Ultrasound Applications in Dialysis Access

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**Subject:** Re: Sample Chapter

This link takes you to the index for Module 15 - which is the text of the document you sent.
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The first section is a great example of the linking:
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The green text links take you to a glossary entry

Red takes you to the illustration for each figure. Red is also used for "References"

Blue links take you to extra documents

Hovering over purple text shows all the words of the acronym.
Delete the above. **DOCUMENT** starts here at CHAPTER 2 below. We may include MIDA as it is basically Ultrasound procedures.
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# CHAPTER 2. Ultrasound Applications in Dialysis Access

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## Kidney Academy – Ultrasound Applications

### Section 1. The Many Applications of Ultrasound in Hemodialysis Access

#### 1.1 The "Preservation" scan

An US scan performed to "map" the arterial and **venous "real estate"** (**Fig 1**) of the patient's Right and Left upper limb to determine *which upper limb* has the best venous real estate and subsequently **which limb to protect** from veno-punctures, IV lines etc.

This scan can be performed months to years before **Renal Replacement Therapy** (RRT) is needed in patients whom the attending nephrologist thinks are likely to need RRT at some stage.

For example, *Protecting the non-dominant limb for future fistula formation is an **erroneous strategy*** as this may protect the limb that does NOT contain vessels suitable for AVF creation. **Ref 1JS** and **Case 1**

The vascular anatomy of the upper limb as it pertains to preoperative planning (**Fig 2**).

### 1.2 The Planning scan

An Ultrasound scan performed prior to fistula formation to determine what is the patient's best **Venous Real-Estate** and what is the best option AV access configuration.

The Planning Scan looks at both the **Venous Real Estate** and the **donor arteries** (usually the Brachial and Radial arteries).

If there is a **Preservation Scan** in the last year, a **Planning Scan** is not needed (**Ref 1JS**).

### 1.3 The Preoperative scan

An "on table" scan performed by the surgeon in the operating room immediately prior to surgery to assess:

- Confirm the findings of the **Planning Scan**,
- Assess the effect of the **arm block** on the state of the selected upper limb's venous and arterial vasculature
- Mark the exact site of **arterio-venous anastomosis** and the incision on the skin.

The Planning Scans often under-estimate vessel suitability for fistula creation because of vessel spasm (See **Venous Tone and Spasm** in The Deep and Superficial Venous System. The "true" state of the upper limb vasculature is invariably revealed by an effective **arm block** (**Ref 2**).

The commonest consequence of this Preoperative Scan (compared with the Planning Scan) is to change the operative site for an arm fistula to a forearm fistula (i.e. the forearm cephalic vein deemed too small on the Planning Scan is, when fully **dilated** by the arm block, in fact of a good size and quite suitable).

The preoperative scan allows the surgeon to pick the optimum anastomotic site (**Fig 3**).

### 1.4 Ultrasound Guided Arm Block

The upper limb arm block, also known as the Brachial Plexus Block is an **essential tool** in both **Open Fistula Surgery** and **Endovascular Fistula Surgery**. It is a form of **Regional Anesthesia** where infiltration with Local Anesthetic of the nerves to the upper limb block pain sensation and induces full **vasodilatation of veins and arteries** in the limb (as well as motor paralysis). The arm block should be ***placed under ultrasound guidance*** to maximize effectiveness and minimize complications. It provides very effective analgesia

as well as maximal vasodilatation in both the arterial and venous bed, leading to easier surgery and better outcomes (**Ref 3**).

Arm block in AV access work should ***always be placed in an infraclavicular*** position. Above this level (**supraclavicular,** intra-scalene) there is risk of causing block of the ipsilateral **phrenic nerve**, leading to temporary paralysis of the ipsilateral diaphragm. This puts the patient at risk of respiratory failure (**Fig 139**).

### 1.5 Diagnostic scan for AV access Failing to Mature

An ultrasound scan performed to determine why a fistula is failing to mature. Fistula maturation is a relative concept and can mean either that AVF is:

**a.** Not maturing
**b.** Not maturing fast enough.

A diagnostic Ultrasound scan is performed to determine why maturation is delayed or blocked. This scan requires advanced ultrasound skill and a clinical understanding of the fistula circuit.

Having diagnosed what is impeding or delaying the maturation, steps can then be taken with **Open Surgery** or **Endovascular Surgery** to make the fistula mature, so called **Assisted Maturation**.

### 1.6 Diagnostic scan for the "Dysfunctional Fistula"

An ultrasound scan performed to determine why a fistula is causing a problem. The AVF can be a problem to one of *four* different categories:

1. A problem for the **Dialysis Machine**, that is, the Dialysis Machine cannot perform the dialysis process as intended. (e.g. **Venous Return Pressures** causing recirculation or Inadequate Dialysis).
2. A problem for the person cannulating or **needling the fistula**
3. A problem for the **patient's upper limb** (e.g. **Ischemia** of the hand due to Steal or fistula ulceration and bleeding)
4. A problem for the **patient's heart** (Heart failure from excessive fistula flow (**Qa**) so called Giant Fistula,

This scan requires advanced ultrasound skill and advanced clinical understanding of the fistula circuit and the dialysis process (**Ref 4JS**).

### 1.7 Scan for Occluded Fistula

Like a Diagnostic Scan for the Dysfunctional Fistula, but with special imaging and clinical considerations specific to the problem posed by the occluded fistula.

*The Ultrasound Scan* aims to answer the following questions:

- Is the fistula occluded?
- If yes, is it a focal occlusion (inflow or outflow) with extensive thrombosis of the whole circuit? (**Fig 92a-c**).
- What is the state of the fistula's three components (**Fig 4**) – the **Inflow**, the **Useable Segment**, and the **Outflow**
- Can you identify the **index** lesion (stenosis) that caused the thrombosis?
- Can the fistula be salvaged?
- Can it be by **open surgery**, **endovascular surgery** or hybrid surgery
- What endovascular approaches are possible for salvage
- *Occasionally,* alternative **Venous Real Estate** does the patient have if salvaging this occluded fistula is not possible? (**Ref 10JS**).

### 1.8 Scan for post-op follow up

A Scan done after **Open** or **Endovascular fistula intervention** to determine:

a. The success of the intervention
b. As quality control feedback to the Interventionist.

The constant "feed-back" loop between ultrasound –angiography and Intervention and then post-operative ultrasound allows *to maintain and refine the accuracy of the ultrasound scans and the effectiveness of the hemo access interventions.*

### 1.9 Surveillance scan

An Ultrasound Scan performed on selected AC access to check their status. This includes the **"dormant" fistula** (a good fistula which the patient keeps after receiving a Renal Transplant for possible future HD use), the **Pre-dialysis Fistula** (which is not being used yet), the **"frequent fliers"** (the fistula requiring frequent interventions, > every 12 months) and the **"precious" fistula** (The patient's last good access site).

It is claimed that there are no Random Control Trials (RCT) showing the efficacy of Fistula Surveillance. There are no RCT's showing the efficacy of parachutes either. Like servicing and maintaining a car, it seems intuitive that "servicing and maintaining" your dialysis access will improve outcomes. **Ref 11JS**

### 1.10 Cannulating scan

An Ultrasound performed by the person who is going to cannulate ("**access**") to perform the dialysis. This scan is done to improve the success rate of cannulation and reduce the complications **Ref 10**.

The cannulation scan can be done in two different ways:

- A "mapping" scan, particularly of the "**useable segment**". Prior to cannulation, the Dialysis Nurse "maps out" the desired sticking sites. The Dialysis Nurse will be

looking for the size of the vein, the depth, tortuosity, and other factors that may affect cannulation success.
- A "real time" scan of the fistula as it is being needled by the Dialysis Nurse. This is technically a much more demanding procedure than a Mapping Scan requiring skilled use of both hands simultaneously.

### 1.11 Research

Ultrasound is a useful tool in AV Access research as it allows for combined clinical, anatomical, and physiological follow up of the fistula circuit in a safe, in a non-invasive fashion.

Compared to **angiographic** follow up it is a less costly option (**Ref 7JS**) and (**Ref 12JS**)

### 1.12 Ultrasound Guided angioplasty

Endovascular intervention can be performed on the fistula circuit purely under ultrasound guidance without the use of contrast or exposure to radiation. The more **distal** the lesion, the easier this becomes; per contra, lesions in the upper **arm** and shoulder are difficult to treat and **Central Vein Stenosis** are not at all accessible.

Contra-Indications for US guided angioplasty include **contrast** allergy, severely impaired **pre-dialysis** renal function and limited technical resources to do x-ray guided **angioplasty**.

### 1.13 Ultrasound Guided placement of all central vein catheters

Ultrasound guidance should be used for all central vein catheters (**Vascath**) placements. Like with Ultrasound Guided Fistula cannulations, the ultrasound guidance can be used in two different ways.

- Use the ultrasound pre-procedure to assess the patency, size, depth and tortuosity of the target (usually Central) vein. This allows for a confident puncture, often mapped on the skin with a pen using the ultrasound image.
- The vein puncture can be performed under direct ("real time") ultrasound guidance. Although this should improve puncture safety and accuracy, it is a more difficult task as it requires ambidexterity and coordination between probe hand and needle hand.
- Vascaths, Central Venous Catheters, (CVC) should not be placed on Left neck side unless the patient has a limited life expectancy.

### 1.14 Ultrasound Guided Peritoneal Dialysis Catheters – Seldinger PD

**Seldinger** PD - Placement of a radiologically guided PD catheter, using ultrasound, sheaths and guidewires has become an increasingly common way of

placing PD catheters. Developed and introduced in Sydney Australia. Seldinger PD has many advantages over other techniques

The Seldinger PD is an integral part of Hemodialysis Access Surgeons repertoire, for two reasons:

- When faced with a Hemodialysis Access candidate with very poor venous real estate, poor cardiac reserve or severely damaged arteries (and risk of steal, the correct management could well be (Seldinger) PD.
- Performing a Seldinger PD is essentially an Endovascular Procedure (not a general surgical or abdominal surgery) procedure. The skills involved are essentially endovascular using ultrasound guided puncture, x-ray, and contrast guidance, micropuncture and sheath, wire and catheter skills.

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## Section 2. The AV Fistula Ultrasound: Specialized Scans

This text in chapter 2 *does not* purport to explain how ultrasound works nor to teach the skills needed to perform Duplex Ultrasound scanning or to teach vascular ultrasound scanning.

The aim is to teach sonographers, clinicians and Nurses involved in hemodialysis access how to apply ultrasound in general and to the AV hemodialysis access Arterio-Venous Fistula (AVF) in particular.

An AVF Ultrasound is a specialized area of vascular ultrasound, which in turn is a specialized area of General Ultrasound. Hemodialysis ultrasound is not for casual occasional sonographers (even if they are Vascular Ultrasound trained). A good understanding of how hemodialysis works and of the AV circuit anatomy and physiology is needed to perform meaningful fistula ultrasound. Below are some of the peculiarities of this highly specialized field.

### 2.1 Hemodialysis and Fistulas are *uncommon* conditions.

In Australia in 2018, there were 536 people per million on hemodialysis, roughly 1 person in every 2000. As the average Australian GP has about 1,800 patients in their practice, the experience of these complex patients amongst the average doctor is limited (0 – 1 patient per GP).

### 2.2 RRT is the ~most complex system in modern healthcare.

Patients with critical organ failure – heart, lung, liver – generally end up in ICU or die. The ESRD patients can live near normal lives in the community, some for several decades. This is the result of **complex** technology, highly skilled teams and sophisticated **systems.**

### 2.3 RRT is extremely *expensive* healthcare.

RRT, particularly hemodialysis, is the most expensive branch of healthcare, regardless of how it is funded. In Australia, in 2020, it requires approximately $ 80,000 per year to keep *one* patient alive on in-center hemodialysis (**Fig 124**).

### 2.4 A Hemodialysis Fistula is a disease, a pathology

**The fistula in itself is the pathology** created by the surgeon for the purpose of safe and effective dialysis access. Scanning the fistula circuit is unique in that we are not looking for pathology nor deviance from the normal anatomy or physiology. Every AVF is unique in its anatomy, location, physiology. The fistula scan does not seek to identify normal or abnormal as there is no normal. The fistula scan, therefore, asks whether the fistula pathology we created is behaving in a way that satisfies our dialysis access goals without causing problems for the patient.

Because the AVF is a pathology (hence no "normal" to compare findings with), the Pre-Scan Workup is essential to interpreting your ultrasound findings. The same finding in two different fistulas may have very different implications, depending on the clinical setting. **Cases 1 and 2.**

### 2.5 Fistula Scans must be targeted.

Like all ultrasound scanning, but particularly Fistula scanning, the examination must be targeted. Unlike a CT scan, where vast amounts of accurate anatomical data can be gathered in seconds, ultrasound scanning is slow and laborious. The access circuit runs from the L ventricle to the R atrium; scanning the whole circuit would not only be time consuming, but several areas are inaccessible to ultrasound (e.g. the Proximal Central Veins (**Fig 91**). The fistula sonographer must have an understanding of dialysis and AV access, and do a thorough Pre-Scan Workup to allow for a targeted scan. A targeted scan is one that focuses on those anatomical and physiological features of the fistula circuit that will answer the question posed with the most accuracy.

### 2.6 Fistula U/S produces accurate Grey Scale and Color images

The standout feature of the relevant parts of the fistula circuit is very **superficial** location, a few mm from the skin surface. This means that very **high frequency probes** can be used, or 17 -18 MHz . Detailed and accurate images can be obtained, in grey scale and in colour (**Ref 7JS**). This makes the use of **velocities** to assess fistula anatomy, stenosis, and dynamics (**Figs 66**, **Fig 67a, b**) less important as very accurate, direct anatomic measurements can be made.

### 2.7 Flow is the Central Issue in the Fistula Circuit

Unlike other vascular circuits, where perfusion and perfusion pressure are the critical elements, in the fistula circuit, blood flow is the central issue. Flow can be too little, too much or within parameters.

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## Section 3. The Arteriovenous Fistula Anatomy

### 3.1 Defining A Fistula

A **fistula** is a **communication** between two hollow, **epithelial** lined structures in the body. Examples include Recto-Vaginal fistula (between Rectum & Vagina after traumatic childbirth) or Entero-Cutaneous fistula, between the small bowel and skin.

An Arterio-Venous Fistula (AVF), **Fig 7**, is a **communication** between an artery and a vein, both are epithelial lined structures.

Clinically, in common usage, the word "fistula" is used to refer to the whole fistula circuit, and the visible cannulation **Useable Segment**.

An Arterio-Venous Graft (AVG), **Fig 8,** is a synthetic (usually PTFE) **vascular graft** connecting an artery to a vein. The AVG has many disadvantages compared to the AVF.

**The Advantage of the native AV Fistula over the AV Fistula Graft**
It is widely recognized that the native AVF is significantly superior to the Fistula Graft and most institutions try to minimize their use of AVG. Whether there is a place for using AVGs is debatable and depends on several factors. Generally, the more skilled and dedicated the team becomes in the creation, maturation and maintenance of the native AVF, the better it performs compared to the AVG, **Ref 12**.

**1. Advantage of AVF over AVG**

- **Sepsis:** Although the native AVF can become infected, this happens infrequently, and the infection can almost always be eradicated with good surgical technic and antibiotics. With infected AVGs on the other hand, eradicating sepsis is difficult and often requires explanation of the fistula graft (not a small procedure), temporary Vascath (causing further Central Venous damage and creation of a new fistula.
- **Thrombosis:** Thrombosis / occlusion in the native AVF is rarely "catastrophic" – it is almost always it is the result of a gradually progressive stenosis – over weeks to months. Furthermore, often, there are warning signs of this progressive stenosis becoming more severe. Finally, with good surveillance, most of these progressive stenoses can be picked up before fistula occlusion occurs. In the AVG however, catastrophic failure (i.e. Thrombosis without warning and in the absence of any stenosis) is not uncommon. The reason for the AVG can thrombose without warning relates to its lack of **endothelial lining** (as compared with the native AVF).
- **Cost:** In the developing world, the cost of the AVG is a factor. In the developed world, the inferior performance clinically of the AVG of the native AVF makes it more expensive too.

**Advantages of AVG over AVF**

- **No need for Maturation:** This is the big advantage of the AVG it can be used within 1-2 weeks of implantation, within days if the early cannulation grafts are

used. The main virtue of this is that it decreases the need for central vein catheters prolonged use. An effective HD program, incorporating early referral for fistula creation, assisted maturation to speed up the fistula maturation and "**bridging**" (Seldinger) PD all off-set this advantage.

- **For patients with poor Venous Real Estate:** This advantage is critically linked to the adequacy of the HD Access Service.

It is important to note that the AVF is **not** a normal structure. It is a pathology, or even a disease created surgically for the purpose of hemodialysis. The AVF is neither an artery, nor a vein; it is a hybrid of the two systems, with its own unique anatomy and physiology.

When working with AV Fistulas, it is important to always be aware that the term "normal" is artificial. When we talk about "normal" in hemodialysis and fistula work, normal refers to proper, effective and safe dialysis function.

### 3.2 The Nomenclature for the AVF:

#### 3.2.i "Proximal and Distal"

The convention in venous and arterial anatomy, which also applies to fistulas, is as follows: Proximal means closer to the heart, Distal means further away from the heart as (**Fig 11**). Around the fistula anastomosis this can become confusing; **Fig 77** depicts the anastomotic nomenclature.

#### 3.2.ii Arm and Leg

Throughout the chapters we use the "**Terminologia Anatomica**" nomenclature: The *Upper Limb* consists of an (proximal) *Arm* and a (distal) *Forearm* The *Lower Limb* consists of a (proximal) *Thigh* and a (distal) *Leg*.

#### 3.2.iii Fistula Nomenclature

This is variable, but the nomenclature in **Fig 7** describes the various segments of the fistula circuit and as used throughout the chapters (**Ref 7JS**). An almost identical nomenclature was described independently by another group (**Ref 11**) and (**Fig 43**):

**AVF terminology**

- Inflow artery
- Anastomosis.
- Swing vein
- Useable Segment / Needling Segment.
- Outflow; 6 Central Veins

### 3.3 The Three Components of the AVF:

The AVF can take many different forms (**Fig 9**) and (**Fig 10**), in different anatomical locations. AVFs have the same 3 basic components (**Fig 4**). These 3 components should

always be borne in mind when assessing, examining, ultra-sounding and treating a fistula. The 3 components are:

- The Inflow
- A Useable Segment (Cannulation length or cannulation segment)
- The Outflow, as illustrated in **Fig 4**

For the purposes of this chapter, the Radio-Cephalic Arterio-Venous Fistula (RC AVF) at the wrist is the default setting for all description and discussion.

### 3.3.i Inflow

The distinction between the **anatomical and the functional inflow** is important.

The **anatomical** inflow of the fistula consists of

- The feeding artery (Subclavian, Brachial & Radial artery in the RC AVF),
- The anastomosis.

The **functional** inflow to the fistula consists of

- The feeding artery
- The anastomosis and
- The **Swing Vein** (which is technically part of the anatomic outflow) (**Fig 5**)

The anatomical inflow ends at the anastomosis; the functional inflow ends in the fistula vein about 5 cm past the anastomosis at the proximal end of the Swing vein (**Fig 5**). The Swing vein is not used for cannulation; hence any swing vein problems will present clinically as **inflow problems**. This is even more important as about 1/3 of fistula stenoses occur in this critical first 5 cm segment **Swing Vein** (**Fig 6**).

The unique situation of the RC AVF inflow (**Fig 12a,b**, **Fig 13**) and **Video 10**).

The Anastomosis is the surgically created connection between the artery and the vein. The anastomosis can be end-to-side (commonest) or side-to-side (**Fig 27**). With the RC AVF, the anastomosis is made as big as possible – 5 mm or more. With the proximal fistulas i.e. Fistulas onto the Brachial artery (BC and BB ACF), a large anastomosis may predispose to Giant Fistula formation hence the *anastomosis onto the Brachial artery should be between 3 and 5mm*

It is important to note that the anastomosis is "diamond" shaped with a longer longitudinal axis and a shorter transverse axis (**Fig 80**). This has important bearing on how the size of the anastomosis is measured on ultrasound.

With the more common end-to-side anastomosis, there is an arterial segment proximal to the anastomosis (referred to as the "**inflow artery**") and an arterial segment distal to the anastomosis (referred to this as the "**outflow artery**") **Fig 77** and **Fig 78**. The physiology of the "outflow artery" in the RC AVF is different from that in the proximal, Brachial artery based fistulas **Fig 12a,b**, **Fig 13** and **Video 10**.

### 3.3.ii Useable Segment or Cannulation Segment

The **useable segment** (**Fig 42**) is that part of the fistula which receives the dialysis needles and is derived (usually) from the Superficial Venous System. The useable segment needs to have certain characteristics, as conveniently summarized in the "Rule of 6's". This is a very useful **"rule of thumb"** and the interpretation of this rule of thumb needs to be individualized to each fistula. In several institutions, the Rule of 6's is misused as an absolute requirement, where all conditions must be met before the fistula gets used.

### 3.3.iii Fistula Outflow

The fistula outflow starts immediately **proximal** to the most proximal needling point in the fistula circuit. Fistula outflow is the most variable segment of the various fistula configurations used, and often the most difficult to treat.

All fistula outflows consist of 2 components; the immediate **Regional Outflow** of the fistula into the larger veins of the limb, and the **Central Venous Outflow** (**Fig 143**). Central Venous outflow is a major problem in Dialysis Access as this part of the fistula circuit is often damaged, partly or completely, by the frequent use of Vascaths - Central Venous Catheters for dialysis.

The standard RC AVF has the best outflow configuration of any fistula – one of the many advantages of the RC AVF. Under "normal" circumstances, the RC AVF has 3 outflow channels at the elbow: The Cephalic Vein, the Basilic Vein and the Perforator (**Fig 15**, **Fig 16a,b** and **Fig 201**. Only one good outflow channel is needed for a happy fistula. Furthermore, because the RC AVF is remote from the Central Veins, Central Venous obstruction does not necessarily cause RC AVF problems.

Although the RC AVF should have **"Triple Outflow"**, often this is not the case. This is not anatomical variation but damage to the outflow veins caused by medical access to these vessels: The Median Cubital vein, the Cephalic Vein and even the Basilic vein at the elbow are frequently used for veno-puncture, drip sites and for the injection of medications. All these can damage or occlude the vein by inflammation (**thrombo-phlebitis**), infection or thrombosis. This is particularly a problem in developed countries with advanced Renal Transplant programs where fistulas are principally used in the sick and elderly, unsuited for transplantation, and who usually have a long history of medical intervention and venous damage – See "Section 17. Hemodialysis Ultrasound in the Developed & Developing World".

