MEDISTIM

Guidebook - Transplantation

IMPROVE YOUR INSIGHTS

Intraoperative guidance and quality assessment using TTFM and HFUS during liver and renal transplantation

VOLUME 1 FEBRUARY 2023

"From our experience with intraoperative measurement of absolute flow in the graft vessels, we believe that the causes of technically imperfect perfusion of the graft can be identified and instantly corrected so that primary graft dysfunction or graft infarction can be avoided." [1]

Rasmussen et al. 1997,
"Intraoperative measurement of graft blood flow - a necessity in liver transplantation"

This guidebook is written by Medistim for the medical community with information and guidance on how to use our systems and probes during transplant surgery. The content is based on clinical experience and published articles and is not intended to be a substitute for medical advice, diagnosis or treatment. Each surgeon should exercise his or her own independent judgment in the diagnosis and treatment of the individual patient. Please refer to the Medistim Instructions for Use (IFU) for indications, contraindications, warnings, precautions, and further specifications and descriptions. Copies of this guidebook can be ordered at medistim.com.

Table of Contents

1. Introduction

Medistim background

Medistim launched its first flowmeter based on transit time flow measurement (TTFM) technology in 1994 (CardioMed). Since then, the company has developed several generations of quality assurance equipment. Medistim introduced the first ultrasound imaging probe approved for direct contact with the heart in 2009, and is currently the only supplier in the world that can offer a user friendly integrated TTFM and intra-operative high frequency ultrasound (HFUS) imaging system, MiraQ TM systems.

Medistim technology is a versatile tool in various transplantation procedures. Surgical findings can be documented through flow tracings and images provided by the system. Medistim's TTFM probes utilize transit time technology to accurately measure blood volume flow intraoperatively. The imaging functionality provides the surgeon with both guidance before and during surgery and the opportunity to uncover the cause of poor blood flow measurements. Combining the spatial information from ultrasound imaging and quantitative data from TTFM enables the surgeon to make informed decisions, and revise when necessary.

Medistim provides reusable TTFM probes, a sterilizable ultrasound imaging probe and a Doppler probe. Most of the TTFM probes are available with or without a handle.

To measure blood flow with TTFM is a standard clinical practice in many countries and supported by numerous publications documenting the clinical value.

Medistim High-frequency Ultrasound Imaging Probe™

Medistim MiraQ™ Ultimate

Medistim Vascular TTFM Probes™

Medistim QuickFit™ TTFM Probes

Objective

The objective of this guidebook is to provide a comprehensive overview of the Medistim TTFM and HFUS technology and to provide information on how to interpret measurements and images. The information provided is recommended to be used together with Medistim's online learning platform, EduQ *(medistim.com/education).*

Why perform TTFM and HFUS?

The authors of the initial quote in this booklet explain this well: "From our experience with intraoperative measurement of absolute flow in the graft vessels, we believe that the causes of technically imperfect perfusion of the graft can be identified and instantly corrected so that primary graft dysfunction or graft infarction can be avoided." [1]

Liver transplantation

Adequate graft perfusion is essential for successful liver transplantations. Intraoperative TTFM provides surgical guidance to assess anastomosis quality, allowing the surgeon to adjust any imbalance in the intrahepatic portal and arterial flow and pressure. High-frequency Ultrasound (HFUS) is useful in assessing anastomotic morphology and detecting thromboses.

Graft dysfunction can be avoided by using TTFM, HFUS & pressure measurements to:

- Detect technical anastomotic imperfections such as intimal flaps or misplaced stitches [6]
- Detect Hepatic Artery Thrombosis and/or stenosis [14, 9]
- Assess Hepatic Artery Buffer Response and reduce risk of Portal Hyperperfusion [7]
- Prevent and guide treatment of Small for Size Syndrome [5, 2, 12]
- Quantify hemodynamic imbalances and tailor graft inflow modulation: [11, 2, 12, 13]
  - Management of Spontaneous Porto-Systemic Shunts
  - Splenic Artery Ligation / Splenectomy
  - Hemi-Portacaval Shunt
- Detect median arcuate ligament compression and confirm restored flow [20]

Renal transplantation

The benefit of using TTFM and HFUS during renal transplantations is not as well documented as for liver transplantations. Although feedback from several surgeons is that quality control during these surgeries is very useful.

Intraoperative renal artery flow measurement in renal transplantation to provide a rapid objective assessment of renal graft patency[17].

Other relevant procedures

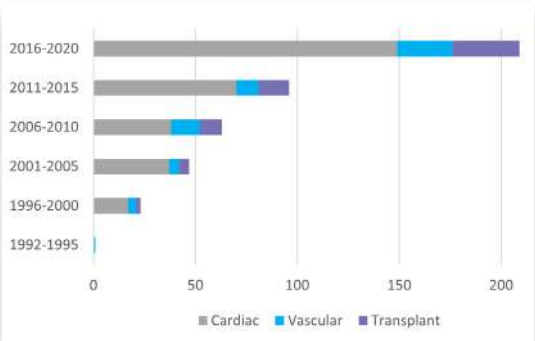
There are a few publications that mention the use of TTFM in transplantation of uterus and pancreas. Quality control with Medistim systems has also been found useful in gastric procedures such as pancreatectomy and major hepatectomy.

Documentation

The Medistim systems can store accurate flow measurement and produce a documented report. All measurements may be saved and later selected to prepare a customized report. This can be used as documentation of intraoperative quality control, as records for referring physicians, and for preparing publications.

Body of evidence

Documentation on the benefits of using TTFM and HFUS technology in transplant surgery is growing. There are currently over 60 clinical publications that include the use of Medistim TTFM and HFUS devices during transplantations. The diagram below illustrates the increased interest in using Medistim systems during transplantations - as the relative portion of publications in this application increases relative to the total amount of publications.



Liver Transplantation

The International Liver Transplantation Society (ILTS) Living Donor Liver Transplant Recipient Guideline [2]

Miller CM, Quintini C, Dhawan A, Durand F, Heimbach JK, Kim-Schluger HL, Kyrana E, Lee S-G, Lerut J, Lo C-M, Pomfret EA. Transplantation 2017;101: 938–944.

Hemodynamic and Size Considerations

"The most common factor limiting LDLT is represented by small for size syndrome (SFSS). SFSS can be defined as functional impairment of a partial liver graft during the first postoperative week as evidenced by coagulopathy, cholestasis, encephalopathy and ascites after the exclusion of other causes (vascular, immunological, and so on). The etiology of SFSS is multifactorial and consist of graft and patient factors. Graft factor include size and parenchymal quality. Based on the existing literature, most of the LDLT transplant centers would consider as safe a graft greater than 40% of the recipient's standard liver volume or greater than 0.8% of the recipient's body weight. With improved experience, skills, and better patient selection, the safety limit for minimum graft-weight-to-standard-liver-volume ratio can be reduced to 35% and to less than 0.8% of graft to recipient body weight. Importantly, the graft regeneration and size requirement has been shown to be higher when the donor is older than 50 years. Patient factors include the degree of portal hypertension and the overall clinical status. The severity of portal hypertension and the consequent graft hyperperfusion occurring after reperfusion have been the object of intense animal and clinical research.

Numerous studies have shown that modulation of portal vein pressure and flows are key in successful LDLT using small grafts. It is therefore important to carry out hemodynamic monitoring during surgery (intraoperative arterial and portal venous flow measurement, portal vein pressure measurement) for the identification and management of patients at risk of developing SFSS. If the portal pressure exceeds 20 mmHg, portal inflow modulation can be achieved by performing splenic artery ligation, splenectomy, splenorenal shunting, hemiportocaval shunting, and mesocaval shunting."

Recommendations for Hemodynamic and Size Considerations

Monitoring of the portal vein and hepatic artery hemodynamics are highly recommended for the early diagnosis, prevention and management of SFSS.
(Class 1, level B)

Portal inflow modulation by splenic artery ligation/ embolization or other portosystemic shunts is effective in the prevention and treatment of SFSS.
(Class 1, level B)

Hepatic venous outflow augmentation is essential to optimize graft function and can be achieved with a number of surgical techniques
(Class 1, level B)

ILTS
International Liver
Transplantation Society

Renal Transplantation

EAU Guidelines on Renal Transplantation

Breda A, K. Budde K, Figueiredo KA, Lledó García E, Olsburgh J, Regele H.
European Association of Urology 2021

This guideline includes recommendations regarding diagnosis of thrombosis and stenosis in kidney recipients. These complications are often connected to technical errors during surgery and could likely be detected by TTFM and/or HFUS.

EAU
European
Association of Urology

Arterial thrombosis

Transplant renal artery thrombosis is a rare complication (prevalence 0.5-3.5%). Usually, it is a consequence of a technical error during the anastomosis.

Venous thrombosis

Transplant renal vein thrombosis is an early complication (prevalence 0.5-4%) and one of the most important causes of graft loss during the first post-operative month. The etiology includes technical errors and/or difficulties during surgery and the hypercoagulative state of the recipient.

Recommendations	Strength rating arterial thrombosis	Strength rating venous thrombosis
Perform ultrasound-colour-Doppler in case of suspected graft thrombosis.	Strong	Strong
Perform surgical exploration in case of ultrasound finding of poor graft perfusion.	Strong	Weak

Transplant renal artery stenosis

The incidence of transplant renal artery stenosis is 1-25%. Risk factors include small caliber and atherosclerosis of the donor artery, trauma to donor artery at procurement, absence of arterial patch, suturing technique (interrupted vs. continuous), and damage to the iliac artery during transplantation. It is more common at the site of the anastomosis.

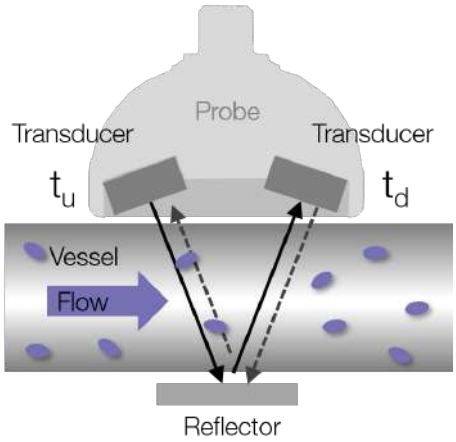
Recommendation	Strength rating
Perform ultrasound-colour-Doppler to diagnose an arterial stenosis, in the case of undetermined results on ultrasound, consider a magnetic resonance or computed tomography angiogram.	Strong

3. Transit Time Flow Measurement (TTFM)

3.1 Principles of TTFM

With TTFM, ultrasound is used to measure blood flow volume directly. This differs from the Doppler principle. TTFM is based on the fact that the time required for ultrasound to pass through blood is slightly longer upstream (t_u) than downstream (t_d).

$$\text{Flow } (Q) = \text{Constant} \times (t_u - t_d)$$



The TTFM probes fit around the vessel, and selecting an appropriate probe size ensures the correct measurement conditions. Two ultrasound transducers fire ultrasound pulses in opposite directions through the bloodstream. Both pulses travel the same distance, but due to the bloodstream, the time from transmission to when the pulse is received will be different. The difference in transit time is recorded by the system and is directly proportional to the blood volume flowing through the measurement area (ml/min). The Constant is unique for each probe and is set during the manufacturing process.

Using the wide beam ultrasound principle, volume flow can be measured regardless of the vessel diameter or flow velocity, as long as the whole cross section of the vessel remains inside the measurement area of the probe.[11]

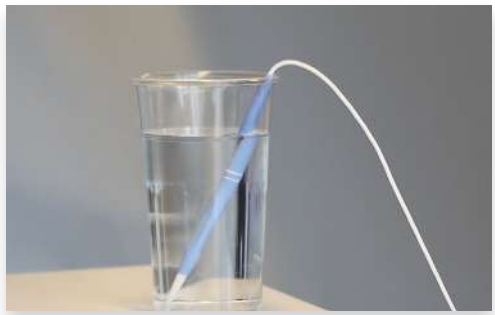
3.2 How to measure

The following section will describe the most important factors necessary for performing TTFM.

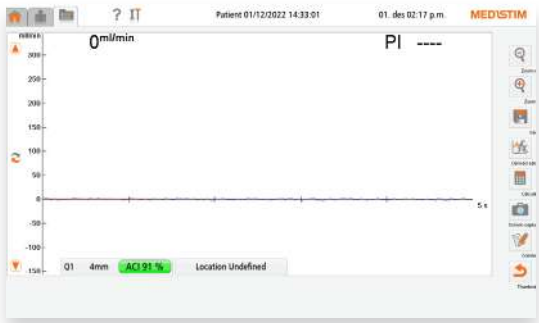
Perform functionality test before surgery

Before using a TTFM probe, a functionality test must be performed to ensure that the probe and system are functioning optimally.

1. Connect the probe to the system and place the probe stationary in a plastic container with sterile saline solution. Due to their acoustic properties, glass and metal containers can disturb the measurement. If using one, line the bottom with cotton balls or gauze.



2. Verify good Acoustic Coupling Index (ACI). The indicator should be green and display a value of >90%. If the ACI is below 90%, try stirring the liquid with the probe to dislodge air bubbles and recheck the ACI.
3. Check that the offset in mean flow (red line) is close to zero.



Zero point offset

4. If the ACI is less than 90% and/or the offset is large, try plugging the probe into a different channel or try a different probe.

Acoustic Coupling Index (ACI) during surgery

To verify that the measurement is reliable during surgery, the ACI needs to be greater than 30%. It is important to have a green or yellow ACI when measuring TTFM. Red or orange ACI may lead to inaccurate and inconsistent measurements.

ACI	50-100 %	Good
ACI	30-50 %	Suboptimal
ACI	10-30 %	Unacceptable
ACI	0-10 %	No measurement

Red Line

The red horizontal line on the screen is the average mean flow, calculated over the last 7 seconds. It is possible to change this preset in the settings of the system. Wait 7 - 10 seconds for the red line to flatten out before saving. Probe repositioning must be followed by an additional 7 seconds waiting period. Pressing “Save” will save up to the last 60 seconds of the measurement.

Filter setting

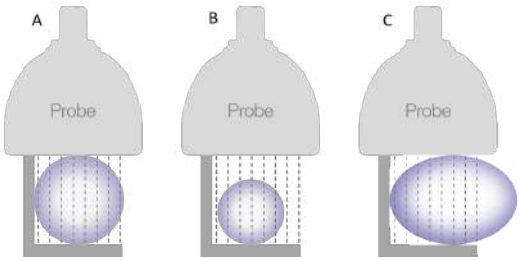
The default and recommended filter setting for Medistim systems is 20Hz. A lower filter setting will result in a “smoother” TTFM curve and lower PI, making it important to adjust the expectation of PI. The reference values presented later in this guidebook are based on using the 20Hz filter setting.

Select correct probe size

In order to achieve correct measurements, it is important to choose the right probe size. The probe should be placed so it wraps around the vessel in a way that it does not compress, bend or twist the vessel itself. Different probe sizes are available to optimize contact between the vessel and the probe. If the ACI is low, the space between probe and vessel may be filled with a coupling agent like saline or ultrasound gel.

Place the probe with the arrow in the expected blood flow direction. A Negative value for flow indicates either a reverse placement of the probe or net retrograde flow.

For probes with handle, the neck of the probe can be bent for easier attachment, but avoid bending the neck of the probe handle all the way to 90° as this will weaken the wire inside the probe unnecessarily and may lead to breakage. Probes are also available without a handle to accommodate for placement on vessels that are difficult to reach.



A. Correct probe size will provide a reliable measurement.

B. A probe that is too large will give poor contact with the vessel and a correct alignment of the graft is more difficult.

C. A probe that is too small will compress the vessel and flow will be underestimated.

3.3 TTFM parameters

To assess flow volume and/or the patency of a graft, several parameters should be evaluated.

