow and must be adjusted to velocity.

3. Interpretation of Doppler Curves

To interpret the information provided by Doppler curves, some concepts must be familiar:

- **PSV**: peak systolic velocity, which is the maximum velocity in the systolic phase.
- **EDV**: end diastolic velocity, which is the velocity at the end of the diastolic phase.
- **Resistivity index** (RI): this is the resistance and compliance of a vessel. It is the relation between PSV - EDV and PSV. (Fig. 3)

Flow in a blood vessel is regulated by Ohm's law ($Q=\Delta P/R$), which means that it is directly proportional to the difference of pressure between two points, and inversely proportional to the resistance to flow offered by vessels. It differs in central and peripheral vessels.

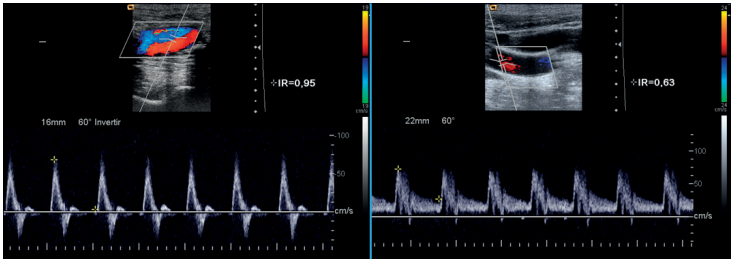


Figure 3. Resistivity Index (RI). High RI (left) and low RI (right).

In *central arteries*, such as the carotid or renal arteries, resistance is low, arteries are compliant, so RI is low. Throughout the cardiac cycle, velocity is positive in the graph.

In *peripheral arteries*, such as the brachial or femoral, resistance is high, arteries are not very compliant, so RI is high. In the cardiac cycle, there is a systolic peak, with fast acceleration and a later negative phase with little positive rebound. This is a triphasic curve.

Veins do not have systolic acceleration and display a continuous flow with low velocity that can be modified with different manoeuvres, such as distal compression or breathing.

When a vascular access is created, the peripheral artery, which normally presents a triphasic curve, leads to a vein, that is, to a very low resistance vascular bed. Because of that, the curve in this artery becomes biphasic, with a low resistive index and high turbulence.

Moreover, Doppler curves help us to identify vessel stenosis. Since flow in a closed circuit must be constant, when some segment of this circuit decreases in size, velocity at this point increases in an attempt to keep flow constant. Flow depends directly on the area that it is passing through and its speed.

Flow = volume / time = area x velocity. Thus, when velocity at one point increases two- or threefold in relation to the velocity in the previous segment, the existence of a stenosis at that point should be ruled out.

4. Volume Flow Assessment

Flow estimation allows us to make a functional access evaluation. Modern US equipment has volume flow measurements as part of the standard parameters assessed during vascular evaluation.

Volume flow measurements have low reliability and are not accurate for normal vascular systems. But when an arteriovenous fistula is placed and flow increases one to two thousand percent, ultrasound flow estimation becomes a good method for functional evaluation. In this case, a range of error between 5 and 10 percent becomes acceptable. In fact, volume flow measured with a US scan has shown good correlation with other accepted methods of flow measurement.

Flow refers to the volume that passes through a vessel in a time unit, or in other words, a cross-sectional area of the vessel multiplied by the velocity of its flow:

$$Q = V/t = a \ x \ v = \pi r^2 \ x \ v_{tam}$$

Where: V is volume, t = time, a = area, v = velocity, r = vessel radius, and v_{tam} = time averaged mean velocity.

Echography allows us to calculate the flow since vessel diameter (and then the area) can be obtained thanks to B-mode, and v_{tam} is calculated from Doppler curves. These measurements (area and v_{tam}) should be obtained at the same vessel point, and to correct flow estimation, this vessel segment should be homogeneous, without dilations and not

easily compressible. Brachial artery proximal to its bifurcation meets these criteria. Moreover, to measure V_{tam}, sample volume should include two-thirds of the vessel in order to take full range of vessel velocities. (Fig. 4)

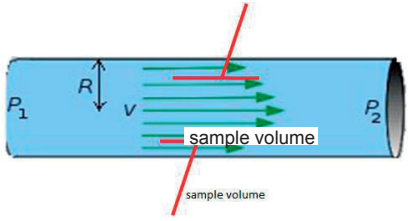
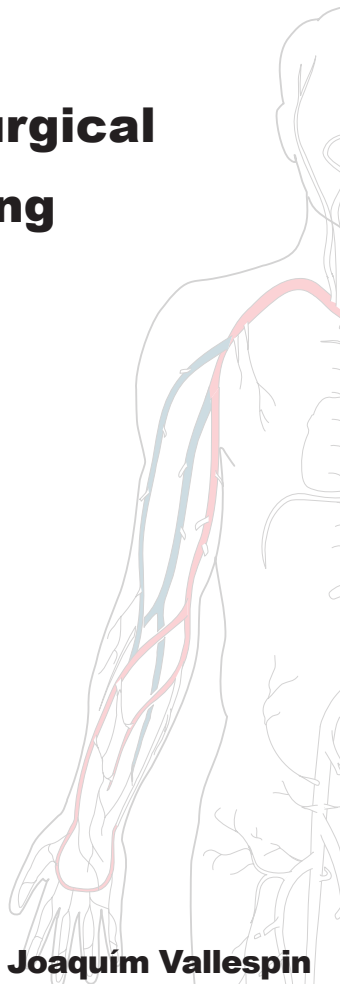


Figure 4. Sample volume

Bibliography

1. Hangiandreou NJ. AAPM/RSNA physics tutorial for residents. Topics in US: B-mode US: basic concepts and new technology. Radiographics 2003;23:1019-33
2. Thrush A, Hartshorne T. Peripheral Vascular Ultrasound. 2 ed. Michigan-. Elsevier; 2007
3. Hofer M. Ultrasound Teaching Manual. The basics of performing and interpreting ultrasound scans. Thierme, 2nd ed, 2005
4. Fontcuberta J. Doppler ultrasound examination in vascular pathology. Vol I. Barcelona: Viguera; 2009
5. Vascular diseases. Vol I. SEACV. Barcelona: Viguera;2006
6. Hennerici MG, Neuberger-Heusler. Vascular diagnosis with ultrasound. 2 ed. Amolca 2009.
7. Fontcuberta J. Manual práctico de exploración eco-doppler del sistema arterial y venoso de las extremidades inferiores. CDVNI. Sociedad española de angiología y cirugía vascular
8. Hollenbeck M. Flow measurement in dialysis shunts. Nephrol Dial Transplant 2001; 16: 2445
9. Malik J. Local haemodynamics for the vascular access for hemodialysis. Kidney Blood Press Res 2009; 32: 59-66
10. Zanen AL. Flow measurements in dialysis shunts: lack of agreement between conventional doppler, CVI-Q, and ultrasound dilution. Nephrol Dial Transplant 2001; 16:395-399
11. Van Holand S, Malik J. Hemodialysis vascular access ultrasonography: tips, tricks, pitfalls and a quiz. J Vasc Access 2010;11(4):255-262

Pre-Surgical Mapping



Joaquím Vallespin

Jose Ibeas

1. Introduction. Types of vascular access and best choice

Patients with advanced chronic kidney disease with planned initiation of renal replacement therapy via haemodialysis (HD), need the creation of a definitive vascular access (VA) for HD.

Of all the available access types, native arteriovenous fistula (nAVF), also called autologous arteriovenous fistula, is undoubtedly the best option. It lasts a long time, has a low rate of complications, and is relatively simple to create, so it has been in general use since it was described in 1967. It has thus allowed the universal uptake of renal replacement therapy via haemodialysis.

However, nAVF are not possible in all patients, as in most of these cases there are no superficial veins with the necessary characteristics that can be used for repeated cannulations. Sometimes it is necessary to plan the creation of a prosthetic arteriovenous fistula (pAVF), in which a synthetic conduit, usually expanded polytetrafluoroethylene (PTFE), is provided between the artery and the vein. pAVF have an acceptable level of patency but a higher rate of complications, especially thrombosis and infections, Thus they are considered as the second-choice option, following nAVF.

Even so, in many patients the arteriovenous fistula (nAVF and pAVF) becomes exhausted in time, or cannot even be created initially, so HD has to be performed by placing a central venous catheter (CVC). The high rate of associated complications means that CVC has to be considered as the last resource for HD.

When access creation is planned, there are other considerations which must be taken into account, namely proximal or distal location. Distal VAs (nAVF in wrist and forearm) are created in vessels with a lower diameter using a radial artery to provide

forearm cephalic venous flow. This has a higher rate of primary failure, but offers a longer segment for cannulation (arm and forearm veins). In addition, it enables the subsequent creation of another access in proximal vessels, making a distal VA the VA of first choice. However, nAVF created in antecubital fossa and upper arm (brachio-cephalic, brachio-perforating and brachio-basilic nAVF) usually have higher inflow into the access, but can impede future distal access creation, and are associated to higher incidence of ischaemia (steal syndrome or distal hypoperfusion syndrome).

Finally, an nAVF can be placed in either upper limbs with no differences in complications, but the generalized opinion is to first choose the non-dominant arm in order to stimulate and motivate patient activity with the dominant limb and allow the highest comfort possible in HD sessions.

For that reason, the order of priority for vascular access creation is recommended as following:

I. First choose native arteriovenous fistula; secondly, prosthetic arteriovenous fistula and last CVC.

II. Make the access as distal as possible, that is:

   A. Carpus

   B. Forearm

   C. Elbow (antecubital fossa).

III. Use the non-dominant limb.

Therefore, the most frequently used order of creation will be:

1. nAVF radio-cephalic
2. nAVF brachio-cephalic

3. nAVF brachio-basílic
4. pAVF in arm
5. pAVF in thigh
6. CVC

As explained, the dominant limb should be respected whenever possible.

2. Clinical history

The main tools used when deciding where to place the future VA is both correct physical examination and ultrasound mapping of the limb.

Nevertheless, a correct medical history must be firstly gathered before proposing a VA. Knowledge of a patient's medical history can provide data to help us be aware of the presence of non-evident pathology, which has to be confirmed by different complementary examinations (Doppler Ultrasound and angiography).

For instance, Diabetes Mellitus usually produces calcifications in artery walls; these calcifications in the artery wall can impede correct vessel dilation and with that hinder the increase in blood flow needed for correct maturation of the nAVF, so in diabetic patients it is very important to evaluate the dilation capacity of the limb arteries, as will be seen below (hyperaemia test).

A background of CVC placements in upper central veins is another factor that has to be taken into account because it is frequently associated with the presence of central venous stenosis, which can compromise the correct development of the future access.

Finally, in patients with peripheral arteriopathy, physical examination and ultrasound mapping have to rule out the possible presence of arterial stenosis that can impede nAVF maturation.

3. Physical examination

Physical examination of the patient, along with ultrasound mapping, can provide the best quality information in order to plan the future access.

It should be performed in a warm environment, to avoid vessel spasms, with the patient sitting and the arm lowered. Attention must be paid to the presence of asymmetries between both upper limbs and to the development of superficial collateral circulation, signs that will make us suspect the presence of stenosis or central venous occlusions.

It is also important to evaluate the presence of significant adipose tissue: in an obese patient, the depth of the veins may hinder and even prevent the cannulation of the vessel.

3.1. Arterial Examination

It is essential to explore the arterial tree in the upper limb in order to determine the correct permeability of the vessels that will provide the flow to the nAVF. The presence of pulses, as well as their amplitude, should be investigated at all levels of the limb (radial, ulnar and brachial pulses in the antecubital fossa), paying attention to the presence of asymmetries between the two upper limbs.

Blood pressure at the brachial level should be taken routinely, as the presence of asymmetries is a very sensitive and early sign of the presence of arterial stenosis.

Finally, the Allen test (Table 1) will allow the determination of the permeability of the palmar arch, and assess the dominance of the distal (radial and ulnar) arteries in the vascularization of the hand.

AllenTest
Manually compress the arteries of the wrist (radial and ulnar) until the presence of signs of ischaemia are visible in the hand (paleness, lack of capillary refill).
Decompress the radial artery to assess the degree and speed with which the signs of ischaemia disappear.
Repeat the compression of both arteries until you see the presence of ischaemia signs again.
Decompress the ulnar artery to assess the disappearance of ischaemia signs.

Table 1. How to conduct an Allen test

3.2. Venous Examination

The aim of venous examination is to detect the presence of a venous duct with sufficient length and continuity to the deep venous system (axillary veins and subclavian). This duct must not have significant tortuosity, must be easily compressible during palpation along its entire length and have the capability of distension after positioning the compressor.

It includes the evaluation of both superficial veins of the upper limbs: cephalic vein and basilic vein, both at the level of forearm and antecubital fossa.