### 3.4 Native Fistula Configurations:

Native AVF configuration can have great variability (**Fig 9** and **Fig 10**), but the following combinations are the "standard" configurations and some of the variations used by our unit.

- Radio-Cephalic Fistula (**Fig 18**), the gold standard. Variations include proximalisation of the inflow (**Fig 19**), variations due to diseased radial artery inflow (**Fig 20**) and variations of Radial artery anatomy – the High Brachial Artery bifurcation (**Fig 21**).

The different AVFs in the upper extremity are described in **Figures 9 and 10**:

- Brachio-Cephalic Fistula
- Brachio-Basilic Fistula
- Other forearm Fistulas
- Other arm Fistulas
- Long Saphenous Vein Fistulas
- Deep Femoral Vein Fistulas
- Other variations

### 3.4.i RC AVF

The RC AVF is the gold standard as it produces the best, most reliable, most problem free and longest lasting fistulas - 25 years +.

The biggest drawback of RC AVF is that it is a more difficult fistula to create and mature, for three reasons.

- Firstly, the vessels involved (Radial a & forearm Cephalic v) are small (2-3mm) making surgery more technically difficult.
- Secondly, because these forearm vessels are often damaged in the older, sicker population, due to venous damage from IV lines, **thrombophlebitis** etc.
- Thirdly, the Radial artery, especially more distally is often damaged from atherosclerosis, particularly, Diabetic Runoff Disease.

The RC AVF has the best outflow configuration – "triple outflow": cephalic vein, basilic vein and perforator (**Fig 15**, **Fig 16a,b** and **Fig 201**).

### 3.4.ii BC ACF

BC ACF (**Fig 24**) are easier to create than RC AVF's and mature more reliably as the involved vessels are larger and less likely to have been estrogenically damaged. However, it suffers from several short- and long-term problems.

- Cephalic Vein Arch problems. The arch is the only significant outflow of the BC AVF; arch problems are common and difficult to manage (**Fig 192** and **Fig 193a,b,c**).
- Poor tolerance of Central Vein stenosis or occlusion. Because it is situated proximally in the limb, and has only the single outflow channel, by the time the returning blood from the AV fistula reaches the Central Vein stenosis, there are few alternative routes to the deep system. This causes High Venous Pressures interfering with dialysis and it can also lead to severe arm swelling.
- Giant Fistula formation. Because the BC vessels are significantly larger than the forearm vessels, progressive and run-away growth of the fistula circuit is not uncommon. Risk factors for Giant Fistula development include: Male sex; large, muscular arms with big brachial artery; genetic tendency to **vessel ectasia**; large (> 5mm) surgically created AV anastomosis.

- *Depth of the Useable Segment.* The upper arm cephalic vein is, by its nature, deeper than the forearm cephalic vein. In thin patients this doesn't matter; in the obese population, the incidence of the arm cephalic vein being too deep for needling is significant and may require a secondary **superficialization** operation a larger procedure than the AVF creation (**Fig 86**) and (**Fig 196**).
- *Forearm – hand Ischemia*. The Brachial artery is not a "spare part" (whereas the Radial artery is expendable). Hence, in the process of BC ACF creation, revision and unblocking, damage to or embolization from the Brachial artery can cause severe **ischemic** problems of the forearm and hand. See also "The High Brachial artery bifurcation".
- The BC ACF in the Upper Limb with a high brachial artery bifurcation is a hybrid of RC & BC in terms of anatomy and characteristics. It will have inflow properties like the (wrist) RC AVF and outflow properties like the (arm) BC ACF.
- Steal Syndrome: This is seen mainly in diabetics, and mainly in the proximal, Brachial artery-based fistulas. Hand ischemia with RC AVF is unusual or <1%.

### 3.4.iii BB AVF

#### 3.4.iii.a BB AVF is a good fistula with advantages.

- *Good outflow*. Unlike the BC ACF, it generally has excellent outflow (Segment 5 in the Westmead nomenclature (**Fig 7**) via the brachial / axillary vein complex which has many branches. In addition, the Brachial vein is usually bifid, and the 2 channels are well interconnected. It does not suffer from an "**arch vein**" problem.
- *Sizeable and well-preserved vein*. The Basilic vein in the **arm** is not a target for veno-puncture nor IV sites because it is deep and generally poorly accessible. That means this vein, usually of reasonable caliber, is "preserved" for the fistula surgeon (This may be changing with the advent of ultrasonically placed central lines and porta-catheters via the arm basilic vein).

#### 3.4.iii.b The BB AVF has several disadvantages.

- *Available length* of Basilic vein in the arm can be a problem. Although the diameter of the arm basilic vein is usually reasonable, its length / insertion into the deep venous system is quite variable. Since the Basilic vein must be transposed, extra length to do this adequately is important. **Fig 28** and **Fig 30** illustrate some of the anatomical issues that are important in BB AVF pre-operative mapping and fistula creation.
- *Staged formation*. Generally, BB fistula formation is a lengthier, two stage procedure (**Fig 29**). The Brachial artery and basilic vein need to be anastomosed, plus the Basilic vein needs to be **superficialized** (even in thin people it is generally too deep) and it needs **transposition** to the more lateral arm. The natural course of the Basilic vein is contiguous to the Brachial artery and Median nerve, making these structures vulnerable to repeated needling in the un-transposed position (**Fig 215**). In addition, its medial location makes needling access very difficult. Adequate lateral **transposition** is a problem (because of lack of length), and several steps can be taken to improve this (**Fig 30**):

a. Use part of the forearm Basilic v if adequate in size.
b. Use the Median Cubital vein if adequate / un-injured.
c. Mobilize the Brachial vein towards the axilla (particularly suitable when the Brachial vein is bifid) or
d. Use an **interposition graft** harvested elsewhere. We usually use an **ultrasound mapped** piece of forearm Basilic vein from the R or L forearm

- *Single stage BB AVF creation* can be affected if the Basilic vein is of good caliber (> 5mm in diameter) but performing the extensive dissection and transposition of single stage BB AVF creation on a small, immature Basilic vein is associated with a high failure rate. The single stage BB AVF creation is commonly done when the patient has a failed ipsilateral RC AVF that has been present for a while and has caused hypertrophy of the veins in the arm of that upper limb.
- Like BC ACF it suffers from Giant AVF formation
- Because the BB AVF is connected to the Brachial artery, there is a risk of Steal, mainly in the Diabetic, and the hazard of Forearm-hand ischemia due to Brachial artery injury or embolization.
- When transposing the Basilic vein, torsional forces at the proximal pivot point can lead to an outflow stenosis. This will need endovascular correction, often requiring a **bare Nitinol stent**.

### 3.4.iv Other Forearm Fistulas

Other forearm fistulas are possible, and may offer some of the advantages of RC AVF

- Forearm fistula based on the Forearm Basilic vein (**Fig 31**). The Basilic vein can be left in situ, with anastomosis to the Ulnar artery, but cannulation becomes awkward (**Fig 32**). Better is to **transpose** the Basilic vein across the volar aspect of the forearm and anastomose onto the Radial artery.
- Forearm fistula using an interposition vein graft (**Fig 34**). Usually this is the LSV but any harvested vein can be used. The LSV generally performs very poorly in the fistula circuit, whether left **in situ** or **transposed** to the upper limb, with a high rate of aggressive and recurrent stenosis. We have limited use of it.

### 3.4.v Other Arm Fistulas

Other arm fistula configurations in patients with limited options. They suffer the disadvantages of the arm fistulas Giant AVF brachial artery injury / embolism and Steal and are technically more complex.

- Vein interposition graft from the Brachial a to the Axillary vein. Our preferred graft is the Superficial Femoral vein which is large and does not stenose; harvesting this deep vein is a major undertaking (**Fig 35a and b**). LSV can be used but suffers from aggressive and recurrent stenosis as mentioned above.

Any harvested vein can be used to create a fistula. **Fig 33a** and **Fig 33e** show how the Useable Segment of a failing fistula (in the R forearm, because of untreatable Central Venous Obstruction) can be used to create a functional new fistula within 4 weeks.

- Brachio-Axillary AVF using the Brachial vein or one of the bifid Brachial veins. This is an extensive operation and requires careful pre-operative ultrasound assessment to determine the suitability of the patient's anatomy for this procedure.

### 3.4.vi LSV Fistulas

Although the LSV is the "gold standard" conduit for arterial bypass and reconstruction, for some reason the LSV behaves very badly in the fistula circuit. When the LSV is used in the fistula circuit, **in-situ** in the thigh or **transposed** elsewhere, it often undergoes early, extensive, and aggressive stenosis that is hard to treat. For this reason, we now make limited use of this vessel.

- **In-situ** LSV AVF. Straight or as a loop in the thigh (**Fig 36**). In addition to stenosis, any thigh fistula puts the circulation of the lower limb at risk – **claudication** or **critical ischemia** – because the **vascular reserve** of the lower limb is much less than that of the upper limb. Lower limb fistulas should not be created in patients with **Peripheral Vascular Disease**, especially if this is symptomatic (**claudication**) or the peripheral pulses (Anterior Tibial and Posterior Tibial) are not palpable.

Hence, Lower Limb fistulas should only be created in patients with normal or near normal arterial circulation: foot pulses present, no claudication, ABI > 80% or, in Diabetics with calcified vessels, Toe **Plethysmography** > 100mm Hg.

- Transposed LSV AVF to the upper limb, multiple configurations. Venous stenosis remains the biggest problem (**Fig 34**).

### 3.4.vii Superficial Femoral Vein Fistulas (SFV AVF)

Note the confusing anatomic nomenclature of this vessel.

SFV AVF are an option for younger patients who need longer term HD access but who have run out of **Venous Real Estate** on their upper limbs. SFV fistulas are big operations and need to be carefully planned and executed. Like with the LSV, SFV AVF can be **in-situ** or, better, **transposed** to the upper limb.

The main advantage of the SFV is that it is a large (6 – 10mm), reliable, long (15 – 20cm), straight conduit that **does not stenose!** In addition, because the useable segment is so big, maturation is generally reliably reached as soon as the wounds are healed at 2-6 weeks. It is our fistula of last resort when we need a reliable fistula for long term use, especially in a young or non-transplantable patient.

Disadvantages depend on the site.

- *In-situ SFV fistula (Fistula in the thigh)* (**Fig 37a-k**)

The biggest hazard is **arterial insufficiency** as explained above.

**Venous insufficiency** or swelling of the limb is uncommon in our practice or in the limited reported literature.

Wound healing, even in healthy patients, can be problematic because of the large, deep wound. Stepped incisions make surgery difficult but may improve wound healing (**Fig 38**).

Giant Fistula development is also a big risk (because the native vessels being anastomosed may both be > 8mm), and a small anastomosis (<5mm) is mandatory. We often place a "prophylactic" band or choke on the **Swing vein** of these fistulas at the time of fistula creation (using a short synthetic wrap) to prevent this. (**Fig 37a**)

The harvest of the SFV is an advanced Vascular Surgical procedure, taking 1-2 hours.

- Transposed (to the upper limb) SFV fistula avoids the significant risk of arterial insufficiency in the leg and can produce an excellent, problem free arm or forearm fistula. It is our solution when we cannot find or develop suitably upper limb fistulas. (**Fig 39a,b** and **Fig 35a,b**)

### 3.4.viii Other Fistula Configurations

Other fistula configurations.

Ultimately, any patient can be given a native fistula if

1. The patient's heart can support the flow of the fistula,
2. The donor artery has sufficient reserve to supply the fistula and the donor limb (i.e. No steal syndrome,
3. The patient's skin is suitable for repeated needling and
4. The sonographer/surgeon can find the 3 essential components of the fistula circuit: a suitable donor artery, a suitable length of vein for the Useable segment and adequate

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## Section 4. The Physiology of the AVF

As stated in Section 3, the **hemodialysis** fistula is a **pathology**, a disease, not a "normal" structure. Therefore, talking about the Physiology (normal function) of a fistula is somewhat artificial.

The principle of hemodialysis is simple: remove blood from the patient's circulation, filter it thru the dialysis machine and then return the dialyzed blood back to the patient's circulation.

In practice, the difficulty with hemodialysis lies in the **access** , meaning being able to safely and repeatedly:

1. Access the patient's circulation with 2 large bore cannulas,
2. Remove blood from the patient's circulation and then
3. Return the blood to the patient's circulation after it has passed thru the dialysis machine, all at a rate of 200 ml – 600 ml/minute.

Access can be through an indwelling central line catheter ("**Vascath**"), a synthetic fistula graft (AVG), or an AVF. The native vein AVF is recognized as the best access solution for HD in most but not all cases.

### 4.1 Qa and Qb:

**A critical concept in the physiology of dialysis is the difference between Qa (Fistula circuit flow) and Qb (Dialysis circuit flow). They are closely related but very different and a thorough understanding of both is essential to perform meaningful fistula ultrasound** (**Fig 44**)

### 4.1.i Qa:

In the normal circulation, blood flows from the Left Ventricle of the heart, down the arteries, thru the capillary bed in the tissues and organs and then into the veins and back to the Right Atrium of the heart. In the patient with an AVF, some of the blood that is pumped out by the Left Ventricle is diverted from the normal arterial circulation thru the arterio-venous anastomosis and "short circuits" the **capillary bed** and sends the blood back to the Right Atrium **Fig 45** and **Fig 46**. The amount of blood flowing thru the fistula circuit is the Qa or "Fistula Volume Flow".

There are a number of different ways of measuring the Qa of a fistula, including by Duplex Ultrasound Qa assessment.

Ultimately, none of these methods is very precise due to several factors. These include:

- The inherent technical limitations of the various modalities,
- The fact that the Qa of a particular fistula is not fixed, varying with Blood Pressure, hydration, Dialysis Status amongst others and,
- The systems for measuring Qa operate best when the Qa of the fistula is within "normal" parameters (500 – 2000mls/min). Once a fistula becomes "Giant"), the error range of Qa increases progressively.

Therefore, *Qas in fistula management are more an approximate figure"* than an exact number; furthermore, *the trend in the Qa over time is very significant*.

### 4.1.ii Qb:

Also known as dialysis machine **pump speed**, is the Fistula circuit flow as illustrated in **Fig 44**. It is the amount of blood (in ml/min) taken out of the arterial side of the fistula circuit through the arterial needle, then passed through the dialysis machine and then returned via the venous needle to the venous side of the fistula circuit.

The arterial and venous sides of the fistula circuit is a relative concept: the arterial needle is the needle placed closer to the **inflow** part of the circuit, the venous needle is closer to

the **outflow** part of the circuit, even though both needles are actually in a vein, the **Useable Segment** (**Fig 47**).

Dialysis needles incorrectly placed (i.e. the arterial needle proximal to the venous needle) will lead to major recirculation.

*Qb, is a major determinant of:*

1. The effectiveness of dialysis
2. The patient's well-being.

This relationship tends to be inverse, is complex and is part of the "slow" vs "fast" dialysis debate.

*Qb is also closely related to "Dialysis Pressures"* (**Fig 48**)..

This is the "Arterial (Dialysis) Pressure" (AP), the pressure required to extract the blood from the fistula circuit by the arterial needle (sucking pressure i.e. negative pressure), and the Venous (Dialysis) Pressure (VP), the pressure required to return the blood to the Venous side of the fistula circuit via the Venous needle (pushing – injecting pressure i.e. positive pressure). Both AP and VP should be around 100 mmHg**, at a *Pump Speed of 300 ml/min***!! This is a very important concept because, in the presence of an inflow or an outflow problem in the fistula, the Dialysis Pressures can be "normalized" to 100mmHg by decreasing the Pump Speed. See also Interpretation of Dialysis Numbers.

### 4.2 "Pathophysiology" of the AVF

The AVF is a pathological creation. Accordingly, normal function of AVF refers to what is considered normal for performing good hemodialysis of the patient. In that sense, it is the Dialysis Pump (which dialyses the patient) and the Dialysis Nurse (who needles the patient) determines whether the AVF is functioning normally or not.

*The following are the "fistula pathologies" encountered in Dialysis:*

- Stenosis in the Dialysis Circuit - the most common problem. This can be on the Venous or Arterial side of the Dialysis Circuit, as illustrated in **Fig 49** and **Fig 50** or occasionally within the useable segment.
- *Inadequate **useable segment***; as per the rule of 6's, this can be due to one or more issues – size, depth, tortuosity, length & aneurysmal dilation.
- Giant fistula is excessive growth of the fistula circuit. It is very important to note that a Giant fistula and a Fistula aneurysm are two very different entities, though they may coexist.
- Steal Syndrome: Where the presence of the fistula produces ischemia or critical ischemia in the index limb.

## Section 5. Fistula Pathology

This is a slightly peculiar concept as, in fact, the fistula itself is the pathology. However, we look at this from the perspective that we created a Hemodialysis Access Fistula on the patient's arm so that the patient can dialyze safely and successfully to control their ESRD.

So we see a "normal" fistula as one that does not cause the patient any complications (e.g. steal syndrome) and allows the patient successful needling and subsequently successful dialysis by the dialysis pump.

Any fistula characteristic that negatively impacts on the patient's health, on the dialysis nurse's ability to cannulate the fistula or on the effectiveness of dialysis session becomes a fistula pathology**.**

### 5.1. Stenosis

The concept of stenosis in the fistula circuit is difficult to define. Ultimately, stenosis can lead to one or two problems:

- *Inadequate flow* in the fistula circuit (Qa <500mls/min say) that leads to inadequate dialysis and
- *Fistula thrombosis*. Generally, dialysis malfunction will start first, and fistula thrombosis will occur later when the stenosis becomes very severe (Qa < 300mls/min in our experience) especially when complicated by **other pro-thrombotic** factors e.g., Hypotension. See also Why is the AVG more prone to sudden thrombosis than the AVF.

### 5.2. Giant Fistula formation

This is a complex, poorly understood and widely under-recognized problem in Hemodialysis Access.

It is important to emphasize that the "Giant"/High Flow Fistula and Fistula Aneurysms are two totally different entities.

When a fistula is created, its flow is powered by the Left Ventricle and requires extra **resting cardiac output** to keep it working. The effect of this on the heart and the body performance depends on two things: How big is the fistula flow (Qa) and how healthy is the heart. So, a fistula does not have to be Giant (often defined as flow >2 l/min) to have a deleterious effect on the patient's heart if there is significant pre-existing cardiac disease.

Radio cephalic fistulas rarely become Giant – one of their many advantages Generally, the RC AVF will not have Qa's much over 2 L/min, and progressive growth beyond this is rare.

Proximal Brachial artery-based fistulas are prone to Giant fistula development and progressive growth up to 6 L/min and more. This can adversely affect the unhealthy heart,

causing angina and shortness of breath, but even a normal heart can be driven into High Output Heart Failure by a very large fistula. In addition, any flow to the fistula above and beyond that needed for dialysis (600-1000ml/min) is cardiac output that is no longer available for the patient for exercise, with adverse effects on quality of life.

The diagnosis and management of Giant AVF is a complex subject described under The "Giant" or High Flow Fistula.

### 5.3. Fistula Aneurysm

It is important to emphasize that the "Giant"/High Flow Fistula and Fistula Aneurysms are two totally different entities (**Fig 22a-b**).

Fistula aneurysm occurs when the venous part of the fistula circuit, almost invariably the usable segment, becomes very large. Giving an exact number as to what constitutes an aneurysm is not possible.

### 5.3.1 The following features (grades) would suggest aneurysm formation:

**+** somewhat suggestive **++** suggestive **+++** strongly suggestive

**5.3.1.i** A very dilated portion of the fistula circuit with respect to the size of the fistula / the size of the patient **++**
**5.3.1.ii** Marked caliber difference between the "aneurysm" and the afferent / efferent vein to the aneurysm **+**
**5.3.1.iii** Sluggish flow with spontaneous echogenicity due to Rouleaux Formation within the ?aneurysm **+**
**5.3.1.iv** Laminated thrombus depositing within the aneurysm +++ **Fig 145a and b**.
**5.3.1.v** Abnormal thinning of the overlying skin **++**
**5.3.1.vi** An aneurysm diameter over 2.5 – 3cm **+++**

### 5.3.2 Consequence and Management of Fistula Aneurysm

Fistula aneurysms are generally benign" and should be left alone. The much-feared risk of rupture ( **Abdominal Aortic Aneurysm**) is unfounded as it is a low-pressure circuit.

This however is not the same as excessive thinning of the fistula skin in the useable segment – often over aneurysmal segments with which the problem is associated – which does represent a real danger of fistula rupture. The problem here however is NOT the aneurysm, but the damaged, thin skin.

Surgically reducing the size of a fistula aneurysm often does not work as the repair is affected by the same weak, stretchable tissue that produced the aneurysm in the first place.

### 5.3.3 Cause of fistula aneurysm

**5.3.3.i** Diffuse *Fistula aneurysm* (**Fig 147b**) is in some way the natural consequence of creating an AVF and then stopping the body from closing it down – as a result, the whole fistula circuit keeps growing over time. Excessive growth of the venous component, Fistula Aneurysm, is related to several factors. This includes genetic (weakness of the vessel wall), giant AVF, male sex and proximal fistulas.

**5.3.3.ii** *Fistula Aneurysm caused by area puncture* (**Fig 147a**) is different in that the aneurysmal section of the fistula involves the punctured, weakened area only. Rotating the needle position as in **laddering** is a way of treating / preventing this type of aneurysm. Thinning of the skin, skin **ischemia**, non-healing of the puncture sites, ulceration and (potentially catastrophic bleeding) can result.

### 5.3.4 Ultrasound of Fistula Aneurysm

Although measuring the size of the aneurysm on ultrasound is of some use, the severity/size of the aneurysm is usually clinically evident. The important features to look for on ultrasound are:

**5.3.4.i** *The presence of "laminated thrombus"* **Fig 145a, b** and **Fig 146**. When the luminal size in a vascular circuit suddenly increases in size – due to an aneurysm for instance – the blood flow through that dilated segment slows down dramatically (just like the blood flow accelerates through a stenosis). If the slowing of the blood flow is substantial, Virchow's Triad (80) may kick in and the blood at the periphery starts clotting. The clot forms in layers on the vessel wall and grows towards the lumen. As this happens, the lumen gets narrower, the blood flows faster and the clotting process stops, leaving an aneurysm partially thrombosed by laminated thrombus (**Fig 145**).

**5.3.4.ii** *Flow with spontaneous echogenicity*.

**5.3.4.iii** *The overlying skin*. The integrity and health of the overlying skin of the aneurysm is the main concern, particularly if the aneurysm is an **area puncture**.