Mean flow

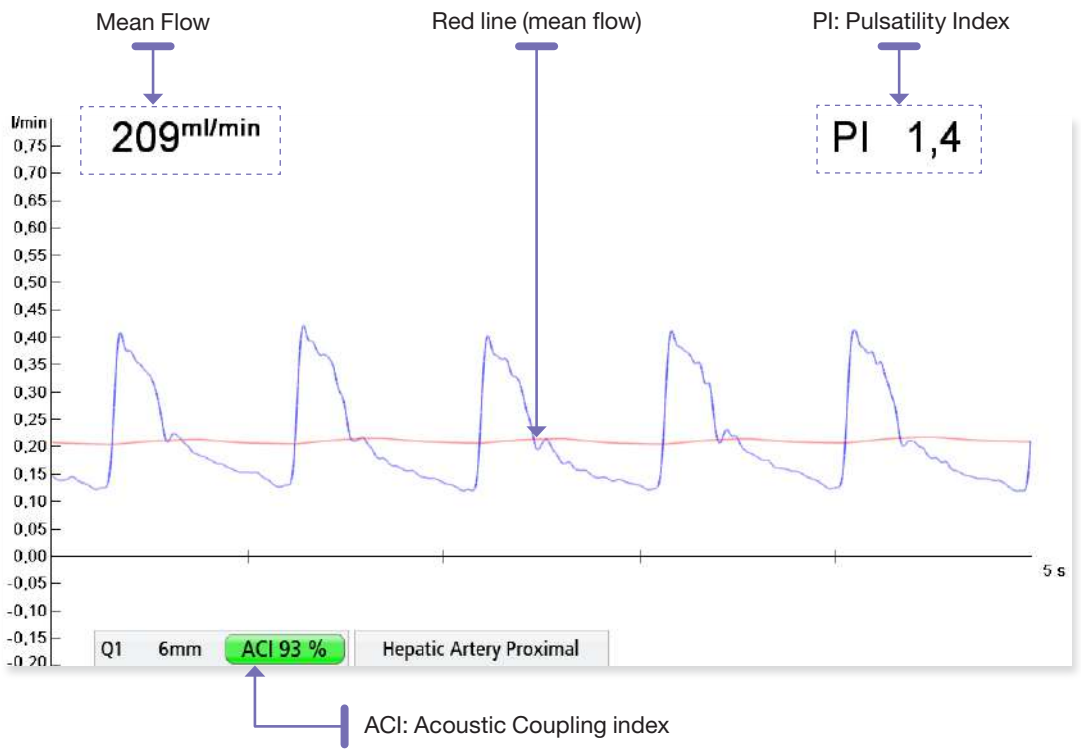
Mean flow is the numerical value of the red horizontal line. Factors influencing mean flow are blood pressure, size of the vessel, the quality of the vascular bed, size difference donor/recipient vessels and possible spasm in vessels. Mean flow expectations should be adjusted according to these factors. A low mean flow value in itself is not an indication of a compromised graft, but a part of the diagnostic information.

Pulsatility Index (PI)

Pulsatility index, or PI, is defined as the difference between the maximum and minimum flow divided by the mean flow. A large difference between the maximum and minimum flow will lead to a high PI value.

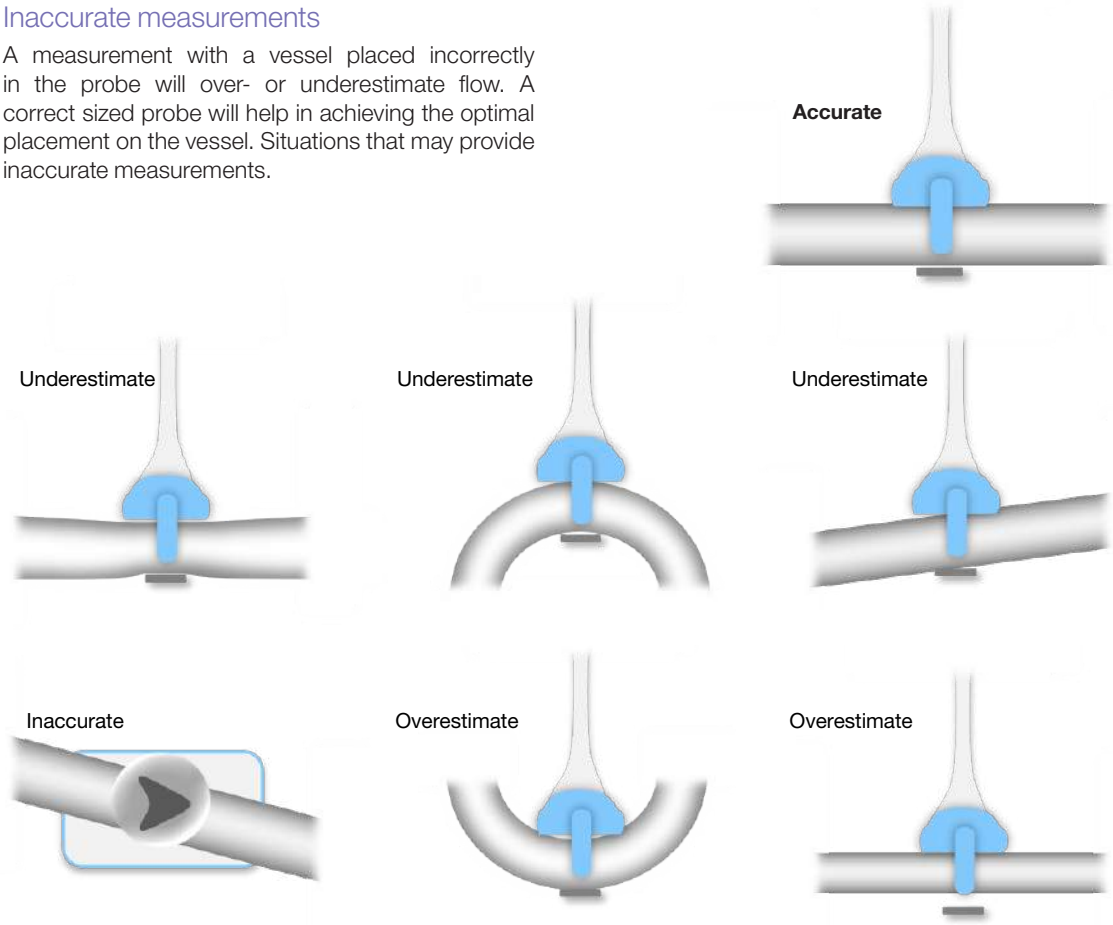
$$PI = \frac{\text{Maximum Flow - Minimum Flow}}{\text{Mean Flow Volume}}$$

Turbulence results in elevated PI and spikes in the flow tracing. If the probe is positioned over an internal valve, the PI may be elevated due to turbulent flow. Reposition the probe to see if PI improves. Before making the final decision to redo an anastomosis, wait a few minutes to allow the flow to normalize and measure again. Spasm in an artery or the perfused bed can cause a decrease in flow with an increase in PI.



Inaccurate measurements

A measurement with a vessel placed incorrectly in the probe will over- or underestimate flow. A correct sized probe will help in achieving the optimal placement on the vessel. Situations that may provide inaccurate measurements.



3.4 Synthetic grafts

The Medistim TTFM probes are calibrated to be used on biological vessels (native or e.g. bovine). High acoustic impedance in synthetic graft materials may make it difficult to perform reliable TTFM even if the acoustic coupling (ACI) is acceptable. If possible, graft flow should be measured on a native vessel close to the synthetic graft. Synthetic graft types will impact TTFM and HFUS differently. There are four main types of synthetic grafts:

PTFE (Polytetrafluoroethylene)

Newly inserted PTFE and ePTFE (Expanded PTFE) grafts are not eligible for TTFM or HFUS due to air in the material that will interfere with the ultrasound transmission. The graft has to be heavily pinched or clamped with a soft vascular clamp in order to push the air from the prosthesis wall, a practice that might damage the prosthesis, and therefore should be questioned.[1]

Dacron (Polyethylene)

A polyethylene prosthesis has less air in the wall and TTFM may be performed about 15 min after blood has been released to the prosthesis and has saturated the graft material.[1]

Polyurethane

Performing TTFM and HFUS on polyurethane grafts is acceptable.

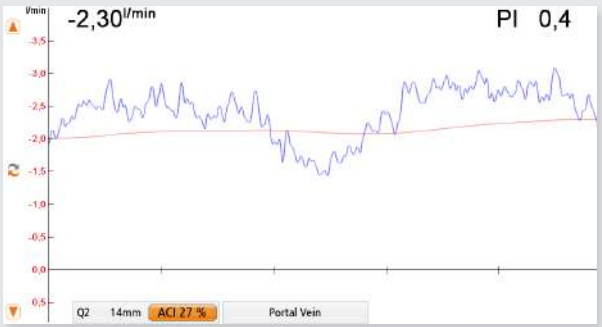
Hybrid grafts

Synthetic grafts coated with endothelial cells may provide adequate ultrasound transmission for TTFM to be performed.

3.5 Mistakes to avoid - TTFM

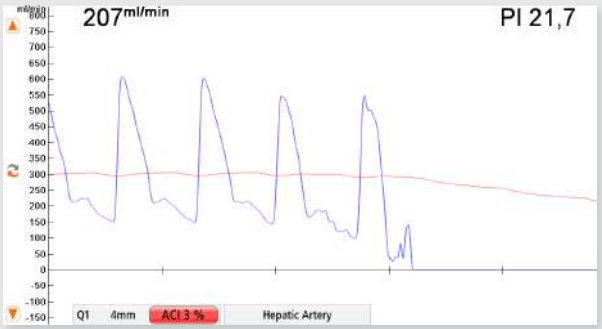
In order to achieve reliable transit time measurements, the ACI must be green or yellow and the red line must be horizontal. Below are some examples of flow measurements under suboptimal circumstances:

In this case, the ACI was orange (below 30%), meaning that the measurement is not reliable. The low ACI may be caused by using the wrong size TTFM probe, not applying enough gel/fluid in the probe/vessel contact area, or by air or fat caught between the probe and the vessel.



While performing TTFM, we advise to wait 7 seconds before saving for more accurate flow and PI values. In this example, the measurement is saved prematurely.

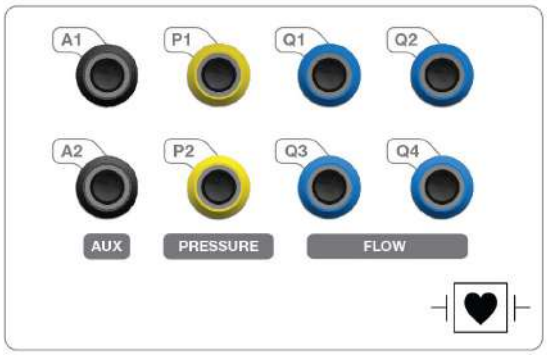
In this measurement, the probe is removed from the vessel too soon. ACI is red and PI is very high. The measurement up until this point was good, so the SAVE button should have been pressed slightly earlier.



4. Pressure measurements

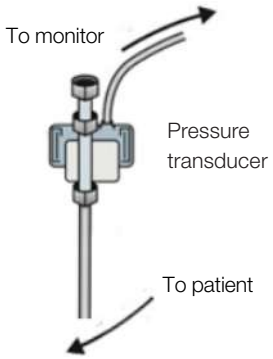
Flow will vary proportional to systolic pressure. The MiraQ system can provide information on the screen with up to four flow channels and two pressure channels simultaneously.

The pressure inputs (P1 and P2) allow connection of pressure transducers for direct monitoring of the patient's blood pressure.

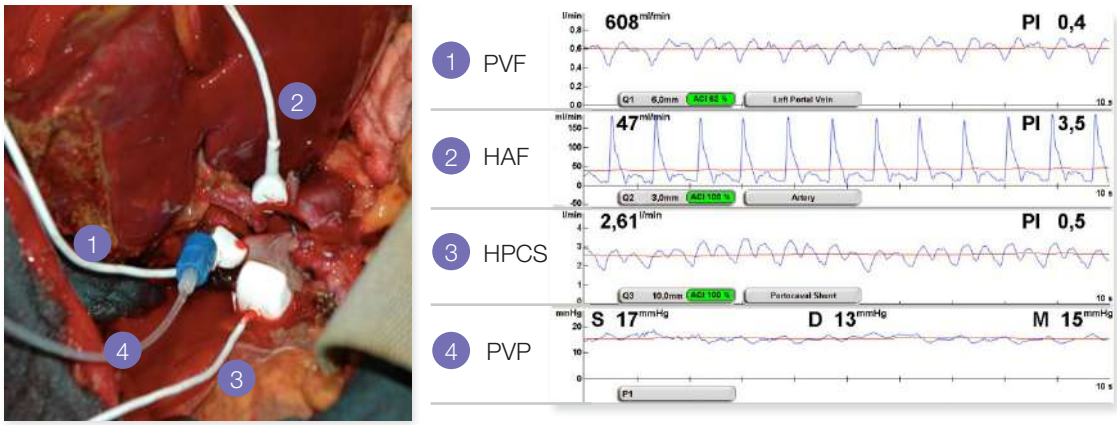


The auxiliary channels (A1 and A2) can be used to interface a pressure signal from another device. When cables from a pressure device are connected to the MiraQ AUX channel, they show up as P5 [A1] or P6 [A2].

Medistim provides connecting wires to most pressure transducers. Contact your sales representative for more information.



Below is an example of simultaneous measurements with three flow probes and one pressure transducer. The ratio between the blood flow in the Portal Vein and Hepatic Artery can be calculated by activating "Derived curves" (explained in Chapter 7).



Three TTFM probes without handles are placed on the Portal Vein (1, PVF), Hepatic Artery (2, HAF) and on a Hemi-Porto-Caval Shunt (3, HPCS). In addition, a pressure transducer is inserted in the Portal Vein to measure PVP (4, Portal Vein Pressure).

5. High-frequency Ultrasound (HFUS)

5.1 Principles of HFUS

Background

Medistim launched the first system with high-frequency ultrasound (HFUS) imaging in 2009, offering an added value to intraoperative guidance and quality control.

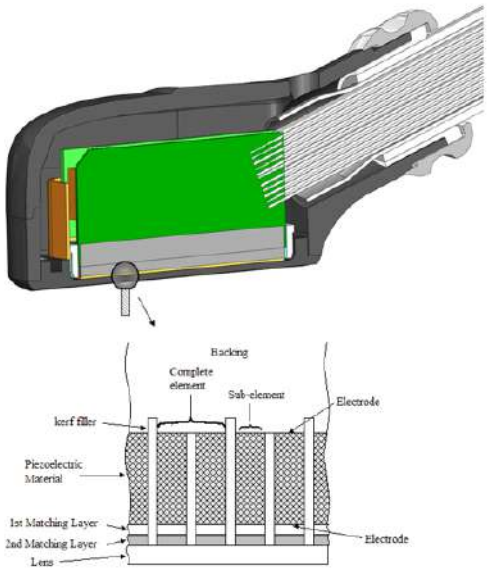
Ultrasound

Ultrasound consists of sound waves with frequencies higher than 20 kHz.

Diagnostic ultrasound has frequencies between 1 and 30 MHz.

Higher frequency of ultrasound will provide higher image resolution with lower penetration. Lower frequency will give more depth, but lower resolution.

The L15 imaging probe contains 128 piezoelectric elements. It has a frequency range from 11 to 18 MHz, with a center frequency of 15MHz. The probe is designed to provide high resolution images in the extreme near field (0-20 mm).



128 element linear array imaging probe.

Image / ultrasound reflection

Different tissues appear differently on the screen of the ultrasound system. Fluids appear dark, solid organs appear gray, and air and bone appear white.

Bone/air Tissue Fluid

When a sound wave hits a boundary, some of the energy of the wave will be reflected back to the probe. How much of the wave that is reflected depends on the type of boundary. High reflection will appear white, while low reflection will appear black on the image created.

Percentage of energy reflected at tissue interfaces:[12]

Muscle/blood	0,07
Soft tissue/water	0,23
Fat/muscle	1,08
Bone/fat	48,91
Soft tissue/air	99,90

Coupling agents

Ultrasound will not penetrate air, so the use of gel or fluid is necessary to obtain good contact with the tissue examined. Moisture on the tissue surface may be enough, but often an optimal image is achieved by adding some type of moisture like saline, blood or ultrasound gel indicated for intraoperative use. The illustration below shows how using enough gel will avoid compressing the vessel.

Illustrations of adequate and too little gel.