The evaluation comprises determining the diameter, vein continuity and distensibility, and determining the increase in

percentage of the diameter after the placement of a proximal tourniquet.

4. Indications for other examination

A properly performed physical examination can provide fundamental information required to create the access, but it may not be enough. In patients with poorly visible veins, obese arms, non-palpable pulses, central or peripheral pathways, or with cardiovascular risk factors, it may be necessary to have additional information about the condition of the vessels in the limb.

Phlebography is a test that provides precise anatomical information in two dimensions, but it is an invasive exploration that requires the administration of radiological contrast with the risk of nephrotoxicity.

In contrast, Doppler ultrasound (echo-Doppler) is a test that provides accurate information in 3 dimensions, with morphological as well as dynamic information, without deterioration of the patient's renal function. Therefore, it is considered the better investigation method as it provides more information on the state of the patient's vessels.

Last editions of the clinical guidelines on vascular access recommend Doppler ultrasound to perform mapping in all patients who are candidates for vascular access, as it allows the best available vessel to be determined, and also the venous capital of each patient to be identified, in order to plan both the best access in each situation and possible alternatives.

Doppler ultrasound scanning should be performed with a high-frequency ultrasound probe, 7-12 MHz, with a Doppler signal greater than 5 MHz, which allows for satisfactory visualization of the superficial tissues.

Doppler ultrasound devices currently rely on four modes:

1. B-mode: Provides morphological information on tissues and is useful for venous study
2. Mode M: Morphological changes information per unit of time, but this has little utility in the VA study.
3. Echo-Doppler: Simultaneously provides B-mode morphological information and Doppler spectral analysis of the flow at the selected point. This is the most useful mode for VA scanning.
4. Echo-Doppler colour: Supplementary mode to the previous one, in which the flow detected is transcribed in colour scale. It is useful for the assessment of the arterial tree and to detect the appearance of stenosis in nAVF.

The examination should be performed with the patient in a semi-recumbent position in a warm environment and with the arms lowered, in a similar way as described in the physical examination.

5. Vascular anatomy of upper limbs

In order to perform correct echographic mapping, it is imperative to know the normal anatomy of the explored vessels.

5.1. Arterial anatomy

The **subclavian artery** is the artery that provides the vascularization of the upper limb. It is the branch of the aorta on the left side and the terminal branch of the brachiocephalic trunk on the right side. It lies for a short distance beneath the clavicle, which prevents its correct echographic visualization.

The **axillary artery** is the continuation of the above, and covers the sector from the outlet below the clavicle to the anterior axillary line. It is easy to visualize in the axillary space with the arm in hyper-abduction.

The **brachial artery** is a continuation of the axillary artery in the arm, and is located in relatively deep position in the inner side of the arm. It is accompanied by two brachial veins and the median nerve, in the groove between the biceps and triceps muscles. As it approaches the antecubital fossa, it progresses from an internal location to a location at the front of the arm, bifurcating at the elbow.

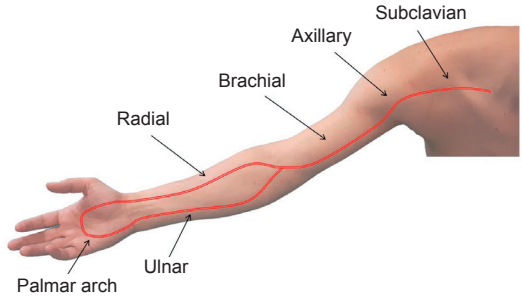
The **radial artery** is the terminal branch of the previous one, which runs through the outer border of the forearm, progressively coming out to its superficial location on the wrist. In 10-15% of the cases there is an anatomical anomaly consisting of the early exit of this artery from the brachial or even the axillary artery.

The **ulnar artery** is the branch of the brachial artery that follows a path from the antecubital fossa along the inner border of the forearm, progressively coming to the surface at the wrist.

It usually has a common origin with the interosseous artery (ulnar-interosseous trunk), a deep artery that follows a deep course in relation to the interosseous membrane.

The **palmar arch** is the distal anastomosis between the radial and cubital arteries, where the digital arteries emerge. It usually consists of two arches, superficial and deep, and is often not fully developed. Its functionality is explored through the Allen Test.

Arterial anatomy

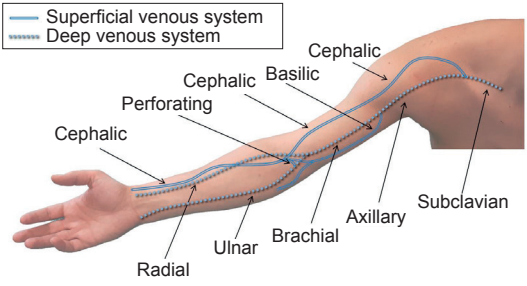


5.2. Venous anatomy

Venous drainage in the upper limbs depends on two systems: superficial and deep.

The deep venous system, usually undeveloped, accompanies the major arteries, in an even number, which causes the echographic image known as “Mickey Mouse ears”. (Fig. 1)

Venous anatomy



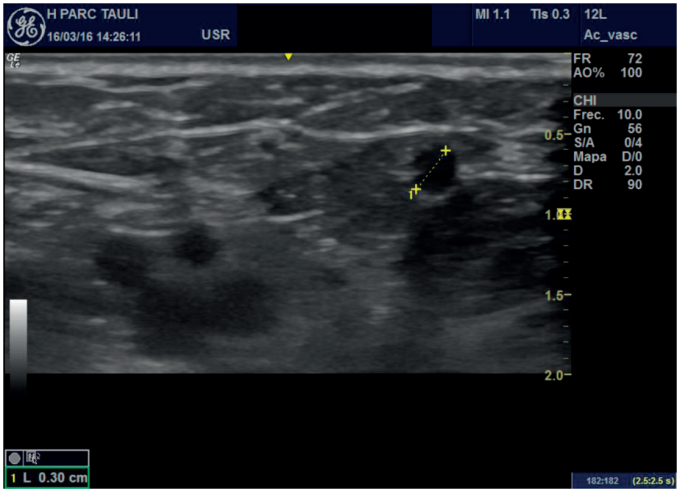


Figure 1. B-Mode. Brachial artery in the left side with accompanying veins (Mickey Mouse ears). Basilic vein in right side (3 mm).

The superficial venous system is usually more developed than the deep one in the upper limbs, and it consists of two main veins:

The **cephalic vein** is the most constant superficial vein, as well as the longest. It is located on the external side of the forearm and arm, and is superficial throughout its course, so it is the best vein for cannulation during HD. At the elbow level, in the antecubital fossa, it usually receives a vein from the perforating vein, called the cephalic communicant. It drains into the deep venous system at the level of the axillary vein in the deltopectoral groove near the lower edge of the clavicle.

The **basilic vein** is located on the inner edge of the arm and forearm. It is a vein that lies deeper in the forearm than the previous one, which makes it difficult to cannulate, but at

the same time it is usually better preserved from cannulation injuries. In the antecubital fossa it is superficial, suitable for cannulation, and can receive a collateral vein coming from the perforating vein, called the basilic communicating vein. Proximal to the elbow, it is placed below the superficial fascia of the arm, and this is the reason why it must usually be surgically raised to a more superficial level for cannulation. Its drainage in the deep venous system is located in the middle to proximal third of the brachial vein. Because of its greater depth and shorter length, it is a vein that is less suitable for HD cannulation than the cephalic vein.

6. Ultrasound mapping

The equipment must be adjusted to detect slow flows by decreasing PRF and increasing colour gain. Abundant gel should be used to avoid losing information at the sides of the probe where the forearm has curves. Pressure should not be placed on the skin as superficial veins easily collapse.

The patient should initially lie down on their back, without bending the elbow. The arterial system is examined in this position to measure arterial pressure and to assess subclavian and axillary veins. To assess veins in the arms, it is advisable to raise the patient's head by 45º, to make sure the arm is relaxed and to place a tourniquet to dilate the veins. It is important to have a warm atmosphere to avoid venous vessel spasms. In leg examination, the leg must be rotated externally.

Morphological examination is carried out transversally and dynamic examination is performed longitudinally. It is advisable to begin the examination transversally, starting with the artery at distal level and moving proximally. The same examination is then repeated in veins, thereby allowing observation of the whole anatomy. Afterwards, the same examination is repeated

longitudinally to the vessel: first, the artery with colour, which allows us to assess areas with aliasing, and then with Doppler, to measure PSV.

6.1. Pre-surgical Mapping of the Arterial System

Doppler ultrasound examination of the arterial tree should be made initially by transversal sections in B-mode, to assess and record the presence of arterial calcifications and measure the internal diameters (diameter of true lumen) of the arteries explored. Likewise, through B-mode, the presence of anatomical anomalies (abnormal output of the radial artery) can be determined.

The examination is followed by longitudinal sections with colour Doppler and Doppler curve analysis which, in the absence of pathology, will be typically three-phase, with an accentuated systolic peak followed by a diastolic inversion of lower amplitude and a new positive wave corresponding to the end diastolic velocity.

The insonation angle of the Doppler beam should ideally be 60°, in no case bigger, since different angles will cause errors in the measurement of flow velocity inside the vessel.

Thus, the Doppler wave should be checked both in the brachial artery and in the distal trunks, mainly in the radial artery. The three-phase morphology of this curve under normal conditions should be maintained along both arteries. The presence of haemodynamically significant stenosis will result in an acceleration of peak systolic velocity (PSV) together with a widening of the spectral wave located at the point of the stenosis, all of which is associated with a flattening of this wave in the distal arteries to the stenosis.

Ultrasound Signs of Haemodynamically Significant Stenosis
Place of stenosis
⟶ Increased PSV
⟶ Spectral Widening
Distal arteries to Stenosis
⟶ Decreased PSV
⟶ Flattening of the Spectral Wave

6.2. Pre-surgical mapping of the Venous System

As discussed, the objective of venous mapping is to identify a candidate vein suitable for nAVF. Therefore, this examination should be done mainly by transversal sections in B-Mode, which will allow a morphological study of the vessel. (Fig. 2)

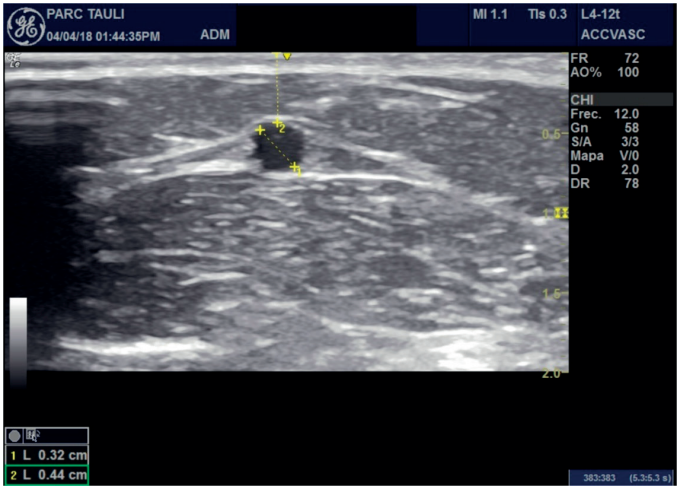


Figure 2. B-mode. Pre-surgical mapping.
Measurement of the diameter of the cephalic vein in the forearm: 3.2 mm. Depth 4.4 mm.

In the evaluation of the veins in the upper limbs, the candidate vessels must have two ultrasound characteristics:

First, the vessel must be permeable, which in the case of superficial veins is detected by compressibility and by the wave surge to distal compression.

Compressibility is checked in B-mode by placing the probe transversely to the major axis of the vessel and pressing on it until the vein totally collapses. The presence of thrombus prevents the total collapse of the vein's walls, whereas the existence of thickenings in the vein's wall is a sign of phlebitis (current or old) of the vessel.

The rising wave at distal compression is scanned in echo-Doppler colour mode with the probe placed transversely over the vessel to be scanned. If compression is exerted on the distal area, by manually compressing the forearm or hand, an increase in the venous return flow will occur, which can be easily detected using colour, whereas in occluded vessels no flow will be visualized.

The second characteristic to be explored in the venous system is the distensibility of the vessels, which is also evaluated in B-mode with the probe placed transversely, showing the change in calibre that occurs in the veins after the placement of a proximal tourniquet, where the higher the distensibility, the greater the increase in vessel calibre.