### 5.4 Steal

Although fistula ultrasound is often requested when a patient develops or is suspected of having a steal problem, **fistula ultrasound is NOT useful in the *diagnosis* of steal**, although it is helpful in the management of steal.

### 5.4.i Fistula steal **Ischemia of the hand/fingers in the presence of a fistula**

Steal occurs when the blood flow to the hand is inadequate to meet its **basal metabolic demands** because of the presence of the fistula. The best way to assess this is to perform finger plethysmography. In addition, it may be necessary to do **Nerve Conduction Studies** for **Carpal Tunnel Syndrome** as these two conditions may co-exist, cause similar symptoms in this patient population and cannot be confidently diagnosed clinically, again in this population.

*Scanning the fistula brings no meaningful information to the **diagnosis** of the problem.* However, assessing the fistula and measuring the Qa will help you manage the problem if the diagnosis is established.

### 5.4.ii Mechanism of Significant Clinical Steal

**The underlying problem that makes a fistula creation produce a significant steal is primarily *the inflow Brachial Artery*! The runoff disease in the forearm affecting the Radial, Ulnar arteries & the UIT may contribute but is very secondary.**

### 5.4.iii Scanning the Fistula when Significant Clinical Steal has been diagnosed:

Note that most steal problems occur with the Brachial artery-based fistulas in 5-10 %. is One of the many advantages of the RC AVF is the unlikely to cause steal, less than 1%.

From the fistula point of view, there are 3 different Clinical Steal scenarios: High Flow Steal and Low Flow Steal and localized arterial stenoses.

### 5.5. "Failure-to-Mature" (FTM).

### 5.5.i What Constitutes Failure-to-Mature (FTM).

Fistula Maturation is a relative concept. It refers to a fistula that was created recently and does not develop to the point to be suitable for performing dialysis.

As with so many things in fistulas and dialysis, defining what constitutes suitable for performing dialysis is variable. The Rule of 6s (68) is a guide that helps us decide whether a fistula has matured, but they are not strict rules and the Rule of 6's should always be interpreted in the context of each individual fistula.

### 5.5.ii What is the Time Frame for Failure-to-Mature.

What time frame constitutes FTM is also very variable. The traditional teaching is that fistulas should reach maturity 6-8 weeks after placement. We believe that most fistulas fall into one of two categories:

Category 1. Those that will mature and will do so rapidly
Category 2. Those that will not mature or will take a very long time

Deciding early on which category your fistula is in is important: We believe that by using "Assisted Maturation" techniques we can bring the vast majority of fistulas to maturity, and in a minimum amount of time.

Failure-to-Mature, however it is defined, has many causes, discussed in detail in Why Fistulas Failure-to-Mature.

We have an aggressive protocol that addresses these many causes, including Assisted Maturation to maximize the number of fistulas created that reach maturity.

### 5.5.iii The Ultrasound Scan for Failure-to-Mature

Regardless of how and when FTM is defined, our practice is to scan all fistulas for about two weeks post op, when post-surgery inflammation has settled. At this stage, we can usually decide whether the fistula is in Category 1 or 2 as defined above. Occasionally, it is not clear whether the fistula will need assistance in maturation or not, and a further wait of 2 to 4 weeks can be warranted.

*The fistula scan at 2 weeks post op will be looking for the following features:*

**Qa:** This is the single most important measurement. If the fistula Qa at 2 weeks is under 300 – 400 ml/min (depending on other factors like patient size, RC vs BC etc) then this fistula very likely has a problem that needs fixing, probably an **inflow problem.** The likely cause of inflow problem, in order of importance, will be **Swing vein**, inadequate artery

or **juxta-anastomotic stenosis**. If the fistula after 2 weeks has a flow of 500-600 ml or more, then it is probably OK, but there may be other problems e.g. an inadequate useable segment or too deep for needling.

**The useable segment**: If the useable segment is going to be adequate, the scan should show numbers consistent with the Rule of 6's. This applies particularly to depth: if the fistula vein is > 9mm deep, superficialization will be needed. Inadequate diameters will improve with time, but diameter < 3mm suggests assistance will be needed. Finally, bifid or tripled systems can be a problem, as illustrated in **Fig 72** and discussed under Vein Branches and the Useable Segment.

**Outflow problems** with the fistula will often present with a pulsatile fistula but generally do not present as FTM or an un-dialysable fistula. They will, have recirculation problems with dialysis.

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## Section 6. Steps and Procedure of Fistula Ultrasound

Ultrasound scanning, in general, and fistula scanning should be **targeted ultrasound**.

Unlike a CT scan, where vast amounts of accurate anatomical data can be gathered in seconds, ultrasound scanning is slow and laborious.

In addition, because the fistula being scanned cannot be compared to normal, the fistula itself is a pathology. The sonographer must compare findings with what we expect from this pathology (good dialysis without problems) and what in fact this fistula pathology is currently delivering.

Therefore, the sonographer must work out as accurately as possible, prior to starting the scan, what the clinical issue or question is that needs to be answered. The sonographer can then spend the allocated time looking specifically at those anatomical features and physiological characteristics of the fistula circuit that will allow this question to be answered.

Also, remember that the fistula circuit starts at the left ventricle, goes down the arteries through the AV anastomosis and via the venous system, back to the R atrium; scanning the entire circuit is not only impossible but would be very time consuming.

### 6.1 Setting up your Ultrasound room and patient.

An ultrasound scan is a bit like a surgical procedure; to get good results, you need to prepare your theatre and equipment properly.

#### 6.1.i Equipment:

- For fistula scanning, use the **best ultrasound machine** available.

- You need **large amounts of gel**, to use as a gel standoff pad - about ½ bottle per patient (**Figs 52-55**).
- You need **3 transducers** (**Fig 152**).

i. The workhorse transducer is a linear, high frequency (minimum 10 MHz) probe to examine the circuit. The authors use 17 MHz on the Philips and 18MHz on the Canon (formerly Toshiba).
ii. A small, curvilinear probe (around 8 MHz) to look under the clavicle at the arch, or in difficult-to-get-at parts of the circuit (**Fig 194**).
iii. A lower frequency linear probe (around 8 MHz) for obese patients and for vessels and vascular access in the lower limb.

### 6.1.ii Contact Precautions, COVID-19, Hepatis C, HIV etc.

- For Covid19, use PPE as appropriate.
- Wipe down the US machine, probes, and patient / sonographer chairs *before and after* each patient.
- Place a clean sheet across working surface for each patient.
- Blood contamination is a common problem when scanning fistulas. Patients bleeding from recently cannulated sites – use a Condom on the Ultrasound Probe. Alternatively, clean and cover the bleeding puncture site with some gel and an *Opsite* dressing.

### 6.1.iii Set up of Patient and Sonographer:

Set yourself and your patience up so that you are both comfortable. **Fig 51** shows one of several approaches. Particularly, your hand / wrist should rest on the fistula limb so that you have fine control of your probe **especially the pressure you exert with the probe on the fistula**. Because the fistula is such a superficial, and low-pressure structure, excessive pressure can very easily lead to **artefactual** stenoses. **Fig 55** shows the images produced by the correct use of the gel standoff pad.

Get yourself comfortable seated to protect your neck, back and shoulders.

Get the patient comfortable so they can remain still during the exam.

### 6.2 Pre-scan "Workup"

The "Pre-scan Workup" is an essential step before a diagnostic fistula scan for 2 reasons.

**First,** you need to perform a **Targeted Scan** as defined above. This is only possible if the Pre-scan Workup identifies a target.

**Second,** scanning the fistula circuit is unique in that we are ***not*** looking for pathology nor deviance from the normal anatomy or normal physiology. The fistula itself is the pathology.

Ultimately, the fistula scan must determine whether the "fistula pathology" we created is behaving in a way that satisfies our dialysis access goals without causing problems for the patient.

To do this, a variety of *information needs to be collected before starting the scan* and this information must then be married up with the findings of the scan.

Below are the components of the Pre-scan Workup; by clicking the link, you can get a more detailed description of this Workup.

### 6.2.i Select the correct Standard AVF Scan Reporting Form Doc 1a-v.

This will give you the correct image for your report, it will gather the relevant pre-scan information and allows for a report, conclusion & (in conjunction with the attending physician), recommendations.

### 6.2.ii Type of Scan: "Why are we scanning this fistula today?"

The options are:

- Failure to Mature
- Is AVF ready for dialysis?
- Problems Initiating Dialysis
- **Problem fistula** i.e., a fistula currently used for dialysis experiencing dialysis problems or causing problems for the patient. See Section 9 for further details.
- Surveillance
- Post-op Follow-Up
- Other

Further Pre-Scan information collected will depend a lot on the Type of Scan being done for this fistula today e.g., **Dialysis Numbers** on a "**pre-dialysis fistula**" will obviously not be available.

### 6.2.iii Dialysis Status

The options are:

- **Predialysis** – Patient does not need dialysis yet.
- Dialysis through the Index Fistula (Patient dialyses through the fistula being scanned)
- Dialysis thru other AVF (The patient has 2 fistulas; the (new) fistula you are scanning today & the old, failing fistula thru which the patient is still dialyzing)
- Dialysis through central vein catheter or **Vascath**
- CAPD (patient is on PD; their PD may be failing OR the PD was placed as "Bridging Dialysis to fistula formation"
- Transplanted
- About 3% of fistula patients have an AVF for non-hemodialysis purposes. This may be RRT related – e.g., a fistula for **plasmapheresis** – or could be non-renal such as a fistula for Hemophilia and Factor VIII infusions.

### 6.2.iv Type of Problem:

Many of the fistula scans you perform will be done because someone has perceived a problem – the Dialysis Nurse, the patient, their Renal Physician. This is a critical piece of information to obtain before starting to scan.

### 6.2.v Dialysis Numbers - Qb's

This bit of info is only available for patients in the category dialyzing through the Index Fistula", but it is our biggest group of patients and the Qb's in this group are very important in performing an efficient and correct scan. The interpretation of the Dialysis Numbers is discussed separately.

### 6.2.vi History

This is a broad category, including patient history, RRT history, dialysis history and history of the index fistula that you are scanning.

### 6.2.vii Physical Examination

This is an essential part of the fistula ultrasound procedure. Remember, in some ways the fistula ultrasound is a Physical Examination of the fistula but using a more sensitive and accurate tool.

By the time the sonographer has done the Pre-scan workup as outlined above, he/she will have a reasonably good idea of:

- Whether there is a problem with the fistula.
- If there is a problem, is it an **inflow**, **outflow** or "**useable segment**" problem.
- What type of problem to expect.

Do not regard this "Pre-Scan Workup" as laborious or a waste of time. A good "Pre-Scan Workup" will result in much faster and much more accurate scans.

## 6.3 Measuring Qa with Ultrasound

The Qa is the volume of blood flowing through the fistula circuit (**Fig 44**). It is a critical measure in Hemodialysis / Fistula management. The Qa of a fistula can be measured in several different ways. This document discusses Qa measurement with Ultrasound.

### 6.3.i Measuring the Qa is the first step in scanning the AVF

The reason for this is that the Qa (both the absolute value measured today as well as the Qa today compared to previous Qas for that fistula) will divide fistulas into THREE broad categories. How you perform the rest of the scan is strongly influenced by which "Qa category" your fistula is in:

1. Low or declining Qa – strongly suggests an **inflow problem**.
2. High or progressively rising Qas, suggests giant AVF development (59).
3. Stable or normal Qas, consistent with a "happy" fistula, but not diagnostic thereof.

### 6.3.ii How the Ultrasound Machine measures Qa's.

### 6.3.ii.a Poiseuille's Law

Measurement of Qa is derived from Poiseuille's Equation which describes the pressure gradient of an incompressible fluid flowing in a tube. Although mathematically complex, Poiseuille's equation says this:

The amount of fluid (blood) flowing through a tube (blood vessel) depends principally on:

- The pressure gradient across that tube,
- The length of that tube and
- ***The diameter of that tube*; this last factor has a disproportionately large effect on the flow!**
- Other factors such as **viscosity** play a minor role.

Of the above 3 important parameters, the diameter is critical as diameter affects flow to the 4th power.

This is explained diagrammatically in **Fig 56a-c** using a vessel **stenosis** as an example. Essentially, halving the diameter of the vessel (50% stenosis) decreases the flow thru that vessel by 2x2x2x2= **16x**.

### 6.3.ii.b Volume Flow Calculations on Ultrasound:

Each brand of ultrasound machine uses a proprietary formula for calculating the Qa. The factors listed below go into that calculation.

- The *diameter* of the blood vessel in which Qa is being measured (critical)
- The measurement of the **velocity waveform** through that vessel using **spectral analysis of the flow** (**Fig 148**). The formula works best with parabolic, laminar flow.
- Measuring the *heart rate* and multiplying this by the Velocity waveform of one Cardiac Cycle.

### 6.3.iii Requirements for accurate Qa measurement on Ultrasound

For the ultrasound to measure most accurately the Qa in a fistula circuit therefore, the following are required (**Fig 59**):

- *All the flow* in the fistula circuit must be measured.
- The *diameter* at the point of Qa measurement must be very accurate as diameter has a huge effect on Qa.
- For accurate diameter measurement, the structure measured must be circular. The diameter measured must be **luminal**, NOT the outside diameter of the vessel.
- *The **wave form*** at the point of measurement must be clear & crisp so that the machine can most accurately do a Spectral Analysis of the velocities at that point **and** so that a single, typical Cardiac Cycle can be clearly recognized.
- The site of Qa measurement should be clearly identifiable & reproducible.

Taking all the above requirements for accurate Qa measurement into account, only one place in the Fistula Circuit is suitable for Qa measurement:

**The Brachial Artery**

The Swing Vein is NOT the place to measure Qa

### 6.3.iv The Brachial artery for Qa Measurement:

The Brachial artery is the only site at which Qa should be measured because:

**a.** The inflow Brachial artery carries ALL the fistula flow, but also the flow to the upper limb. However, the flow to the limb (at rest) is relatively constant and small (80 ml/min) compared to the fistula flow. This upper limb flow can be ignored.

Note the inflow brachial artery should be used to measure Qa regardless whether it is an arm or a forearm fistula, as illustrated in **Fig 12a**, **Fig 13** and **Fig 60** and **Video 10**.

*There are two caveats to this rule:*

- When the Brachial a has a high bifurcation as illustrated in **Fig 21** and **Fig 61**. The true Brachial artery must be found (often in the axilla) and the flow measurement should be done there.
- When the fistula is created in the Lower Limb, it is obvious that the Qa is NOT measured in the Brachial artery.

**b.** The Brachial artery is a reliably repeatable site of measurement

**c.** It should have laminar flow with a clear waveform and a clear cardiac cycle (See *arrhythmia* below)

**d.** It is a straight, circular, clearly examinable structure making the vital diameter assessment accurate.

### 6.3.v Steps in measuring and assessing the Qa:

**Step 1.** With the ultrasound in transverse, in the distal 1/3 of the arm, determine whether the brachial a has a standard or high bifurcation (from 10 – 20% of the population) **Fig 62**. Clues suggesting a high bifurcation are a small "brachial artery" of less than 5 mm; 2 pulsating structures that do not compress readily. If the brachial artery bifurcation is high, in transverse, trace the two pulsating structures proximally until they join – the brachial a bifurcation. This is usually in the distal axilla but can be anywhere. With a high bifurcation, the radial artery is the more superficial, more tortuous vessel; the Ulnar-interosseous trunk is straighter and more axial **Fig 25**. Pre-fistula formation, the Radial artery is always the smaller structure; post-fistula formation, the structure that has the vein connected to it (Radial artery or UIT) will become the bigger of the 2 structures.

**Step 2.** Having identified the brachial artery (in the distal arm or just before its bifurcation in the case of a High Bifurcation), put the probe into longitudinal and measure the diameter of the brachial artery in grey scale and/or in colour. Generally, the grey scale picture is the more accurate. The diameter measurement should be **luminal** (i.e. we are measuring the **flow channel**, not the size of the vessel) and our convention is that we

effect all measurements in **peak systole**. Remember how important the accurate measurement of the brachial artery diameter is to measuring flow: Radius4 See **Fig 63** and **Fig 64a**.

**Step 3.** Next, turn on the pulse doppler and set your "gate" (2 in **Fig 64b**) – sample volume – to the vessel size (4 in **Fig 64b**). Then, obtain a good wave form in the brachial artery at that point (3 in **Fig 64b**), using the correct angle of 60° or less (1 in **Fig 64b**). To do the volume flow calculation, your ultrasound machine will ask you to select one complete cardiac cycle (3 in **Fig 64b**), and it will ask you the vessel diameter (2 and 4 in **Fig 64b**): the number you obtained very accurately in **Step 2**.

A correct Qa sample will have:
**1.** The correct angle, 60 degrees or less,
**2.** The correct sample volume (the diameter previously determined on grey scale and color),
**3.** One clear, complete, and representative cardiac cycle (If you pick a shortened or extended cardiac cycle, as in arrhythmias, the "flow per minute" will be incorrectly calculated) (**Fig 65**).

**Step 4.** Repeat this three times. If the readings are in the same "ballpark", you are probably getting accurate measurements. Generally, the difference between readings should be within 100-200mls/min.

**Troubleshoot:** *If the Qa varies wildly, there are a few possibilities:*

- You are not performing the Qa assessment correctly.
- The patient has an irregular pulse, particularly Atrial Fibrillation, making the choice of "correct" cardiac cycle difficult. In these cases, we do multiple Qa samplings – 6 or more – and average the numbers out. **Fig 65**
- The patient has a large or Giant Fistula with high flow volumes: it is our experience that, as flows progressively exceed 2 liters/minute, the accuracy of the Qa decreases and the individual measurements vary more widely.

### 6.3.vi Interpreting the Qa

The absolute value: Generally, Qa should be between 500mls/min and 2 liters/minute. Our Rule of Thumb is:

- Qa < 500 ml/min - Too Small
- Qa > 2000 ml/min - Too Big
- Qa 500 - 2000 ml/min - Just Right!

Bigger patients, bigger fistulas, arm fistulas vs forearm fistulas will have flows by these determinants.

Most importantly is the "trend" in the Qa. A Qa of 600 ml/min may be OK of itself, but if this fistula had a Qa of 1400mls/min 6 months ago it is very likely that there is a progressive stenosis in the circuit. Likewise, a Qa of 400 ml/min in a small forearm fistula may be OK if the fistula has been stable at that value for several years.

A change in Qa of more than 500 ml/min over a period of 6 months as significant.

### 6.4 Scanning the fistula circuit

From the **Pre-Scan Workup** and the Qa measurement, you should now have a reasonable idea whether there is a fistula problem, and if so, where in the circuit the problem is: Inflow, Outflow or the Useable Segment (**Fig 4**).

**Stenosis** is a common problem in the fistula circuit. The concept of stenosis in the fistula circuit is poorly understood and not well defined. We have researched this topic and our system and reasoning on this can be found under Stenosis in the AVF. Essentially, we do not use velocities or percentages to define fistula stenoses, we use absolute diameters.

### 6.4.i The Inflow

As described in **Fig 5**, the **Anatomical inflow** and the **Physiological inflow** to the fistula are not the same. The **Inflow Scan looks at the Physiological Inflow**: The Arteries, Anastomosis & **Swing vein**

### 6.4.i.a Arteries:

At this stage you have already established whether the brachial artery bifurcates below the elbow or higher up, and what the Qa is.

Scanning the proximal and mid brachial artery is generally not a useful exercise; problems proximal to the level of the distal brachial artery are rare.

### 6.4.i.a.*1* Standard Inflow Scan of the RC AVF includes:

- Scanning the Brachial artery bifurcation below the elbow is an important and useful step, especially if you suspect an inflow problem.

Normally the Brachial artery bifurcates below the elbow into the Radial artery and the Ulnar-Interosseous Trunk (which gives off the Ulnar artery and the Interosseous Trunk**). In the forearm with no fistula, the Radial artery is the smaller vessel**. Again, in the absence of a fistula and at rest, all three vessels (Brachial a, Radial and UIT) have **triphasic flow**.

In the presence of a RC AVF, the flow in the Radial artery, providing the direct feed to the fistula, should be continuous, including a lot of **diastolic flow**, **Video 8**. Per contra, the **UIT**, providing only indirect feed to the fistula via the palmar ach, will contain a more **triphasic flow** pattern. If this is not the case ie the UIT has a lot of diastolic flow, or the UIT has more diastolic flow than the Radial artery, then the radial artery has a problem somewhere between your probe at the elbow and the start of the **anastomosis**. See **Fig 76** and **Video 4**.

Again, in the presence of a fistula, the Radial artery, feeding the fistula directly, will enlarge considerably and is often the same size or bigger than the UIT (This is often NOT the case in patients with Diabetic Runoff Disease – see below – as the rigid, calcified

diabetic artery cannot grow). If the UIT remains the larger vessel, it also may suggest an inflow problem. (**Fig 76**).

In practical terms, examine the Brachial artery bifurcation in colour (to see the differential flow pattern of Radial artery & UIT: **Video 4** and **Video 8**) in Grey scale and if there is a problem, do a spectral analysis at the origin of the two vessels – **Fig 125**.

- *In the non-diabetic patient*, stenoses problems in the radial artery are rare (except **JB4 the anastomosis**, see **Fig 69a**) and a thorough examination is not necessary. Juxta-anastomotic problems will be suggested by poor flow in the Radial artery origin compared to the UIT (see above).
- *In the diabetic,* the whole radial artery should be scanned as progressive disease as you move distally is common: see **Fig 20b**. As the Ulnar-Interosseous Trunk (UIT) - Ulnar artery - Palmar ach may be a significant additional blood supply to the RC AVF in these patients (via the Outflow Radial Artery), the UIT should also be scanned **Fig 12a** and **Fig 13**. In the diabetic, we take a sample grey scale and colour picture of the radial artery origin, proximal 1/3 forearm, mid 1/3 forearm, distal 1/3 forearm and JB4 the anastomosis.
- Always scan the "Outflow Radial Artery" as it can be quite important for a number of different reasons. Note that ***antegrade flow in the Outflow Radial artery is diagnostic of an Inflow Radial artery problem*** – **Fig 12a**, **Fig 13**, **Fig 60** and **Video 10**.

### 6.4.i.a. *2* Arterial inflow to the BC & BB AVF

The arterial inflow in both cases will be the brachial artery in about 80-90% of cases, and the radial artery or UIT when there is a high brachial artery bifurcation. This poses a certain "nomenclature" problem as discussed under 1d in The High Brachial Artery Bifurcation.