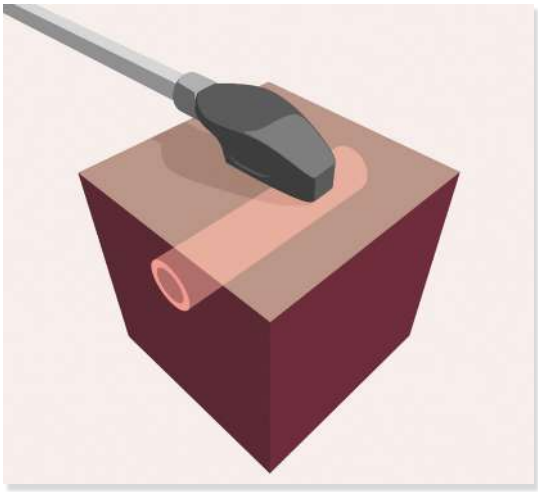
Another technique is to fill the operating wound with saline during imaging. This is especially useful when it is difficult to reach the target area with the imaging probe.

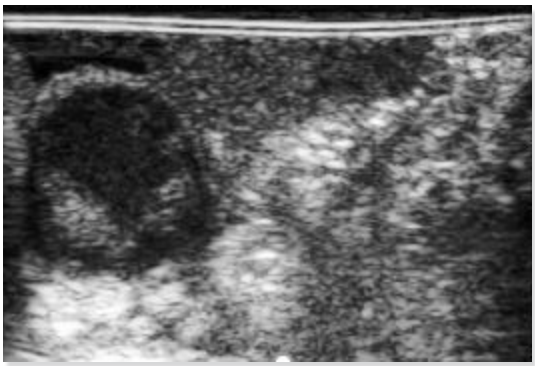
5.2 Imaging views

There are two main views for imaging: transverse and longitudinal. The easiest way to image a vessel is to locate it in transverse view and then rotate the imaging probe for a longitudinal view.

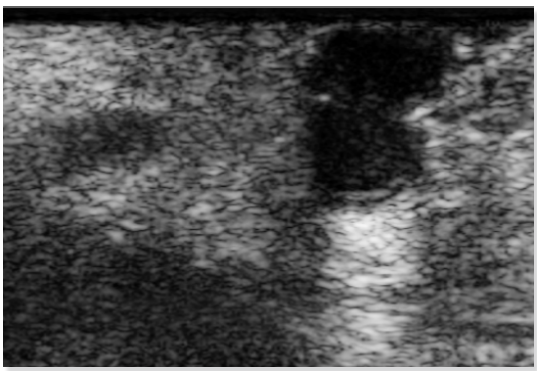
Transverse / cross section scanning

View to locate vessels and look for optimal anastomotic site as well as to check anastomosis.





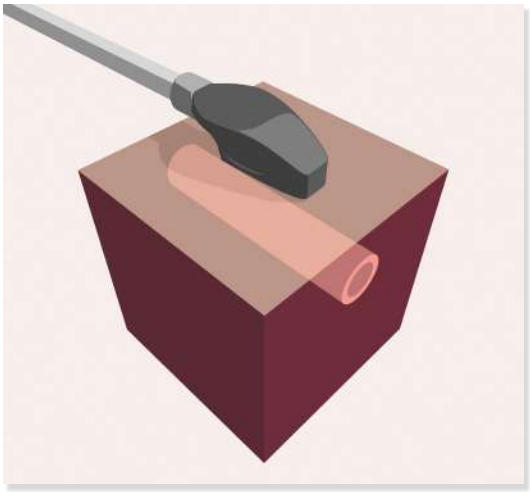
Transverse view of a vessel.

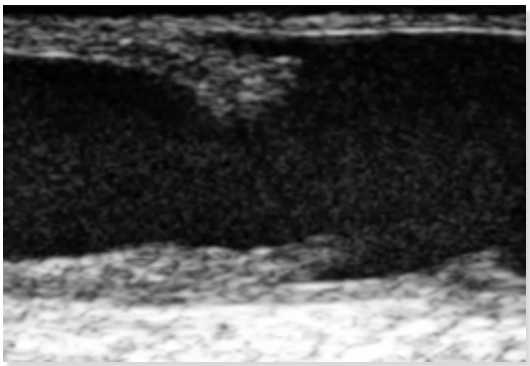


Transverse view of an anastomosis.

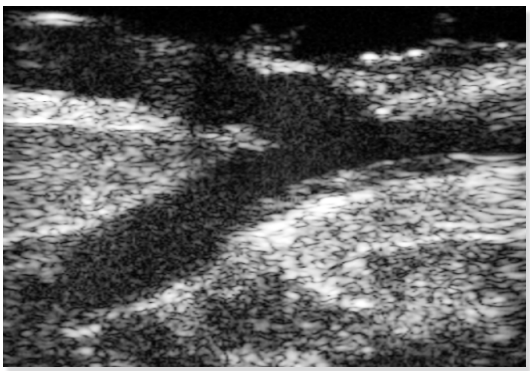
Longitudinal scanning

View to evaluate calcifications or obstructions and to check anastomosis.





Longitudinal view of a vessel.



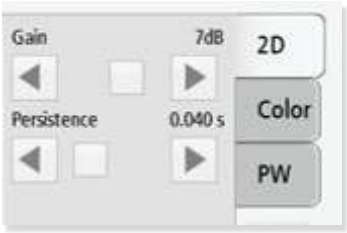
Longitudinal view of an anastomosis.

5.3 HFUS modalities and settings

There are three imaging modalities available on the Medistim system: 2D mode, Color Flow Mapping (CFM), and Pulsed Wave Doppler (PW). The modes may be changed by selecting the different tabs in the top right corner on the screen.

2D-Mode (B-Mode, Grayscale imaging)

B-Mode provides the highest frame-rate which is useful when you need to view the anatomy, examine structures and find defects. In this mode, you can also adjust the gain and persistence. Gain adjusts the brightness in the displayed image. Persistence provides a temporal average filter to decrease random noise in the image.



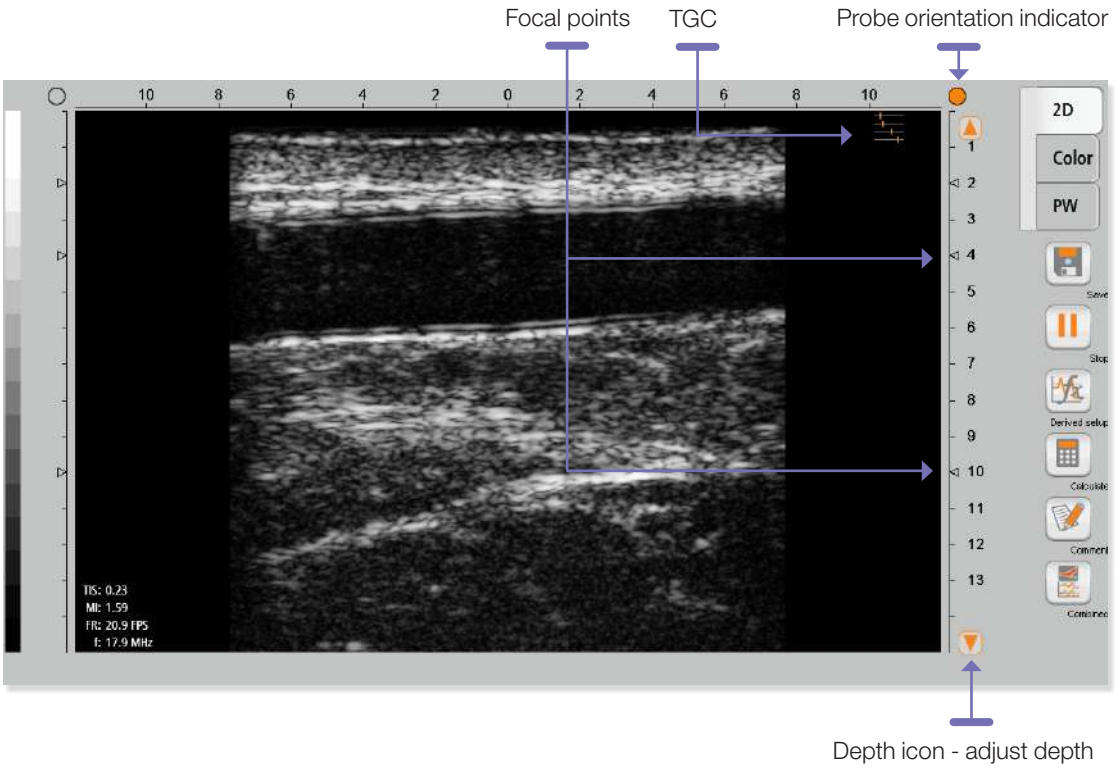
Focal Points

Make the image sharper at the defined depth. It is possible to select up to four focal points, but using all of them will reduce the frame-rate. Focal points are already set on the different preset options, but can also be set manually.

Time gain compensation (TGC)

Adjusts the gain for specific sections in the image and allows different gain settings for different parts of the image. To access these, press the TGC icon to access the TGC slider controls.

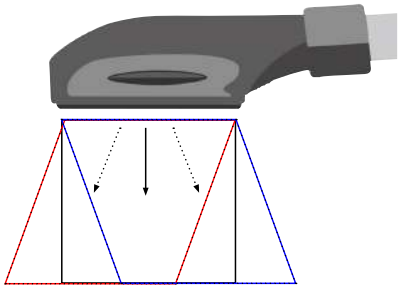
Screen elements in 2D-Mode



Spatial Compound imaging

Spatial compound imaging is a method that acquires images from several different angles and combines them to produce a single image. This reduces the speckle and improves the definition of tissue planes, generally decreasing image noise and improving image quality. Imaging artifacts like wall shadowing and enhancements will be less prominent in compounded images.

For users that prefer the traditional image with more speckle, the compounding can easily be switched off.



Spatial compounding principle

With and without Spatial Compound imaging

The images below show transverse and longitudinal views of a radial artery without and with spatial compound. Notice how spatial compound has made image artifacts like wall shadows and enhancements less prominent. In the longitudinal view (image 3 and 4), the small transverse vessel in the bottom right part of the images is much more visible with spatial compounding enabled.

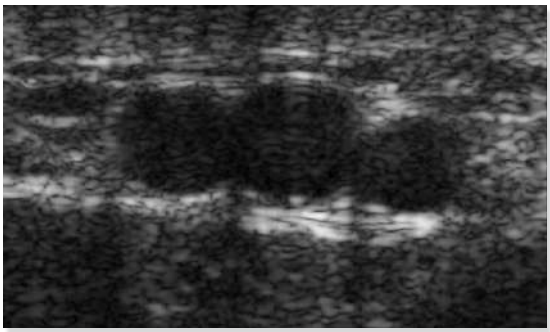


Image 1: Transverse view of radial artery and veins

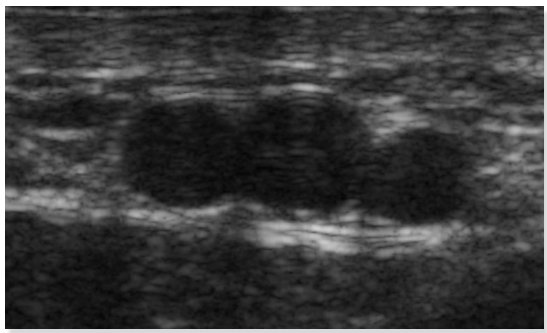


Image 2: Radial artery and veins with spatial compound

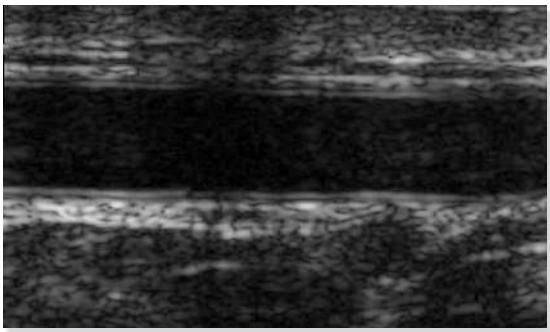


Image 3: Longitudinal view of radial artery

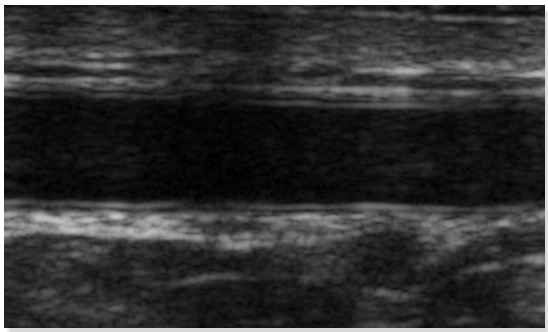


Image 4: Radial artery with spatial compound

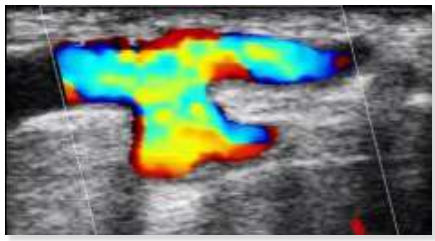
Color flow mapping (CFM)

In color mode, the system performs fast time-sharing between B-mode scanning and Doppler operation, which provides a live 2D image for orientation plus color flow. There are two different mapping techniques with color flow:

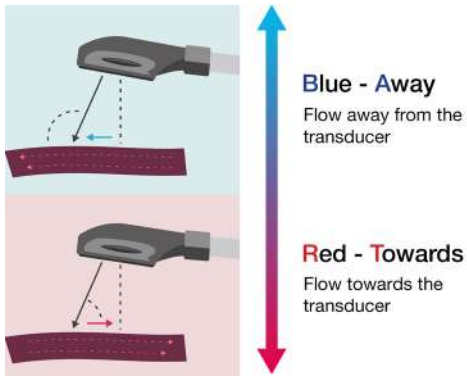
- **Velocity mode** uses the Doppler shift to detect flow and provides information about flow direction relative to the probe and flow velocity.
- **Power mode** uses the power in the returned Doppler signal to detect the presence of flow but gives no information about direction or velocity. This mode is more sensitive to flow movements than velocity mode.

Aliasing may occur when the blood flow velocity is higher than what the system is set to measure. The red or blue color will change through green to the opposite color. This effect makes it difficult to discern flow velocity and flow direction but can be corrected by adjusting the velocity scale.

Region of interest (ROI) is the area of the image that the system is analyzing for blood flow. A wide ROI will often slow the frame rate down. Press and drag the steering icons to adjust the angle, position and size of the ROI.

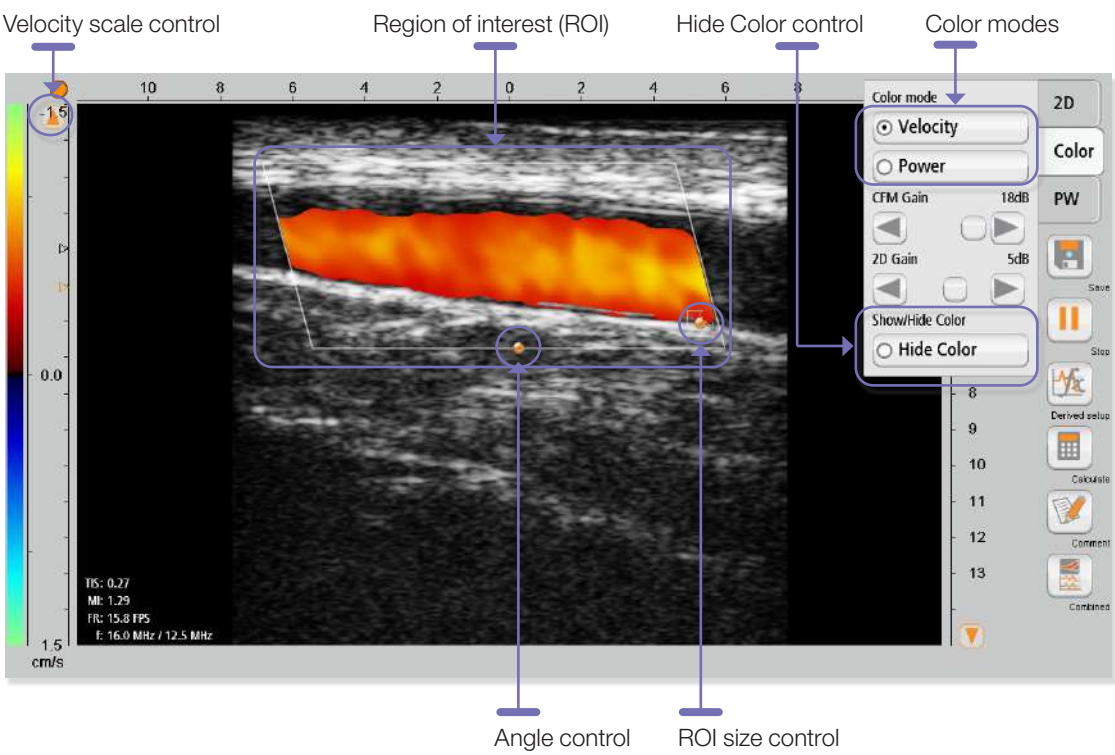


CFM image with suboptimal velocity setting (aliasing).