Ultrasound Characteristics of the Venous System
Permeability
→ Compressibility
→ Augmentation wave at distal compression
Distensibility
→ Diameter increase after proximal tourniquet placement

The characteristics mentioned above should be evaluated at all levels of the superficial venous system to be explored:

Proximal veins. Axillary and Subclavian. As has been commented, it is not possible to directly visualize the subclavian vein and the brachiocephalic trunk in all its extension because of its anatomical location, so the study of these vessels must be performed by the detection of indirect signs of permeability:

Respiratory Phasicity. Under normal conditions, a negative pressure occurs at the level of the thorax during inspiration, which causes the central veins to fill, producing a blood sucking effect from the veins of the upper limbs to the intrathoracic veins and cardiac cavities. In the absence of pathology, a "surge" will be detected in the venous flow, detectable in the more proximal axillary and brachial veins, by an increase in flow during inspiration.

The presence of stenosis and / or an occlusion in the central veins (subclavian vein, brachiocephalic trunk and superior cava vein) will cause the absence of this wave.

Transmitted Cardiac Pulsatility. In normal conditions, the closure of the heart valves also exerts a pressure wave that is transmitted retrograde through the blood column that fills the central veins, so there will be small oscillations in the Doppler curve coinciding with the cardiac cycle. These oscillations will not be visualized in cases of significant stenosis or occlusion of the central venous trunks.

The cephalic vein is the best candidate vein for vascular access, so it should be carefully examined by assessing its total continuity and permeability, variations of calibre along its path, as well as any type of anatomical abnormality that it may present.

Basilic vein: Apart from the aforementioned characteristics of permeability, distensibility, diameter and calibre changes,

it must be taken into account that much of the basilic vein's course lies at a deeper plane than the other superficial veins. Consequently, its depth must be carefully evaluated, since depths greater than 8-10mm will not allow an adequate cannulation and it may need to be surgically raised to a more superficial level prior to its use for HD.

Antecubital fossa veins: The veins of the antecubital fossa usually connect both superficial venous drainage systems and the cephalic and basilic drainage systems. In addition, they usually connect to the deep venous system through the perforating vein. They have a great anatomical variability as well, so it is important to explore and note their layout and connections to correctly plan the VA.

6.3. Criteria of Pre-surgical Mapping

An association between patency and arterial diameter ≥ 2 mm and a PSV of at least 50 cm/s has been put forward, with a significant increase in the risk of failure with a diameter ≤ 1.6 mm and especially ≤ 1.5 mm. There is no clear recommendation level for the brachial artery, because it is larger in size. B-mode is recommended to measure the vessel lumen diameter between the internal faces of the vessel wall. The correct maturation of the VA requires an increase in flow through the feeding vessel 10-15 times higher than its normal flow. This is achieved by dilating and enlarging the said artery, which facilitates assessment of its compliance using the reactive hyperaemia test. Here the shape of the Doppler spectral wave is observed during reactive hyperaemia induced by the patient. Ischaemia is induced by fist clenching. The high-resistance triphasic wave observed with a closed fist turns into a low-resistance biphasic wave when opened. The RI in the reactive phase can be easily calculated: RI=PSV – EDV/PSV. A resistance index lower than 0.7 after hand ischaemia is

associated to 95% AVF success, while values superior to 0.7 decrease clinical success to 40% (Fig. 3).

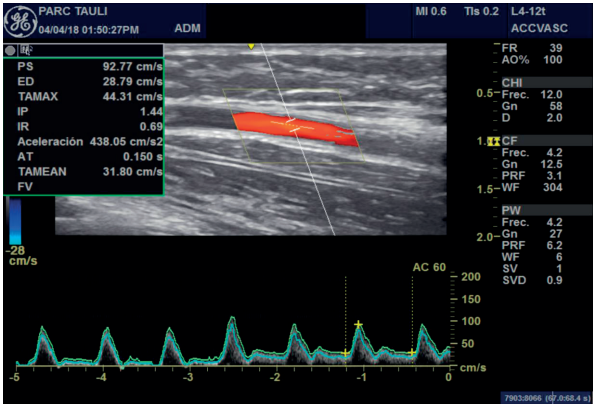


Figure 3. Doppler spectral wave. Pre-surgical mapping.
The hyperaemia test. Note: see change of RI from 1,0 a 0,69

Venous mapping has shown that a diameter ≤ 1.6 mm is the limit for observing a high failure rate. A minimum diameter of 2 mm in the forearm and 3 mm in the arm is established in the study with compression using a tourniquet to achieve an observable success rate (76%). Another study using compression demonstrates a limit of 2.5 mm for native arteriovenous fistula and 4 mm for prosthetic arteriovenous fistula. The association between compliance following compression with a tourniquet and failure is important, however, as success is related to a 48% increase in diameter.

Artery	Vein
Wrist > 1.5-2 mm.	Cephalic wrist >2 mm
PSV > 50 mmHg	Cephalic arm > 3 mm
RI (hyperaemia test) > 0.7	Increase in size after tourniquets > 40-50%
Morphology of wall and calcifications	
Central Patency	
Respiratory phasicity	
Transmitted cardiac pulsatility	

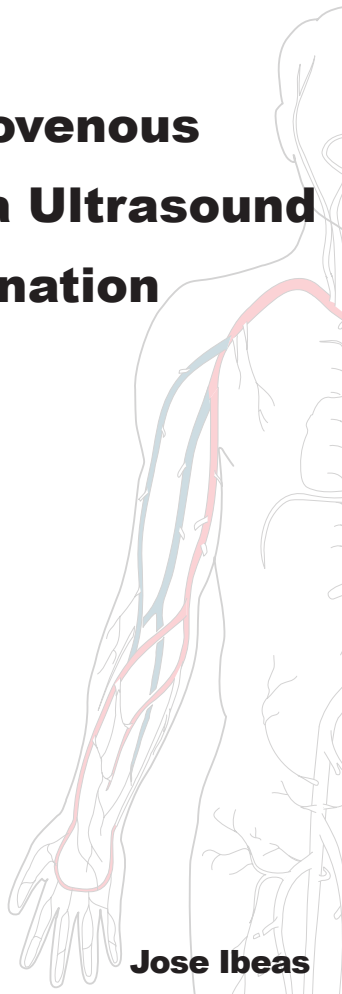
Table 2. Criteria of pre-surgical mapping

RI: Resistivity Index; PSV: Peak Systolic Velocity

Bibliography

1. Ibeas J, Vallespin J. Ecografía del acceso vascular para hemodiálisis: conceptos teóricos y prácticos. Criterios Nefrologia Sup Ext. 2012;3:21-35.
2. Ferring M, Henderson J, Wilmink A, Smith S. Vascular ultrasound for the pre-operative evaluation prior to arteriovenous fistula formation for haemodialysis: review of the evidence. Nephrol Dial Transplant. 2008;23:1809-15.
3. Malovrh M. Non-invasive evaluation of vessels by duplex sonography prior to construction of arteriovenous fistulas for haemodialysis. Nephrol Dial Transplant. 1998;13:125-9.
4. Jordi Fontcuberta. Exploración eco-Doppler en patología vascular: manual práctico de exploración eco-Doppler vascular en el ámbito de un laboratorio vascular no invasivo. Viguera Editores, 2009
5. Tordoir J, Canaud B, Haage P, Konner K, Basci A, Fouque D, et al. EBPG on Vascular Access. Nephrol Dial Transplant. 2007;22 Suppl 2
6. Ibeas J, Roca-Tey R, Vallespín J, Moreno T, Moñux G, Martí-Monrós A et al. Spanish Clinical Guidelines on Vascular Access for Haemodialysis. Nefrologia. 2017 Nov;37 Suppl 1:1-193.
7. Camblor-Santervás LA, Menéndez-Herrero MA, Carreño-Morrondo JA, Llaneza-Coto JM, Rodríguez-Olay J. Estudio preoperatorio del paciente: examen físico y pruebas de imagen. Angiología. 2005;57 Supl 2:23-34.
8. Wong CS, McNicholas N, Healy D, Clarke-Moloney M, Coffey JC, Grace PA, et al. A systematic review of preoperative duplex ultrasonography and arteriovenous fistula formation. J Vasc Surg. 2013;57:1129-33.
9. Georgiadis GS, Charalampidis DG, Argyriou C, Georgakarakos EI, Lazarides MK. The necessity for routine pre-operative ultrasound mapping before arteriovenous fistula creation: a meta-analysis. Eur J VascEndovasc Surg. 2015;49:600-5.
10. Kosa SD, Al-Jaishi AA, Moist L, Lok CE. Preoperative vascular access evaluation for haemodialysis patients. Cochrane Database Syst Rev. 2015;(9):CD007013
11. Shenoy S, Darcy M. Ultrasound as a tool for preoperative planning, monitoring, and interventions in dialysis arteriovenous access. AJR Am J Roentgenol. 2013;201:W539-43.

Arteriovenous Fistula Ultrasound Examination



Jose Ibeas
Joaquím Vallespin

1. General examination

Arteriovenous fistula (AVF) examination is recommended in the semi-recumbent position, with the arm extended at an angle of 45º. In the case of the lower limb, the leg should be in external rotation. The arterial territory, peripheral and central veins are assessed and the examiner must be on the same side as the limb to be explored.

To locate pathology, a transversal and longitudinal examination must be made from the feeding artery, through the anastomosis and along the venous territory to the central vessels. The arterial trajectory must also be examined from the subclavian artery to the anastomosis. The perivascular space must be traced in search of structures that could cause extra-luminal functional stenosis, like collections (Fig. 1), haematoma (Fig. 2) or seroma. Access depth must be assessed throughout the trajectory, identifying the areas where needling will be difficult, > 6 mm in depth.

In the first place, the examination is performed in B-mode and then in colour to detect possible areas with significant changes in velocity due to *aliasing*. In the following phase, spectral Doppler measurements are taken to assess PSV and EDV, although the latter is hardly ever used; usually PSV of between 150 and 300 cm/s is found. The anastomosis is also evaluated and venous PVS and spectral morphology documented. The characteristic spectral wave width, both in native arteriovenous fistulae (nAVF) as well in prosthetic arteriovenous fistulae (pAVF), should be recognized instead of the characteristic triphasic wave of the normal high-resistance peripheral arterial territory prior to the VA creation. The venous trajectory is followed to the central vessels and the graft trajectory is examined in the case of prosthesis. In this latter case, it is especially important to examine the anastomosis,

especially in veins, as there is a tendency for stenosis to form there.

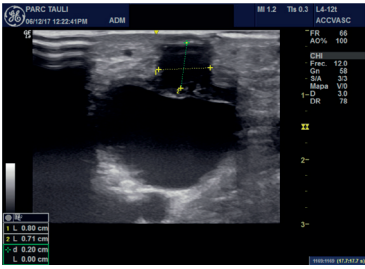


Figure 1.B-Mode. Collection (abscess).

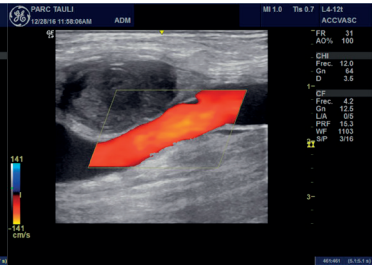


Figure 2. Colour mode.Haematoma.

2. Maturation assessment

One of the main uses of ultrasound is the identification of maturation of nAVF. Lengthy waits are not infrequent before cannulation is possible and there are often doubts about viability in usual clinical practice. For this reason, if physical examination generates doubts about nAVF maturation, an ultrasound examination must be performed as the test of choice. A 4 mm diameter with a flow of 500 ml has been established as the maturation criterion. In the later phase, the ideal VA is one that fulfils the rule of “6”: no more than 6 mm of depth, at least 6 mm of diameter and with a minimum flow of 600 ml/min.

3. Flow determination

When the VA is considered mature, periodic surveillance must be taken into consideration. This is based on the periodic control of flow (Q_A). Flow can be determined during the haemodialysis session using dilutional methods based on ultrasound, like Transonic® or the concentration of haematocrit. Measurement

using ultrasound must be done outside the haemodialysis session, unless the patient is undergoing dialysis via catheter, in which case it can be done during the first hour of the session to avoid bias in the volume depletion. Both methods have equal proven capability in flow measurement and in predicting stenosis and re-stenosis compared with angiography. The advantage that ultrasound flow measurement offers relates to morphological study and needling guidance from the first cannulation in the maturation process.

Flow measurement at the brachial artery using spectral Doppler shape allows for a rapid approach to access quality (Fig. 3). While measurement can be taken in any area of the graft, (Fig. 4) nAVF measurement is recommended in the brachial artery, where there is a proven correlation with VA flow. Measurement in the radial artery in wrist nAVF can be underestimated, given that in a great number of cases, the nAVF receives part of the flow from the ulnar artery through the palmar arch. Although it would really be ideal, it is usually difficult to take measurements in the venous segment due to curves, bifurcations, variations in diameter, turbulence, etc.