An important part of the scan in the Brachial artery-based fistula is the outflow Brachial artery. Unlike RC AVF:

- The outflow Brachial artery does NOT feed the fistula.
- Unlike the RC AVF, the Brachial artery is not an expendable "spare part". No flow, poor flow, significant reverse flow, or stenosis in the outflow Brachial artery may be associated with ischemic problems of the forearm & hand, ranging from claudication to gangrene & amputation – See **Figs 167-169**.

Hence, in the standard BC or BB AVF, flow in the "**inflow Brachial artery**" will be antegrade.
Flow in the "**outflow Brachial artery**" will vary from – **Fig 217**:

- Antegrade during systole
- "Oscillating": Antegrade during systole (ie to the hand) & retrograde during diastole (i.e. back up to the fistula), **Fig 219**, **Video 5** and **Video 6**.
- Retrograde throughout the cardiac cycle. This situation is associated with steal syndrome, but is not diagnostic thereof. Even if there is no forward flow to the hand

at any stage in the Brachial artery, **critical ischemia** may still be avoided if the collateral supply thru the **Profunda Brachii artery** to the hand and forearm is strong – **Fig 218**.

### 6.4.i.b The anastomosis

The anastomosis consists of 3 components, shown in **Fig 77**. The optimum blood flow to the fistula occurs when all 3 components are fully patent – **Fig 77 A** and **Fig 78 a**.

However, a variety of configurations can provide the fistula with adequate inflow, depending on the number and severity of the **stenoses** and the degree of **collateralization**.

If the anastomosis proper is significantly stenosed – uncommon in our practice where all fistulas are created by experienced fistula surgeon – the fistula will have inadequate inflow and treatment will be needed **Fig 77 D** and **Fig 78 e**.

The "outflow anastomosis" is only important when the inflow radial artery and / or the inflow anastomosis is compromised **Fig 78 d**. If that is the case, adequate inflow to the fistula vein will depend on the contribution from the outflow radial artery and outflow anastomosis (and the integrity of the ulnar collateral circulation / palmar arch).

In our practice, we have several fistulas with severely stenosed "inflow arteries", including a few where the inflow artery is completely occluded, yet their Qa's and fistula function are satisfactory because of strong flow from the outflow radial artery collateral circuit **Fig 78 c**, **Fig 79a** and **Fig 79b**.

We measure the anastomosis in transverse, with grey scale and colour imaging as shown in **Fig 80**. The definition of the anastomosis in this view is usually very clear and obvious from the anastomotic sutures. A drawback of this method is that our measurement technique assumes the anastomosis is circular whereas it is almost always elliptical, with a bigger longitudinal axis – **Fig 80a**. In theory, we should measure all anastomoses in both longitudinal and transverse and then calculate an anastomotic "area". In practice, this is too difficult and time consuming. In practice we find that the transverse only measurement of the anastomosis works well.

A way round this problem would be to use velocities. However, velocities give a % stenosis which, as discussed in Stenosis in AVF, doesn't make sense. Furthermore, according to a study by our group, **Ref 9JS**, the average anastomotic / peri-anastomotic velocity in the fistula circuit is 3.75m/sec; a > 75% stenosis (quadrupling the velocity) would produce velocities > 12 m/sec: **Higher frequency probes** cannot measure these high velocities.

*The Anastomosis in the BC and BB AVF*

One of the important differences between these arm fistulas and the RC AVF is the ramifications of anastomotic size.

The RC AVF anastomosis is either adequate or too small; There is no problem with anastomoses that are "too big" because Giant fistula is a rare problem with forearm based fistulas.

Per contra, the arm fistula anastomosis (if connected to the Brachial artery – see High Bifurcation of the Brachial artery - can be too small, can be adequate (around 5mm) or can be too big. Big anastomosis in the arm fistula predisposes to Giant Fistula development.

### 6.4.i.c The Swing Vein

This is both the most difficult and the most important part of the fistula circuit to image. Swing Vein stenosis is the commonest site in the fistula circuit – **Fig 6**.

The definition & length of the **Swing Vein** is not fixed or clearly defined. It can variably be described as:

- The portion of vein was mobilized by the surgeon to swing onto the artery for anastomosis.
- That part of the fistula circuit immediately after the anastomosis but b4 the most distal arterial needling point. This is the more functional, physiological definition.
- The fistula veins within 2 cm or within 5 cm of the anastomosis.

Imaging the swing vein includes the use of multiple duplex modalities, multiple angles, and *time*. In some cases, clear ultrasound definition of a swing vein problem may not be possible and Fistulography may be needed.

**Once you get to the Swing Vein (and more proximal), you are examining a low pressure and very superficial part of the fistula circuit. Even gentle pressure from the probe can produce artefactual stenoses. It is therefore critical to use a Gel Standoff Pad and acquire images showing there was no pressure on the structures when they were assessed (Fig 55).**

### 6.4.ii The Useable Segment

This is the portion of the fistula circuit used by the nurses (or the home dialysis patient) for needling.

### 6.4.ii.a The Rule of 6's

For this part of the fistula, we use the well know "Rule of 6s" as set down below in modified form:

- At least 6cms of cannulation length is needed.
- The diameter of the usable segment should be > 6 mm.
- The depth of the usable segment should be < 6 mm.
- The flow through the circuit should be more than 600 ml/min.
- The useable segment should be straight.

Our usual definition of fistula stenosis does not fully apply here as we need a diameter big enough for adequate flow (2.7 mm), but we also need a diameter big enough to allow for successful needling; for this we need a diameter more like 6 mm.

The standard practice for imaging the Useable Segment is to take 3 images – the distal, mid and proximal useable segment as shown in **Fig 220**, to demonstrate that the fistula complies with the Rule of 6's.

### 6.4.ii.b Other Important features in the Useable Segment

However, the sonographer needs to look beyond the issues of fistula size, depth, and length. This includes:

- Is the Useable Segment straight or tortuous. A big, superficial vein may be hard to cannulate if it is very tortuous, and occasionally the vein needs to be "straightened" to be useable – **Fig 81**.
- When Useable Segment channel are more than one introduces the concept of Benign & Malignant Branching, **Fig 222**.
- Are there branches associated with the Useable Segment, running parallel to or across it – **Fig 213**. This will complicate needle placement, especially if the nurses are working without ultrasound. These things should be noted on the Ultrasound Report – **Fig 221**.

### 6.4.ii.c The Useable Segment in the BC & BB AVF

The usable segment in the BC AVF tends to be deeper than the in the RC AVF (because the normal Cephalic vein is more deeply located in the arm than the forearm- **Fig 196**). The need for superficialization is therefore more frequent with the BC AVF than the RC AVF, especially in the obese population **Fig 86**.

BB AVF is formed by transposition, either at the time of Brachio-basilic anastomosis or more commonly as a 2-stage procedure (See BB AVF under **Section 3 Fistula anatomy**). Unless precautions are taken, there may be insufficient length of Basilic vein to adequately lateralize the usable segment, resulting in an awkwardly positioned, excessively medium-sized segment making needling and dialysis difficult. If you have trouble scanning the useable segment because it has not been transposed far enough laterally, you can be assured the nurses will have trouble needling it and dialyzing the patient.

### 6.4.iii Regional Outflow

The outflow is the most variable component of the various fistula circuits. Problems with the outflow are also the most difficult to deal with. The RC AVF has the best outflow configurations, one of the many advantages of the RC AVF.

### 6.4.iii.a RC AVF Outflow

In the normal forearm, there should be 3 outflow channels at the elbow – **Fig 15**, **Fig 16a, b**, **Fig 23** and **Fig 201**. Only one normal outflow channel is needed for normal function of the fistula.

- *The Cephalic vein.* This is the continuation of the forearm "useable segment" cephalic vein into the arm. Not uncommonly, this vein has been damaged or occluded at the elbow by phlebotomy or IV lines. Furthermore, this outflow channel

is dependent on a patent **Cephalic Arch** as the Cephalic vein in the arm has few or no branches.

- *The Median Cubital vein*. This is the constant communication of the Cephalic vein with the Basilic vein across the elbow joint. Again, often damaged or occluded by IV lines. However, as it feeds into the Basilic / Brachial vein system, it has superior proximal outflow to the Cephalic vein arm.
- *The Perforator*. Usually, a single large perforator can be multiple. In some ways this is the most reliable outflow for RC AVF as it feeds directly into the deep system and hence multiple outflow channels and as it is generally not damaged by IV lines.

### 6.4.iii.b BC AVF Outflow

This is the greatest weakness of this otherwise good fistula. Essentially it has only one outflow channel, the Cephalic vein in the arm thru the **Cephalic arch** and into the Subclavian vein – **Fig 15**. This system has few or no significant branches which means that any arch stenosis will usually cause a significant outflow problem. Furthermore, the Cephalic arch is commonly inadequate: stenosed, absent or in the form of multiple channels – perhaps in 20% of cases. Finally, Cephalic arch stenosis is hard to treat.

### 6.4.iii.c BB AVF Outflow

Much superior to the BC AVF outflow as it feeds into the richly collateralized deep system. A not infrequent problem is the "proximal pivot point" of the BB AVF when it is surgically transposed – **Fig 87**, **Fig 88** and **Fig 89**.

### 6.4.iv Central Venous Outflow

Only the peripheral (distal) parts of the Central Venous System are examinable by conventional ultrasound - **Fig 91**.
In addition, in the presence of fistula flow, interpretation of Central Venous Waveforms becomes impossible.
In general, therefore, Central Venous Outflow is not examined in the course of fistula sonography.
The main exception is the Pre-operative or Planning Scan where assessment of Central Vein patency can by usefully done.

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## Section 7. The Fistula Planning Ultrasound

The "**Planning Ultrasound**" comes in 3 forms depending on when and why it is performed:

- Preservation Scan
- Planning Scan
- Preoperative Scan

### 7.1 Preservation Scan (See **Doc 2a**, **Doc 2b**)

The Preservation Scan and the Planning Scan are performed in the same way but for different reasons and at different times.

The Preservation scan is performed when the patient's attending Nephrologist anticipates the need for RRT - Hemodialysis at some stage in the future (months to years) and to identify which upper limb to protect from phlebotomy and IV lines in anticipation of an AVF formation. Traditionally, the Nephrologist will advise the patient to protect the non-dominant upper limb. This takes into consideration that the patient will want the dominant limb free to use during dialysis sessions, and the possibility of home dialysis where the patient will be self-cannulating with the dominant hand.

Although half our Hemodialysis patients are on Home Hemo**, we *do not* follow this traditional teaching of dominant limb preservation**. Instead, the patient needs to protect their best **venous real estate**, not their non-dominant venous real estate, as many patients have assiduously protected their non-dominant upper limb for years only to discover when they develop ESRF that their good venous real estate is on the other side. This is particularly important in developed countries like Australia where a vigorous Kidney Transplant program means that most of the Hemodialysis population is elderly with co-morbidities, and where damaged venous real estate is the rule rather than the exception (Section 17, Dialysis Issues in the Developed vs Developing (LMIC regions) World as well as **Case 3**.)

*The recommended system is as follows:*

1. Nephrologists anticipates a patient will need RRT in their lifetime
2. Preservation Scan is performed by one of our sonographers
3. The Preservation Scan is read by one of our Access Surgeons, who advises which limb to protect. **Fig 151**
4. If the patient needs AVF formation within 1-2 years, a Planning Scan does not need to be repeated pre-operatively.
5. When the patient comes to needing hemodialysis, we know they have good venous real estate available for fistula formation.

The Sydney experience is published here – **Ref 1JS**.

***Take home message:* The patient is much better off with a GOOD fistula in the dominant arm (on the R or L) than a bad fistula in the non-dominant upper limb!**

### 7.2 The Planning Scan (See Doc 2a, Doc 2b)s

#### 7.2.i Vasospasm and the Accuracy of Planning Scans

Unlike other fistula scans, which are very accurate, **AVF Planning Scans have limited accuracy** because of several variables.

The biggest problem with the Planning Scan is the venous tone (contraction or dilatation) in the Superficial Veins used for fistula creation, as discussed in The Deep and Superficial Veins of the Limbs. Spasm of the Superficial Veins -making them look smaller than they really are and hence unsuitable for AVF creation – is caused by many different things.

This includes anxiety, **sympathetic tone**, dehydration, dialysis state and medications but by far the most important variable is **patient body temperature / room temperature**.

The only guaranteed way to block venous spasm – and see the true size of the Superficial Veins – is an **arm block**, which totally removes all sympathetic tone and causes maximal venous and arterial vasodilatation. Arm Block is of course not a practical intervention for a Planning Scan: However, since we do almost all our fistula creation under Arm Block, we take advantage of this vasodilatory effect to make the final decision on fistula creation at the time of operation: hence the importance of the Pre-operative Scan (see below).

### 7.2.ii To minimize vasospasm during your Planning Scan

It is important to minimize vasospasm during the Planning Scan to minimize the "false negatives"; i.e. Reporting the patient has small, inadequate veins for fistula formation whereas in fact, the veins are big and adequate. At the time of the Planning Scan, the veins were in spasm, partial or complete.

- Heating the room; this is more of an issue in cold climates but air-conditioning in hot climates can also induce serious Superficial Vein spasm.
- Warming the patient: advise them to come warmly dressed
- Use of a venous tourniquet. We use this routinely to encourage vasodilation. Although this is helpful in overcoming venous spasm, it does not always work.
- Performing the scan with the arm in a hot water bath: This is something first suggested by the Otago Hospital Ultrasound department in Dunedin, NZ (a cold place!).

### 7.2.iii Information sought from the planning scan

The planning scan is done with the 3 components of the fistula circuit in mind – inflow, useable segment and outflow – **Fig 4**. For example, if the patient has a big radial artery at the wrist, a big Cephalic vein in the forearm, but has no outflow at the elbow, then a RC AVF is not a suitable configuration – see **Fig 93**.

Different rules apply to the 3 different components:

### 7.2.ii.a Inflow artery:

**Contemplating a RC AVF**, we look for 2 inter-related aspects of the Radial artery at the wrist: Size and disease state. From our study – **Ref 5JS** – a minimum diameter of 2.7mm is needed for the inflow.

*If the artery is healthy*/disease free, a diameter down to about 2mm is acceptable, because a healthy artery will grow with fistula development. The limitation of how small a healthy artery we use is technical: performing an anastomosis on a vessel under 2mm, even with magnification, is difficult.

*If the artery is significantly diseased* – a rigid, calcified pipe that cannot grow – then the feeding Radial artery must be at least 2.5mm to give adequate flow to the fistula. Furthermore, a severely diseased Radial artery makes anastomosis technically more difficult. So, in the case of significant Radial artery disease – a common situation with the

Diabetic patients – we scan the artery all the way proximally to its origin to assess possible alternative anastomotic sites – **Figs 20a-d**. As outlined in Diabetic Runoff Disease, a big, healthy Cephalic Vein in the forearm can still be used as a "RC AVF" despite a small, severely diseased Radial artery at the wrist by "looping" it proximally on the arm – **Figs 20a-d**.

**Contemplating a proximal, Brachial artery-based fistula**, the Brachial artery is almost always big enough to create a fistula. The problem however, with the small, rigid, calcified Brachial artery is that it puts the patient at risk of a significant Steal problem.

### 7.2.ii.b Useable Segment:

The "Rule of 6's" is important here. Generally, we want:

- The Cephalic vein in the forearm to be 2 - 3mm in diameter (fully dilated!) See the problem with vasospasm in The Deep & Superficial Veins of the Limbs; if the forearm Cephalic vein is <2-2.5 mm, fistula maturation is unlikely (**Ref 6**).
- We do not want to see any scarred/thickened/ diseased segments in the Cephalic Vein – **Fig 95** and **Figs 204a-g**.
- We want to establish that there is only one cephalic vein (see "Malignant Branching" **Fig 222**
- We want to assess the depth of the Cephalic Vein. If the Planning scan show a depth greater than 7-8mm, then the fistula vein should be superficialized at the time of the original operation or as a second procedure.

### 7.2.ii.c Outflow:

This is the hardest to assess in the planning scan as flows in the non-fistulized superficial veins are low. As illustrated in **Fig 93**, the regional outflow of the fistula should be assessed. For the RC AVF, at least 1 good outflow channel is needed to ensure success; The Perforator should always be looked for and recorded.

### 7.2.iii

Steps in Protocolized AVF Planning Scan as per our system **Doc 2**

### 7.2.iii.a Examine the Cephalic Vein from wrist to arch

In the Index limb, first without then with venous tourniquet at the axilla (Venous tourniquet: Done up tight enough to block venous return but not so tight as to block arterial inflow).

- Note and record the *external diameter of the vein*: it is very important that you measure outer wall to outer wall, NOT inner wall to inner wall as in the fistula circuit. The reason for this difference is this: When assessing the fistula circuit, we are interested in FLOW i.e., luminal diameter. When assessing veins and arteries for fistula formation, all studies on this have used external diameter measurements. Others like in the United States use the inner or luminal diameter for all circumstances. The important information here is to report, what is being measuring and including the vein wall thickness as appropriate (**Fig 94**).

- *Measure the depth from the skin to the vein*. For Depth and Diameter, we take 8 standardized measurements as shown in **Doc 2**.
- Trace the vein and see if there is *evidence of venous damage*; this may be thickened vein wall, narrowed vein, occluded vein or thickened, damaged valves as illustrated in **Fig 95** and **Figs 204a-g**.
- *Repeat the examination with a venous tourniquet*; it is only the diameter you are interested in (the depth of the vein will not change with a tourniquet).
- Look for and record the *perforator(s)* and their size at the elbow.
- Assess the *Median Cubital vein* and its connections
- *Examine the Arch vein*. In the thin/lithe patient you may get good views with the standard 18 MHz probe **Fig 152**. In larger patients or those with awkward anatomy, the "sector probe" (**Fig 152**) is the ideal tool: it has a lower frequency – 8-5MHz – and its small curvilinear footprint allows you to see around and behind the clavicle. Note that full examination of the arch may not be possible and that the findings of the ultrasound in the arch are not 100% reliable (unlike elsewhere in the fistula circuit).

### 7.2.iii.b Examine the *Basilic vein from wrist to junction with the brachial vein* in the same way.

Be careful to note the level of the Basilic to Brachial vein junction as this is very variable. **Figs 28-30**

### 7.2.iii.c Next *examine the brachial artery*.

First, assess the level of brachial artery bifurcation. Then, examine the brachial artery from the elbow to the mid arm for size and disease status.

### 7.2.iii.d Next *examine the radial artery*

In the non-diabetic, it can be safely assumed that the radial artery at the wrist is representative of the vessel: if it is a good caliber (>2.5mm) and healthy at the wrist, the rest of the radial artery will be OK and careful study is unnecessary.

In the diabetic, "Diabetic Runoff Disease" - a form of **atherosclerosis** particular to diabetics – is often present; It has major implications in fistula planning

*The features of Diabetic Runoff Disease include:*

- Medial calcification, at times so severe the vessel cannot be imaged properly (**Fig 20b**).
- Progressive severity of the disease as you move distally from the elbow to the wrist (**Fig 20b**). Not uncommonly, the disease is mild in the brachial artery, mild-moderate in the proximal 1/3 of the forearm, moderate-severe in the mid forearm and severe at the wrist.

### 7.2.iv Ultrasound Mapping the Lower Limbs for fistula creation

The following Lower Limb mapping scans are useful in Hemodialysis Access

### 7.2.iv.a Superficial Femoral Vein mapping for Upper Limb AVF creation

This is appropriate when no suitable vein can be found in the upper limbs for AVF creation (no suitable Cephalic, Basilic or Brachial vein in either upper limb).

*Performing the Superficial Femoral Vein scan:*

- Obtain a Lower Limb venous history; history of past DVT; Varicose Veins and varicose vein surgery; leg swelling, leg ulcers.
- Determine the patency of the CFV, PFV and SFV as per standard practice. Evidence of current or past DVT **excludes** the use of the SFV on that side.
- Determine whether the SFV is single or double along its course.
- Determine the bifurcation of the CFV into SFV and PFV and mark / record this. Preserving the PFV – CFV continuity at the time of SFV harvest is essential to preventing **venous insufficiency** in the Lower Limb (**Fig 96**).
- Measure the diameter of the SFV in the proximal, mid, and distal thigh.
- Determine and mark / record the **Adductor Hiatus** where the SFV passes thru to become the popliteal vein (**Fig 96**).
- Determine the size of the Above Knee Popliteal Vein (scanning posteriorly from the popliteal fossa). When harvesting the SFV for use as an AVF, part of the above knee popliteal vein often needs to be harvested as well to obtain sufficient length (**Fig 96**).

### 7.2.iv.b Superficial Femoral Vein mapping for In Situ AVF creation

- The **in-situ** SFV can make an excellent, stenosis free long-term fistula, but two major caveats apply.
- The operation to create an In Situ SFV AVF is a very major vascular intervention!
- The operation can only be safely done in patients with Normal or near normal **arterial** circulation.
- The SFV Mapping is performed as outlined above. The only difference is that you will also examine the Common Femoral artery, its bifurcation, and the Superficial Femoral Artery, which will be the "**donor artery**" in this patient. A severely diseased or occluded SFA precludes the creation of an in-situ SVF fistula.

### 7.2.iv.c Long Saphenous Vein Mapping for AVF creation:

- The LSV is a POOR conduit for AVF creation and repair! Unlike in the arterial circuit (e.g., The Femoral-popliteal bypass), where the LSV functions very well, the LSV in the fistula circuit performs very poorly because of a strong tendency to undergo early, severe, and extensive stenosis.
- A dilated and incompetent LSV (Varicose Vein) can be used as a fistula circuit but only if the varicose dilatation is not severe (< 1cm in diameter).
- The LSV can be used in the **ipsilateral** thigh as an **in-situ** AVF connected to the SFA, or it can be transposed to the arm as the **Useable Segment**for an upper limb AVF creation in various configurations (**Fig 97**).

### 7.2.iv.d Transposing the SFV or LSV to the Upper Limb (Fig 97).

When using either of these vessels for Upper Limb AVF creation, you must find in the upper limb:

- A suitable **donor artery** (usually not too difficult), preferably a forearm artery as your fistula will then not have Brachial artery type problems (Steal, Giant AVF).
- A suitable outflow vein: You will be looking to use LSV or SFV because of inadequate upper limb veins. Your outflow vein therefore is likely to be the brachial vein or axillary vein. Check that these are of suitable size (>5mm) and accessible to the surgeon.
- Make sure that there is no Central Venous Obstruction to the Upper limb selected for Lower Limb venous transfer.