To evaluate the flow direction, use the "BART color convention" (Blue Away, Red Towards)

Screen elements in Color mode



Pulsed Wave Doppler (PW)

Similar to Color flow, pulsed wave Doppler (PW) mode performs fast time-sharing between B-mode scanning and Doppler operation in order to provide a live 2D image for orientation plus measuring flow velocities using Doppler pulses.

Adjust the strength of the Doppler signal by using the gain control. Too low gain will result in a weak signal and too high gain results in mirroring artifacts and noise pollution.

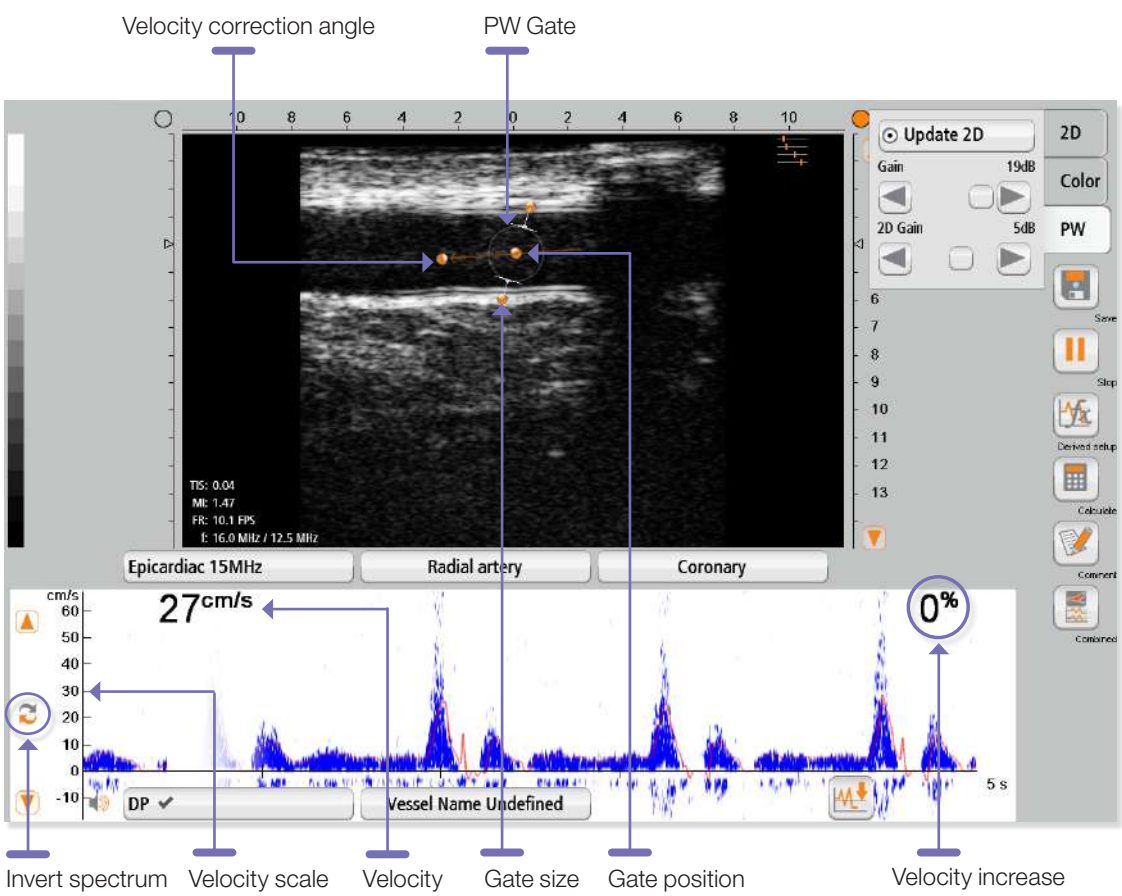
A small angle between the incoming Doppler pulses and the bloodstream will yield the best measurement results. At 90° to the flow, no flow will be detected. The system will always select the optimal steering angle based on the PW-gate placement and velocity correction angle combination.

PW Gate adjustment
The size and position of the Doppler gate can easily be adjusted to suit the situation at hand.

- Press the Position icon and drag the gate to the desired position.
- Press and drag the Size icons to achieve the desired gate size.
- Press and drag the Velocity correction angle icon to align the line so that it is parallel to the flow.

Pulse Repetition Frequency (PRF) sets the sampling rate of the measurements and is adjusted by the velocity scale. High or low velocities will sometimes not fit within the measurement range. The measurements will then either wrap around and appear as negative velocities at the bottom of the range (aliasing), or not be registered at all.

Screen elements in Pulsed Wave Doppler



5.4 Imaging artifacts

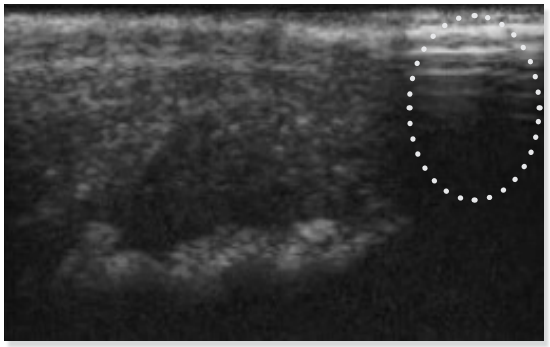
Imaging artifacts are elements in the image that are caused by the ultrasound technology, and are not actual tissue. Typical artifact categories are presented below.

How to identify an artifact?

Try to move the probe to check if a different angle will make the artifact disappear.

Reverberation

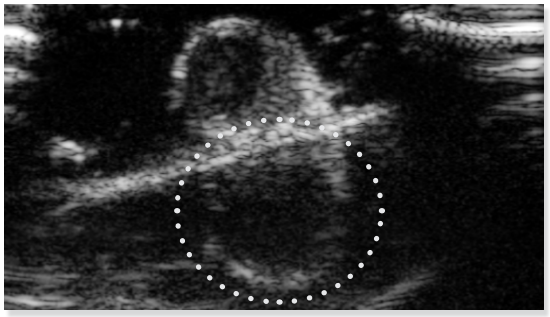
Reverberation artifact occurs when an ultrasound beam encounters two strong parallel reflectors. This can help identify foreign bodies like surgical clips, catheter tips, debris, glass or metal. It is seen by repetitive patterns in the image.



Reverberation at the top right of the image.

Mirroring

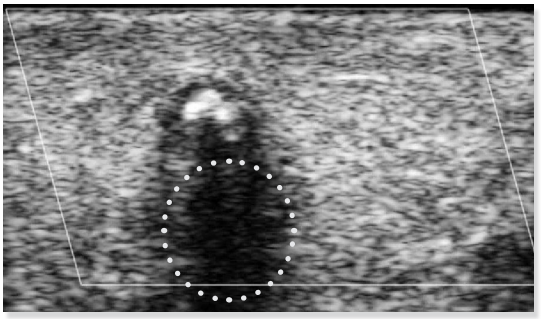
This happens when the ultrasound waves hit a strongly reflective surface. The example below shows mirroring from a glove held under an ITA.



ITA shown over the white line and the mirroring underneath.

Shadowing

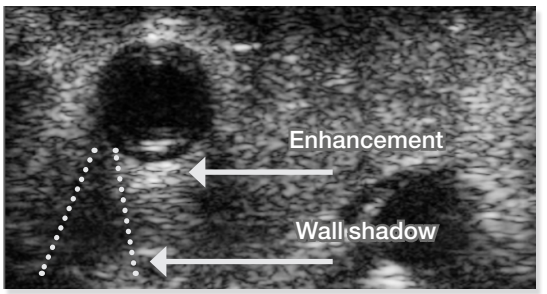
When the ultrasound waves hit hard tissue like calcified plaque, a shadow is formed on the image below this area. In the following image example, a shadow is created below a piece of calcified plaque.



Shadow under a calcified area (white).

Enhancement and wall shadow

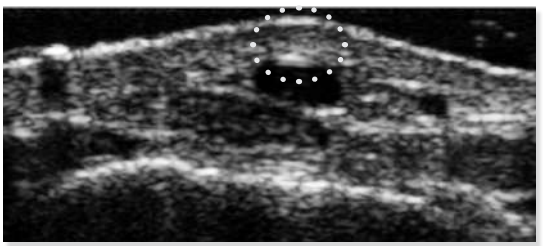
When the sound-waves go through an area with low attenuation and hit tissue, enhancement of the signal may occur. The difference in attenuation between the two media will create a stronger signal (white area). Unlike the case for calcified plaque, there will be no shadow under an enhancement.



Enhancement (white) and dark wall shadow.

Specular reflection

This artifact appears when a smooth surface perpendicular to the ultrasound ray reflects the sound waves. In the example below, the top side of a blood vessel reflects the ultrasound, creating a white area.

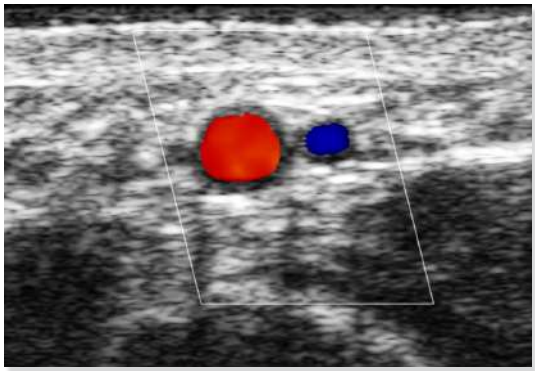


Specular reflection in the upper part of the vessel.

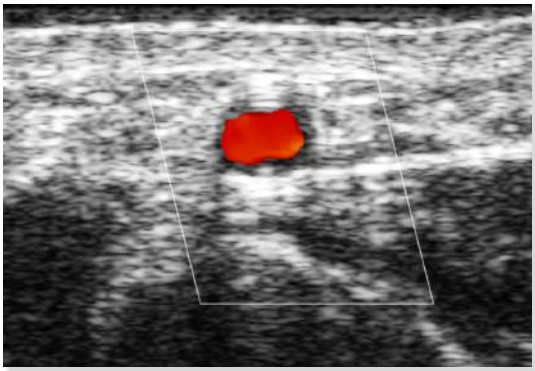
5.5 Mistakes to avoid - Imaging

Compressing vessels

While it is important to have good contact between tissue and the imaging probe, pressing too hard might hide important information or completely compress veins.



Imaging performed with little pressure showing an artery and a vein.



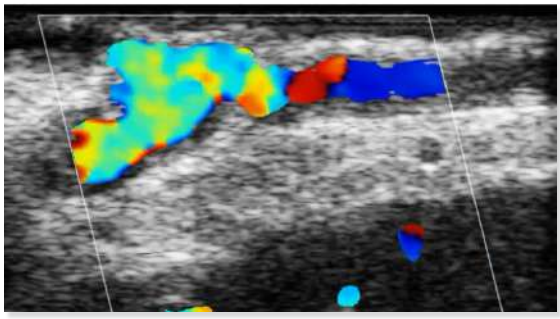
Imaging performed with excessive pressure showing only the artery. The vein is completely compressed.

Aliasing

Aliasing may occur if the blood flow velocity is higher than what the system is configured to measure. The peaks of the velocity spectrum will exceed the highest values of the velocity scale and reappear at the bottom of the scale, now represented as negative values. Aliasing can be corrected by adjusting the velocity scales.

If the CFM image is displaying the color green the velocity scale range should be increased.

CFM utilizes the Doppler principle for estimating the blood flow velocities. To correctly estimate the velocities, the functionality must be set up appropriately for the velocity being estimated. If the velocity scale is set to a range that is too large, the measurement will not have the sensitivity required to detect the low flow velocities. If the velocity scale is set to a too low range, the high velocities will not be adequately sampled and the resulting estimation will be incorrect.



CFM image with aliasing

An example: If the velocity scale is set up for measurements in the range +/- 5 cm/s, and the actual velocity is 6 cm/s, the velocity will wrap around the scale and display as -4 cm/s instead. This phenomenon is called aliasing and will, at best, cause the CFM image to be very confusing. More often than not, if aliasing is not corrected it will make the CFM information useless as it is not possible to determine the direction or nature of the flow. Aliasing is often seen as green color, but can also be a mix of all the colors.

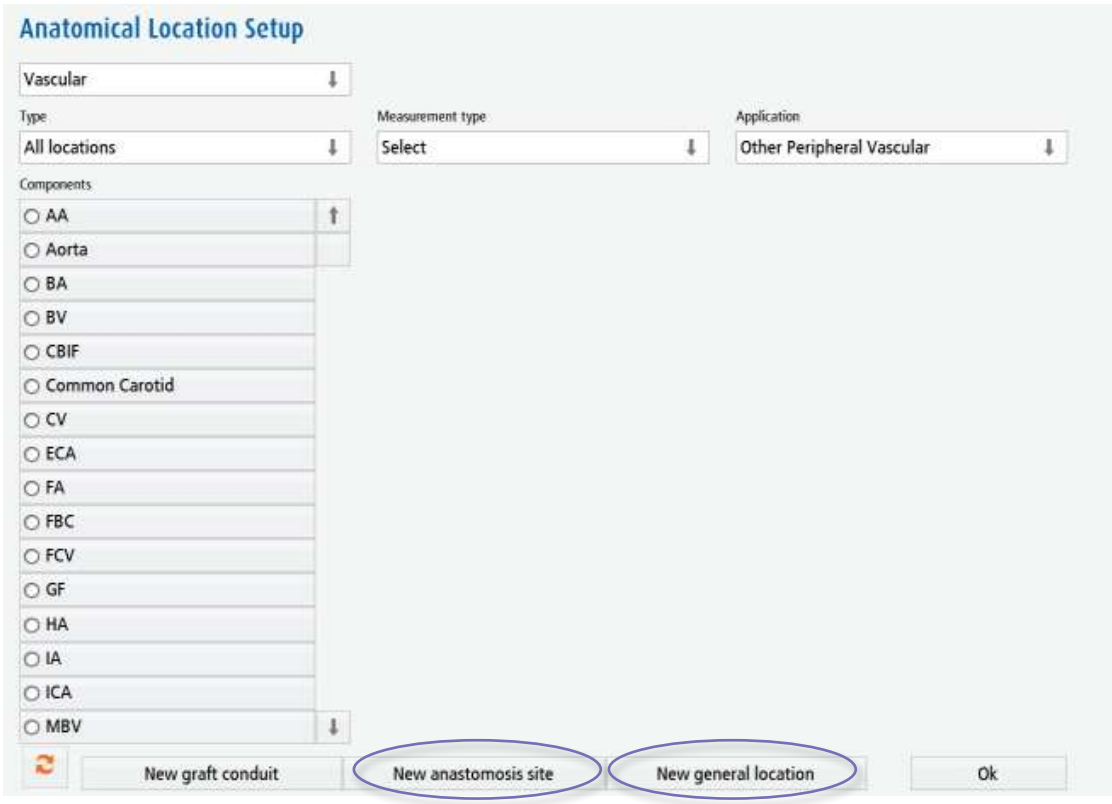
6. Setting up the MiraQ for transplantation

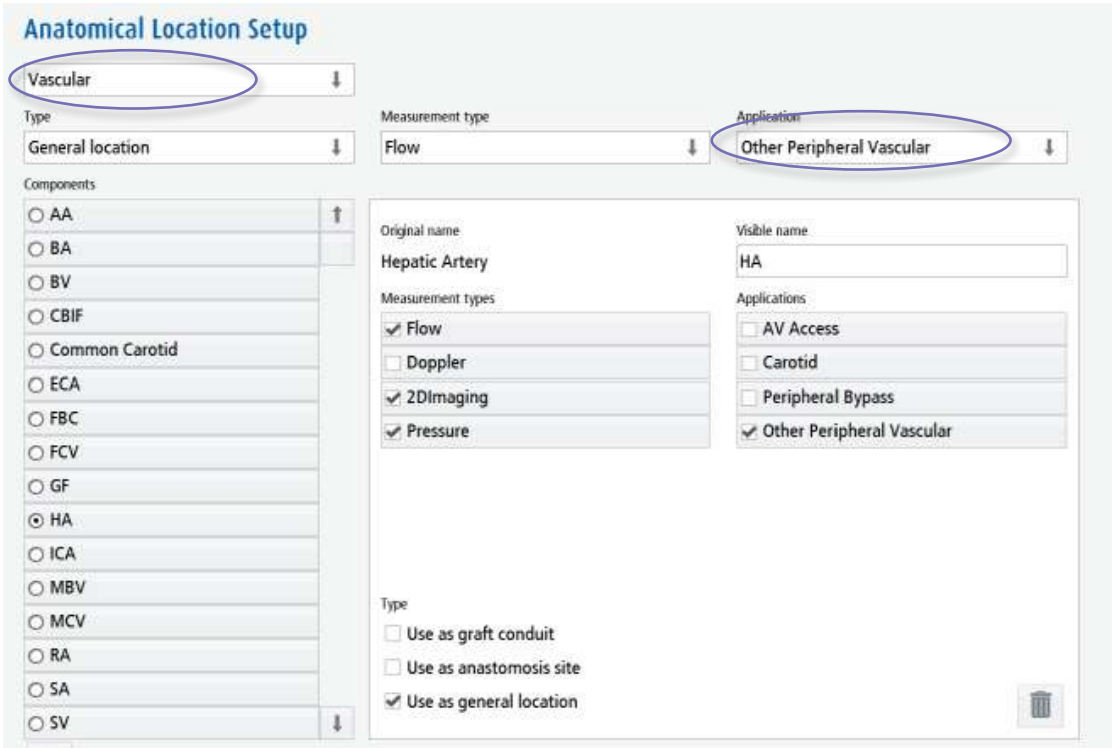
The MiraQ systems can be set up to facilitate use during transplantation surgeries by changing some of the settings.