The data needed to measure flow are vessel diameter and the mean of the average velocity, which usually appears as TAV mean or TAMEAN (time averaged mean velocity) on devices. It is essential to remember that the insonation angle must be less than 60º (between 30 and 60º). Sample size should be wide enough to cover the vessel lumen, although there are also authors who advise it should comprise between 50% and 70% of the lumen to avoid interferences produced by vessel wall vibration. Lastly, 3 flow measurements are recommended to obtain the mean to avoid variability. The formula on which it is based is the following:

$$Q_A\ (ml/min) = TAV\ (cm/S)\ x\ section\ area\ (\Pi r^2; cm^2)\ x\ 60$$

There is no cut-off point from which a clear risk of thrombosis can be established. Between 500 and 800 ml/min is suggested in pAVF, and in nAVF it can be as wide as 300 to 700 ml/min, given their great vascular adaptability and ability to provide an adequate flow to the dialysis machine, with flows close to 300 ml/min. In the lastest guidelines 500 ml/min in nAVF and 600 ml/min in pAVF, or a decrease of 20-25% for stenosis screening, are suggested.

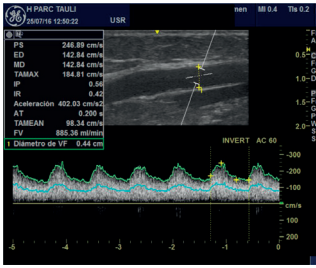


Figure 3. Flow measurement in native arteriovenous fistula.

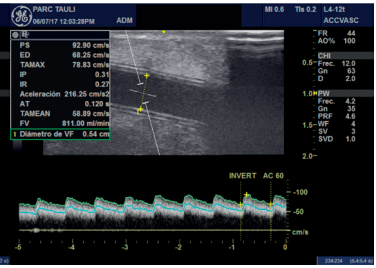


Figure 4. Flow measurement in prosthetic arteriovenous fistula.

4. Resistivity index

An index that may be relevant is the RI, derived from the PSV-EDV/PSV ratio, for which, at higher EDV values, there is lower RI. In VA surveillance, an inversely proportional change in flow has been observed. In fact, a relationship between its decrease after nAVF creation and maturation has been established. An increase detected during surveillance must lead to suspected stenosis complications. An increase from 0.6 in measurement at the brachial artery is suggestive of the presence of stenosis. (Fig. 5)

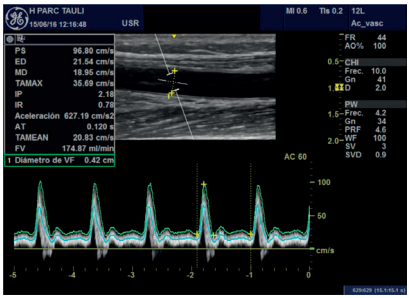


Figure 5. Doppler Mode. High Resistivity Index (0.78).

5. Stenosis detection

Stenosis in the venous segment of the nAVF can be produced in central vessels, the middle segment and the juxta-anastomotic area (first 5 cm), although the latter is the most frequent; in the pAVF, it usually appears in the anastomosis exit site into the vein. At these points there is intimal hyperplasia caused by *shear stress* in the areas most exposed to it (Fig. 6). Where the diameter of the lumen is modified, there is always acceleration in the velocity (PSV) which can give rise to *aliasing* (Fig. 7). It is an effect that appears when PRF is less than twice the

highest frequency of the Doppler signal, as happens in the turbulent areas of high velocity in stenosis.

If stenosis is detected, the percentage of the normal lumen it covers is measured. To calculate the stenosis, the minimum intraluminal diameter is compared with the normal diameter of the segment proximal to the nAVF:

% stenosis:
original lumen – residual lumen/original residual lumen x 100

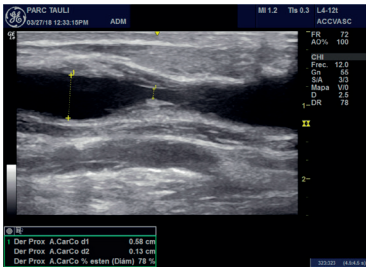


Figure 6. B-mode. Stenosis. Quantification >75%..

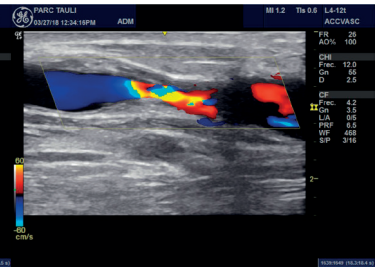


Figure 7. Colour Mode. Stenosis. Aliasing reflects high velocities.

Although it is easy to measure this reduction in pAVF, it is not so easy in nAVF because of large pre- and post-stenosis dilations. Likewise, in the juxta-anastomotic area, the angle of the vessel does not allow for easy measurement. In this case, indirect parameters must be used in the nAVF-feeding artery to obtain indirect evidence of a possible large stenosis. This can also happen in grafts made of radio-opaque material.

Ultrasound examination begins in the brachial artery, enabling us to assess the flow (in the case of significant stenosis, decreased) and the RI, which can be higher. These findings, however, might not be present in a proximal stenosis if there were prior collaterals that maintained an acceptable flow. Afterwards, if the nAVF is radio-cephalic, the remaining

segment of the artery must be examined as far as the anastomosis. Then the study continues proximally along the whole venous tract, first transversally to provide an anatomical study in search of changes in size. Once the stenosis has been located, colour Doppler can be used to confirm the existence of *aliasing*, always adjusting PRF upwards (Fig. 7). Doppler can quantify PSV in the pre-stenotic area (Fig. 8) as well as at the stenosis in the acceleration area and the post-stenotic area. PSV measurement > 400 cm/s is considered haemodynamically significant. The PSV ratio between the stenotic and pre-stenotic area is established. A ratio of at least 2 is considered to interpret the haemodynamically significant stenosis both in pAVF and in nAVF; some authors consider a ratio of 2.3 and even 3 more specific in the latter. A characteristically turbulent Doppler register can be observed in the post-stenotic area.

Arterial stenosis is usually caused by progressive arteriosclerosis. It is usually located in the pre-anastomotic area, although it may be found in any part of the arterial tract. It is identified in the same way as in the venous territory, by a reduction in the lumen as well as significant acceleration and PSV ratios. When arterial pathology is suspected, the examination of the ulnar, as well as the radial artery, can provide decisive information. When measuring the flow, for example, if 400 ml/min of the brachial flow of 500 ml/min is distributed in the ulnar and the rest in the radial, we should focus the pathology in the radial. Another manoeuvre is to compress the radial artery distal to the anastomosis. This will clearly suggest radial stenosis if it causes a decrease in PSV or an increase in RI at brachial level, as the passage of the retrograde flow through the palmar arch from the ulnar is closed. Haemodynamic modifications are imperceptible if the radial artery is unaffected.

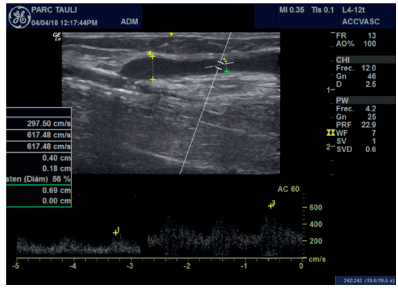


Figure 8. Doppler Mode. Stenosis 56%. Ratio stenosis / pre-stenosis (617 / 297 cm/s) = 2.

Ultrasound sensitivity in the detection of a stenosis > 50% with respect to the angiogram ranges from 76% to 95% with a specificity of 97%.

When a significant stenosis has been diagnosed, indication and intervention moment is not clear. In this context, ultrasound becomes a highly useful tool, given that the examination provides information about the severity of the stenosis and its functional repercussion. It can allow the nephrologist to take decisions at the patient's bedside, avoiding delays in decisions involving early treatment and those involving aggressive tests in cases in which decisions can be conservative.

The concept of haemodynamically significant stenosis has been previously defined from the purely vascular point of view, but highly variable criteria are used to establish indications for intervention. Initially, intervention was recommended with the single criterion of a lumen reduction > 50% by angiogram, a concept which is still being used in many centres; others, following DOQI Guideline recommendations, in addition to lumen reduction, include some unspecified parameter other than dysfunction and some clinical or physiological anomaly like physical examination, alteration in Kt/V, venous pressure and reduction in flow < 600 ml and decrease in flow.

The latest Spanish Guidelines introduce a new concept of significant stenosis which would only include stenosis with high risk of thrombosis. Some criteria were established to define it: some main criteria (reduction of vascular lumen > 50% + PSV > 2) and some additional criteria should be added (residual diameter < 2 mm and/or Q_A < 500 ml/min in nAVF or < 600 ml/min in pAVF and/or reduction in Q_A >25% if Q_A if < 1000 ml/min).

What's more, there are centres that only use morphological reduction of the lumen with ultrasound measurement, possibly leading to infra- or overestimated errors. Infra-estimation is as important as overestimation: infra-estimation due to the risk of thrombosis; overestimation due to the unnecessary number of angioplasties performed, which lead to risk of re-stenosis. For this reason, a combination of morphological and haemodynamic criteria is advised (Table 1).

Table 1. Criteria for significant stenosis and lack of maturation.

Morphological		
Stenosis > 50%		
Functional		
Velocity (PSV by Doppler US)	> 400 cm/s (not assessable in anastomosis)	
	PSV ratio (pre-stenosis / stenosis)	nAVF: 2.0-3.0 pAVF: 2
Q_A. Absolute value	nAVF: < 500 ml/min	
	pAVF: < 600 ml/min	
Indirect characteristics in brachial artery	High resistance Doppler wave	
	RI > 0.6	
	Flow reduction	
Lack of maturation		
Diameter	< 4 mm.	
Q_A	< 500 ml/min	

PSV: peak systolic velocity
nAVF: native arteriovenous fistula
pAVF: prosthetic arteriovenous fistula
Q_A: flow
RI: resistivity index

Last but not least, it is important to rule out the possible presence of central stenosis. Although ultrasound has limitations in this area, on occasions central stenosis can be seen directly. Haemodynamic criteria are like the rest of the venous territory, describing a stenosis/pre-stenosis PSV ratio of 2.5.

6. Thrombosis diagnosis

Ultrasound is the best non-invasive method to detect thrombosis in nAVF and pAVF. It allows for early diagnosis, especially straight after intervention, either by direct or indirect signs. Ultrasound criteria for thrombosis are based firstly on the absence of flow both in Doppler and in colour (Fig 9). At the same time, it is essential to note the non-compressibility of the thrombosed vessel, as the thrombus may not be visible in the acute phrase. This, moreover, allows us to assess the extension of the thrombus. Old thrombotic material with greater echogenicity can be seen more clearly in B-mode.

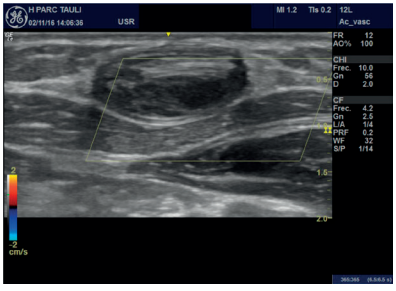


Figure 9. Colour Mode. Thrombosis.

Indirect signs are based on the visualization of a high-resistance triphasic wave in the feeding artery, which is like a normal artery, not connected to the nAVF. However, it is important to diagnose a thrombus, as indirect signs in the artery in the case of thrombosis can be similar to those of critical stenosis.

7. Aneurysms and pseudoaneurysms

Both appear in the cannulation areas because of vascular damage and poor cannulation techniques such as area cannulation. Ultrasound allows us to differentiate between aneurysm or venous dilation and pseudoaneurysm. An aneurysm is a venous dilation higher than 1.5-2 times the vessel diameter of the undilated vessel (Fig. 10). It can be caused by repeated needling or a proximal stenosis. A pseudoaneurysm is an extravascular cavity generated by a haematoma, in which the vessel orifice does not close and bleeding is constant. Ultrasound is especially useful in differentiating the pseudoaneurysm of a haematoma by allowing us to see an active flow of blood out of the vessel in colour mode (Fig. 11) and Doppler mode (Fig. 12), observing the presence of characteristic signs of 'entrance-exit' in the Doppler register. Ultrasound allows us to differentiate, therefore, between an aneurysm, a haematoma, a pseudoaneurysm requiring surgery and a thrombosing pseudoaneurysm, which can be managed conservatively.

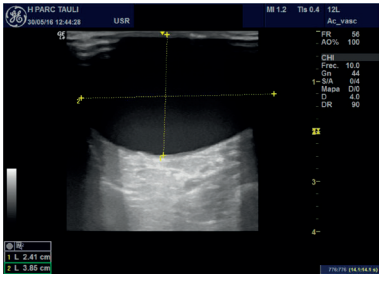


Figure 10. B-Mode. Aneurysm.