### 7.3 Preoperative Scan:

### 7.3.i Reasons for always performing a Preoperative Scan

There are several reasons for performing an ultrasound scan in the OT immediately prior to fistula creation or revision:

**7.3.i.a** Confirm the findings of the planning scan; the Planning Scan may be incorrect, **see 7.2.i** above.

**7.3.i.b** We believe that most Fistula surgery – creation, revision, open and endovascular – should be performed under *Ultrasound Guided Arm Block*, see Section 15, Regional Anesthesia in AVF Surgery: "Arm Block". The arm vasculature fully and reliably vasodilated under the influence of an effective **Arm Block** can be very different from that demonstrated on the Planning Scan or Preservation Scan. Arm Block produces maximal **vasodilatation** of both the arterial and venous bed due to blockade of the **Sympathetic outflow**. This means that a forearm Cephalic Vein deemed unsuitable for AVF creation on the planning scan – e.g. 1.5mm – in fact dilates up to 4.2mm under the influence of an Arm Block. The Surgeon is then likely to change the operative plan from BC AVF creation to RC AVF creation.

**7.3.i.c** Accurate choice of the anastomotic site can significantly contribute to the success rate / maturation rate of AVF surgery as illustrated in **Fig 3**. The anastomotic site should be selected before starting the operation, using the ultrasound probe.

### 7.3.ii Steps in the Pre-operative Scan:

- Wait for the US guided arm block to produce full vasodilation.
- Check the proposed fistula configuration to see if it is suitable. If the proposed fistula configuration is proximal in the arm, it may be worth checking to see if a forearm fistula is possible. **Fig 98**
- Choose the optimal anastomotic site on the artery and vein considering the venous and arterial branches and possible "sweet spots" on a calcified, diseased artery.
- Mark your final decision & planned incision on the skin with a permanent marker.

**Explore the patient's vascular anatomy with the US probe, not with a scalpe.**

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## Section 8. Scan for the Fistula that "Fails-to-Mature"

### 8.1 The Meaning of "Failure-to-Mature" (FTM)

Fistula Maturation is a relative concept. It refers to a fistula that was created recently and has not yet developed to the point where we consider it suitable for performing dialysis.

As with so many things in AVF and dialysis, defining what we mean by these terms is variable. The best guide to defining what constitutes "suitable for performing dialysis" is the Rule of 6s. However, the Rule of 6s is only a guide that helps us decide whether a fistula has matured and the Rule of 6s should **always be interpreted in the context of each individual fistula**.

The time frame of when a Fistula has "Failed-to-Mature" is also very variable.

### 8.2 The Causes of Failure to Mature

A critical concept in fistula management is an understanding of why fistulas grow or develop ("fistula maturation"). Ultimately, **it is growth of the feeding artery that drives fistula growth**; growth of the fistula vein is secondary and has other causes (e.g., weakening of the venous wall by repeated needling will cause aneurysmal dilatation of the vein).

The underlying reasons why a unit's fistulas have a "poor maturation rate" are multiple and varied and often occur in combination. They fall into the following broad categories, further described in the causes of Failure to Mature.

**8.2.i** Poor or Damaged Arterial and / or Venous "Real Estate"

**8.2.ii** Inadequate planning

**8.2.iii** The balance of Forearm vs Arm fistulas i.e. The more RC AVF's you create, the better for your patients, but also the lower your maturation rate because it is a more technically difficult fistula.

**8.2.iv** Inadequate surgery

**8.2.v** Lack of forced maturation

### 8.3 The Underlying "Pathology" of FTM

Again, we need to be cognizant that the Fistula is the Pathology! "The Underlying Pathology of FTM" refers to the fistula characteristics that stops it from developing and used for cannulation.

This can be an inflow problem, a Useable Segment problem, an outflow problem (uncommon) or not infrequently, a combination of the above, further described in the Underlying Pathology of FTM.

**8.3.i** *Inflow Problem*: Note the very important difference between the Anatomic and Physiological inflow to the fistula as illustrated in **Fig 5**.

**8.3.ii** *Usable Segment Problem*: This is a common site for FTM.

Causes of the Useable Segment FTM include the following:

Excessive depth, multiple venous channels (malignant branching) **Fig 222**, tortuosity and accessibility.

**8.3.iii** *Outflow problems* generally do not present as FTM; usually they will present as a useable but hypertensive / recirculating fistula or with arm swelling.

### 8.4 The Incidence of Failure-to-Mature (FTM).

The incidence of FTM is very hard to quantitate as there are so many factors that affect this: e.g. If you only create Brachial artery-based arm fistulas under the best of circumstance, and use AVG for all others, you will have very high maturation rates; If you do not use AVG's and try to create native AVFs in all your patients, and / or try to maximize the number of patients with forearm fistulas, FTM becomes an issue.

### 8.5 Scanning the Fistula that Fails-to-Mature

**8.5.i** Timing of the Post Fistula Creation Scan

When a fistula is created it will either
**a.** Mature rapidly without problems or,
**b.** Have poor or delayed maturation and will need **Assisted Maturation** as discussed in Meaning of and Time Frame of Fistulas that "Fail to Mature".

The difference between the 2 groups is clear early on. Therefore, all fistulas are scanned about 2 weeks post op, when the worst of the inflammation has settled. At this stage, we can usually decide whether the fistula is in category a or b. Occasionally, it is not clear whether the fistula will need assistance in maturation or not, and a further wait and see of 2 to 4 weeks can be useful.

We occasionally scan a fistula two weeks before there is a specific indication (e.g., a very small, failing fistula), but the post-operative inflammation makes ultrasound examination difficult, especially of the crucial anastomotic / swing vein area. The most useful piece of information in these early scans is the Qa: If this over 400mls/min, the AVF is unlikely to thrombose and you can wait and see; if the Qa is lower than that, the fistula is probably doomed unless you do something.

### 8.5.ii The fistula scan at 2 weeks post op

***All*** newly created fistulas in our service are scanned early and routinely to ensure that adequate maturation is occurring, and if not, why not.

### 8.5.ii.a The Pre-Scan Workup for FTM is different to the troubleshooting scan:

- You do not have the dialysis history, fistula history or Qb's to guide your scan as to the likely cause of the FTM.

- The **operative history** is important; a copy of the Operation Note attached to the Ultrasound Request form is most helpful.
- Relevant info includes the type of fistula created; problems encountered by the surgeon; early return to theatre for thrombosis.

**Physical examination** is particularly useful and important before performing a scan for FTM.

One of the main issues in assessing a new fistula is: "Is the useable segment long enough to be reliably and repeatedly used for dialysis by the Dialysis nurse"? This is as much a clinical as an US issue. If the useable segment is long and prominent and straight and easily palpable, US will not add much to the assessment. Per contra, if the useable segment is short and hard to feel and you think it is not possible to cannulate - then it is probably not the case, regardless of the flow.

An important exception here is Depth of the Useable segment i.e. The Useable Segment may be large, long, and straight but is not palpable because it is covered by 1-2 cm of fat.

The augmentation test and elevated arm collapse test are both useful in this setting (as well as in standard fistula scans).

### 8.5.ii.b Performing the FTM scan

**Qa:** This is the single most important measurement. If the fistula Qa at 2 weeks is under 300 – 400 ml/min (depending on other factors like patient size, RC vs BC etc) then this fistula very likely has a problem that needs fixing, probably an **inflow problem**. The likely cause of inflow problem, in order of importance will be **Swing vein**, inadequate artery or **Juxta-Anastomotic stenosis**. If the fistula at 2 weeks has a flow 500-600mls or greater, then it is probably OK, but there may be other problems e.g., an inadequate **useable segment** or too deep for needling.

**The useable segment**: If the useable segment is going to be adequate, the scan should show numbers consistent with the Rule of 6's. This applies particularly to depth: if the fistula vein is > 9 mm deep, superficialization will definitely be needed. Inadequate diameters will improve with time, but diameter < 3mm suggest assisted maturation will be needed. Finally, bifid or tripled systems ("malignant" branching) (**Fig 222** can be a problem, as illustrated in **Fig 72**.

**Outflow problems** with the fistula will often present with a pulsatile, hypertensive of re-circulating fistula (**Fig 49**) but as stated above they are uncommonly the cause of FTM.

### 8.6 Multiple Causes for FTM

Unfortunately, in elderly, co-morbid Developed Nation patient population, this is common (See Section 17, Dialysis Issues in the Developed vs Developing

*The approach in this situation is as follows:*

- If the fistula has major problems in all three segments, it may be best to abandon the fistula and try elsewhere. This decision depends very much on the adequacy of your fistula planning in the first place: If there was no Planning Scan, you may

find a better fistula site; on the other hand, if the current fistula was the best site you could find on the Planning Scan, trying elsewhere is unlikely to be successful.
- In making the above decision, consider that the OUTFLOW is the hardest thing to fix, by open or endovascular techniques. If the outflow is bad, consider abandoning the fistula (**Fig 93**).
- If there are problems in multiple parts of the fistula, and forced maturation is intended, the first thing to sort out is the inflow. Without adequate inflow, the fistula will never work. Furthermore, without adequate inflow, it is hard to judge the state of the other parts of the fistula (**Case 6**).
- If the problem is the Useable Segment (Good inflow and outflow) forced maturation with a Bare Nitinol Stent as described is an option (**Ref 3JS**).

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## Section 9. Scan for the Dysfunctional Fistula

This is the most common US scan most units will perform requested because the patient is experiencing problems. There are several different reasons why an AVF may be "problematic":

1. Problems with dialysis such as recirculation.
2. Problems with needling (cannulation) the AVF.
3. Problems with the fistula itself, usually at the **Usable Segment**, such as ulceration.
4. Problems relating to blood supply of the limb the fistula (steal).
5. Problems with the heart supporting the fistula.
6. Problems picked up on various Surveillance modalities.

The scan is guided by what sort of AVF problem is being considered, as outlined in each sub-section below.

### 9.1.i A problem with the effectiveness of dialysis

In this situation, the patient is not being adequately dialyzed despite receiving the prescribed dialysis. The patient may have fluid overload or may have inadequate solute clearance despite what appear to be adequate dialysis cycles. There are several different reasons why a patient's dialysis may be inadequate; sorting out the underlying cause is essential to correcting it.

### 9.1.i.a A Fistula Problem

The most likely explanation is that the patient is Recirculating due to an Outflow Stenosis or an Inflow Stenosis - **A Fistula Problem**.

### 9.1.i.b A Needling (Cannulation) Problem

Alternatively, the Dialysis Nurses may have Reversed Needling, or they may not have separated the A & V needles adequately. **A Needling Problem.**

### 9.1.i.c A Needling Problem caused by a Fistula Problem

Thirdly, the Recirculation may be caused by inadequate needle separation (as in 9.1.i.b above), but the cause of the inadequate needle separation is a lack of **Useable Length**: a Fistula problem – Rule of 6's. **A Needling Problem caused by a Fistula Problem.**

### 9.1.i. A Compliance Issue

It is important to realize that HD or PD do not give the patient normal renal function; far from it, as shown in **Fig 153** and **Fig 154**. Both therapies must be supplemented with other strategies to maintain **Renal Homeostasis**, of which oral fluid restrictions and dietary restrictions are the most important. If these are not adhered to, dialysis may appear to be compromised although the actual fistula & dialysis treatment are working normally. See **Case 4** as an illustration.

### 9.1.ii A problem with the process of dialysis

The second reason a patient may not be dialysing adequately is a problem with the **process of dialysis**. In this situation, the nurses are unable to give the patient the prescribed dialysis in terms of duration or speed. Typically, the dialysis numbers are abnormal: AP, VRP, Qb or a combination. The problem can be anything from high pressures, reduced **pump speed**, reduced time on dialysis or complete failure of a dialysis therapy.

A common and important Dialysis Problem for which patients are referred is "**Prolonged Decannulation Bleeding**". Obviously, everyone bleeds when you poke them with a needle; therefore, when a patient is referred for a fistula scan because of bleeding, it will be different, more or worse than usual! This makes Prolonged Decannulation Bleeding one of the "hard signs" in Dialysis Access: you will almost always find a problem, usually an outflow stenosis or occlusion. Prolonged Decannulation Bleeding is usually accompanied by **HVRP** on Dialysis Numbers and a firm or pulsatile fistula on Physical Examination.

**Three different reasons for problems with the Process of Dialysis:**

1. *Needling problems:* A nursing / access problem, there is no fistula problem. e.g., an inexperienced Cannulator
2. *A fistula problem:* The nursing / access is OK but there is a fistula problem e.g. Arch stenosis causing HVRP and recirculation.
3. *A Needling problem due to a fistula problem:* The needling is problematic, but not because of Nursing issues; the needling is problematic because of a fistula problem, such as **Useable segment** is short, needles are too close (**Fig 114**) and recirculates.

### 9.1.ii.a A Needling problem

There are several things that indicate the problematic dialysis is due to a "needling" problem, as opposed to a problem with the fistula itself. Admittedly, a fistula with a poor Useable Segment will be more prone to being needled badly, so the 2 problems (a poor fistula that gets badly needled!) can co-exist.

- *The experience of the person accessing the fistula*. Herein one of the many advantages of **Home Hemo**. If the patient does their own needling – and these patients know their fistulas well – they will be able to tell you whether the problem lies with the fistula or the needling. The experience of the Dialysis Nurse is also very important; often the patient will point out that the success of their needling depends on which nurse they get to access them.
- *The pattern of the **Qb's***. If the problem is related to the fistula, the abnormal Qb's e.g., **HVRP**, will be consistently abnormal on every dialysis. If it is a needling problem, the Qb's will fluctuate considerably, some dialysis sessions being normal (needles correctly placed) and some being abnormal (bad needling). - Doc **??** with Qb's reflecting needling problems and fistula problems.

### 9.1.ii.b A Fistula Problem affecting the Dialysis Process

As opposed to the Needling problem, intrinsic fistula problems will be present on every dialysis session and with every Dialysis Nurse. The Dialysis Numbers will show a consistently disturbed pattern, often progressive; in themselves, these numbers will suggest what the fistula problem is.

### 9.2 A Problem with the Fistula itself

The patient may be referred because there is a fistula "pathology" such as an aneurysm, an ulcer, thin skin etc. See Section 5 Fistula Pathology.

### 9.3 Patient referred because of ?"steal" syndrome

This is discussed under Steal Syndrome Note that scanning the fistula is of limited use when the question is ? Steal ?. Finger Plethysmography is the appropriate investigation. The most important information in the fistula scan itself is the determination of the Qa: question - a High Flow or Low Flow Steal.

### 9.4 Patient referred because of Cardiac problems

This is discussed under The Giant or High Flow Fistula. Note that it is the heart which must "power" the flow thru the fistula. This can become a problem for the normal heart if the flow becomes grossly excessive (Qa > 3 liters/min); Alternatively, a "normal" fistula running at 900 ml/min may be too much for a compromised heart.

### 9.5 Patient referred because of problems detected on "Surveillance"

Surveillance includes:

- Many units are now doing fistula surveillance using Qa measurements – fistula flow surveillance, and patients will be referred because of this. This is our unit's practice (Westmead Blacktown Western Renal Dialysis Monitoring) as discussed in Section 13 Surveillance Scanning (**Fig 202** and **Fig 203**).
- All Dialysis Nurses and Home Hemo patients are encouraged to examine their fistulas regularly and if abnormalities or problems are detected e.g. a pulsatile fistula with an **aberrant thrill**, a referral for an US scan is made.

The subsequent scan is guided by the type of problem the surveillance has detected.

**9.6** Acting on the findings of the Ultrasound Scan

A problem in the Dialysis world is the disconnect between the many, complex, expensive, and specialized entities within it – **Fig 171**.

One of the advantages of the AVF over the AVG is that it fails gradually, over weeks or months, not catastrophically. Therefore, with proper care and surveillance, fistula failure or thrombosis is preventable.

However, this is only possible if:

1. The fistula problem is diagnosed in time and
2. Once alerted to the problem, there is a system in place that will promptly fix it.

It is worth noting that when fistula dysfunction becomes manifest, the underlying pathology – usually a stenosis – is advanced. When a severe stenosis is detected (<1.5mm) or very low Qa's (<250ml/min), anticoagulation is indicated with LMWH as an outpatient until the AVF is revised – usually within 48 hours.

The implication is that US scans for Problem Fistulas should be performed promptly, usually within 1 week or so of referral. Likewise, severe problems detected on US must be treated promptly within the next few days.

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## Section 10. Scan for the "Occluded AVF"

The terms "Occluded" and "Thrombosed" AVF are used interchangeably. One of the advantages of the native fistula over the fistula graft is that the AVF generally does not occlude "catastrophically": usually, the AVF thromboses because of a progressive stenosis that develops over weeks to months, often with warning signs and symptoms. This is quite different from the AV graft which can fail suddenly without underlying problems. See Differences between AVF and AVG.

### 10.1 US is essential in the management of the "occluded fistula".

### 10.1.i Confirmation of the Diagnosis.

Clinical diagnosis of occlusion is not always accurate. Low flow states and critical stenoses are not the same as fistula thrombosis, though clinically it might be hard to tell them apart. **Certainly, a fistula with a critical stenosis that is still in flow is *much* easier to fix than one that has thrombosed.**

***Note:*** We have seen fistulas that fluctuate between "thrombosed" and critically stenosed. This is reflected in the long-standing practice by Renal Physicians in "milking" a recently thrombosed fistula to try and restore flow. In this situation, the severely stenosed fistula clots and lyses clot depend on factors like hydration, blood pressure, arm elevation and mechanical lysis of the clot by pressure and movement. When we encounter this situation,

because the un-thrombosed fistula is so much easier to treat than the thrombosed fistula, we will fully anticoagulated the patient immediately and organize for emergent repair (<24 hours).

### 10.1.ii To Determine the Extent of the Thrombosis.

When the fistula does thrombose, the extent of the thrombosis is very variable and usually the major determinant of *whether* and *how* you are going to fix it – **Fig 92a-c**.

### 10.1.iii To Diagnose the Cause of the Thrombosis

It is often but not always possible to find the index lesion that caused the thrombosis on ultrasound examination, despite the lack of flow as illustrated in **Figure 242**. This allows for better and quicker management when you know the specific site / cause of thrombosis.

### 10.1.iv To Plan Management of the Thrombosis.

US is essential to planning management:

**10.1.iv.a Whether or not to intervene on the thrombosed fistula.** This ties in with how important that fistula is to the patient. In some patients we will elect not to unblock the fistula.

**10.1.iv.b How to intervene on the fistula.** Intervention has developed into a hybrid approach to the occluded AVF using mainly as endovascular but also open techniques – **Ref 10JS**.

If the decision is made to try and salvage the fistula, the patient should immediately be anticoagulated fully to prevent progression and extension of the thrombotic process between the time of performing the US and the time of the **endovascular** or surgical intervention.

### 10.1.v A contemporary AVF planning scan.

In the situation where the patient is fistula dependent (for dialysis thru the fistula) and where salvage looks difficult on ultrasound, a **Fistula Planning Scan** should be done to look at the available options for creating a new fistula. If creating a good new fistula looks very difficult, it would push us towards attempting to salvage the thrombosed fistula, and vice versa.

### 10.2 Pre-Scan Workup for the Occluded AVF

This will complement the actual fistula scan in what happened to the fistula, why it happened and what to do about it.

The patient's pre-occlusion dialysis history and **dialysis numbers** can be very helpful. For example, a BC AVF that has had progressive problems with **HVRP** and prolonged decannulation bleeding, and is now thrombosed, is likely to have an **arch** occlusion. Per contra, a fistula that has been dialyzing poorly because the Dialysis Nurses have been progressively reducing the pump speeds probably has an **inflow** occlusion.

Physical examination will reveal the size of the fistula, and the thrombosed sections of the fistula can be palpated as hard and thickened. The site of occlusion and extent of

occlusion (when the problem is not an Extensive Thrombosis) may be determined on physical findings. Inflammatory changes in the skin – usually **thrombophlebitis** – suggest that the thrombotic process has been going on for several days.

### 10.3 Scanning the Occluded AVF

#### 10.3.i Obtaining the Qa – Waveform in the Brachial Artery

As with many fistula scans, the first step is doing a Qa on the Brachial artery. There are three possibilities:

1. Normal of near normal Qa: Either the fistula is not thrombosed, or the thrombosis is localized and/or limited.
2. Poor Qa (<200mls/min) and very limited diastolic flow. This indicates significant occlusion, but parts of the fistula may still be patent. This is often seen in **Outflow Thromboses** (Fig 156).
3. Triphasic signal. This indicates a complete Inflow Thrombosis or an Extensive Thrombosis involving the whole circuit.

#### 10.3.ii Establishing the Extent of the Thrombosis

We divide fistula thrombosis into 3 categories, Limited Inflow Thrombosis, Limited Outflow Thrombosis and Extensive Thrombosis, as illustrated in Fig 155, Fig 156 and Fig 157. We have published on this and our Endovascular based method of management (Ref 10JS).

As with all fistula work, we must consider three components:

1. Inflow
2. Outflow
3. Useable Segment (conduit).

Ultimately, to resuscitate the thrombosed fistula, all 3 components must be “cleared”.

The Interventionist who is going to unblock the fistula needs to know what is patent and what is thrombosed, but the difference is not always clear-cut. In practice, the transition from patent fistula to clotted fistula is usually gradual and can occur over many centimeters of the fistula. So, the Swing Vein may be fully thrombosed; the Useable Segment may contain jelly-like clot – no flow but still fully compressible; and the triple outflow has normal venous flow and no evidence of thrombosis.

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## Section 11. The Post-Operative Follow-up Scan

We routinely perform post-operative scans on all our fistula interventions, be they Endovascular (85%+) or open. In Australia, a fistula ultrasound costs about 280$; an Endovascular Fistula Intervention costs about 5000$; the cost of the scan is therefore a small component of the **fistula maintenance**.

### 11.1 The aims of the postoperative scan include:

**11.1.i** To determine whether the operative intervention was a success. NB An AVF angioplasty is no guarantee that the stenosis has been successfully corrected; inadequate angioplasty, recoil after seemingly successful angioplasty (as determined by **completion angiography**) and early stenosis recurrence are all common.

**11.1.ii** A "quality control" on the surgical / interventionist team. Clinical assessment of the success or otherwise of a fistula intervention is a CRUDE tool. Only AVF ultrasound will accurately inform the interventionist of the operative result. This constant feedback loop between Pre-Op Diagnostic Ultrasound, Fistula-plasty and then Post-op Ultrasound has allowed us to improve both the quality of our fistula ultrasound as well as that of our fistula interventions.

### 11.2 The timing of the post-operative scan:

This depends on many things:

- How successful was the intervention?
- How "**precious**" is the fistula?
- What is the track record of this fistula?