Set up new anatomical annotations

1. Enter **System settings** and go to **Anatomical Location Setup**.
2. Choose **Vascular** in the top left drop-down menu
3. Under **Application**, choose **Other Peripheral Vascular**
4. Choose **New anastomosis site** or **New general location** and click **OK**.
5. Enter the original name of the anatomical site. (The site name should pop up as you begin typing.)
6. Choose desired location and click **OK.** The **Visible name** can be chosen/set as preferred.
7. After entering the new locations, tick off the desired **Measurement types** and **Applications** that will be activated for the application.

Repeat these steps for each new location or anastomosis. It is recommended to delete the locations that are not relevant for your department in order to be able to make annotations during surgery easier and faster.





Suggested Measuring sites for LTx:

Flow:
Hepatic Artery (HA)
Hepatic Vein (HV)
Portal Vein (PV)
Portosystemic Shunt (PSS)
Mesocaval shunt (MCS)

HFUS imaging:
Hepatic artery anastomosis
Hepatic Vein anastomosis

Pressure:
Central Venous Pressure
Portal Vein Pressure
Hepatic Venous Pressure Gradient (HVPG)

Suggested measurement sites for RTx:

Flow:
Renal Artery (RA)
Renal Vein (RV)
Iliac Artery

HFUS:
Renal Artery anastomosis
Renal Vein anastomosis
Iliac artery

7. Ratios and derived curves

Flow and pressure ratios and gradients

With more than one probe connected to the system, different options for calculations will become available. These calculations are called derived curves. In order to perform these calculations, ensure that derived curves are enabled in the **Software customization** in **System settings**. The rest of the settings are performed during the measurements.

Direct calculation of the PVF/HAF ratio

Connect two flow probes to the system and place the probes on the Hepatic artery (Q1) and the Portal Vein (Q2). Press the **Derived Setup** and choose Q2/Q1 in the pop-up menu **Enable derived curves**. An example of this calculation is included below. The PVF/HAF ratio is shown as a curve and is calculated to 11,77 on average for the last 5 seconds.

TTFM measurements of Hepatic Artery and Portal Vein with direct calculation of PVF/HAF flow ratio (Q2/Q1).

Direct calculation of total Hepatic flow

In the pop-up menu above, there is also an option to choose addition or subtraction of flow values. With flow probes attached to the Hepatic artery (Q1) and the Portal Vein (Q2), choosing Q1 + Q2 will calculate total hepatic flow (THF).

Direct calculation of HVPG

The Hepatic Vein - Portal Vein pressure gradient (HVPG) can be calculated directly either by connecting two pressure transducers directly to the system or by connecting another device through the AUX channels. The easiest method is to connect two pressure transducers to the channels P1 and P2. An example of this setup is shown below. Another option is to connect a cable with the Central Venous pressure to an AUX channel and a pressure transducer to either P1 and P2.

Pressure measurements with direct calculation of HVPG (hepatic vein - portal vein pressure gradient). The HVPG gradient is calculated as PVP-CVP in the lowest curve.

Derived setup with pressure transducers

1. Insert pressure transducers in the P1 and P2 channel
2. Press the Derived Setup
3. Enable the **P1-P2** in the **Enable derived curves** pop-up menu and press OK
4. The curve for **P1-P2** is drawn, and the difference in the mean value is shown in the upper right corner

Derived setup through AUX connection

1. Connect a pressure transducer in the P1 channel and an AUX probe in to the A1 channel (this curve will come up as P5)
2. Open the toolbox and set the A1 channel to **No ECG**
3. Press the A1 button and set **Unit measured** to **mmHg** and press **OK.**
4. Set zero value on the curve
5. Press **Derived setup** and enable the **P1-P5 [A1]** in the **Enable derived curves** pop-up menu and press OK
6. The curve for **P1-P5** is drawn

8. Liver Transplantation

Secure short and long-term graft patency

TTFM can be used to quantify hemodynamic imbalances and tailor graft inflow modulation during liver transplantation.[2]
Pressure measurements are also very useful during assessment of the hemodynamics. Signals from pressure measurements can be presented on the MiraQ either by inserting pressure transducers directly or by connecting another device to the system. See more details on this in Chapters 5 and 8.

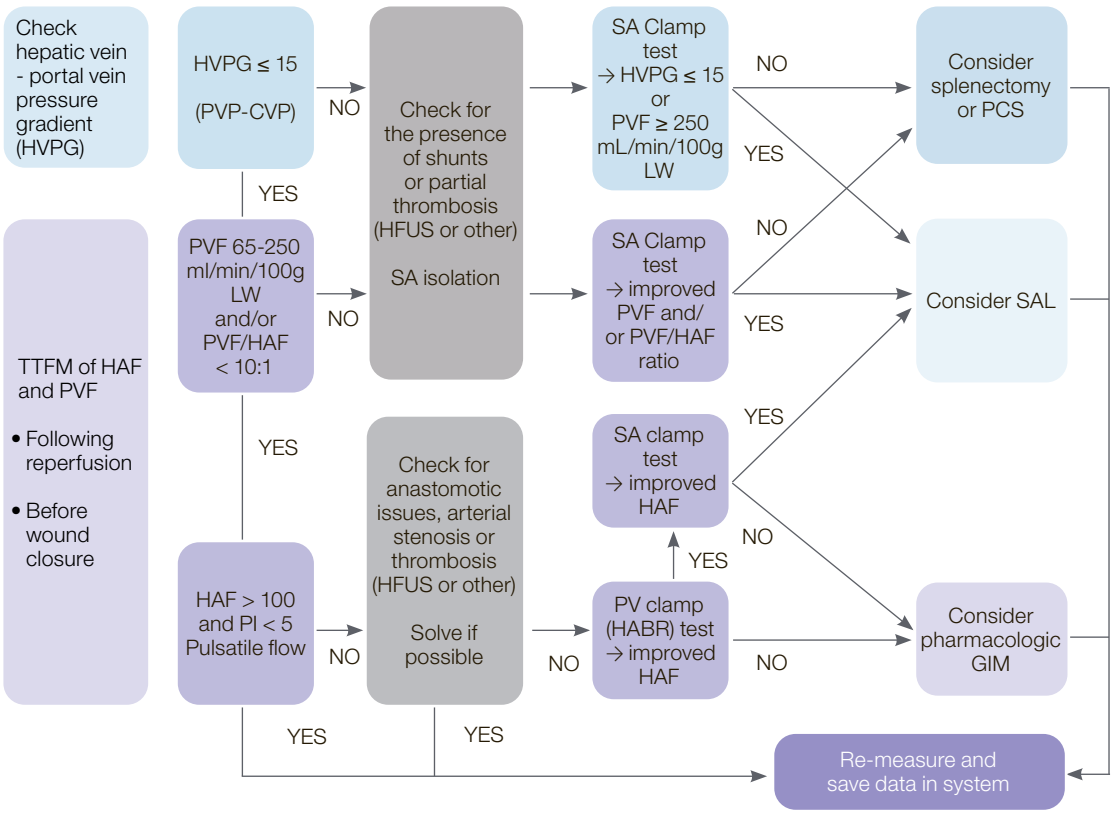
8.1 Workflow for Liver Transplantation

Several experienced liver transplantation surgeons have published suggested workflows for the use of TTFM and pressure measurements.

Below is a suggested workflow for LTx developed in collaboration with Professor Mauricio Sainz-Barriga and Professor Roberto Troisi. This workflow includes both flow and pressure measurements, since both of these factors are important for the long-term graft survival. [7]

The measurements should be performed under stable hemodynamic conditions in the absence of active bleeding.

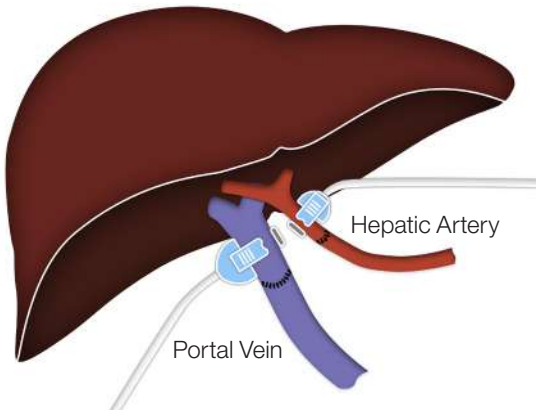
If TTFM shows suboptimal values, a new measurement should be performed at a later time to see if it will resolve by itself.



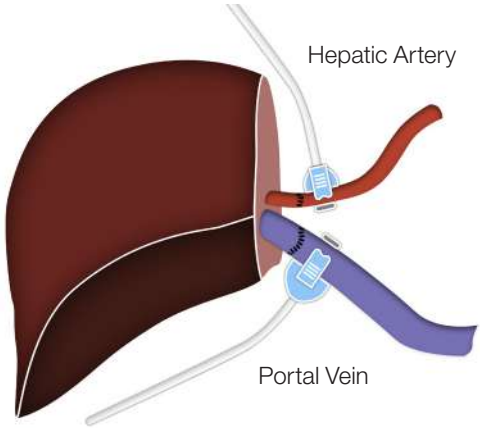
Probe placement

For TTFM of Hepatic Artery and Portal Vein, we recommend different placement of the probes for living donor (partial graft) and deceased donor: Place the probe pre-anastomotic for LDLT, and post-anastomotic for DDLT.

A measurement both proximal and distal to the anastomosis might be best.
Perform simultaneous PVF and HAF measurements to check the flow ratio. Compression of the PV may be performed to check the HABR response.



DDLT probe placement



LDLT probe placement

8.2 Reference values

There are currently no official guidelines for reference values for TTFM during transplant applications. Medistim refers to published peer-reviewed articles and guidelines to suggest reference values for different applications.

Note that there are multiple factors that can affect the flow volume. Physiological factors like spasm in the graft or native vessels, blood pressure and run-off in the vessel bed will affect the flow volume. The size of the graft and the patient's weight are also factors that will affect the flow volume.

Vessel issues such as thrombus formation, twists or kinks of the vessel, or air bubbles and misapplied stitches will reduce the flow. Poor TTFM readings may also be a result of an incorrect measurement technique. Therefore, it is important to keep all of these factors in mind when assessing the flow after surgery and before closure.

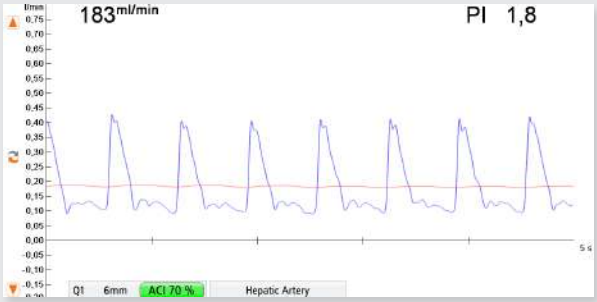
HAF	≥ 100ml/min [5, 6]
PVF LDLT	100-250 ml/min/100g liver graft [5, 8]
PVF DDLT	65-155 ml/min/100g liver graft [9]
PVF + HAF	> 1 liter/min or ~total graft weight [10]
PVF/HAF	≤ 10:1 [7]
PI HA	< 5 [10]
PVP	< 20 mmHg [5, 7, 8]
HVPG (PVP-CVP)	≤ 15 mmHg [7]

8.3 Normal TTFM in LT

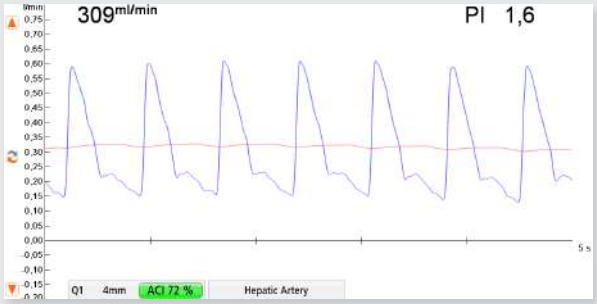
Normal flow curves are relatively smooth, repetitive and show a flow value within the expected range.

The Pulsatility Index (PI) should be below 5.

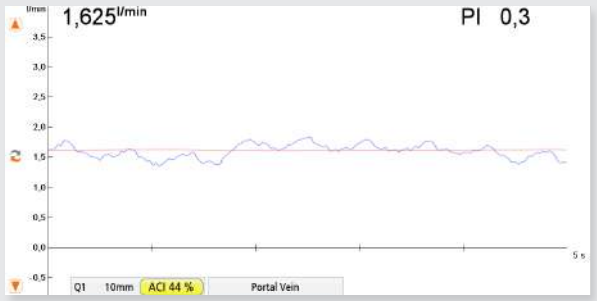
TTFM of Hepatic Artery. This flow curve shows a steep systolic peak that quickly falls again after systole is over. This is a sign of a patent anastomosis and free flow in the artery.



TTFM of Hepatic Artery with high flow, steep increase and reduction of flow, indicating patent anastomosis and low resistance in the graft.



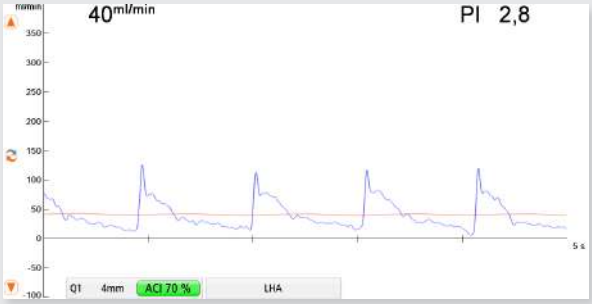
TTFM of Portal Vein with slightly low, but acceptable ACI. Mean flow and PI is adequate.