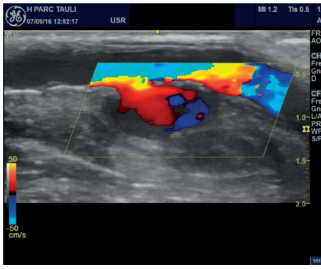


Figure 11. Colour Mode. Pseudoaneurysm.

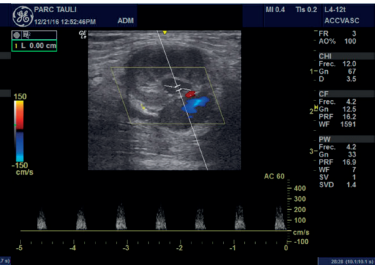


Figure 12. Doppler Mode. Pseudoaneurysm.

8. Steal Syndrome (Distal Hypoperfusion Syndrome)

A patient who enters the haemodialysis program has an increased risk of ischaemia from the VA due to increasingly higher comorbidity, especially diabetes and arteriopathy. It is especially frequent in pAVF because of higher flow. The VA steals not only blood from the feeding artery, but also retrogradely from the hand, and is thus able to compromise vascularization. In fact, it is assumed that this 'steal' occurs in 75-90% of patients following surgery. Usually this phenomenon occurs symptomatically through compensatory mechanisms. However, when these fail to maintain distal perfusion, steal phenomenon turns into steal syndrome. This is characterized by pain following dialysis or when resting, appearance of trophic ulcers, etc. For this reason, it is important to screen for any pathology which may bring it about. This implies careful assessment both radial and ulnar artery to rule out stenosis and occlusions. Spectral Doppler, especially in the reactive hyperaemia manoeuvre, has been associated with unrelated high flow steal syndrome because the arteries of the palmar arch are unable to vasodilate. The direction of the flow distal to the anastomosis is easy to show using Doppler, once steal is documented.

From an etiopathogenic point of view, there are 3 different kinds of steal syndrome: a) arterial stenosis with an anterograde decrease in flow; b) high flow in the VA caused by a large anastomosis, suggested from 1600 ml/min and c) failure of the vascular bed in the forearm to adapt to new haemodynamic conditions of the VA, generally in relation to arteriosclerosis.

Ultrasound is used to identify the cause and plays a strategic role in focusing treatment. In the first place, it is used to measure brachial flow, which can exclude the possibility of high-flow steal; then it is necessary to try to identify lesions in the arterial vascular bed, and finally to study the flow direction in the artery distal to the anastomosis. If this is inverted, it is assumed that the adequate direction will be recovered by compressing the VA.

The next objective of ultrasound is to suggest possible treatment to solve or improve symptoms before having to close the VA. Angioplasty is possible in the case of arterial stenosis. When flow is high, several treatment procedures to reduce it could be considered, such as ligation of drainage veins to the deep system or reconstruction surgery like DRIL (*Distal Revascularization-Interval Ligation*), RUDI (*Revision Using Distal Inflow*), banding, etc.

9. Vascular access and cardiovascular disease

The risk that a VA with inappropriate high flow can cause cardiac failure is well-known. The overload in the myocardium implies remodelling characterized by an increase in the ventricular diameter due to eccentric hypertrophy. An increase in mass of the left ventricle is also observed, a phenomenon that retrogrades with the closure of the VA. There is, however, a lack of consensus as to what is understood by a high-flow VA and its possible related cardiovascular effects. It has been

considered that a Q_A of over 1000-1500 ml/min may cause cardiac complications. However, an important current of thinking points out the importance of the flow-cardiac output ratio (Q_A/CO ratio), highlighting that if the ratio exceeds 30%, a congestive heart failure can present itself independently of absolute Q_A value. At the same time, patients with high flow in the VA experience an increase in tele-diastolic volume with the risk of cardiac failure. In fact, it has been proposed that patients with Q_A>2000 ml/min in comparison with those of Q_A< 1000 ml/min show a marked tendency to high left ventricular volume, and once this is done, in the event of cardiac failure, the value of elevated flows, especially from 2000 ml/min, must be weighed up (Fig. 13). On the other hand, the controversy surrounding the extent to which cardiac function is altered after nAVF creation should not be forgotten, given the presence of multiple confounding factors in these patients. In other words, is it the nAVF that contributes to the onset of heart failure, but from a limit, or is it really an underlying heart disease that is decompensated by the nAVF.

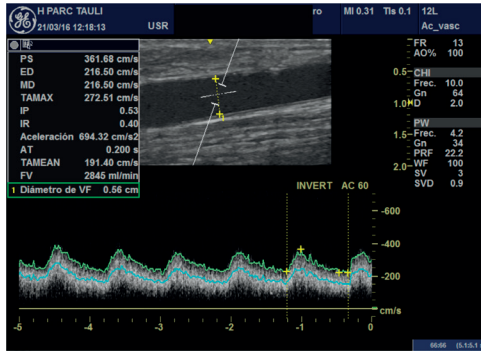


Figure 13. High flow arteriovenous fistula (2845 ml/min).

Bibliography

1. Teodorescu V, Gustavson S, Schanzer H. Duplex ultrasound evaluationofhemodialysis access: a detailed protocol. Int J Nephrol. 2012;2012:508956
2. Napoli M, Russo F, Pati C. AVF Monitoring. Echo Colour Doppler &Vascular Accesses for hemodialysis. Milano: Wichting Editore;2011. p. 46-66.
3. Kohler T, Mraz B. Dialysis access procedures. Dupplex Scanning in vascular disorders. Philadelphya: Lippincott Williams & Wilkins; 2010. p. 350-83.
4. Ibeas J, Vallespin J. Ecografía del acceso vascular para hemodiálisis: conceptos teóricos y prácticos. Criterios. Nefrologia. 3 - 6, pp. 21 - 35. 2012
5. Vascular Access Work Group. Clinical practice guidelines for vascular access. Am J Kidney Dis 2006;48 Suppl1:S248-S273.
6. Krivitski NM. Theory and validation of access flow measurement by dilution technique during hemodialysis. Kidney Int 1995;48(1):244-50.
7. Sands J, Glidden D, Miranda C. Hemodialysis access flow measurement. Comparison of ultrasound dilution and duplex ultrasonography. ASAIO J 1996;42(5):M899-M901.
8. Wiese P, Nonnast-Daniel B. Colour Doppler ultrasound in dialysis access. Nephrol Dial Transplant 2004;19(8):1956-63
9. Besarab A, Sherman R. The relationship of recirculation to access blood flow. Am J Kidney Dis 1997;29(2):223-9.
10. Hollenbeck M, Nonnast-Daniel B, Krumme B, Klews PM. Flow measurement in dialysis shunts. Nephrol Dial Transplant 2001;16(12):2445.
11. Hollenbeck M, Nonnast-Daniel B, Krumme B, Klews PM. Flow measurement in dialysis shunts. Nephrol Dial Transplant 2001;16(12):2445.
12. Van Hooland S, Malik J. Hemodialysis vascular access ultrasonography: tips, tricks, pitfalls and a quiz. J Vasc Access, 2010;11(4):255-62.
13. Ibeas J. Monitorización del acceso vascular: ¿Quo vadis? NefroPlus. 2012;4(2):11-20.

14. Koseoglu K, Akar H, Cildag B, Ozsunar Y, Gayret P. Resistive index measurement of native hemodialysis arteriovenous fistula feeding artery as a predictor for fistula dysfunction. ASAIO J 2004;50(6):577-80.

15. Roca-Tey R, Rivas A, Samon R, Ibrik O, Martinez CR, Viladoms J. [Noninvasive assessment of forearm vessels by colour Doppler ultrasonography (CDU) before and after radiocephalic fistula (RCF) placement]. Nefrologia 007;27(4):489-95.

16. Lee T, Roy-Chaudhury P. Advances and new frontiers in the pathophysiologyof venous neointimal hyperplasia and dialysis access stenosis. Adv Chronic Kidney Dis 2009;16(5):329-38.

17. Lockhart ME, Robbin ML. Hemodialysis access ultrasound. Ultrasound Q 2001;17(3):157-67.

18. Napoli M, De Pascalis A, Montagna C. Steno-thrombotic complications of nAVF. Echo Colour Doppler & Vascular Accesses for hemodialysis. Milano: WichtingEditore; 2011. p. 67-86.

19. Middleton WD, Picus DD, Marx MV, Melson GL. Colour Doppler sonography of hemodialysis vascular access: comparison with angiography. AJR Am J Roentgenol 1989;152(3):633-9.

20. Tordoir JH, de Bruin HG, Hoeneveld H, Eikelboom BC, Kitslaar PJ. Duplex ultrasound scanning in the assessment of arteriovenous fistulas created for hemodialysis access: comparison with digital subtraction angiography. J Vasc Surg 1989;10(2):122-8

21. Tessitore N, Lipari G, Poli A, Bedogna V, Baggio E, Loschiavo C, et al. Can blood flow surveillance and pre-emptive repair of subclinical stenosis prolong the useful life of arteriovenous fistulae? A randomized controlled study. Nephrol Dial Transplant 2004;19(9):2325-33.

22. Tonelli M, James M, Wiebe N, Jindal K, Hemmelgarn B. Ultrasound monitoring to detect access stenosis in emodialysis patients: a systematic review. Am J Kidney Dis 2008;51(4):630-40.

23. Paulson WD, White JJ. Should arteriovenous fistulas and synthetic grafts undergo surveillance with pre-emptive correction of stenosis? Nat ClinPractNephrol 2008;4(9):480-1.

24. Tuka V, Malik J. Vascular access surveillance: no benefit? Am J Kidney Dis 2008;52(3):628-9.

25. Paulson WD, Moist L, Lok CE. Vascular access surveillance: an ongoing controversy. Kidney Int 2012;81(2):132-42.

26. Chang CJ, Ko PJ, Hsu LA, Ko YS, Ko YL, Chen CF, et al. Highly increased cell proliferation activity in the restenotichemodialysis vascular access after percutaneous transluminal angioplasty: implication in prevention of restenosis. Am J Kidney Dis 2004;43(1):74-84.

27. Dumars MC, Thompson WE, Bluth EI, Lindberg JS, Yoselevitz M, Merritt CR. Management of suspected hemodialysis graft dysfunction: usefulness of diagnostic US. Radiology 2002;222(1):103-7.

28. Ibeas J, Vallespin J, Rodriguez-Jornet A, Branera J, Fortuño J, Bermúdez P, et al. Portable Doppler-ultrasound used by the nephrologist in the hemodialysis Unit for the immediate detection of fistula pathology and ultrasound guided cannulation: consolidation of a technique incide a protocolized interdisciplinary team with vascular surgeons, interventional radiologists and infirmary. A 4 years experience. J Am SocNephrol2008;19:254A.

29. Tuka V, Slavikova M, Krupickova Z, Mokrejsova M, Chytilova E, Malik J. Short-term outcomes of borderline stenoses in vascular accesses with PTFE grafts. Nephrol Dial Transplant 2009;24(10):3193-7.

30. Ibeas J, Roca-Tey R, Vallespín J, Moreno T, Moñux G, Martí-Monrós A et al. Spanish Clinical Guidelines on Vascular Access for Haemodialysis. Nefrologia. 2017 Nov;37 Suppl 1:1-193.

31. Van Hooland S, Malik J. Hemodialysis vascular access ultrasonography:tips, tricks, pitfalls and a quiz. J Vasc Access 2010;11(4):255-62.

32. Labropoulos N, Borge M, Pierce K, Pappas PJ. Criteria for defining significant central vein stenosis with duplex ultrasound. J VascSurg 2007;46(1):101-7.

33. Roca-Tey R, Ibeas J, Moreno T, Gruss E, Merino JL, Vallespín J, Hernán D, Arribas P; Spanish Multidisciplinary Vascular Access Group (GEMAV). Dialysis arteriovenous access monitoring and surveillance according to the 2017 Spanish Guidelines. J Vasc Access. 2018 Mar 1:1129729818761307. doi: 10.1177/1129729818761307. [Epub ahead of print]

34. Napoli M, Tondo S, Montagna E. Major complications of nAVF. Echo Colour Doppler & Vascular Accesses for hemodialysis. Milano: WichtingEditore; 2011. p. 87-103.

35. Chemla ES, Morsy M, Anderson L, Whitemore A. Inflow reduction by distalization of anastomosis treats efficiently high-inflow highcardiac output vascular access for hemodialysis. Semin Dial 2007;20(1):68-72.

36. Konner K. Complications of the vascular access for hemodialysis. In Hemodialysis vascular access and peritoneal access. ContribNephrol. Ronco C, Levin NW (eds.). Basel, Karger; 2004, Vol 142, p: 193-215.

37. Lomonte C, Casucci F, Basile C. Cardiovascular disease and nAVF. Echo Colour Doppler & Vascular Accesses for hemodialysis. Milano: WichtingEditore; 2011. p. 104-9.