### 11.3 Performing the Post-operative scan:

- This is quite different and often much faster than a diagnostic scan for FTM or Dysfunctional Fistula. In addition to the standard **Pre-Scan Work Up**, a copy of the Operative Report or access to the Interventional Images increases both the speed and accuracy of the scan.
- As most intervention will be for stenosis, a critical determinant of the post-operative scan will be the **Qa**. If the problem was an **Inflow Stenosis** the Qa should improve significantly.
- After Qa assessment in the standard method, *scan that part of the fistula circuit that was treated. Performing a full, proforma fistula scan is a waste of time and effort!* Determine the diameter of the treated stenotic area. In most cases that is all that needs to be done in the postoperative scan.

### 11.4 Special Post-Operative Scans:

### 11.4.i The Post-Operative scan for FTM.

As FTM may have more than one cause the post-operative scan for the FTM fistula should be more thorough / inclusive. If the FTM was due to a single, specific lesion e.g., severe swing vein stenosis, then a successful treatment of this should produce a functional fistula.

If the FTM scan showed multiple problems, then the whole fistula circuit needs to be carefully re-assessed after intervention to determine whether there are any other problems that are impeding further development of the fistula.

### 11.4.ii Fistula interventions where complications were encountered.

The commonest problem would be with the Endovascular Fistula **Access** puncture, especially in the immature fistula. The access puncture site should be scanned and assessed as stenosis can develop at the access site.

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## Section 12. The US Scan for AVF Needling or Cannulation

This is one of the most important applications of US to hemodialysis access, and it takes a somewhat different form from most of the other fistula applications of US.

### 12.1 These differences include:

- It is principally a bedside scan, performed by the Dialysis Nurse, for the purpose of better fistula needling (like US for CVC placement) rather than a diagnostic scan.
- The quality of the ultrasound machine and the probe is basic compared to diagnostic scanning where high end machines with high frequency probes are needed. Only **Grey Scale** imaging is needed.
- The scan is performed in the most expeditious way possible to achieve successful needling, with limited pre-scan workup or post scan documentation.

### 12.2 The Needling Scan can be performed in 2 very different ways:

### 12.2.i To give the Dialysis Nurse a "Road Map" of the Useable Segment

For this application, the fistula – essentially the Useable Segment – is examined with the Ultrasound prior to needling, with or without marking the skin with a pen. **Fig 158**.

OR

### 12.2.ii To access the Usable Segment under Real Time Ultrasound:

The actual needling can be performed under direct ultrasound guidance in "real time". This requires significant skills in needling and ultrasound scanning as the operator needs to perform both tasks simultaneously. The use of this modality can be facilitated by having 2 people perform the task (awkward) or perhaps a new generation of Dialysis Nurses trained ab initio in Real Time ultrasound guided puncture may become the norm.

### 12.3 Indications for a Needling Scan

All Dialysis Nurses do not need to perform Needling Scans on all fistulas all the time! Many big, mature fistulas can be assessed and needled on physical examination. The use of the Needling Scan will be operator dependent on the Nurse's experience with fistula cannulation as well as their familiarity and experience and skill with ultrasound.

*The Indications for a Needling Scan include:*

- The new fistula that has not been needled before.

- The small fistula where access sites are not obvious.
- The fistula which **has** problematic needling.
- The fistula which **develops** problematic needling.
- The fistula with "area puncture" where new / different needling sites need to be found. **Fig116a-d** and **147a**.

In some patients, with inadequate, short Useable Segment, area puncture may be hard to avoid. However, *in my experience, most area puncture is due to poor Dialysis Nursing practice*, where plenty of needling sites are available, but they are not used – **Fig 116b**. Part of the problem comes from patient pressure to use the same site over and over because it gives reliable access and because repeated puncture renders the scarred skin somewhat anesthetic.

### 12.4 Information that should be acquired with the Needling Scan

- The Needling Scan looks principally at the Useable Segment and as such, seeks to acquire information related to the "Rule of 6's".
- Sites in the fistula circuit that are >6mm wide, <6mm deep and STRAIGHT
- To access the big AVF (>6mm) that is situated at moderate depth (between 6 and 9mm deep; deeper than 9mm requires superficialization.

Obstacles to successful needling and fistula flow such as intramural thrombus, extramural hematoma (often from complicated previous puncture) either in front of the fistula vein or behind it from "**back walling**" **Fig 206a,b**; valves within the vein, **Fig 204d**; tortuosity of the target vein not evident on examination – **Fig 81**.

When "Road Mapping", a certain amount of "diagnostic scanning" will occur (e.g. the difficulty with the needling is due to a 2mm stenosis in the Useable segment) especially as Dialysis Nurses get more skilled at fistula scanning, and the quality of the ultrasound machines available to them improves as prices come down

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## Section 13. Scan for AVF Surveillance - Monitoring

US Scanning is one of the methods of Vascular access and Fistula Surveillance. In some ways this is the best form of surveillance, especially when the scan is done by someone who understands dialysis, the fistula circuit and can examine the patient. The main drawback is that it is expensive and demanding of skilled labour and specialized machines.

### 13.1 Westmead Hospital Surveillance Program

- Essentially all our +/- 800 fistulas are native.
- The Surveillance of each fistula is individualized; generally, surveillance is more intense early in the fistula's life, until the fistula fully matures and stabilizes, and we get a "feel" of how closely we need to watch it.

- All fistulas are under surveillance by Physical Examination, by our Dialysis Nurses or by the patients themselves (Half of the dialysis population in on Home Dialysis).
- All fistulas receive Dialysis Machine based Qa monitoring every 6 months.
- About 30% of our "fistula fleet" (the **Precious Fistulas**, the **Frequent Fliers** and the young fistulas) receives Ultrasound monitoring, from 3 monthly to yearly.

### 13.2 Performing the Surveillance Scan

- How this scan is performed will be determined by why the fistula is under US Surveillance as opposed to the simpler and cheaper modalities.
- The Pre-Scan Workup as always is essential, with particular attention to the above question.

*The types of scans done for Surveillance include:*

*1. Frequent Fliers:* These are fistulas that stenose frequently and repeatedly; genetic factors probably play a significant role in these patients. There are often multiple new and / or recurrent problems in these fistulas (although **Drug Elution** balloon interventions has had a dramatic impact on this group (**Ref 12JS**). The standard Pre-Scan Workup is required to try and determine what the current problems with the fistula might be. The scan needs to be thorough of the complete fistula circuit.

*2. The High Flow fistulas:* In these patients, the critical question is the Qa. If this is stable, obtaining much further detail about the circuit is usually unnecessary and this is a quick scan. The important points are measurement of the inflow artery size (? Progressive arterial enlargement – arterio-megaly - or localized **aneurysm** formation) and multiple Qa measurements.

*3. Fistulas with localized problems:* Many of the fistulas we surveyed with US have localized though possibly recurrent problems. An example will be the otherwise good and problem free BC AVF with an Arch Problem. Surveillance scans in these patients all need Qa's, but apart from that the Sonographer can keep the scan brief and focus on problem area – the Arch in this case.

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## Section 14. Ultrasound Guided Angioplasty

US in the fistula circuit is normally used as a diagnostic tool and the intervention to the fistula is then performed by open surgery or a radiological and contrast guided

**Endovascular Intervention**.
Endovascular Intervention can also be done under (real time) US guidance. Our unit has some experience of this.

### 14.1 The 3 indications for US Guided Angioplasty

### 14.1.i Severe Contrast Allergy:

This is the principal indication for using US guidance.

In Mild-Moderate or uncertain cases of contrast allergy, proceed with Radiologically guided, contrast intervention, after standard contrast allergy prophylaxis.

If the patient has well documented and severe contrast allergy (anaphylaxis / severe respiratory compromise), studies have shown that contrast allergy prophylaxis reduces the severity of the reaction, but not the mortality. In these cases, we have used US guided fistula intervention.

### 14.1.ii To Protect the Failing Kidney from Contrast Toxicity:

The severity of Contrast Toxicity to the Kidney is somewhat unclear. Brief decline in renal function following iodinated contrast is well documented and accepted, but it is uncertain whether this damage is permanent.

Large doses of contrast (>200 ml) in a kidney with advanced renal failure (Chronic Renal Failure Stages 3 and 4) may cause significant renal damage and could precipitate premature ESRF in patients with failing kidneys.

This consideration is particularly relevant in treating fistulas that are failing to mature in **Predialysis patients**.

On occasion, we have used US guided AVF intervention for this indication, particularly if the segment needing treatment was peripheral and well visible on US.

The default management for these patients is standard x-ray guided intervention with special Contrast Toxicity precautions.

### 14.1.iii To offer an Endovascular treatment with no access to Radiology.

In LMIC regions, access to US is easier and cheaper than to radiological facilities. Several units have developed extensive experience in US guided endovascular intervention as a result.

## 14.2 Principles of Ultrasound Guided Endovascular fistula intervention

### 14.2.i Careful Preprocedural Ultrasound

As a separate procedure, a careful clinical assessment and a pre-operative US first to determine:

- Are there Central Venous Problems. (these cannot be treated at all under ultrasound guidance). The target lesion must be readily visible.
- Proximal lesions, very medial arm lesion, deep lesions, and lesions in patients with limited arm mobility may not be suitable.
- Is the planned intervention simple and straightforward? Complex endovascular reconstructions e.g., extensively thrombosed AVF, are not possible under ultrasound guidance.

### 14.2.ii Two Operators are needed.

Two separate operators are essential: one to do the imaging real time, and one (or 2 operators) to manipulate the sheaths, wires, balloons etc.

### 14.2.iii Interventional Setup

Although the procedure is under US guidance, an appropriately set up, sterile interventional suite with all the necessary endovascular equipment is needed. The ergonomics of this venue will be different from an x-ray guided endovascular suite.

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## Section 15. Regional Anesthesia in Vascular Access Surgery: "Arm Block"

(The terms "Brachial Plexus Block" and "Arm Block" mean the same thing and are used interchangeably)

### 15.1 Indication

### 15.1.i Safer form of Anesthesia

Arm block is the safer option of anesthesia for patients with comorbidities. There is an increased prevalence of concurrent comorbidities amongst the chronic renal failure population such as diabetes, hypertension, ischemic heart disease, in addition to renal failure pathology itself. There is an increased risk of General Anesthesia complications.

### 15.1.ii Full Venous & Arterial Vasodilatation

A major advantage of Arm Block is the complete vasodilation of both the Venous and Arterial vascular bed which maximizes the size of the vessels operated on and prevents **vasospasm**, which makes surgery difficult and predisposes to thrombosis. This holds true for both Open Surgical and **Endovascular procedures** and is particularly important in the new fistula or the Fistula that **Fails-to-Mature** where the vessels are small and the tendency to spasm is strong.

### 15.2 Clinically Relevant Anatomy of Brachial Plexus block

Arm Block has been utilized in regional anesthesia for decades.

***Ultrasound Guided administration of Regional Anesthesia*, particularly in the Arm Block, has been a breakthrough development! It makes the block far more effective, much faster and much safer than the traditional "blind", landmark-guided procedure!**

There are four "classical" levels of Arm Blocks depending on the level at which the Brachial Plexus is blocked – **See Fig 139**. : Interscalene, Supraclavicular, Infraclavicular and Axillary nerve block.

Choosing which block to perform can be confusing for the inexperienced regional Anesthetist.

### 15.3 The Axillary Arm block is the only level used in AVF surgery

The reasons for this are as follows:

**15.3.i** It will effectively cover most of the surgical target areas (wrist to forearm for RC AVF, elbow, and upper arm for BC AVF and BB AVF).

**15.3.ii** It has the fastest onset of action as the local anesthetic is placed around the brachial plexus nerves where they are at their smallest diameter i.e. shortest distance for local to diffuse into the nerve and take effect.

**15.3.iii** The risk of bleeding complications is the least at the Axillary level. Patients in ESRF are all **coagulopathic** to a greater or lesser extent – what surgeons call "The Renal Ooze". Arm blocks at Infraclavicular and Supraclavicular Levels are closer to the major vessels and, if a vascular needling injury occurs, those areas are poorly compressible.

**15.3.iv** Studies have shown that *Nerve injuries are fewest with the Axillary Block* and greatest with the Interscalene Block – **Ref 17**.

**15.3.v** Axillary Block has the lowest incidence of **Pneumothorax** and Phrenic Nerve Palsy. Both these injuries can cause major respiratory problems; in the compromised ESRF patient, who may already have respiratory compromise from fluid overload, this can precipitate **Respiratory Failure**.

**15.3.vi** The relatively superficial location of the axillary nerves makes this block feasible in obese patients. This is particularly important as the safety and efficacy of the block depends on US guidance – the deeper the target, the lower the probe frequency, the less reliable the US guidance becomes.

### 15.4 Challenges of the Axillary Level Brachial Plexus Block

There are two challenges with the Axillary Brachial Plexus Block:

**15.4.i** At the Axillary level there are 4 target nerves (*musculocutaneous, radial, medial, and ulnar nerve*) the most of any level of Arm Block. Hence 4 different local anesthetic depositions must be used. usually be done with a single needle entry.

**15.4.ii** At the Axillary level there is considerable anatomy variation of the 4 nerves, making target recognition an US skill that needs to be acquired.

### 15.5 Performing Axillary Nerve Block

Studies have shown that, since the introduction of "real time" US Guided Regional Anesthesia, the success rate of regional blocks has increased and the complication rate has decreased, **Ref 17**.

#### 15.5.i Preparation

Depending on the country of practice, and its regulatory framework, the appropriate training, equipment and setting up for performing Arm Block will vary. In Australia and New Zealand College of Anesthetists require the following:

- Patient has been properly consented
- The block is performed by trained medical personnel assisted by a skilled assistant
- The block is performed in a safe environment (e.g. anesthetic bay)
- Patients are monitored during the block establishment (ECG; pulse oximetry, 5 minutely BP) and this continues immediately post block to monitor for potential complications.
- Correct side of Surgery is established (by "Time Out" or other system) to assure blocking the correct side.
- Intravenous cannula is in situ before the block
- Aseptic technique throughout
- Procedure and drug dosage documented clearly and communicated to the surgical team to avoid local anesthetic overdose if the surgeon also uses local anesthetic infiltration.
- Consideration for immediate availability of *Intralipid*, the antidote for systemic local anesthetic toxicity (a rare but serious event).

### 15.5.ii Establishing the axillary brachial plexus block

1. Position patient sitting slightly up in the bed, abducting the arm and supinate the forearm

2. Place the linear ultrasound probe across the armpit and scan from the armpit and down slightly *to recognize all the 4 target nerves*. The first landmark to find should the axillary artery which is easily recognizable. Three of the nerves - median, ulnar, and radial nerve -are positioned immediately around the axillary artery. The Musculo cutaneous nerve is imbedded within the brachioradialis/biceps muscle.

- The Median nerve is usually positioned superior and lateral to the artery, the Ulnar nerve is usually superior and medial to the artery and Radial nerve is inferior to the artery. If one or more of these nerves cannot be identified, an injection of 8-10ml of local anesthetic immediately above the axillary artery, laterally and medially, will usually cover the median and ulnar nerves, while an injection of 8-10 ml of local anesthetic below the axillary artery will usually cover the radial nerve.
- The Musculocutaneous nerve is either obvious or inconspicuous. It may be hyperechoic. Distally from the armpit, it is embedded in the Brachio-radialis-Biceps muscle; scanned proximally, the nerve moves towards the axillary artery, and away from the artery more distally.

3. Use an Echogenic Block Needle (short bevel), 50 mm length for small or skinny patients and 75 mm length needle for average to bigger patients. Set the patient arm height to be ergonomic for the operator and the ultrasound screen, probe, and operator in straight alignment. Once the best US anatomy image has been achieved, stabilize your hand holding the probe, and insert the needle about 2 cm distal to the probe edge (to allow for wider needle angulation). When first inserting the needle, look at the probe and align the needle in the middle of and perpendicular to the US beam; then confirm the needle visibility on the US screen. If the needle does not show up well on the first pass, pull out

the needle and try again. Do not move the probe! This must be kept in position to obtain the optimal view of the nerves.

4. Inject the local Anesthetic around each nerve. The total volume is typically 20 ml but always check what the maximum recommended dose is for the patient's weight. For operations of up to 3 hrs., 20 ml 2% lidocaine with 1:200 000 adrenaline or a mixture of 15 ml of 2% lignocaine with 1:200 000 adrenaline + 5 ml of 1 % Ropivacaine can be used. The latter mixture provides longer analgesia.

For procedures that may take longer than 3 hrs., 0.75% or 1 % Ropivacaine will provide surgical blockage for at least 6 hrs. The lower concentration allowed for more volume. The patient should be informed that arm paralysis may last 12 hrs. before full recovery.

Onset for 2% lignocaine usually around 15-20 minutes while slower for 0.75%/1% Ropivacaine will usually take around 30 minutes to achieved surgical anesthesia.

### 15.5.iii Troubleshooting

*1. Patchy block*

If the block does not take effect as expected, further Local anesthetic can be injected if the maximal dose has not yet been given. Further injections, according to the above recipe, can be injected to the distal radial nerve and/or musculocutaneous nerve for *forearm* fistula creation only. The distal radial nerve is best accessed at the junction of the distal 1/3 and proximal 2/3 of the forearm before its branching point.

The Musculocutaneous can be blocked distally by subcutaneous infiltration of the lateral half of the anterior aspect of cubital fossa.

*2. Intercostobrachial nerve*

While the Intercostal-brachial nerve is not part of the brachial plexus, it provides sensation to the medial aspect of the upper third of the arm and the armpit. This is important in proximal arm fistula work, particularly involving Stage II BB AVF surgery or revision of BC or BB fistulas at that level. It is also useful to block this nerve if an upper arm tourniquet is used.

The intercostal-brachial nerve needs to be blocked separately from the Brachial Plexus. This is done by subcutaneous infiltration of the medial aspect of the distal arm just distal to armpit fold from mid to posterior axillary line.

A volume of 5-8 ml of the same Local Anesthetic recipe should be used, again ensuring that the total dose of Local Anesthetic used does not exceed individual maximum recommended dose.

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## Section 16. Ultrasound Guided Vascath (Central Vein Catheter, CVC) Placement

***Central vein Catheters (CVCs)*** are both a blessing and a curse in Renal Replacement Therapy (RRT), allowing life-saving emergency dialysis in patients to rapidly correct the life-threatening complications such as **Pulmonary Edema** and **Hyperkalemia**.

CVCs bring, many short- and long-term complications that in themselves can damage or kill the patient.

**16.1** Indication for CVC - (Vascath) Placement**, and "acceptability" grading.**

**16.2** Site of CVC-Vascath Placement

This depends much on the indication and the circumstances. Over the years the practice has changed. Current protocol is attached in **Doc 3**.

**16.3** Vascath - (CVC) Complications

The list is long, including complications during the operative procedure and delayed complications days, weeks, months, or years after placement.

**16.3.i** *Operative Complications* are dependent on the operator skills and the imaging support, both US Guidance and Radiological / Contrast Guidance **Ref 14**.

**16.3.ii** *Delayed Complications.* The three most important are:

- **Vascath Sepsis**, often in the form of Septicemia, with a high mortality.
- Central Venous Stenosis or Occlusion, with limb swelling of various degrees or Superior Vena Cava Syndrome when the damage is bilateral.
- **Fistula problems or failure**. If a fistula is created on a limb with Central Venous Obstruction, problems can arise varying from High Venous Return Pressures with recirculation to severe arm swelling, **venous gangrene** and limb loss. Once again, the RC AVF tolerates Central Venous Stenosis better than any other fistula configuration, one of the Many Advantages of the RC AVF.

### 16.4 Ultrasound Guidance for CVC - Vascath Placement

Older operators, with years of experience, can accurately access the Central Veins – IJV, SCV, Femoral Vein – using landmarks and years of experience.

Ultrasound Guided Central Venous Access makes it possible for the young and inexperienced operator to achieve this accuracy and safety in a very short time and the use of US Guided Central Venous Access will make the experienced operator even more accurate and safe. **In many countries, Central Vein Access under US Guidance has become mandatory.**

Like US Guidance for Vascular access Cannulation, US Guided Access to the Central Veins can be done in 2 ways:

### 16.4.i Use the ultrasound to "map" the Central Vein and plan the puncture.

The operator scans the vein to establish its patency, size, depth and location.

***Patency:***

A normal Central Vein (such as the Internal Jugular Vein (IJV) is considerably larger than the accompanying artery common carotid artery

An IJV that has been damaged by previous Vascaths or manipulations will be small or smaller than the artery or absent. In addition, it will often have a thickened wall, and there may be many collaterals present, particularly the External Jugular Vein is the main collateral.

Occasionally, an undamaged IJV but completely obstructed more proximally (by a BCT occlusion) may be exceptionally larger than a normal IJV. Useful for working out this situation is the Pulsatility in the vein; if it is large and normal, the vein will be very pulsatile. If it is large with no Pulsatility (**Fig 90**), suggests severe, proximal stenosis or occlusion.

***Size & Depth & location:***

When satisfied that the circuit is patent, the next step is to use the US to plot the exact location of the IJV, how big it is and how deep from the skin. From this information, the operator can then puncture at the right spot, at the right angle and go to the right depth to confidently hit the vein (and not another structure like the Carotid artery).

If the circuit is occluded, small or damaged, it may still be possible to insert the catheter through a damaged vein. However, after gaining access to a damaged vein, Radiological **Contrast** Guidance is needed and often also **Endovascular Techniques** like **angioplasty** to access the Right Atrium.

***Alternative Central Venous Access:***

If the IJV is occluded, or unable to navigate from the IJV access site to the Right Atrium, US can be used to select a large and hopefully direct collateral vein (particularly the External Jugular Vein) to place the CVC into the Central Veins and then Right Atrium, via that collateral **Fig 160**. This is an important technique to avoid being forced to use Left side central vein catheters.

### 16.4.ii Real Time puncture of the vein under ultrasound guidance.

This is probably the best way of doing the puncture but requires ambidexterity and more skill. The younger generation has taken to this method.

Even under Real Time US Guidance Arterial and lung injuries can still occur. It is not always clear where the tip of the needle is if the US probe is not perfectly aligned, especially in short or fat necks.

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## Section 17. Hemodialysis Ultrasound in the Developed and in LMIC Regions (Low to Medium Income Countries)

There are great differences in how ESRF is managed (or can be managed) in the developed world compared to the developing world. This impacts on all aspects of RRT, including how US used compared to countries like Australia with special reference a large

Dialysis - Transplant Center (Westmead Hospital in Sydney). where the author has worked for 20 years. International experience is based on lectures, teaching at workshops, visited hospitals in LMIC such as the Philippines, Malaysia, Indonesia, Thailand, and Pakistan but also in nations like Hong Kong, Singapore, and the US. The markedly different aspects of RRT around the globe is appreciated.