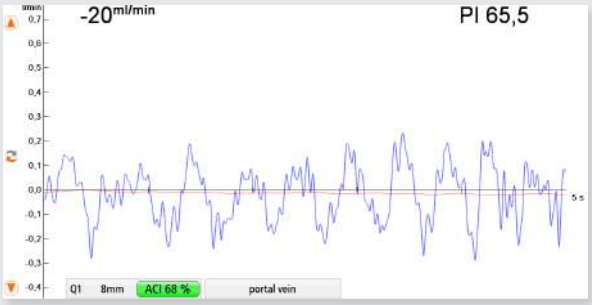
8.4 Suboptimal TTFM in LT

Suboptimal flows may indicate different problems. Poor run-off (resistance) distally to the graft is one major challenge. Issues with the graft itself or technical imperfections in the anastomosis may lead to disorganized TTFM curves that have low flow and often high spikes.

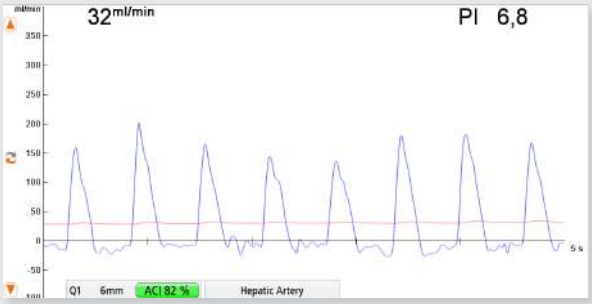
TTFM of left Hepatic Artery with mean flow below the recommended value (100mL/min). PI is acceptable, but the curve's sharp peaks might be a sign of obstruction in the anastomosis.



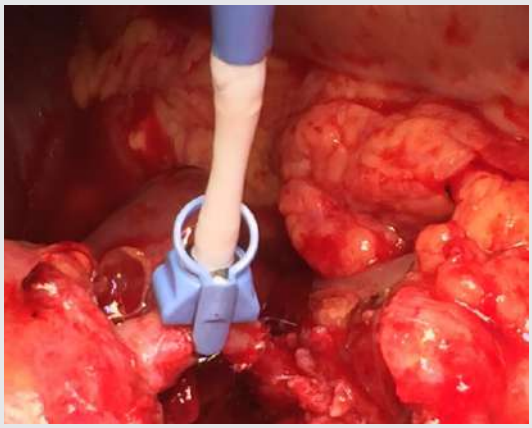
This TTFM result should alert the surgeon that something is wrong. The flow is almost zero and the PI is very high. This is probably due to an obstructed Portal Vein.

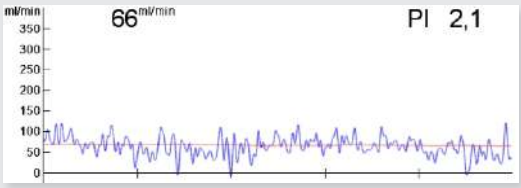


TTFM of Hepatic Artery revealed low flow and high PI. The surgeon chose to re-measure after several minutes and experienced that the flow increased substantially and that PI decreased to 2.5.

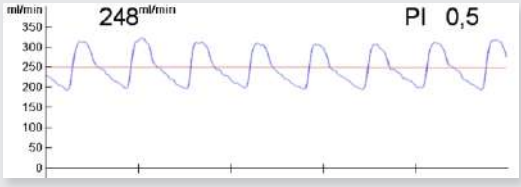


8.5 Detect compromised anastomosis with TTFM and HFUS





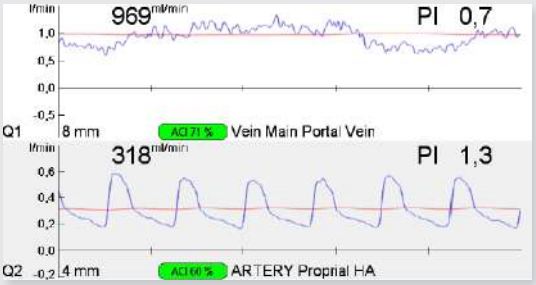
Before revision



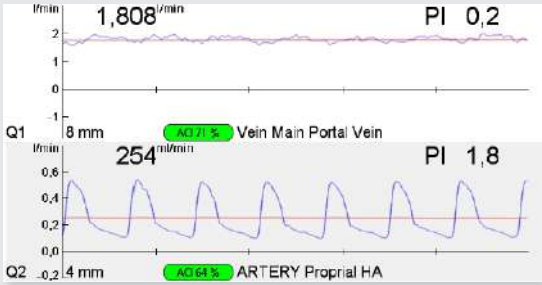
After revision

These TTFM tracings are from the Hepatic Artery. The first measurement showed low flow of 66 ml/min with a jagged flow curve, indicating a possible compromised anastomosis. After revision of the anastomosis, HA flow improved to 248 ml/min with a pulsatile flow curve.

8.6 Guide inflow modulation with TTFM



Before shunt closure



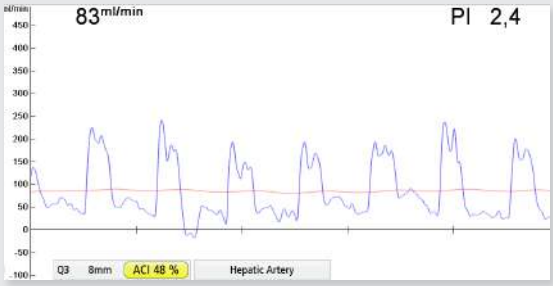
After shunt closure

These TTFM tracings are from the Portal vein and the Hepatic artery. The Portal vein flow (PVF) was lower than expected, only 969 mL/min, and a spleno-renal shunt was identified. This shunt caused hepatofugal flow.

After closure of this shunt, PVF improved to 1,808 mL/min. Reduced hepatofugal flow (flow directed away from the liver) increases the chance for graft survival.

8.7 Poor TTFM may improve with time

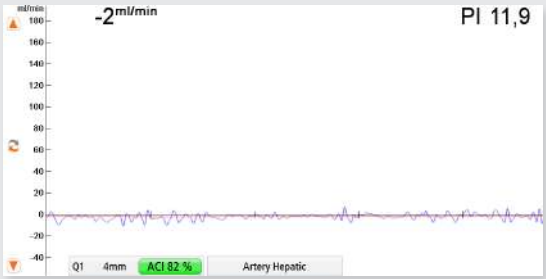
First measurement



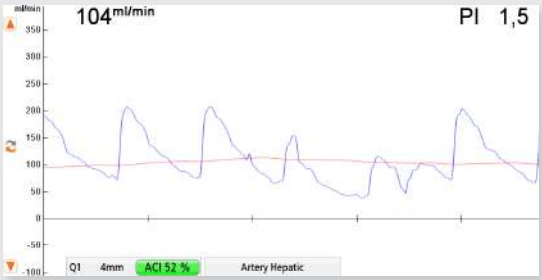
Second measurement

This example demonstrate how flow values can improve over time. The measurement shows poor TTFM parameters in the Hepatic Artery at first, but both mean flow and PI are improved after 45 minutes. HAF is still low, but was deemed acceptable.

8.8 Embolus in Hepatic Artery



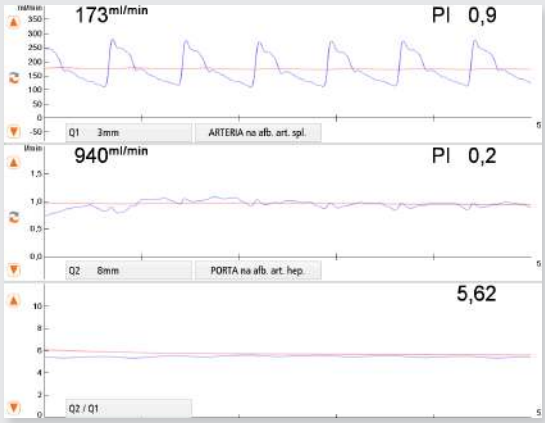
Pre embolectomy



Post embolectomy

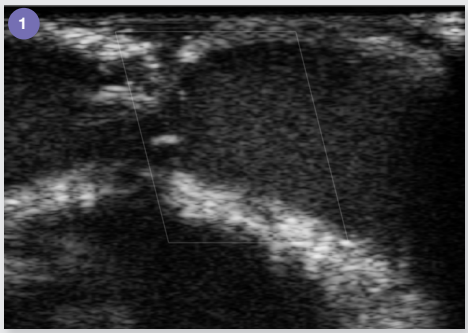
This TTFM of the Hepatic Artery shows lower flow than expected. An embolus was discovered and an embolectomy was performed. The second TTFM shows increased and acceptable flow. The curve is not completely repetitive and a final TTFM should probably have been performed after waiting a few minutes.

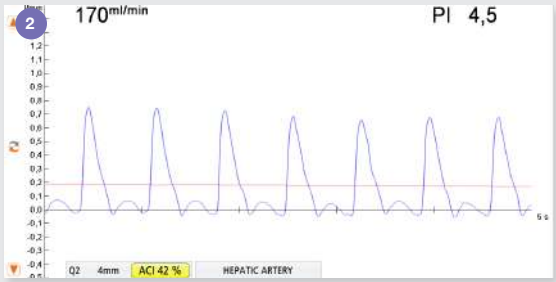
8.9 Simultaneous measurements showing suboptimal PVF/HAF ratio

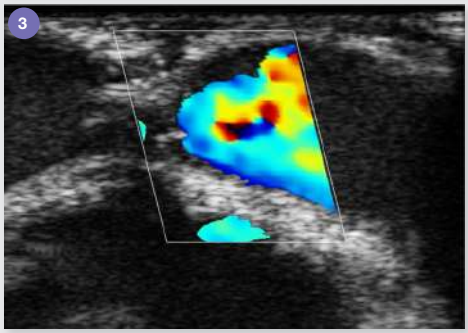


Simultaneous measurement of Hepatic Artery and Portal vein shows a suboptimal PVF/HAF ratio >10. A second measurement was performed more than one hour later. This measurement shows a higher HAF and the PVF/HAF ratio is now approximately 5. Total Hepatic Flow is >1000 mL/min.

8.10 Stenosis in Hepatic Artery





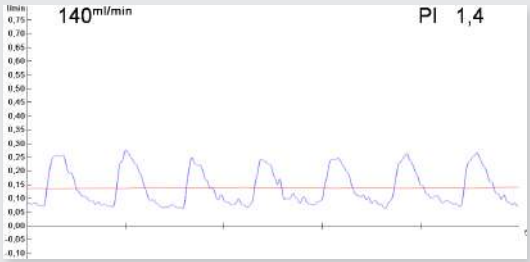


1. HFUS of an obstruction in Hepatic Artery (HA).
2. The TTFM shows a flow curve that is spiky and drops below the zero line.
3. When adding CFM, it's easier to see how the flow is obstructed.

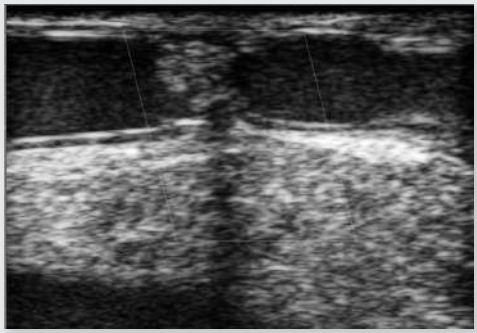
8.11 Example with thrombus in Hepatic Artery

Although TTFM is usually able to reveal any flow-related issues, a newly developed thrombus that is not yet obstructing flow will not be identified.

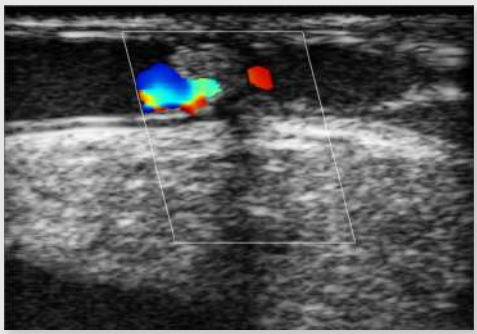
This example shows that adding HFUS to the armament for quality control may reduce the risk of missing issues that otherwise could cause complications.



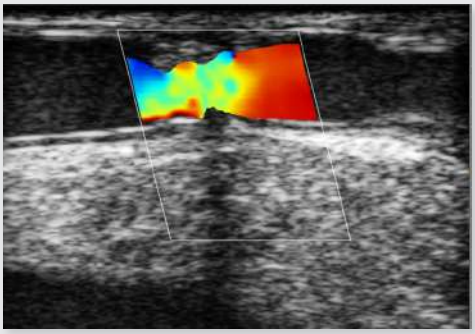
TTFM was normal with HAF >100mL/min and PI <5.



HFUS showing thrombus in Hepatic artery.



HFUS with Color Flow Mapping (CFM) of the thrombus in Hepatic Artery visualize that the flow is able to pass by the thrombus.



HFUS with Color Flow Mapping (CFM)

8.12 TTFM in ALPPS

Robotic liver partition and portal vein embolization for staged hepatectomy for perihilar cholangiocarcinoma

Di Benedetto et al. Updates Surg. 2022 Apr;74(2):773-777

In a published technical note from 2021, Di Benedetto et al. presents a technique for a minimally invasive approach for Associating Liver Partition and Portal vein ligation for Staged hepatectomy (ALPPS) using TTFM.

Portal inflow was reconstructed with a direct anastomosis with running 6-0 prolene suture. After having completed the anastomosis and released the clamps, the portal flow was assessed with TTFM and ultrasound is performed to check both inflow and outflow.

The image below is part of the full video of the procedure that is provided online with the publication.

9. Pediatric LT

Bueno et al. published an article on pediatric liver transplantation in 2007 with data from 53 children. Following are some quotes from this paper:

“Flows were measured in the native organ and in the allograft. In the native liver, PVF and HAF are similar; after transplantation they return to the physiological situation. No flow differences were seen between whole and partial grafts.

Children are at high risk of vessel thrombosis when compared with adults. Advanced hepatic disease increases PV pressure, alters splanchnic circulation, and leads to development of collateral circulation.

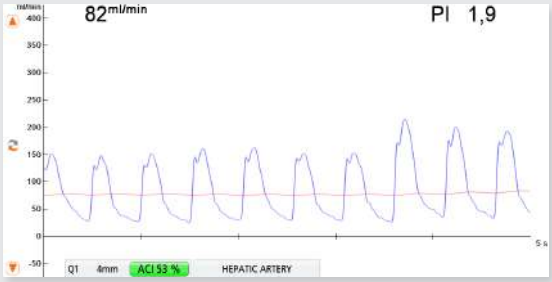
In children, more often than “true” thrombosis of the PV, it is more likely to find hepatofugal, absent, or poor PVF due to neoformation of spontaneous collaterals. This situation is especially relevant in infants with biliary atresia and hypoplasic PV. This fact explains the high incidence of PV thrombosis (14%) after liver transplantation in this series.[16]

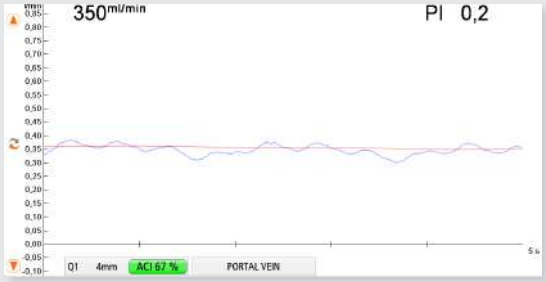
There are several publications including the use of Medistim systems during pediatric Liver transplantation. The Starzl Network partners in the USA are currently evaluating the use of both TTFM and HFUS during pedLT. Preliminary feedback is that the device is useful as guidance and quality assessment in this application.

Reference values

PVF < 5 mL/min/kg has been shown as a risk factor to develop graft portal vein thrombosis[16]

9.1 TTFM in Pediatric Living Donor Transplantation





Pediatric patient (5 years old) undergoing living donor liver transplantation. The Hepatic artery flow (HAF) is expectedly lower than for an adult recipient, as is the Portal vein flow (PVF). The curves are repetitive and smooth, indicating good flow conditions and patent anastomoses.