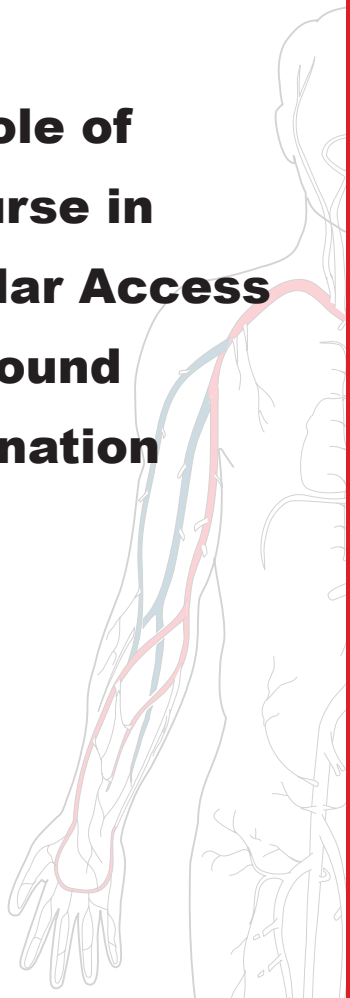
38. MacRae JM, Pandeya S, Humen DP, Krivitski N, Lindsay RM. Arteriovenous fistula-associated high-output cardiac failure: a review of mechanisms. Am J Kidney Dis 2004;43(5):e17-e22.

39. MacRae JM, Levin A, Belenkie I. The cardiovascular effects of arteriovenous fistulas in chronic kidney disease: a cause for concern? Semin Dial 2006;19(5):349-52.

40. Basile C, Lomonte C, Vernaglione L, Casucci F, Antonelli M, Losurdo N. The relationship between the flow of arteriovenous fistula and cardiac output in haemodialysis patients. Nephrol Dial Transplant 2008;23(1):282-7.

41. Guedes Marques M, Ibeas J, Botelho C, Maia P, Ponce P. Doppler ultrasound: a powerful tool for vascular access surveillance. Semin Dial. 2015 Mar-Apr;28(2):206-10

The Role of the Nurse in Vascular Access Ultrasound Examination



Xavier Vinuesa

1. Advantages of using Doppler ultrasound by nurses

In recent years nursing staff have incorporated Doppler ultrasound into nursing practice in various specialities. The field of VA care is probably where the information provided by an ultrasound study has the most significant impact on decision-making and assistance when nurses have to perform an invasive technique

HD indications have been extended to incorporate patients who were previously excluded from the program. Age limits have been extended and the number of pathologies and complications, which very frequently include vascular disease and diabetes, has multiplied.

Advanced age and vascular pathology have been shown to determine a greater complexity of VA for HD. This implies an increased risk when needling, a risk of aneurysm, the appearance of stenosis, extravasations, thrombosis and the possible need to perform a new VA and/or the placement of a catheter for haemodialysis. The length of suitable areas for cannulation in the nAVF can also be shortened.

There is great consensus that nAVF is the VA choice for HD treatment. To fulfill the quality criteria of the VA guidelines (thrombosis rate, percentages of different types of AVF. etc.) requires a multidisciplinary team, made up of the nephrologist, vascular surgeon, radiologist and renal nursing staff, who should all work together. They are professionals who all intervene in VA on a daily basis, and can benefit from the morphological and functional information provided by Doppler ultrasound. The use of this information represents a substantial change in the habitual practice of renal nursing staff since it allows these professionals to play a significant role in the multidisciplinary team and make decisions that allow them to

do more than simply place the needle; in other words, to take part in effective VA management.

2. Real time ultrasound-guided cannulation

Real time ultrasound-guided cannulation, understood as needling with ultrasound control during the cannulation procedure, is of great assistance in channelling complex AVF.

There are two types of approach for ultrasound guided needling according to the visualization planes:

- Out of plane: the vessels are visualized as rounded and dark structures. In this type of approach, the ultrasound probe should be placed so that the long axis of the probe face is perpendicular to the vessel walls, obtaining a transverse view of the vessel. The needle will be inserted in a plane parallel to the vessel, that is, perpendicular to the field of ultrasound vision (Fig. 1). It is the least used technique, so only the needle can be visualized at the moment of entry into the vessel when it is in the field of view (Fig. 2) In order to continue its visualization, the probe has to be moved using the sweep technique.

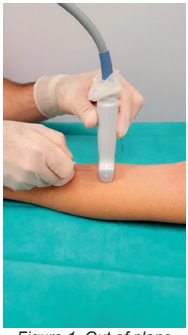


Figure 1. Out of plane approach

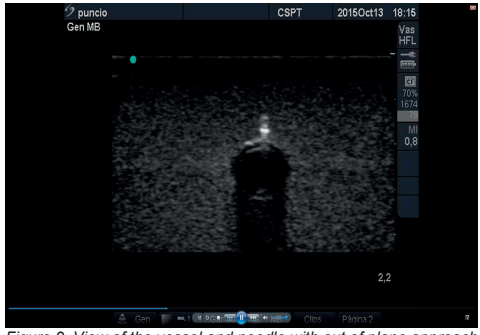


Figure 2. View of the vessel and needle with out of plane approach

- In plane: the vessels are visualized as elongated structures. In this type of approach, the ultrasound probe should be placed so that the long axis of the probe face is parallel to the vessel. The needle will be inserted longitudinally into the vessel, that is, parallel to the field of vision (Fig. 3). With this view the needle can be controlled and visualized all the time when cannulating (Fig. 4).

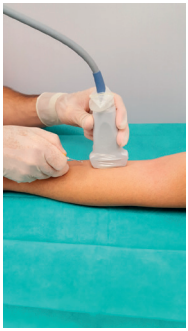


Figure 3. In plane approach to the vessel

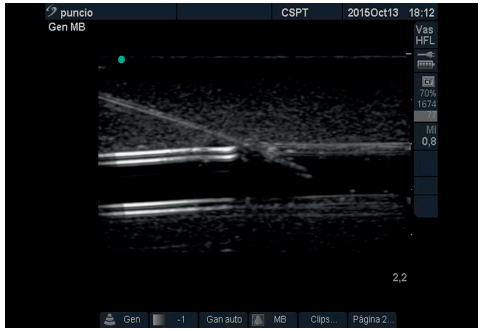


Figure 4. View of the vessel and needle with in plane approach

Due to the characteristics of AVF and the needles used in haemodialysis, the “in plane” approach (Fig. 3) through the longitudinal projection of the vessel to be channelled is usually recommended, as it allows the needle to be kept within the ultrasound vision field throughout the segment, including the approach and the canalization of the vessel (Fig. 4).

In both types of approach, the precaution of placing the structure to be visualized in the centre of the screen should be taken. It should be needled a few millimetres distal to the probe and in the centre, the tip of the needle should always be located and the needling angle adjusted (Fig. 5, Fig. 6).

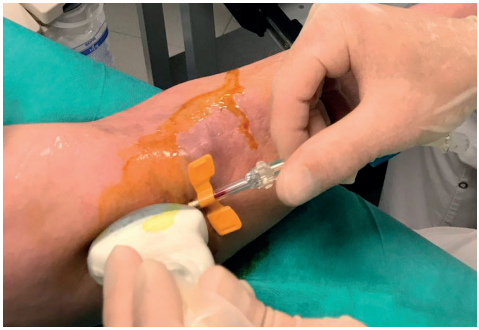


Figure 5. Inserting the needle

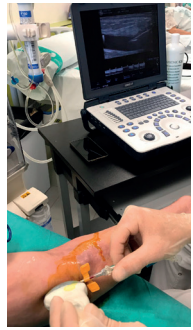


Figure 6. Real example of in plane approach

3. First needling

A morphological and functional study is recommended, performed using Doppler ultrasound, prior to the first cannulation of nAVF. Needling of an immature nAVF may increase the incidence of complications (haematomas, thrombosis) and reduce their survival.

Although the ideal nAVF for puncture is considered to be the one that fulfills the rule of the three 6's (Q_A > 600 ml/min, diameter > 6mm and depth < 6 mm), generally a Q_A of 500 ml/min and a diameter of at least 4 mm are required to consider an nAVF mature. In addition to checking the maturation criteria compliance, the ultrasound study of AVF prior to the first cannulation will allow determination of the appropriate cannulation sites.

The latest Spanish VA guidelines suggest the following criteria:

- To carry out exercises before and after the creation of nAVF to promote maturation.

- Not to start cannulation before two weeks after nAVF creation and to identify the ideal moment to make the first cannulation in each patient.
- To start pAVF cannulation between two and four weeks after construction, (with the exception of early cannulated grafts).

4. Cannulation of non-pathological complex nAVF

There are several variables which can cause difficulty in needling, Q_B deficit, high pressures and / or failed punctures. These factors include the following:

- anatomical variability of the venous and arterial trees
- the flow and direction in which blood circulates through the arterialized veins
- the depth and size of the veins (Fig. 7)
- the existence of aneurysms, haematomas, etc.

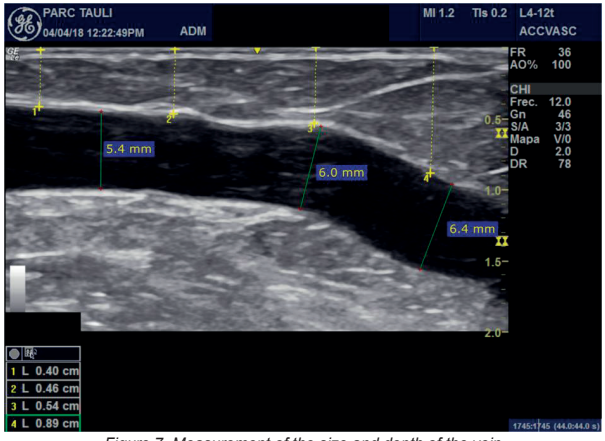


Figure 7. Measurement of the size and depth of the vein

The morphological and haemodynamic study, by means of Doppler ultrasound, of AVF can help to optimize VA performance, choosing the ideal needling zones for both morphological and functional characteristics.

5. Pathological AVF needling

Difficulty in needling can be considered as a sign of early pathology detection. A Doppler ultrasound scan performed by nursing staff, which may suggest the presence of pathology, can speed up diagnosis and possible treatment, in addition to avoiding failed and traumatic cannulations.

Although diagnosis is not a nursing function, the recognition of a pathological AVF by nurses is useful to decide on needling alternatives or, if appropriate, the non-viability of the VA. Beyond the diagnostic criteria discussed in Chapter 3, there is a number of indirect characteristics that can help to recognize a potentially pathological AVF.

Stenosis is the most frequent pathology that an nAVF can present. Indirect characteristics that can be identified are:

- High resistivity Doppler wave in the brachial artery
- RI > 0.6 measured in the brachial artery
- Aliasing in the stenosis area

6. Spectral wave in the brachial artery

The spectral Doppler or Doppler curves consist of a curve of velocity versus time, which represents the variation of the velocity of red blood cells throughout the cardiac cycle. The time is represented on the horizontal axis and the velocity on the vertical. The direction of the flow is shown by the orientation

of velocity: positive values move towards the probe and negative ones move away from it.

It is necessary to assess the characteristic spectral widening, both in nAVF and in pAVF, of a low-resistance system (Fig. 8), instead of the three-phase wave which characterizes the normal peripheral arterial territory of high-resistance prior to the creation of VA or of AVF with significant stenotic pathology (Fig. 9). The resistance is quantified by the resistivity index.

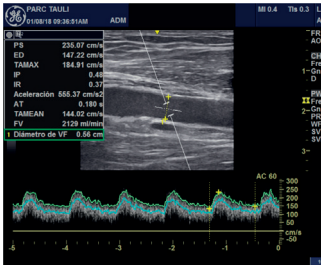


Figure 8. Characteristic low resistance wave

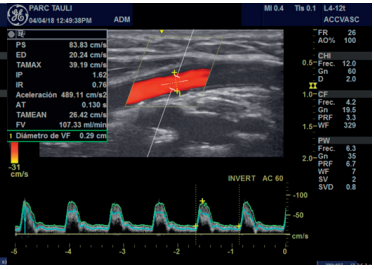


Figure 9. Characteristic high resistance wave

7. Resistivity index

The resistivity index is a value derived from the ratio.

$$RI = PSV - EDV/PSV$$

PSV= Peak systolic velocity, EDV= End diastolic velocity

It is used to measure the effects of changes in peripheral vascular resistance. It shows that when the velocity is higher at the end of diastole, the RI is lower and viceversa. As previously discussed, it has been suggested that an increase higher than 0.6 in the measurement at brachial artery level could indicate stenosis (Fig. 10).