### 17.1 The cardinal differences

There are many differences at many levels between nations in how RRT is managed, but these seem the most important:

- Resources and health care systems.
- Demographics and disease patterns.
- Central Vein Catheter induced damage.
- Transplantation and living donor practices.

### 17.1.i Transplantation Rate

Renal Transplantation rates have a profound impact on the whole of RRT. The system of RRT in countries with high transplantation rates is very different from those with little transplant activity. Furthermore, the difference in transplantation rates is only partly linked to wealth and development: Cultural factors play a big role. With the low transplant rates in Japan, Australia and Malaysia are compared to illustrate this point.

Both countries are “developed”, they have a similar population, and both are multi-ethnic societies. However, transplantation rates are at the opposite end of the spectrum, as depicted in the table below:

| | Malaysia | Australia |
|---|---|---|
| Population | 28 million | 24 million |
| Number of Patients Waiting for a K Transplant | > 19,000 | 1,500 (average) |
| Number of Transplants/yr | 60 | 730 (2015) |

As a result, patients with ESRF in the two countries follow very different pathways. In Australia, if you are in reasonable health, and not very elderly (<80yrs), when you go into ESRF you will be managed with a Renal Transplant. The wait time for a kidney is about 3 years; the transplanted kidneys last for about 10 years; and many younger ESRF patients will receive 2 or more transplants in their lifetime.

In Malaysia, unless you are in a small, select group, your ESRF is going to be managed with HD in the long term, with PD in the shorter term (as PD longevity is 5-8 years, it is not seen as a long term RRT like transplant and HD).
As a result, fistula surgery in Australia is by and large for the elderly, the sick and the co-morbid, i.e., patients prone to fistula complications and frequently with damaged **Venous Real Estate**. Also, in most patients, the fistulas are not needed in the long term (because the patients are sick / elderly and die or because the patients are healthy and young and get a transplant).

In Malaysia, the opposite is true; most young people in ESRF will not get a kidney, and they will need fistula support for life as PD is underutilized.

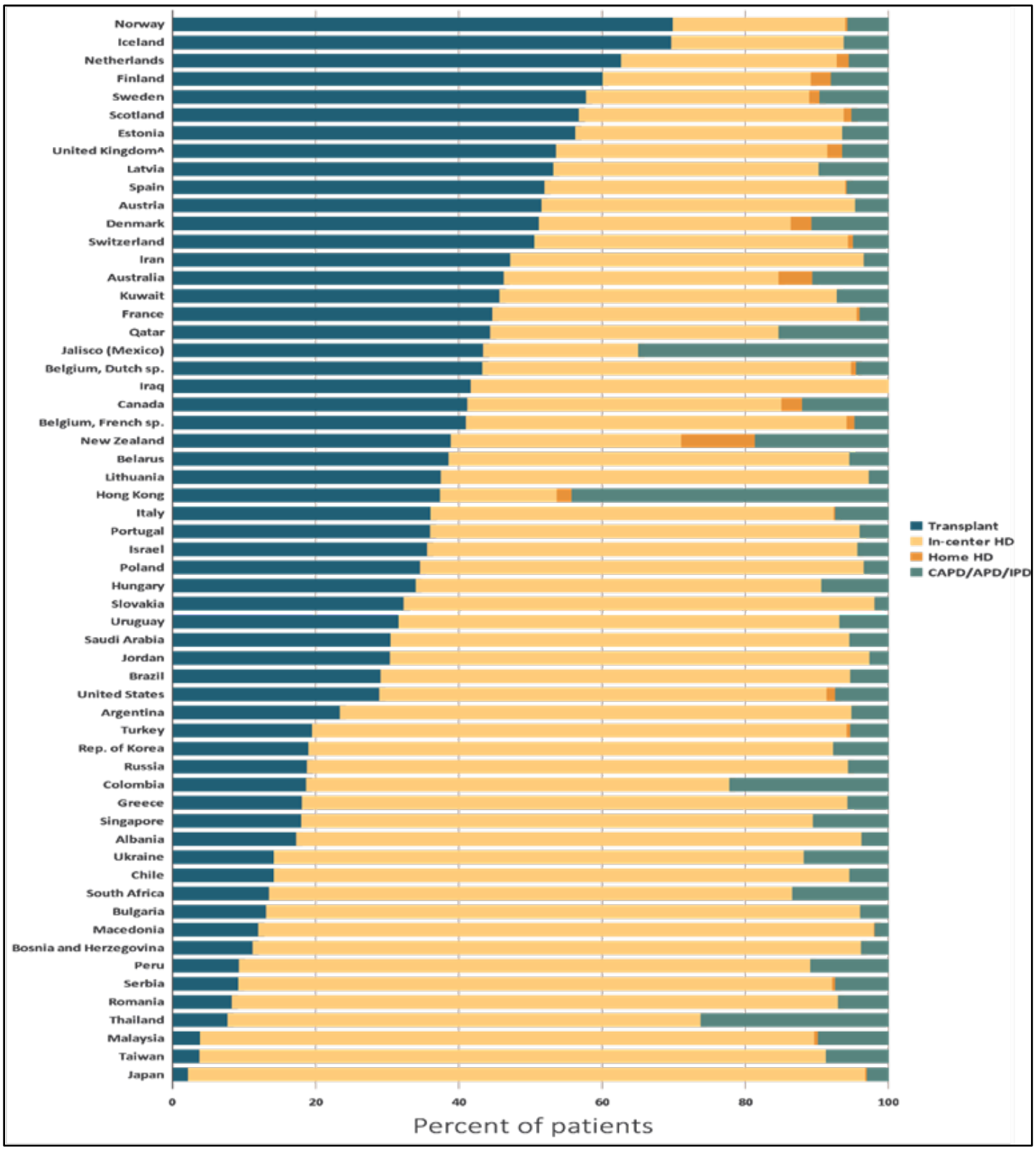
### 17.1.ii Vascath Damage

In developing (LMIC) countries, with limited resources and poorly developed health care systems, much RRT is reliant on HD, delivered by central vein catheters (CVC) also known as Vascath.

As a result, fistula surgery is bedeviled by CVC or Vascath damage. Even young patients in their teens will present for fistula surgery with extensive bilateral *Central Venous Destruction* already present. This affects the whole algorithm of fistula creation, maturation and maintenance, and the US systems that go with it.

In many countries, a partial solution to this problem is to expand the use of PD similar to Hong Kong and Thailand. As PD has a limited lifespan, it does not solve the problem of lack of transplants, it only delays it.

Percentage distribution of type of renal replacement therapy modality used by ESRD patients, by country, in 2016 Data source: USRDS ESRD Database for countries with relevant information available calculated as the sum of patients receiving HD, PD, Home HD, or treated with a functioning transplant.




Percentage distribution of ESRD treatment modality, by country or region, 2021Annual Data Report Chapter 11.

The highest incidence of treated ESRD in 2021 was observed in Jalisco and Aguascalientes, two states in Mexico, which had a collective incidence of 603 per million population (pmp). Incidence was high in Taiwan (522 pmp), Brunei Darussalam (507 pmp), the U.S. (410 pmp), Singapore (380 pmp), and Indonesia (314 pmp). Areas with the lowest ESRD incidence were Colombia (75 pmp), Serbia (66 pmp), Bangladesh (60 pmp), Italy (56 pmp), and South Africa (14 pmp).

Five of the 8 reporting countries or regions with the highest incidence of treated ESRD were in Asia, led by Taiwan at 522 pmp. Among reporting European countries, the highest incidence was in Greece, at 279 pmp; among reporting South American countries, the highest incidence was in Brazil, at 203 pmp. The only reporting country in Africa was South Africa, with a rate of 14 pmp, which likely reflects limited availability of treatment for ESRD.

There was substantial variation in the percentage of incident cases of treated ESRD attributed to diabetes globally (Figure 11.4a). In Brunei Darussalam, nearly three-quarters (72.9%) of all incident cases of treated ESRD were attributed to diabetes; in Singapore, nearly two-thirds (65.8%) were. Countries or regions where <20% of incident cases were attributed to diabetes included Switzerland (18.8%), Lithuania (16.8%), the French-speaking region of Belgium (16.7%), Estonia (16.7%), Norway (16.4%), Serbia (15.9%), Mainland China (15.7%), South Africa (13.5%), Aguascalientes in Mexico (12.9%), Italy (12.4%), El Salvador (12.3%), and Romania (10.1%).

In most, countries in Europe, the highest incidence of treated ESRD occurred among individuals aged ≥75 years (Figure 11.7). The pattern was more variable in other regions: in Asia, for example, ESRD incidence was highest in the oldest age group in Thailand, Mainland China, Singapore, Turkey, Israel, and, especially, Taiwan, but in Hong Kong and, particularly, Malaysia, growth was highest among individuals aged 65-74 years. In North America, incidence was highest among the oldest individuals, while in Central and South America, the pattern varied.

The prevalence of treated ESRD varied by nearly 35-fold across reporting countries or regions (Figure 11.9). Countries or regions with the highest prevalence of treated ESRD in 2021were Taiwan (3839 pmp), Singapore (2577 pmp), the U.S. (2436 pmp), Aguascalientes in Mexico (2231 pmp), Brunei Darussalam (2077 pmp), Portugal (2004 pmp), Malaysia (1584 pmp), and Hong Kong (1506 pmp). Thus, 5 of the 8 countries or regions where the prevalence exceeded 1500 pmp were in Asia. Countries or regions where the prevalence was <500 pmp were Montenegro (434 pmp), Belarus (429 pmp), Italy (424 pmp), El Salvador (370 pmp), South Africa (147 pmp), and Bangladesh (110 pmp).

Only in Iceland (71.0%), Norway (66.9%), the Netherlands (65.0%), Finland (63.9%), Estonia (63.1%), Scotland (61.3%), Sweden (60.1%), Switzerland (56.5%), England/Wales/Northern Ireland (56.4%), Denmark (55.8%), Belarus (53.7%), and Ireland (53.2%) were more than half of prevalent patients with ESRD treated with a kidney transplant (Figure 11.13). In Malaysia, Montenegro, and El Salvador, only 3.6%,

2.2%, and 1.5% of prevalent patients, respectively, were treated with a kidney transplant.

Worldwide, HD was the predominant treatment modality for ESRD (Figure 11.13). PD was used far less commonly: El Salvador (64.8%) and Hong Kong (45.6%) had the highest percentages of prevalent patients treated with PD. Colombia (22.6%) and Aguascalientes in Mexico (21.7%) were the only other contributing countries or regions where the percentage of prevalent patients treated with PD exceeded 20%.

All countries or regions in which the average yearly increase in dialysis prevalence between 2011 and 2021 exceeded 50.0 pmp were in Asia: Thailand (124.2 pmp), the Republic of Korea (122.4 pmp), Singapore (85.1 pmp), Indonesia (80.7 pmp), Taiwan (67.1 pmp), and Malaysia (63.0 pmp) (Figure 11.15b). The average yearly change was 35.5 pmp in the U.S. for comparison.

Only in Hong Kong (68% PD, 3% home HD) and El Salvador (66% PD, no home HD) were more than half of patients on dialysis receiving a home-based therapy as of 2021 (Figure 11.16). Areas where a quarter or more of patients received a home-based therapy were the Mexican states of Jalisco (41% PD, no home HD) and Aguascalientes (31% PD, no home HD), Colombia (28% PD, no home HD), Denmark (20% PD and 6% home HD), Canada (21% PD, 5% home HD), Norway (22% PD, 3% home HD), and Sweden (22% PD, 3.0% home HD).

Incidence of kidney transplantation was highest in the U.S. (77 pmp), followed by Jalisco (58 pmp) and Aguascalientes (57 pmp) in Mexico, and Israel (56 pmp) (Figure 11.17a). Areas where the incidence was ≤10 pmp were Italy, Hong Kong, Ireland, Thailand, El Salvador, Brunei Darussalam, Bosnia and Herzegovina, Montenegro, Malaysia, South Africa, Romania, Serbia, Bangladesh, and Peru.

Bangladesh had the largest increase in the incidence of kidney transplantation between 2011 and 2021, with incidence increasing by 63% over period (Figure 11.18a). Incidence increased by about 52% in Israel, 50% in the Kingdom of Saudi Arabia, and 49% in Kuwait.

In Belarus (98.1%), Lithuania (92.2%), Portugal (91.9%), Estonia (91.7%), and Poland (91.6%), ≥90% of kidney transplants were from deceased donors (Figure 11.19). In contrast, ≥90% of kidney transplants were from living donors in Turkey (91.2%), the Kingdom of Saudi Arabia (91.3%), Bangladesh (100%), Brunei Darussalam (100%), El Salvador (100%), Ireland (100%), and Montenegro (100%).

Countries or regions with the highest prevalence of individuals with a functioning kidney transplant in 2021 were the U.S. (759 pmp) and Portugal (700 pmp); countries or regions where the prevalence was <100 pmp were Thailand (97 pmp), Malaysia (57 pmp), South Africa (28 pmp), Montenegro (10 pmp), Bangladesh (8 pmp), and El Salvador (6 pmp) (Figure 11.20).

# Ultrasound Applications in Dialysis Access

## Introduction

The focus of this chapter is on international comparisons of the incidence and prevalence of treated ESRD. We first report incidence of treated ESRD by country or region in 2021 and the change in treated ESRD incidence around the world in the decade between 2011 and 2021. We next show rates of ESRD attributed to diabetes globally, followed by figures showing the incidence of treated ESRD by age and sex worldwide.

We then move to the prevalence of ESRD. In a fashion analogous to ESRD incidence, we show the prevalence of treated ESRD by country or region in 2021 as well as the change in prevalence of treated ESRD between 2011 and 2021. The prevalence of treated ESRD by age and sex, across countries or regions, is shown next.

The prevalence of dialysis worldwide and its change over time are then reported, followed by displays of the distribution of dialysis modalities utilized worldwide. Finally, global rates and trends in kidney transplantation are shown.

## Methods

The findings in this chapter are based on analyses of data generously collected and supplied by individuals in each participating country or region. In 2023, a total of 51 countries or regions contributed data, and current or legacy data from 80 countries or regions are featured in the chapter as a whole. Each entrant completes a standardized collection form (located on the USRDS website). For the 2023 Annual Data Report (ADR), 51 countries or regions provided current data; for trends over time, the ADR also uses data supplied by contributors in previous years. Extensive efforts are made by the USRDS to contact individuals or authorities across the world who may have access to relevant data, and we welcome new contributors each year. Individuals who may have access to data in their country or region are requested to reach out to the USRDS at usrds@niddk.nih.gov so that their data may be included in future ADRs.

Because methods of data collection vary considerably by country or region, readers should exercise caution when making direct cross-country comparisons. First, data collection can improve over time in countries or regions, especially for incidence of treated ESRD. Second, in the U.S. and some other countries, regulatory and reimbursement frameworks make nearly complete acquisition of data on treated ESRD possible, but this is not the case in many other countries or regions because regulatory

and reimbursement frameworks differ considerably. Third, the COVID-19 pandemic altered the process and completeness of data collection in many countries or regions.

Note that in the U.S. and most other countries or regions, information is available only for treated ESRD; many individuals with ESRD do not undergo treatment (maintenance dialysis or kidney transplantation, collectively known as kidney replacement therapy). This could be because conservative care is deliberately selected or because kidney replacement therapy is not available. In addition to variation in their ability to provide access to dialysis or kidney transplant for ESRD, countries and regions vary in geographic, economic, cultural, historical, religious, and other ways that doubtless affect the treatment of kidney disease, particularly ESRD.

There are several important methodological issues that should be noted. First, data presented in this chapter are not adjusted or standardized in any way; age, sex, and race/ethnicity mixtures differ considerably among countries or regions. As such, this chapter is designed to provide only broad descriptive data about the landscape of treated ESRD around the world. Second, for Figure 11.1, a map representing ESRD incidence worldwide, ESRD incidence for Aguascalientes and Jalisco, two Federal Entities (“states”) in Mexico, are combined in a weighted average and are shown as representative of Mexico for convenience. However, data for Mexico as a whole is not available.

Data tables for the content presented in this chapter can be found in Reference Table N. A complete explanation of the analytical methods used to generate the study cohorts and figures in this chapter can be found in the Chapter 11 section of the ESRD Analytical Methods.

Data collection for this chapter is possible only through major efforts undertaken by individuals in the many participating countries who contribute to the USRDS mission of understanding the epidemiology of kidney disease. In many cases, these individuals contribute data without direct financial support to do so. The USRDS gratefully acknowledges their contributions and welcomes additional data from other contributors so that the USRDS can continually improve its kidney disease surveillance efforts worldwide. Full acknowledgments are listed at the end of the chapter.

Figure 11.1 Geographic variation in incidence of treated ESRD per million population, by country or region, 2021

Figure 11.1 displays the incidence of treated ESRD in 2021 for countries or regions that supplied data to the USRDS. Jalisco and Aguascalientes, two states in Mexico, had the highest collective incidence, at 603 per million population (pmp). Incidence rates were notably high in Asia: other countries or regions that had an incidence of ≥300 pmp were Taiwan (522 pmp), Brunei Darussalam (507 pmp), the U.S. (410 pmp), Singapore (380 pmp), and Indonesia (314 pmp). Areas with an ESRD incidence <100 pmp were Norway (99 pmp), Lithuania (98 pmp), Iceland (86 pmp), Switzerland (83 pmp), Finland (82 pmp), Montenegro (79 pmp), Estonia (77 pmp), Belarus (76 pmp), Colombia (75 pmp), Serbia (66 pmp), Bangladesh (60 pmp), Italy (56 pmp), and South Africa (14 pmp).

Figure 11.2 Incidence of treated ESRD, by country or region, 2021

Sort by Rate

Sort by Country/Region Name

Sort by Continent and Country/Region name

Jalisco, Mexico had the world's highest incidence of treated ESRD in 2021, at 646 pmp. Five of the 8 reporting countries or regions with the highest incidence were in Asia, led by Taiwan at 522 pmp. Among reporting European countries, the highest incidence was in Greece, at 279 pmp; among reporting South American countries, the highest incidence was in Brazil, at 203 pmp. The only reporting country in Africa was South Africa, with a rate of 14 pmp. Particularly low rates in some countries are likely a reflection of limited availability of treatment for ESRD.

Figure 11.3a Incidence of treated ESRD in countries or regions with the largest percentage increase in incidence between 2011 and 2021

Figure 11.3a shows the countries or regions with the highest percentage increase in incidence of treated ESRD between 2011 and 2021. (Note that data for 2021 is not available for some countries or regions; the approach to inclusion or exclusion of countries is described in the Analytical Methods section.) In 2021 (or in 2020, for

countries that did not supply 2021 data) relative to 2011, the incidence of treated ESRD was more than 1.9 times as high in Bangladesh, more than 1.7 times as high in the Republic of Korea and Russia, and more than 1.3 times as high in Greece, Singapore, and Malaysia. In the U.S., which is included for purposes of comparison, incidence increased approximately 14%.

Figure 11.3b Average yearly change in incidence of treated ESRD by country or region, 2011 versus 2021

Jalisco, Mexico (18.7 pmp), the Republic of Korea (18.6 pmp), and Indonesia (18.3 pmp) had the largest average yearly increase in the incidence of treated ESRD between 2011 and 2021 (Figure 11.3b). Taiwan had an increase of 10.4 pmp per year. Other countries or regions with an increase >5 pmp per year were Singapore (9.6), Greece (7.6 pmp), Thailand (7.1 pmp), Malaysia (6.9), Hungary (6.3), and the U.S. (5.3). Incidence decreased in 13 countries or regions, most notably in Austria (-2.3 pmp per year), Turkey (-3.6 pmp per year), Serbia (-7.2 pmp per year), and Italy (-12.1 pmp per year).

Figure 11.4a Percentage of incident cases of treated ESRD attributed to diabetes, by country or region, 2021

Sort by Percentage

Sort by Country/Region Name

Sort by Continent and Country/Region Name

There was substantial variation in the percentage of incident cases of treated ESRD attributed to diabetes globally (Figure 11.4a). In Brunei Darussalam, nearly three-quarters (72.9%) of all incident cases of treated ESRD were attributed to diabetes; in Singapore, nearly two-thirds (65.8%) were. In Malaysia and Hong Kong, slightly more than half of cases were attributed to diabetes. Seven other countries or regions had percentages ranging between 40% and 50%: Taiwan, Colombia, Jalisco (Mexico), the U.S., Israel, Brazil, and Thailand. Countries or regions where <20% of incident cases were attributed to diabetes included Switzerland (18.8%), Lithuania (16.8%), the French-speaking region of Belgium (16.7%), Estonia (16.7%), Norway (16.4%), Serbia (15.9%), Mainland China (15.7%), South Africa (13.5%), Aguascalientes in Mexico (12.9%), Italy (12.4%), El Salvador (12.3%), and Romania (10.1%).

Figure 11.4b Incidence of treated ESRD attributed to diabetes, by country or region, 2021

Sort by Rate

Sort by Country/Region Name

Sort by Continent and Country/Region Name

Brunei Darussalam (370 pmp), Jalisco, Mexico (297 pmp), Singapore (250 pmp), and Taiwan (249 pmp) had the highest incidence of treated ESRD attributed to diabetes in 2021, followed some ways behind by the U.S. (181 pmp) and Malaysia (149 pmp) (Figure 11.4b). Countries or regions with incidence ≤20 pmp were Mainland China (20 pmp), Iceland (19 pmp), Romania (18 pmp), Lithuania (16 pmp), Norway (16 pmp), Belarus (16 pmp), Switzerland (16 pmp), Estonia (13 pmp), Serbia (11 pmp), Italy (7 pmp), and South Africa (2 pmp).

Figure 11.5 Average yearly change in incidence of treated ESRD attributed to diabetes, by country or region, 2011-2021

The Republic of Korea (9.4 pmp per year), Singapore (7.6 pmp), and Taiwan (5.9 pmp) had the largest average yearly increases in the incidence of treated ESRD attributed to diabetes between 2011 and 2021 (Figure 11.5). The U.S., for comparison, ranked fifth, at 3.1 pmp per year. The incidence of treated ESRD attributed to diabetes decreased in Sweden, Argentina, Bosnia and Herzegovina, Japan, Israel, Austria, Iceland, Serbia, and, most strikingly, Italy, where there was an average yearly decrease in the incidence of treated ESRD due to diabetes of -2.7 pmp per year.