10.1 TTFM in Liver Transplantation

Lack of a Correlation Between Portal Vein Flow and Pressure: Toward a Shared Interpretation of Hemodynamic Stress Governing Inflow Modulation in Liver Transplantation[7]

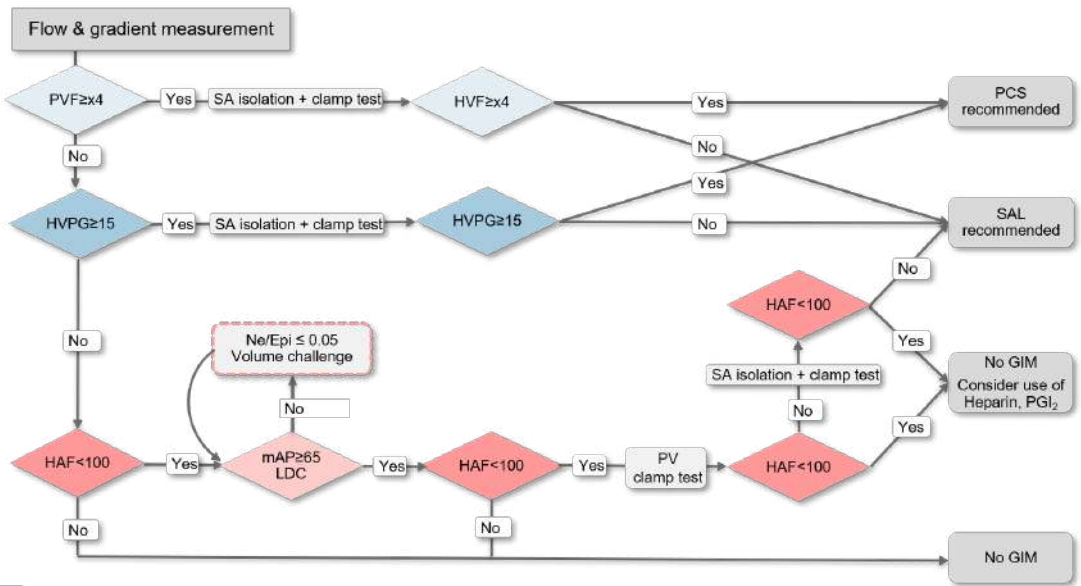
Sainz-Barriga M, Scudeller L, Costa MG, de Hemptinne B and Troisi RI
Liver Transplantation 17:836–848, 2011

Abstract

The portal vein flow (PVF), portal vein pressure (PVP), and hepatic venous pressure gradient (HVPG) were prospectively assessed to explore their relationships and to better define hyperflow and portal hypertension (PHT) during liver transplantation (LT). Eighty-one LT procedures were analyzed. No correlation between PVF and PVP was observed. Increases in the central venous pressure (CVP) were transmitted to the PVP (58%, range = 25%-91%, P = 0.001). Severe PHT (HVPG ≥ 15 mm Hg) showed a significant reciprocal association with high PVF (P = 0.023) and lower graft survival (P = 0.04). According to this initial experience, an HVPG value ≥ 15 mm Hg is a promising tool for the evaluation of hemodynamic stress potentially influencing outcomes. An algorithm for graft inflow modulation based on flows, gradients, and systemic hemodynamics is provided. In conclusion, the evaluation of PHT severity with PVP could be delusive because of the influence of CVP. PVF and PVP do not correlate and should not be used individually to assess hyperflow and PHT during LT.

Medistim comments

The paper includes an algorithm for GIM according to flows, gradients ans systemic hemodynamics. The measurements should be performed under stable hemodynamic conditions in the absence of active bleeding. The interpretation of flows and gradients is meaningful if an optimal outflow (represented by a triphasic waveform on duplex ultrasound) can be confirmed. When graft inflow modulation is being considered, a PVF value < 90 mL minute^{-1} 100 g of LW^{-1} should be avoided. Technical failures of the arterial anastomosis, kinking, or arterial spasms should be ruled out before the evaluation of HAF (mL minute^{-1}). PVF ≥ 4 indicates a PVF value (mL minute^{-1} 100 g of LW^{-1}) greater than 4 times the baseline normal value (≥360 mL minute^{-1} 100 g of LW^{-1}). The MAP and HVPG values are presented as millimeters of mercury (HVPG=PVP-CVP). The LDC (ie, Ne/Epi) dose is ≤0.05 g kg^{-1} minute^{-1}.



10.2 TTFM in the RAPID procedure

A Novel Concept for Partial Liver Transplantation in Nonresectable Colorectal Liver Metastases - The RAPID Concept[22]

Line P-D, Hagness M, Berstad AE, Foss A and Dueland S
Annals of Surgery Volume 262, Number 1, July 2015

Abstract

Objective: Selected patients with nonresectable colorectal liver metastases benefit from liver transplantation and have acceptable 5-year survival rates. However, allocating full-sized grafts to this group of patients is difficult due to the scarcity of grafts. This could be improved by utilizing small partial grafts,which mandates effective strategies to overcome the problems regarding insufficient functional liver mass.

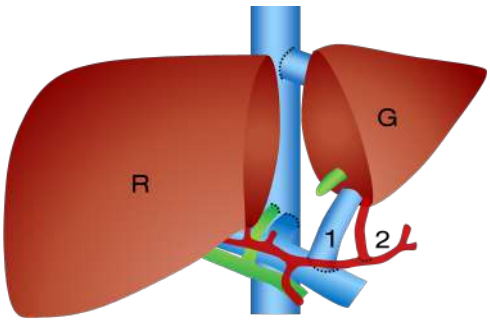
Methods: We have developed a protocol incorporating previously reported experiences from living donor transplantation and recent developments in liver surgery, facilitating transplantation of very small liver grafts. At the time of transplantation, segments 1 to 3 are resected in the recipient and orthotopically replaced by a segment 2 to 3 allograft. Portal inflow is modulated by redirecting the portal flow to the graft with concomitant focus on keeping the portal vein pressure below 20 mm Hg. A second-stage hepatectomy is performed as soon as the graft has regenerated to a sufficient volume.

Results: A graft weighing 330 g was transplanted to a 50-year-old man weighing 92 kg, and the portal vein to the right remnant liver was closed. The volume of the liver graft was doubled 2 weeks after the first procedure, and it increased further after the second procedure, with extended right hepatectomy performed at day 23 after transplantation. There were no signs of liver failure or small-for-size syndrome.

Conclusions: The current protocol and ongoing study could represent a possible strategy to increase the availability of liver transplantation to patients with nonresectable liver tumors such as hepatocellular carcinoma and colorectal liver metastases.

Medistim comments

This method has been validated by other hospitals and the results are very promising. Selection of patients for this procedure must be done very carefully and is an important success-factor. Dr. Line performs TTFM in all transplantation procedures - including liver, renal and pancreatic transplantations. He also refers to simultaneous flow and pressure measurements: “At least 15 minutes after revascularization, a pressure catheter is placed in the portal vein and flow probes attached to the portal vein and hepatic artery. Portal vein pressure is monitored after revascularization for 5 minutes during basal, stable conditions and during clamping of the right portal vein branch to the native liver remnant. If the pressure remains stable below 20 mmHg, the portal vein to the right remnant liver is ligated. If the pressure is higher than 20 mmHg during clamping, the splenic artery is ligated. If this does not alleviate graft portal hypertension, a banding of the portal vein to the right liver remnant is performed to form a stenosis that results in a stable portal pressure value to the graft of less than 20 mmHg. If this does not reduce the portal pressure sufficiently, a portocaval shunt may be constructed using the right portal vein in an end to side fashion to the cava.”



Schematic overview of the operative field after first-stage resection of segments 1 to 3 leaving an extended right liver remnant (R) and the transplanted segment 2 to 3 graft (G). Note the mode of vascular anastomosis with end-to-side anastomosis of the graft portal vein (1) and graft hepatic artery (2) to the main portal trunk and common hepatic artery, respectively.

11. Renal Transplantation

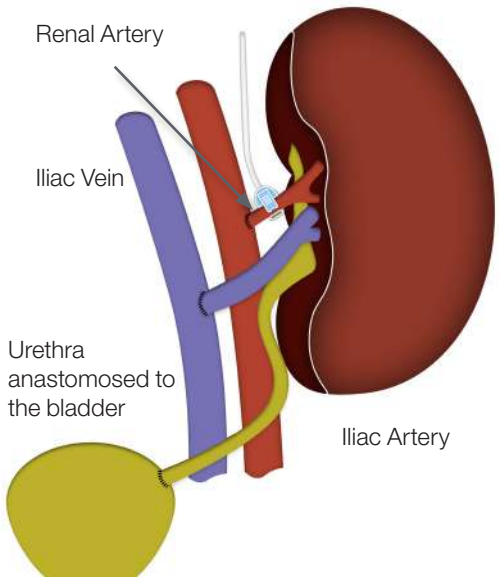
Evaluate renal transplant anastomoses

TTFM and HFUS provide accurate intraoperative assessment of renal graft patency and adequate flow in the renal and iliac arteries[17].

TTFM probe placement

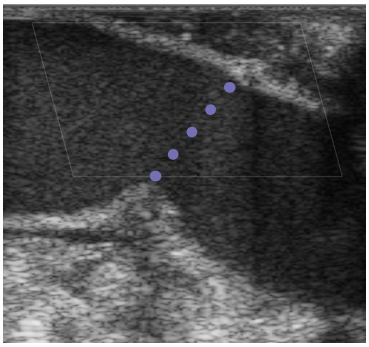
Place the probe on the renal artery and check that the flow is adequate. The expected flow in this artery depends on the quality of the graft, the patient's mean arterial pressure and the size of the patient and graft. Flow in the renal vein can be measured in the same way.

The space in the wound might be very tight, making it challenging to place the probes correctly on the vessels, but attempt to place the probe as correctly as possible. For these measurements, we recommend TTFM probes without handles.



HFUS imaging of the anastomoses

We recommend to check the integrity of the anastomoses in every case to avoid missing any technical issues. Place the imaging probe on the anastomosis both in longitudinal and transverse view. Below is an illustration of probe placement and a longitudinal view of the renal artery anastomosis. The anastomosis is clearly visible and patent.

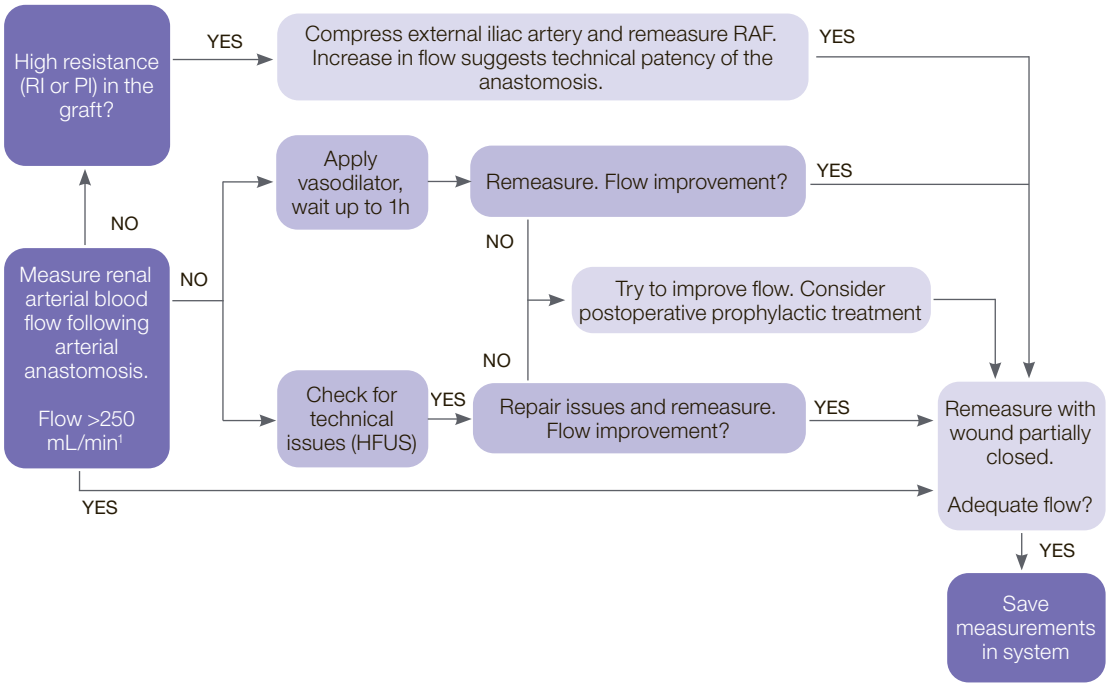


11.1 Workflow for TTFM during Renal Transplantation

As for liver transplantation, we recommend multiple measurements of flow during renal transplantation: immediately after graft reperfusion and then again prior to skin closure.

Lundell et al. identified 250 mL/min as a reference value for adequate renal artery flow[15]. This is a good reference as long as the quality of the renal graft is taken into consideration. In general, good quality (living donor) grafts give higher flows than deceased donor grafts.

Below is a suggested workflow for renal transplantation developed in collaboration with Mauricio Sainz-Barriga and Roberto Troisi in 2022:



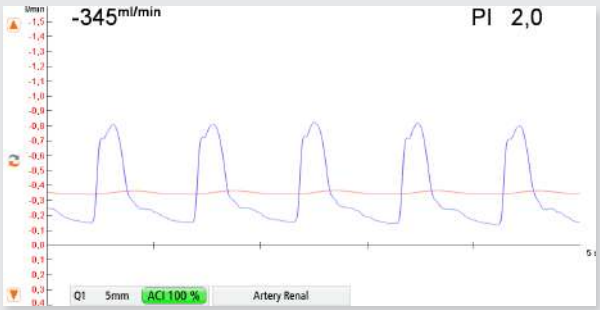
The measurements should be performed under stable hemodynamic conditions (MAP>65) in the absence of active bleeding.

The measurement time can be shorter than for liver transplantation: ~30 seconds may be sufficient to get a reliable measurement.

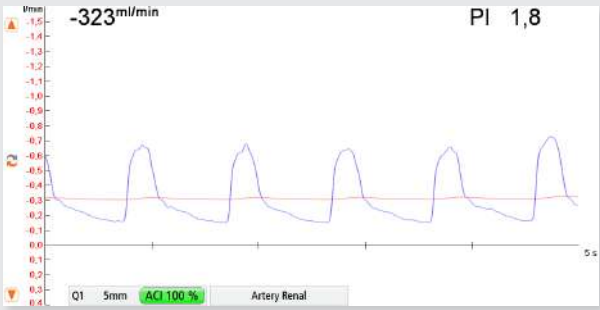
11.2 Normal TTFM in RT

Flow curves for the renal artery during renal transplantation should be repetitive and without sharp spikes. If the flow is lower than expected, a second or third measurement can be performed after waiting a few minutes. According to Lundell 1996, the renal artery flow (RAF) should be above 250 mL/min.

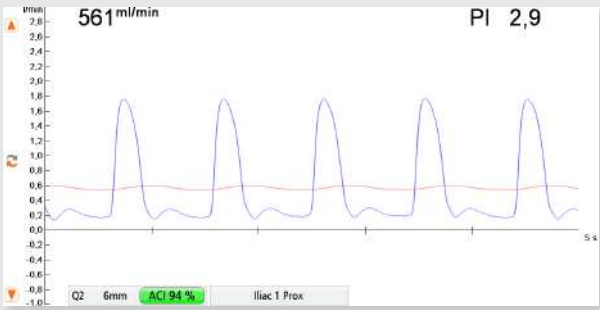
This TTFM shows good mean flow, although the probe is placed with the arrow pointing against the flow direction instead of pointing in the same direction as the flow.
This causes the X-axis to turn red, but does not affect the measurement quality. We still recommend to place the probe with the arrow pointing in the direction of the flow.



Normal flow curve with adequate flow values in Renal Artery during renal transplantation.
As in the previous example, the probe is placed with the arrow pointing against the flow direction instead of pointing in the same direction as the flow.



Proximal Iliac artery with normal flow curve.

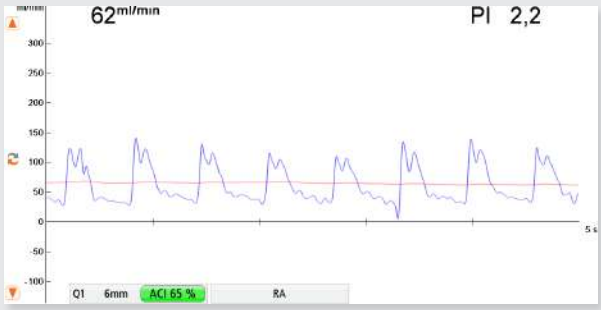


RENAL TRANSPLANT
TTFM EXAMPLES

11.3 Suboptimal TTFM in RT

Low flow values or spiky flow curves might be a sign that there is an issue with the anastomosis. The flow can increase over time.