Figure 10. Resistivity Index measurement

8. Aliasing

This is a heterogeneous pixel, characteristic of areas of high velocities, such as stenosis, when working in colour Doppler mode (Fig. 11).

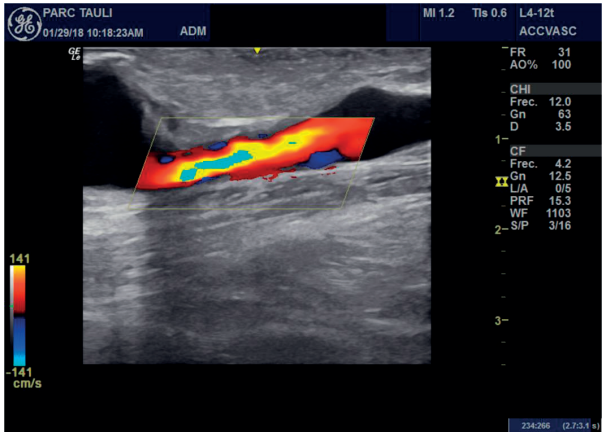


Figure 11. Aliasing effect

As previously mentioned, aliasing is a phenomenon produced when the capacity to measure the blood velocity of the equipment is lower than the blood velocity in the examined vessel, which means that there is a limit to the maximum flow velocity that can be measured. In the colour image, an area of turbulence without a defined colour will be shown and the Doppler curves will have a wider spectral wave or even be decapitated at the maximum velocity peak at the high limit of the scale.

Correct PRF adjustment is fundamental, adapting it to the velocity of the flow to avoid false aliasing. When a low flow has to be analyzed, PRF must be decreased, and if it is high, it must be increased. In Doppler curves the baseline and the velocity scale should be adjusted as well.

9. Individualized AVF approach

The morphological and haemodynamic characteristics of the ultrasound examination allow the approach to be individualized and to optimize treatment. Doppler ultrasound permits decisions to be made regarding needling techniques and material to be used, etc.

Needling technique for haemodialysis is one of the factors that influences VA survival.

Currently there are three needling techniques:

- Area technique: needling is concentrated in a specific area of 2-3 cm of the arterialized vein, which causes micro-traumatisms of the venous wall and favouring the appearance of aneurysms, inside which there are turbulences that stimulate post-dilatation stenosis and thrombosis of the nAVF. In pAVF the risk of

pseudoaneurysms increases due to the destruction of the prosthetic tissue.

- Rope-ladder technique: needling is made along the entire length of the nAVF vein. It minimizes the appearance of dilations although it requires a well-developed venous segment, increases the probability of failed cannulations and produces pain. This would be the technique of choice in both nAVF and pAVF.
- Buttonhole technique: it is another type of of needling in which the vein is firstly canalized with a sharp needle at the same site over several sessions until a subcutaneous tunnel is created. Once the tunnel is established, it can be cannulated with a blunt needle through the tunnel of scar tissue that facilitates the insertion of the needle through it.

There is agreement that rope-ladder technique is the choice for AVF cannulation and that area needling should be avoided whenever possible. In cases of nAVF with a small section suitable for needling, where rope-ladder technique is not possible, the buttonhole technique is an alternative to area needling. Buttonhole technique is not indicated in pAVF.

Doppler ultrasound is useful for assessing which sections can be cannulated, for monitoring the subcutaneous tunnels characteristic of the buttonhole technique (Fig. 12), and for check the VWing position in cases of difficult cannulation (Fig. 13). In deep nAVF, Doppler ultrasound allows assessment of the viability of the use of long needles (3.2 cm), needling assistance devices (VWING), etc.

10. Flow Monitoring

Measurement of AVF flow is an important indicator of satisfactory functioning, as the finding of progressively

decreasing values in flow are, for both nAVF and pAVF, predictive of thrombosis. Potential flow errors can be calculated using different parameters like the vessel area measurement, insonation angle, sample volume size and those related with the haemodynamic stability of the patient.

Although there have been controversial results in different studies on the risk of thrombosis estimation and on the definitive loss of AVF through flow surveillance, the use of surveillance techniques based on flow measurement in nAVF decreases the incidence of thrombosis and access loss. It therefore allows for a reduction in the rate of central venous catheters and their associated morbidity.

The use of the Doppler ultrasound in accordance with a multidisciplinary protocol allows the surveillance of AVF of the prevalent patient as well as in the maturation period. It offers the advantage of important morphological information of AVF in the same procedure.

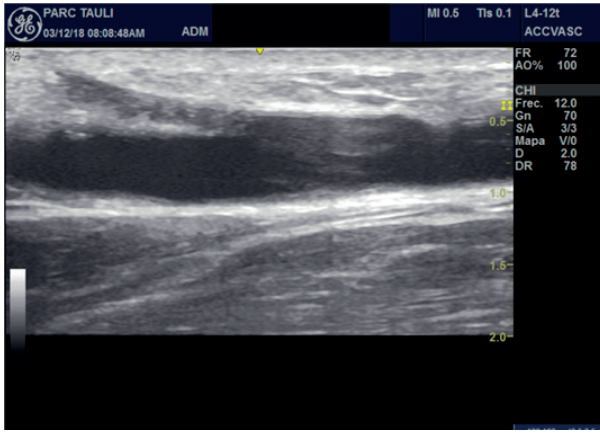


Figure 12. Image of a buttonhole tunnel

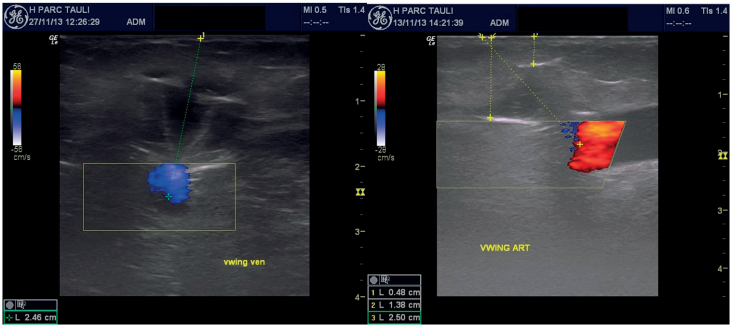


Figure 13. Image of a VWing in out of plane and in plane approach.

Bibliography

1. Roca-Tey R. El acceso vascular para hemodiálisis: la asignatura pendiente. Nefrología 2010;30:280-287.
2. Ethier J, Mendelssohn DC, Elder SJ, y cols. Vascular access use and outcomes: an international perspective from the Dialysis Outcomes and Practice Patterns Study. Nephrol Dial Transplant. 2008;23(10):3219-3226.
3. Astor BC, Eustace JA, Powe NR, Klag MJ, Fink NE, Coresh J, for the CHOICE study. Type of vascular access and survival among incident hemodialysis patients: the Choices for Healthy Outcomes in Caring ESRD (CHOICE) study. J Am Soc Nephrol. 2005;16:1449-1455.
4. Malek T, Álvarez-Ude F, Gil MT, et al. Cambios en el acceso vascular en una unidad de diálisis en los últimos años: ¿problemas de planificación, cambio de preferencias o cambio demográfico? Nefrología 2008;28:531-8
5. Feldman HI, Joffe M, Rosas SE, Burns JE, Knauss J, Brayman K. Predictors of successful arteriovenous fistula maturation. Am J Kidney Dis. 2003 Nov;42(5):1000-12
6. Ibeas J. Montitorización del acceso vascular: ¿Quo Vadis?. NefroPlus 2011;4(2):11-20
7. Konner K, Nonnast-Daniel B, Ritz E. The arteriovenous fistula. J Am Soc Nephrol 2003;14(6):1669-80.
8. Ibeas J, Roca-Tey R, Vallespín J, Moreno T, Moñux G, Martí-Monrós A, Del Pozo JL, Gruss E, Ramírez de Arellano M, Fontseré N, Arenas MD, Merino JL,García-Revillo J, Caro P, López-Espada C, Giménez-Gaibar A, Fernández-Lucas M, Valdés P, Fernández-Quesada F, de la Fuente N, Hernán D, Arribas P, Sánchez de la Nieta MD, Martínez MT, Barba Á; Spanish Clinical Guidelines on Vascular Access forHaemodialysis. Nefrologia. 2017 Nov;37 Suppl 1:1-191
9. NFK/DOQI 2006. Vascular Access Guidelines. American Journal of Kidneys disease
10. Robbin ML, Chamberlain NE, Lockhart ME, Gallichio MH, Young CJ, Deierhoi MH, et al. Hemodialysis arteriovenous fistula maturity: US evaluation. Radiology 2002;225 (1):59–64. PMID: 12354984.
11. Pons C, Vinuesa X, et al.,.Dificultad de punción como indicador de patología oculta del acceso vascular para hemodiálisis: papel de

enfermería en la solicitud y confirmación ecográfica. Enfermería Nefrológica 2012; 15 (1): 39-40.

12. Ibeas J, Vallespín J, Rodríguez-Jornet A, Branera J, Fortuño JR, Bermúdez P, et al. Portable Doppler-ultrasound used by the nephrologist in the hemodialysis Unit for the immediate detection of fistula pathology and ultrasound guided cannulation: consolidation of a technique inside a protocolized interdisciplinary team with vascular surgeons, interventional radiologists and infirmary. A 4 years experience. J Am SocNephrol. 2008;19:254A.

13. Ibeas J, Vallespin J. Ecografía del acceso vascular para hemodiálisis: conceptos teóricos, prácticos y criterios. Nefrología, Suplemento Extraordinario 2012;3(6): 21-35

14. Leal I, Flores A. Fundamentos Físicos. In: Exploración eco-doppleren patología vascular. J. Fontcuberta (coord.). Barcelona: Viguera editores SL; 2009. p. 33-50.

15. Leotta D, Beach K. Physics and instrumentation for Duplex Scanning. In: Strandness'sDupplex Scanning in vascular disorders. Zierlesr R(ed.). Philadelphia: Lippincott Williams & Wilkins; 2010. p. 350-83

16. Parisotto MT, Schoder VU, Miriunis C, Grassmann AH, Scatizzi LP, Kaufmann P, Stopper A, Marcelli D. Cannulation technique influences arteriovenous fistula and graft survival. Kidney Int 2014; 86, 790–797.

17. J.Tordoir , B. Canaud, et al.EBPG on Vascular Access**.** Nephrol Dial Transplant (2007) 22 (suppl_2): ii88-ii117. http://www.vascularaccesssociety.com/education/guidelines

18. Tonelli M, James M, Wiebe N, Jindal K, Hemmelgarn B. Ultrasound monitoring to detect access stenosis in hemodialysis patients: a systematic review. Am J Kidney Dis. 2008;51(4):630-40.

19. Tessitore N, Bedogna V, Verlato G, Poli A. The Rise and Fall of Access Blood Flow Surveillance in Arteriovenous Fistulas. Seminars in Dialysis. 2014;27:108-118.

20. Roca-Tey R, Samon R, Ibrik O, García-Madrid C, Herranz JJ, García-González L, et al. Vascular access surveillance with blood flow monitoring: a prospective study with 65 patients. Nefrologia. 2004;24:246-52.

21. Salman LH. How is arteriovenous fistula longevity best prolonged?: The role of surveillance. Semin Dial. 2015;28:33-34.

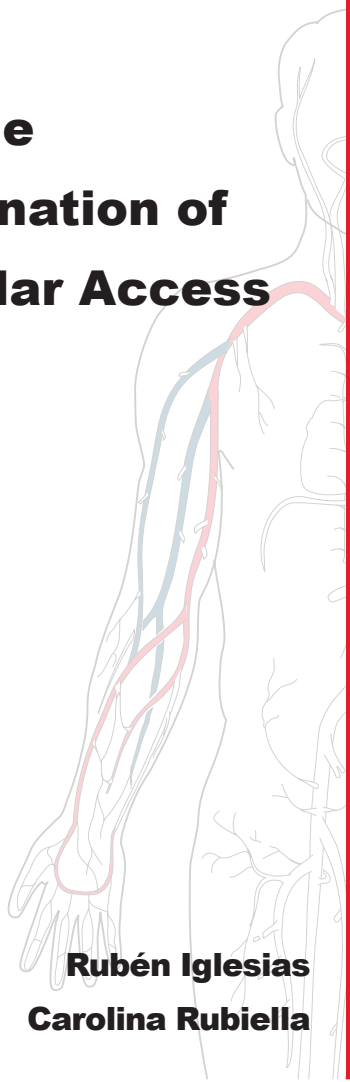
22. Aragoncillo I, Amézquita Y, Caldés S, Abad S, Vega A, et al The impact of access blood flow surveillance on reduction of thrombosis in native

arteriovenous fistula: a randomized clinical trial. J Vasc Access. 2016 Jan-Feb;17(1):13-9

23. Roca-Tey R. Early diagnosis of hemodialysis vascular access stenosis using the non-invasive determination of blood flow. Doctoral thesis, Universitat Autónoma de Barcelona, 2010. http://hdl.handle.net/10803/32023

24. Scaffaro LA, Bettio JA, Cavazzola SA, Campos BT, Burmeister JE, Pereira RM, et al. Maintenance of hemodialysis arteriovenous fistulas by an interventional strategy. Clinical and Duplex ultrasonographic surveillance followed by transluminal angioplasty. J Ultrasound Med. 2009;28:1159-1165.