Figure 11.6 Country or region-level correlation between percentage change in incidence of treated ESRD and percentage change in incidence of treated ESRD attributed to diabetes, by region of the world, 2011-2021

Asia and Russia

Europe and Israel

North & Latin America

The correlation between percentage change in the incidence of treated ESRD overall and the percentage change attributed to diabetes appears to be highest in Asia (Figure 11.6). This suggests that diabetes drove the growth of incident (treated) ESRD most strongly in Asia.

Figure 11.7 Incidence of treated ESRD by age and by country or region, 2021

All

Asia

Europe

North America

South America

The incidence of treated ESRD in 2021 by age group is shown in Figure 11.7. In most, although not all, countries in Europe, the highest incidence of treated ESRD occurred among individuals aged ≥75 years. The pattern was more variable in other regions. In Asia, for example, ESRD incidence was highest in the oldest age group in Thailand, Mainland China, Singapore, Turkey, Israel, and, especially, Taiwan, but in Hong Kong and, particularly, Malaysia, growth was highest among individuals aged 65-74 years. In North America, incidence was highest among the oldest age group in all countries except El Salvador, where incidence was highest among those aged 65-74 years.

Figure 11.8 Incidence of treated ESRD by sex and by country or region, 2021

All

Africa

Asia

Europe

North America

South America

In every country or region except Indonesia and Kuwait, the incidence of treated ESRD was higher in men than women (Figure 11.8). Note that in some countries or regions, the ratio of treated men to treated women was >2:1; in El Salvador, the ratio was >2.5:1.

Figure 11.9 Prevalence of treated ESRD, by country or region, 2021

Sort by Rate

Sort by Country/Region Name

Sort by Continent and Country/Region Name

The prevalence of treated ESRD varied by nearly 35-fold across reporting countries or regions (Figure 11.9). Countries or regions with the highest prevalence of treated ESRD in 2021 were Taiwan (3839 pmp), Singapore (2577 pmp), the U.S. (2436 pmp), Aguascalientes in Mexico (2231 pmp), Brunei Darussalam (2077 pmp), Portugal (2004 pmp), Malaysia (1584 pmp), and Hong Kong (1506 pmp). Thus, 5 of the 8 countries or regions where the prevalence exceeded 1500 pmp were in Asia. Countries or regions where the prevalence was <500 pmp were Montenegro (434 pmp), Belarus (429 pmp), Italy (424 pmp), El Salvador (370 pmp), South Africa (147 pmp), and Bangladesh (110 pmp).

Figure 11.10 Prevalence of treated ESRD by age and by country or region, 2021

All

Asia

Europe

North America

South America

The prevalence of treated ESRD in 2021 was generally higher among individuals aged 65-74 and ≥75 years than among individuals aged <65 years (Figure 11.10).

Figure 11.11 Prevalence of treated ESRD by sex and by country or region, 2021

All

Africa

Asia

Europe

North America

South America

In all reporting countries or regions, the prevalence of ESRD was higher in men than in women (Figure 11.11). The ratio of prevalence in men versus women was particularly high in Greece (2.0:1) and El Salvador (2.7:1).

Figure 11.12a Prevalence of treated ESRD in countries or regions with the largest percentage increase in prevalence, 2011 versus 2021

Indonesia had the largest increase in the prevalence of treated ESRD between 2011 and 2021, during which period the prevalence increased from 40 pmp to 514 pmp, or by roughly 12-fold (Figure 11.12a). (Note that 2021 data is not available for some countries or regions; the Analytical Methods describes the approach used to include or exclude countries or regions.) In the Republic of Korea and Russia, the prevalence of ESRD more than doubled between 2011 to 2020. Prevalence increased by >50% in Romania, Thailand, Malaysia, Colombia, Singapore, and Brazil. By comparison, the percentage increased by 31% in the U.S. during this period.

Figure 11.12b Average yearly change in prevalence of treated ESRD by country or region, 2011-2021

The 6 countries or regions with the largest average yearly increase in the prevalence of treated ESRD between 2011 and 2021 were in Asia: the Republic of Korea (141.7 pmp per year), Thailand (122.9 pmp), Taiwan (90.5 pmp), Singapore (88.9 pmp), Indonesia (79.4 pmp), and Malaysia (62.1 pmp) (Figure 11.12b); the U.S. ranked seventh (58.2 pmp). In contrast, decreases of -10.4 pmp per year in Hungary and -89.5 pmp per year in Italy were reported.

Worldwide, HD was the predominant treatment modality for treatment of ESRD. PD was used relatively infrequently, such that only El Salvador (64.8%) and Hong Kong (45.6%) had >40% of prevalent patients treated with PD. Colombia (22.6%) and Aguascalientes in Mexico (21.7%) were the only other contributing countries or regions where the percentage of prevalent patients treated with PD exceeded 20%. Only in Denmark (2.8%), Canada (2.8%), Finland (2.1%), England/Wales/Northern Ireland (2.1%), and Hong Kong (2.0%) were ≥2% of prevalent patients treated with home HD. (Note that some countries or regions did not supply data for home HD; they are denoted with an asterisk in the figure. Because home HD is infrequent worldwide, the percentages in these countries were presumed to be zero.)

Percentage distribution of ESRD treatment modality, by country or region, 2021 Only in Iceland (71.0%), Norway (66.9%), the Netherlands (65.0%), Finland (63.9%), Estonia (63.1%), Scotland (61.3%), Sweden (60.1%), Switzerland (56.5%), England/Wales/Northern Ireland (56.4%), Denmark (55.8%), Belarus (53.7%), and Ireland (53.2%) were more than half of prevalent patients with ESRD treated with a kidney transplant (Figure 11.13). In Malaysia, Montenegro, and El Salvador, only 3.6%, 2.2%, and 1.5% of prevalent patients, respectively, were treated with a kidney transplant.

## Section 18. The Medical Management of ESRD

Medical Management of ESRF is one of the 4 arms of RRT, together with Renal Transplantation, HD & PD. Unlike the other modalities, however, Medical Management *on its own* will not keep the patient in ESRF alive in the medium or long term.

*Medical Management is used in two contexts:*

### 18.1 In support of the other RRT management modalities

This applies mainly to HD & PD, but even transplanted patients (unless the transplant is from an identical twin) will need ongoing immunosuppression and varying degrees of Renal Support. Neither PD nor HD offers a "complete" RRT (unlike a successful Renal Transplant). Both HD & PD have limited effectiveness and their function in RRT has to be supported by Medical Management to maximize the patient's health and life expectancy.

The most important Medical Management in Dialysis Patients is control / restriction of fluid intake and dietary restriction of K+ containing foods.

### 18.2 Medical Management on its own

#### 18.2.i Indications

Medical Management of ESRF can be used on its own, but only in the very sick or elderly with limited life expectancy. "Active" Renal Replacement Therapy – HD & PD – always comes at a price, in terms of their morbidity (eg the HD fistula requires a significant amount of **Resting Cardiac Output**) or complications (e.g. **Peritonitis** from PD). In the very elderly +/or sick ESRF patient, this price may outweigh the benefit of the Dialysis! As a result, the length and quality of these patient's lives may not be augmented much by dialysis and, in one study, some patient cohorts survived longer with Medical Management than Dialysis. **Ref 19**. Therefore, in co-morbid, elderly patients, Medical Management may be the best management. **Ref 18**.

#### 18.2.ii Components of Medical Management:

**Although Medical Management in ESRF is often confounded and confused with "terminal care", it is nothing of the sort. It is an *active* but *conservative* (non-interventional) treatment of the patient's ESRF!**

The main components of Medical Management are:

- Control of hydration, in practice, restricting how much fluid the patient can drink per day. The patient's **Residual Renal Function** in ESRF is important in this regard.
- Dietary modification, particularly the control of **potassium** (K+) intake.
- Medication treatment of other aspects of ESRF e.g., Erythropoietin to stimulate Red Blood Cell production.

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## Section 19. US Guided placement of PD Catheters – Seldinger PD

*The reader is also referred to Module 16 for detailed description of the modified Seldinger PD placement technique.*

"Seldinger PD" – Placement of a radiologically guided PD catheter, using ultrasound, sheaths & guidewires has become an increasingly popular way of placing PD catheters. We have introduced this technique successfully to our unit. Seldinger PD has many advantages over other techniques of PD placement and is becoming a preferred technique.

### 19.1 Seldinger PD is an "Endovascular Procedure"

The Seldinger PD should be an integral part of every Hemodialysis Access Surgeons repertoire, for 2 reasons.

#### 19.1.i Inadequate Venous Real Estate or other HD Access Contra-Indication:

When faced with a Hemodialysis Access candidate with very poor **venous real estate**, poor cardiac reserve, severely damaged arteries (and risk of steal ) or inadequate skin integrity, the correct management could be (Seldinger) Peritoneal Dialysis (PD). The open and laparoscopic techniques were described in detail in Module 6. The percutaneous techniques requiring Ultrasound (US) and radiologic skills is described in this section.

#### 19.1.ii Technique of Seldinger PD is Ultrasound (US) and Endovascular Skills.

**Figs 223-240**

Performing a Seldinger PD is essentially an Endovascular Procedure (not a General Surgical or Abdominal Surgery) procedure. The reason is that all the skills involved are essentially endovascular: Ultrasound guided puncture, x-ray, and contrast guidance, Micro-puncture and Sheaths, wire, and catheter skills.

Our technique of Seldinger PD involves several steps including "Reverse Mapping" of the PD catheter, Ultrasound & Contrast guided access to the Peritoneal Cavity, introduction of the PD catheter thru a sheath and "Reverse Exit Tunnelling" - **Figs 161-165**. See **Video 7** for an excellent exposition on this by Dr. John Crabtree.

**Safe access to the peritoneal cavity is the crucial step in the procedure of PD placement** involving US Guidance, **Micropuncture** - **Fig 166**, and Contrast **Peritoneography** - **Fig 167**.

*Technique of Ultrasound (US) Guided Peritoneal Cavity access:*

- Fluid **overloaded** patients present an advantage as intra-abdominal fluid pockets from ascites is helpful in achieving safe access to the abdomen as, under US guidance, the needle can be directed into the fluid space – **Fig 227**.
- Having determined and marked the site of access for the PD catheter on the abdominal wall, the highest frequency probe is selected for imaging the parietal peritoneum. In the slim abdomen, this is a Linear Probe of about 10 MHz; In the obese abdomen, the Curvilinear 4MHz probe may be needed.
- Imaging the abdominal wall will delineate the fat, the rectus and linea alba, the extraperitoneal fat and the echogenic parietal peritoneum – **Fig 227**.

With patient breathing in and out, deep, and slow, the bowel and omentum is sliding up and down on the inside of the parietal peritoneum. This confirms the site of the parietal

peritoneum (whose exact location is critical to safely hit target, the peritoneal cavity), as well as indicating the absence of adhesions at the selected entry point. If there is no movement between the parietal peritoneum and the abdominal contents, or if the layers have been mis-identified or when the bowel / omentum is adherent to the inside of the abdominal wall at that point a different entry point *must* be identified.

The inferior epigastric artery must be avoided; below the umbilicus it is generally big enough to be identified, posterior to the rectus muscle; above the umbilicus, it is small, or less than 3mm.

Having decided you have a suitable entry point, line up your probe in the direction of your access stab – from your access point to the Pouch of Douglas. The path of your access stab should not be too steep (kinking of the catheter) nor too shallow (peritoneal entry point too far away) – about 60°.

Under Real Time US visualization, advance the 22g Spinal needle from skin, thru rectus and into the extraperitoneal fat, injecting small amounts of dilute Local Anesthetic as you go. This helps visualize where the tip of your needle is and provides anesthesia for the PD catheter track. Finally, inject a good bleb of Local Anesthesia into the extraperitoneal fat, bulging the parietal peritoneum (and effectively anesthetizing this very sensitive layer). If the patient has ultrasonically visible ascites, peritoneal entry is greatly facilitated by aiming the needle into an ascitic pocket lying against the parietal peritoneum.

Finally, breach the parietal peritoneum: With a higher frequency probe, the tip of the needle may be well visualized; with the lower frequency probe, you may have to rely on the sudden “give” of the injected local.

When the abdomen is entered, remove the US, connect the needle carefully to a short, minimal volume tubing, and inject some dilute contrast under x-ray guidance. The Peritoneography should clearly establish where you are: 1. In peritoneal cavity, 2. In adhesion / omentum, 3. Still in the abdominal wall or 4. In the bowel.

Having entered the peritoneal cavity, insert the 014” microwire under x-ray guidance; the wire should advance without resistance and loop freely in the peritoneal cavity.

Remove the needle and insert the 4F Micropuncture sheath. Repeat Peritoneography to confirm you are in the peritoneal cavity.

Finally, insert a soft nose wire like a Bentson (a Cerebral Vascular wire) and advance this down the Micropuncture sheath. If you are in the peritoneal cavity, and there are no significant adhesions in the way, your wire should loop and come to rest on the floor of the Pouch of Douglas.

Your Ultrasound (US) Guided Peritoneal cavity access is now complete.

The reader is referred to Module 16 for further detail Percutaneous insertion of the PD catheter using the ***Modified Seldinger Technique.***

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## Section 20. IVUS - Intravascular Ultrasound for Dialysis Vascular Access

**Intravascular Ultrasound (IVUS**) utilizes an endovascular ultrasound (US) probe advanced over a guidewire, which allows for accurate visualization of vascular anatomy. This imaging modality allows for detailed cross-sectional views of intra-luminal vessel sizes and morphology, which may guide real-time interventions in dialysis access. Long used in coronary and iliac vein interventions, IVUS is now being applied to also guide dialysis access procedures.

### IVUS Device Instructions

While planar two-dimensional fluoroscopy using digital subtraction **angiography** is the gold-standard method of guiding dialysis access interventions, this imaging modality may not always represent true vessel sizes and shapes. Most interventionalists estimate vessel sizes based on angiographic images. While real-time vessel size measurements are possible with using calibration rulers under fluoroscopy, this approach is time consuming in the clinical setting. Additionally, oblong, or dynamic vessel shapes cannot easily be appreciated with conventional fluoroscopy in a single field of view. While multiple planes can be imaged with fluoroscopy, this leads to higher radiation exposure. Recognition of eccentric or oblong vessel shapes is of particular concern in the central venous system, where vessel shapes and sizes can be dynamic due to the cardiac cycle and thoracic pressure changes with the respiratory cycle (**Ref IVUS-1**). Accurate vessel sizing is of particular concern for central stent or stent-graft placement, where under-sizing of devices may potentially lead to stent migration.

IVUS allows for accurate real-time cross-sectional images of the vessel lumen to precisely guide decisions at the time of intervention. IVUS allows for examination of vessels pre and post angioplasty to gauge vessel response to interventions. Recoil, intraluminal calcifications, dissections, and thrombus are appreciated with IVUS without contrast or radiation exposure.

An early paper from Davidson et al described a series of 38 consecutive dialysis access angioplasty procedures on 28 patients, where IVUS was used to assess lesions in conjunction with conventional contrast **angiography** (**Ref IVUS-2**). Dissections and intra-luminal thrombus were more frequently recognized on IVUS evaluation than on angiography. Non-occlusive thrombus was noted on 6/38 (16%) interventions on IVUS, compared to only 1/38 (3%) by angiography. Dissections were detected in 16/38 (42%) by IVUS as compared to 1/38 (3%) by angiography. Luminal size and morphology were appreciated with IVUS evaluation, and after the recoil angioplasty.

Higuchi et al. analyzed IVUS and angiographic data of 63 lesions in 40 patients with AV fistula dysfunction. Although native veins do not typically demonstrate the tri-layer appearance seen in arteries on IVUS, the authors did note a hyperechoic intima, hypoechoic media, and hyperechoic adventitia in “arterialized” veins of AV fistulae. Softer echoes at areas of **stenosis** were characterized as intimal hyperplasia with fibromuscular tissue, and brighter or “hard” echoes were characterized as collagen-rich fibrous tissue. The fibrous “hard” echoes were found in 5/63 (8%) of lesions, suggesting most lesions were due to intimal hyperplasia. The authors also quantified responses to angioplasty with IVUS, demonstrating improvements of lumen diameter and cross-sectional area post angioplasty. Plaque fractures were detected in 45/63 (71%) of lesions post angioplasty,

suggesting that angioplasty efficacy is due to stretching of the vessel wall in addition to plaque fracture (**Ref IVUS-3**).

Arbab-Zadeh et al. analyzed AV grafts using IVUS and **angiography**. Fifty-four vessel segments were analyzed from 21 studies in 17 patients who had both IVUS, and angiography performed on the same day. Angiographic analysis revealed 17/54 (31%) vessel segments appeared normal, while only 9/54 (17%) segments appeared normal under IVUS evaluation. Further, non-occlusive thrombus was demonstrated in 32/54 (59%) segments on IVUS, versus only 1/54 (2%) segments on angiography. Given that residual thrombus is known to be thrombogenic, the authors suggested that IVUS may be utilized to evaluate grafts with recurrent thrombosis. It was uncertain if the greater sensitivity with IVUS translates into differences in clinical outcomes (**Ref IVUS-4**).

Case reports suggest that IVUS is of benefit in management of central venous occlusions in dialysis access (**Ref IVUS-1**, **Ref IVUS-5**, **Ref IVUS-6**). McFall demonstrated a case where extrinsic rib/clavicle compression was identified with IVUS, not seen on angiography (**Ref IVUS-7**). DeGraaf et al. studied the treatment of central venous stenosis under both angiography and IVUS. In this retrospective study 12 patients with symptomatic central stenosis were evaluated with angiography and IVUS at the time of intervention. Angiography pre-intervention revealed initial >50% stenosis in 8/12 (67%) of patients, while IVUS detected a stenosis greater than 50% stenosis in all 12/12 (100%), suggesting the ability of IVUS to be superior to angiography alone. In response to angioplasty, angiography revealed persistent >50% stenosis in only 3/12 (25%) patients, while IVUS revealed ongoing >50% stenosis in 10/12 (83%) patients. IVUS also detected 9/12 (75%) patients with intraluminal fibrotic trabeculations not seen on angiography. Central venous stents were then placed 10 of these cases. IVUS helps in choosing the optimal treatment strategy for central venous stenosis in cases of fibrous webs, thrombus, and recoil not appreciated with angiography alone (**Ref IVUS-8**).

Ross et al. looked at outcomes in a prospective randomized single center trial in 100 patients with failing AV grafts. Patients were randomized to interventions guided by digital subtraction angiography only vs. angiography and IVUS guidance and then followed for 6 months. The addition of IVUS evaluation to angiography altered treatment plans in 44/58 (76%) of lesions in the study group. This led to additional balloon angioplasty, stent implantation, and/or thrombectomy. Although not statistically significant, there was a doubling in the number of days to re-intervention in the IVUS group compared to angiography. The authors suggested that a larger trial with longer follow-up is needed to analyze clinical outcomes (**Ref IVUS-9**).

Pilot Study of IVUS Imaging During Endovascular Interventions of Failing Hemodialysis Access Grafts

IVUS plays a role in patients with contrast allergies and in pre-dialysis patients accesses requiring intervention. Low contrast studies can be performed on CKD patients, where limitation of contrast exposure is ideal to protect residual renal function (**Ref IVUS-10**). While many patients with a documented allergy may tolerate contrast with pre- and intra-procedure diphenhydramine and prednisone, some patients have anaphylactic reactions even with pre-medications. Other diabetic patients may experience significant hyperglycemia with prednisone and solumedrol based protocols (**Ref IVUS-1**).

Conventional ultrasound and CO2 angiography have been utilized in the past to avoid contrast exposure (**Ref IVUS-11**). However, central venous evaluation is technically difficult with conventional US. CO2 angiography has further safety limitations, particularly in arterial inflow evaluation, thoracic vessel evaluation, and in patients with patent foramen ovale. IVUS offers an alternative option for AV access intervention, and IVUS-guided angioplasty is performed using no contrast (**Ref IVUS-12** and **Ref IVUS-13**).

IVUS has also been used for dysfunctional hemodialysis catheters. Bolz et al. used IVUS to visualize the catheter lumen and the adjacent central veins. In a 14-patient series, 4 patients were found to have catheter-related thrombus detection at the catheters and mural superior vena cava. In 2/12 (16%) of the patients had normal catheter function in the presence of IVUS detected thrombus. The authors concluded that a larger study would be needed to assess the role of IVUS in the diagnosis of catheter dysfunction (**Ref IVUS-14**). Razdan and Miller recently looked at 12 patients over 3 months who presented dysfunctional catheters. IVUS identified thrombus along the catheters in 11/12 (92%) patients, while angiography only detected thrombus in 2/12 (17%) of patients. The authors suggested that fibrin sheaths may mask thrombus detection on angiography (**Ref IVUS-15**).

The IVUS data may play a role in future AV access research. IVUS allows for real-time quantitative vascular measurements, and this information may be used to standardize protocols across multiple study sites for clinical trials. Many multi-center trials in AV access have used post-study core labs to validate operator estimations of percent stenosis and decision making on device sizes. IVUS allows the operator to use precise and standard measurements at the time of intervention - potentially decreasing bias and improving accuracy when pooling data from multiple providers. Ideally this may lead to more reliable outcomes from dialysis access trials.

IVUS virtual histology has been applied in coronary study, using a proprietary colorized tissue map to classify vessel plaques (**Ref IVUS-16**). Sato et al. used IVUS derived virtual histology to characterize the role of neointimal hyperplasia in 10 patients with dysfunctional AV accesses. These selected patients all had histories of severe contrast allergies and underwent angioplasty under IVUS guidance without contrast. The mean follow-up was 10 years. Of the 10 patients, 3 patients underwent surgical revision when there was a failure of angioplasty to treat the underlying lesion. At the time of surgery, tissue samples were taken to correlate virtual IVUS histology with the specimens. The authors used IVUS virtual histology to show that neointimal hyperplasia is the major cause of vascular access stenosis. Vessel wall thickness was assessed, and the authors speculated that myofibroblasts rich in vitamin D receptors were prevalent in areas of neointimal hyperplasia (**Ref IVUS-17**). The role of IVUS based virtual histology might play a role in further analyzing etiologies for stenosis and could play a role in evaluating efficacy of various treatments and drugs for the management of AV access stenosis.

The limitations of IVUS are the added costs and time requirements necessary to use the system. While IVUS often is available in US hospital settings for coronary and other peripheral vascular studies, availability is limited in other outpatient settings. The IVUS catheters themselves are disposable and add costs. Currently there is reimbursement for IVUS in the United States for office-based settings, but not for ambulatory surgery. Cost

efficacy studies on outcomes is a consideration for future study. Of note, none of the cited studies noted any adverse clinical effects with IVUS use. Further studies are needed to shed light on these issues.

IVUS case studies

IVUS AV Access Literature Review

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