Routine Examination of Vascular Access



97

Rubén Iglesias
Carolina Rubiella

In order to synthesize all the previous content and make use of it in daily clinical practice, it is necessary to summarize the main issues for a formal AVF ultrasound examination.

Before starting the examination, parameters must be optimally adjusted. In B-mode this includes gain, focus and depth. In colour mode, gain, PRF and window size should be centred on the examination area and adjusted. Finally velocity scale or PRF should be adapted in spectral Doppler, and the base line situation and volume of the sample size be sought.

It is usually recommended to start examination from the feeding artery anastomosis to the proximal branch of the brachial artery. Firstly, anatomical variability, such as high bifurcation, must be observed (Fig. 1) and in a second phase, the venous trajectory from the anastomosis to the proximal venous territory must be examined.

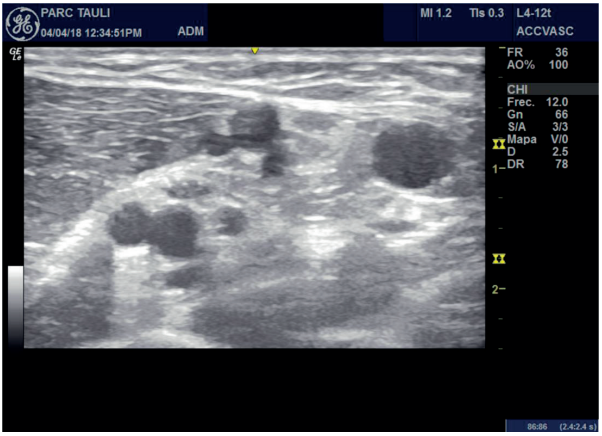


Figure 1. High bifurcation of brachial artery (double artery in arm) . Note the satellite veins ("Micky Mouse ears")

1. Arterial examination

A transverse route in B-mode should be followed in a proximal direction to look for possible variations of calibre. Special attention must be taken to observe bifurcations because flow should be measured above it.

In brachial nAVF, the artery should be examined from the anastomosis to proximal area, ruling out the presence of stenosis, mainly pre-anastomotic. After this, the trajectory must be examined distally through any bifurcation, and the radial and ulnar arteries must be followed up to the hand to ensure correct vascularization. Proximal brachial bifurcation should be identified for correct flow measurement.

In radial nAVF, the radial artery must be followed from the anastomosis proximally up to the radial-ulnar bifurcation in order to identify the best area to perform the flow measurement proximal to the bifurcation at the same time as the brachial artery is examined. The ulnar artery should also be examined from the bifurcation to the hand. The artery vascular bed must be followed in search of possible stenosis,

2. Anastomosis

When the anastomosis is located in B-mode, a transverse image should be obtained. Then, the picture frame must be frozen and the anastomosis width measured. Once recorded, the picture should be taken off freeze-frame and the probe placed longitudinally to see it from this point of view. Then, the width must also be measured.

Still in longitudinal view, colour mode should then be activated to see the anastomosis and identify the presence of reverse flow from the distal radial artery to the anastomosis, which can

be feeding back to the nAVF (Fig. 2). It should be remembered that this can contribute to steal syndrome in the hand.

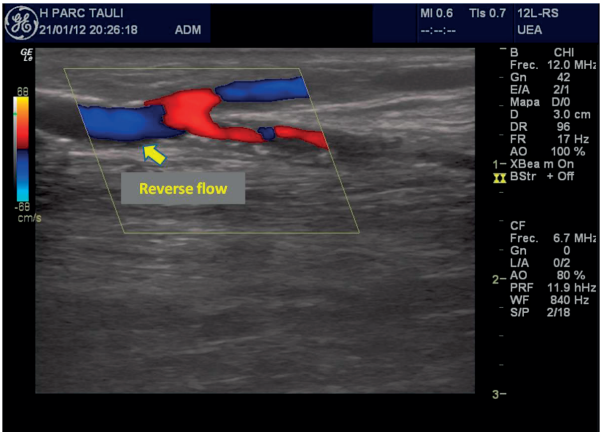


Figure 2. Anastomosis. Reverse flow

3. Vein examination

A transverse view of the vessel should be obtained in B mode along the nAVF venous segment, identifying particularly the basilic and cephalic veins, but it is also important to identify other veins like the perforating as well as collateral veins. The trajectory must be followed as far as the clavicle where the more proximal cephalic vein territory can be examined close to its drainage into the subclavian vein. Any decrease in size that could indicate stenosis or areas with a thrombus stuck to the vein wall must be noted. The presence of extra vascular masses or collections should be located in the examination.

After the transverse examination, the examination must be repeated longitudinally with the same objectives. At the same time, the examination must identify the ideal areas to needle

the access, which is one of the main objectives of ultrasound examination performed by nurses. Measurements of vessel depths and diameters should be taken and, if necessary, the distance between them should also be recorded. (Fig. 3)

After completing the examination in B-mode, the same examination must be carried out in colour mode to look for areas with aliasing, which could indicate stenosis. It must also be performed in transverse and longitudinal view.

During the examination, in areas where a possible stenosis has been identified, diameter measurements must be taken before and inside the stenosis (Fig. 4). These are needed to calculate the percentage of decrease in size (percentage of stenosis). Peak systolic velocities should also be taken in the same places. It must be remembered that in order to measure velocities at one point, the angle must be correct as well as the sample volume size. In the case of velocity measurements, the size must be as small as possible to obtain the exact speed at the specific point in the centre of the vessel lumen.

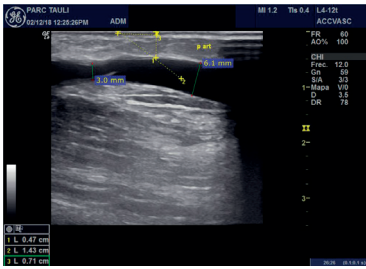


Figure 3. Diameter and depth measurement in B-mode. Best needling approach.

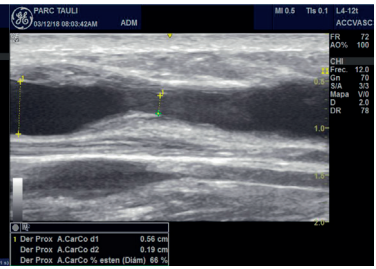


Figure 4. B-mode. Stenosis measurements

4. Flow measure

To obtain the access flow measurement, this must be done in the brachial artery, except in the case of pAVF, in which in the whole graft segment can be measured. To measure the flow, a segment of the brachial artery which is as straight as possible should be located, and in the case of brachial nAVF the segment must be at least 5 cm away from the anastomosis. Any possible anatomical variability, such as a high bifurcation of the artery, should be observed. In this case, flow must be measured above the bifurcation; if this is not possible, it must be measured in both arteries and then added up.

Once the segment of the artery in B-mode has been located, the probe must be placed longitudinally, and the artery must be clearly visible. When the image is centred and clear, Doppler mode should be activated. The flow measurement must be taken with an insonation angle of 60 degrees, which is usually predefined in the device. Once the sample volume is placed inside the vessel, the sample volume must be adjusted to make it as wide as possible. Vessel walls must not be reached to avoid turbulence of the flow generated on it. To obtain the correct value, the sample volume has to be placed parallel to vessel walls: if necessary, this position can be optimized by moving the probe to one side or the other and using the "tip-heel" technique, consisting of tilting the probe longitudinally so that it inclines in order to find the correct position of the sample volume in relation to the vessel walls.

When a stable cycle of spectral record is obtained, the image is frozen. Once frozen and spectral Doppler values are obtained, vessel diameter from wall to wall (internal diameter) must be measured, remembering that it must be measured perpendicular to the vessel walls. A slight variation in diameter measurement can cause a mistake in decision-taking, so it

is absolutely essential to be as scrupulous as possible when measuring. Current ultrasound devices usually calculate the flow value directly using data from diameter and Time Averaged Mean Velocity (TAMEAN), obtained with the spectral record. Due to possible variability when measuring, three measurements must be taken to determine the flow and calculate the average. (Fig. 5)

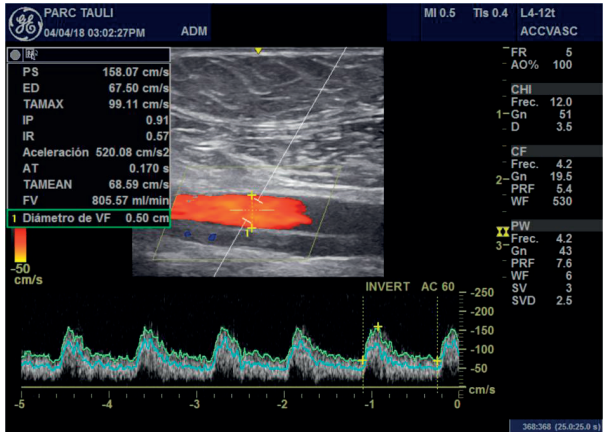


Figure 5. Flow measurement

EDTNA/ERCA
Caring Together

Invest in your Future and Profession
Join the EDTNA/ERCA Community

The European Dialysis and Transplant Nurses Association/European Renal Care Association (EDTNA/ERCA) represents 1400 members from 62 countries and is one of the most important forums in Europe for the exchange of information and experience in Renal Care.

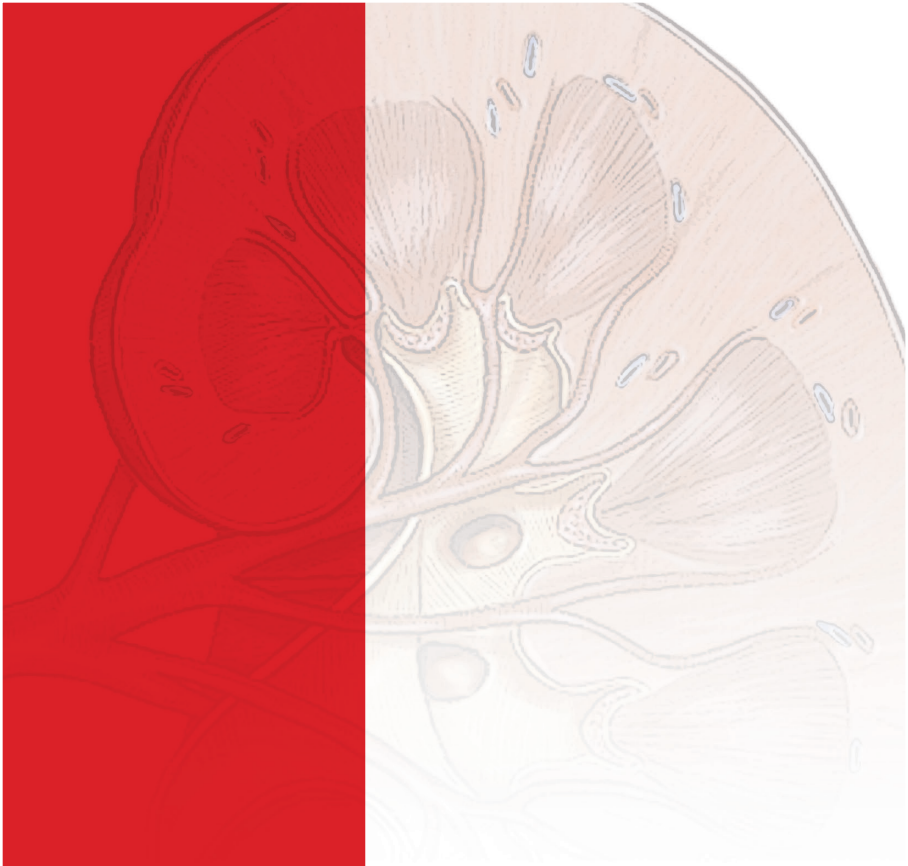
Visit our website to learn about:

- Membership
- Education & Research
- Annual Scientific Conference
- Journal of Renal Care
- News
- Brand Ambassadors
- Consultants (Anaemia, Education, Nutrition, Chronic Kidney Disease, Peritoneal Dialysis, Haemodialysis, Psychosocial Care)
- Publications
- Patients Education Documents
- Apps
- And much more...

www.edtnaerca.org







FRESENIUS
MEDICAL CARE