In this example, a combined liver and renal transplantation is performed. The Renal Artery flow is lower than the recommended value (250 mL/min).

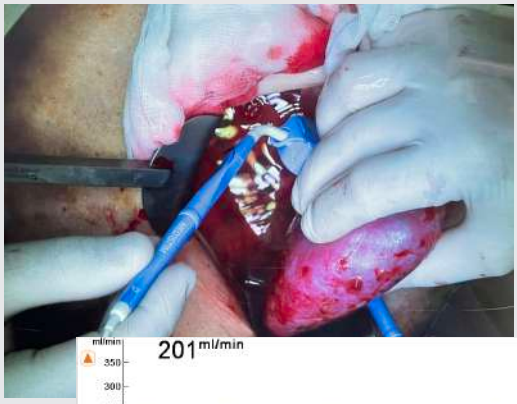


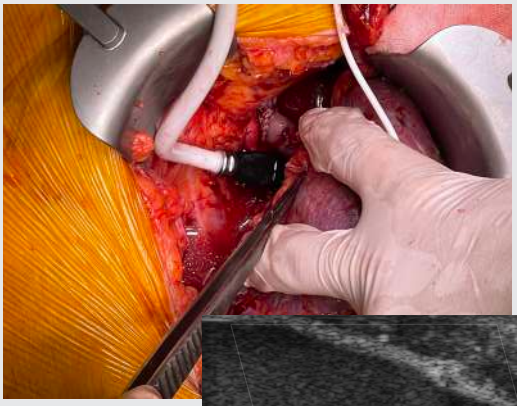
Renal artery flow lower than recommended (250 mL/min) and with high PI indicating obstruction of the flow. In this case HFUS could be used to investigate the reason for flow obstruction.

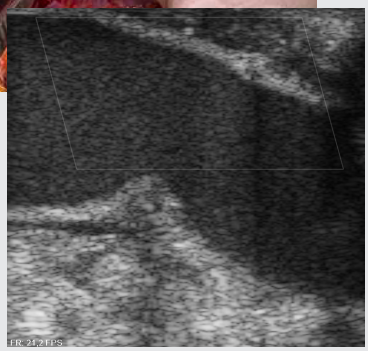
Proximal Iliac artery with retrograde flow and very high PI indicating that there is an issue that needs to be further investigated.

11.4 Case example Renal Transplantation

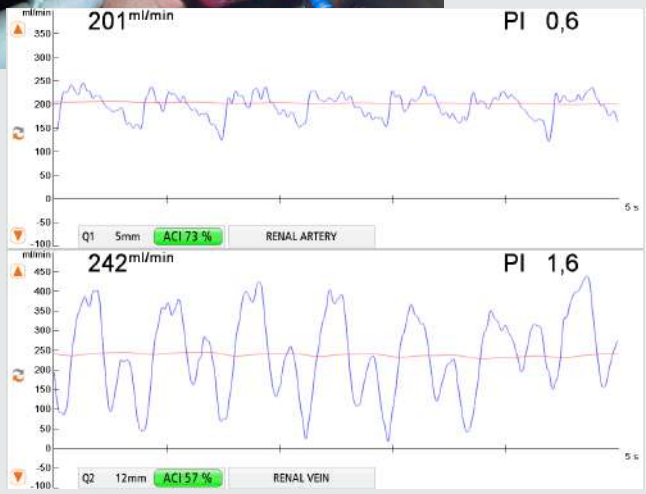
Living donor renal transplantation with robotic laparoscopic harvesting. The donor was the recipient's sister and of similar height and weight. The surgeries went as planned and the graft inflow and outflow was controlled by TTFM before wound closure. HFUS was performed to confirm patent anastomoses.







HFUS confirms that the anastomosis is patent.



TTFM of the Renal artery and the Renal vein show adequate mean flow and PI.

11.5 Published case example Renal Transplantation

The following case was published in Annals of Vascular Surgery in 2017. It shows a situation where neither TTFM nor ultrasound was used for completion control. Could it have revealed this case's technical issue?

Surgical Repair of a Living-Donor Kidney Graft Artery Kink by a Postanastomotic External Iliac Artery Rotation and Reanastomosis

Meier R et al. 2017. Ann Vasc Surg 2017; 44: 414.e5–414.e9

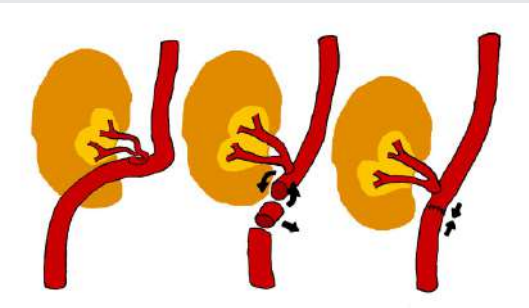
Abstract

A 61-year-old man received a living-donor kidney graft for an end-stage renal disease. In the postoperative course, the patient was oliguric and needed dialysis. The postoperative Doppler showed a normal peak systolic velocity and maintained parenchymal perfusion associated with a parvus tardus signal. The patient was operated, and a kinked renal artery was found.

To reposition the artery, the distal iliac artery was clamped, sectioned, shortened, and reanastomosed after a 90° axial rotation (see illustration). This innovative technic allowed restoration of a normal flow in the parenchyma and avoided an additional clamping, cooling, ischemia, and reanastomosis/reperfusion of the graft. Postoperative diuresis immediately raised >100 mL/hr and creatinine durably returned to normal values.

Medistim comments

This is a very interesting case report that shows a possible complication during renal transplantation. The authors comment that: "Per institutional guidelines, no perioperative Doppler ultrasonography or medistim was performed." It is possible that the use of TTFM and/or HFUS might have revealed this technical issue.



Schematic representation of the procedure used to unkink the renal graft artery. The distal iliac artery was clamped, sectioned (1 centimeter of length was removed), shortened, and reanastomosed after a 90! axial rotation.

12. Extracting images and video clips

This can be done by connecting a USB memory stick to one of the USB ports located on the media panel of the MiraQ device.

Screen capture and video export functionality is accessible through the **Screen Capture** button available on the right hand side menu when viewing a measurement in **Stopped** or **Edit** mode.

Depending on the device software version, ensure the functionality is made available by:

- Setting the device software to **Advanced Mode** under **System Settings** *(device software older than version 4.2.3)*
- Selecting **Enable Screen Capture** under **System Settings** > **Software Customization** *(device software version 4.2.3 or later)*

Go to the **Patient** screen and select **Search** to search for the patient with the relevant measurements. Select a patient from the list and choose **Select Patient**.

Open the **Archive and Reporting** tab and choose the desired measurement. Select **Edit** to open the selected measurement. Now select **Screen Capture** from the menu.

For non-imaging data, a screen shot of the current screen will be exported as a PNG file.

If the selected measurement contains imaging data, either a **Video** or a **Screen Shot** can be exported. When **Video** is selected, the current position of the cursors in the measurement defines the start frame and the end frame of the generated video. The currently selected playback speed will be used in the generated video.

The screen **Specify File name and Folder** will appear. Choose the USB memory stick and which folder to export the file to. Specify a file name and press **OK**. Once the file has been generated, the option for safe removal of the USB device will appear automatically.

MiraQ system media panel

13. Checklists

TTFM checklist

1. Insert the TTFM probe holding the widest part of the connector.*
2. Enter patient information
3. Perform functionality test
4. Choose the vessel to be measured
5. Annotate if relevant
6. ACI should be green or yellow
7. Mean flow red line should be flat
8. Press SAVE

**Never disconnect a probe by pulling on the cable*

HFUS checklist

1. Insert the imaging probe with the cable to the right and the locking lever in the unlocked position.*
2. Make sure connective medium is available
3. Select vessel to be imaged
4. Choose appropriate preset
5. If necessary, optimize settings
6. Label the measurement for future reference
7. Press SAVE once the desired object is in frame

14. Abbreviations

CVP	Central Venous Pressure ≈ IVCP
DDLT	Diseased Donor Liver Transplant
GIM	Graft Inflow Modulation
GRWR	Graft-to-Recipient Weight Ratio
HABR	Hepatic Arterial Buffer Response
HAF	Hepatic Artery Flow
HAS	Hepatic Artery Stenosis
HAT	Hepatic Artery Thrombosis
HFUS	High-Frequency Ultrasound
HVF	Hepatic Vein Flow
HVP	Hepatic Venous Pressure
HVPG	Hepatic Venous Pressure Gradient
IVCP	Inferior Vena Cava Pressure
LDLT	Living Donor Liver Transplantation
OLT	Orthotopic Liver Transplantation
PIM	Portal Inflow Modulation
pLT	Pediatric Liver Transplantation
PVF	Portal Venous Flow
PVT	Portal Vein Thrombosis
PVP	Portal Venous Pressure
RA	Renal Artery
RAF	Renal Artery Flow
SA	Splenic Artery
SAL	Splenic Artery Ligation
SAS	Splenic Artery (steal) Syndrome
SFSS	Small for Size Syndrome
SPSS	Spontaneous Porto-Systemic Shunt
THF	Total Hepatic Flow
TTFM	Transit Time Flow Measurement

15. References

1. Rasmussen A, Hjortrup A and Kirkegaard P. Intraoperative measurement of graft blood flow - a necessity in liver transplantation. Transpl Int (1997) 10:74-77

2. Miller CM, Quintini C, Dhawan A, Durand F, Heimbach JK, Kim-Schluger HL, Kyrana E, Lee S-G, Lerut J, Lo C-M, Pomfret EA. The International Liver Transplantation Society (ILTS) Living Donor Liver Transplant Recipient Guideline. Transplantation 2017;101: 938–944.

3. Breda A, K. Budde K, Figueiredo KA, Lledó García E, Olsburgh J, Regele H. EAU Guidelines on Renal Transplantation. European Association of Urology 2021

4. Lominchar PL, Orue-Echebarria MI, Martín L, Lisbona CJ, Salcedo MM, Olmedilla L, Sharma H, Asencio JM, López-Baena JÁ. Hepatic flow is an intraoperative predictor of early allograft dysfunction in whole-graft deceased donor liver transplantation: An observational cohort study. World J Hepatol 2019 September 27; 11(9): 689-700

5. Troisi RI and de Hemptinne B. Clinical Relevance of Adapting Portal Vein Flow in Living Donor Liver Transplantation in Adult Patients. Liver Transplantation, Vol 9, No 9, Suppl 1, 2003: pp S36-S41.

6. Pratschke S, Meimarakis G, Mayr S, Graeb C, Rentsch M, Zachoval R, Bruns CJ, Kleespies A, Jauch K-W, Loehe F, Angele MK. Arterial Blood Flow Predicts Graft Survival in Liver Transplant Patients. Liver Transpl 17:436-445, 2011.

7. Sainz-Barriga M, Scudeller L, Costa MG, de Hemptinne B, Troisi RI. Lack of a correlation between portal vein flow and pressure: Toward a shared interpretation of hemodynamic stress governing inflow modulation in liver transplantation. Liver Transplantation 17:836–848, 2011.

8. Hashimoto K, Aucejo F, Quintini C, El-Gazzaz G, Hodgkinson P, Fujiki M, Diago T, Kelly D, Winans C, Vogt D, Eghtesad B, Fung J, Miller C. Liver Transplantation at Cleveland Clinic. Clinical Transplants 2010, Kap. 18, 195-206.

9. Matsushima H, Sasaki K, Fujiki M, Uso TD, Aucejo F, Kwon CHD, Eghtesad B, Miller C, Quintini C, Hashimoto K. Too Much, Too Little, or Just Right? The Importance of Allograft Portal Flow in Deceased Donor Liver Transplantation. Transplantation, April 2020, Volume 104, Number 4.

10. Unpublished data communicated by Troisi RI, 2020.

11. Sainz-Barriga M, Reyntjens K, Costa MG, Scudeller L, Rogiers X, Wouters P, de Hemptinne B, Troisi RI. Prospective evaluation of intraoperative hemodynamics in liver transplantation with whole, partial and DCD grafts. American Journal of Transplantation 2010; 10: 1850–1860.

12. Troisi RI, Cammu G, Militerno G, De Baerdemaeker L, Decruyenaere J, Hoste E, Smeets P, Colle I, Van Vlierberghe H, Petrovic M, Voet D, Mortier E, Hesse UJ, de Hemptinne B. Modulation of portal graft inflow: A necessity in adult living donor liver transplantation.Ann Surg 2003, 237(3):429-436.

13. Troisi RI, Ricciardi S, Colle I, Van Vlierberge H, Smeets P, Petrovic M, de Hemptinne B. Effects of hemi-portocaval shunts for inflow modulation on the outcome of small-for-size grafts in living donor liver transplantation. Am J Transpl 2005, 5: 1397-1404.

14. Fujiki M, Hashimoto K, Palaios E, Quintini C, Aucejo FN, Uso TD, Miller CM. Probability, management, and long-term outcomes of biliary complications after hepatic artery thrombosis in liver transplant recipients. Surgery 2017;162:1101-11.

15. Lundell A, Persson NH, Kållen R and Ekberg H. Impaired Renal Artery Blood Flow at Transplantation Is Correlated to Delayed Onset of Graft Function. Transplant International 1996;9(1)57-61.

16. Bueno J, Escartín A, Balsells J and Margarit C. Intraoperative Flow Measurement of Native Liver and Allograft During Orthotopic Liver Transplantation in Children. Transplantation Proceedings, 39, 2278–2279 (2007)

17. Bhatt KA, Karamanoukian HL, Bergsland J, D'Ancona G and Stephan R. Intraoperative Graft Verification in Renal Transplants. Vasc Endovascular Surg 2002; 36; 93

18. Sainz-Barriga M, Naesens M, Gilbo N, Jochmans I, Monbaliu D, Kuypers DR and Pirenne J. Intraoperative Renal Perfusion in Kidney Transplantation: A Retrospective Study. Transplantation: July 2018 - Volume 102 - Issue - p S557.

19. Goodyear SJ, Barnes J, Imray CE, Higgins R, Lam FT, Kashi SH, Tan LC & Imray CHE. The feasibility and applications of non-invasive cardiac output monitoring, thrombo-elastography and transit-time flow measurement in living-related renal transplantation surgery: results of a prospective pilot observational study. Transplant Res. 2014;3:16.

20. Czigany Z, Boecker J, Morales Santana DA, Bednarsch J, Meister FA, Amygdalos I, Isfort P, Liebl M, Neumann UP and Lurje G. Median Arcuate Ligament Compression in Orthotopic Liver Transplantation: Results from a Single-Center Analysis and a European Survey Study. J. Clin. Med. 2019, 8, 550

21. Meier R et al. Surgical Repair of a Living-Donor Kidney Graft Artery Kink by a Postanastomotic External Iliac Artery Rotation and Reanastomosis. Ann Vasc Surg 2017; 44: 414.e5–414.e9.

22. Line P-D, Hagness M, Berstad AE, Foss A and Dueland S. A Novel Concept for Partial Liver Transplantation in Nonresectable Colorectal Liver Metastases - The RAPID Concept. Annals of Surgery Volume 262, Number 1, July 2015.

Additional references can be provided upon request.

"Intraoperative graft flow measurement may provide valuable information to help estimate the risk of early graft loss as well as surgical complications. Our results highlight the importance of securing PF that is "just right" for a grafted liver in successful DDLT." [9]

Matsushima et al. 2020 Cleveland Clinic, Ohio USA
"Too Much, Too Little, or Just Right?"

marketing@medistim.com
medistim.com

Medistim ASA (Head office)
Økernveien 94
0579 Oslo
Norway
Phone +47 23 05 96 60

Medistim ASA (Manufacturing)
Bromsveien 17
3183 Horten
Norway
Phone +47 33 03 17 26

Medistim Norge AS
Økernveien 94
0579 Oslo
Norway
Phone +47 23 03 52 50

Medistim Danmark ApS
Søgade 16
4100 Ringsted
Denmark
Phone +45 23 800 300

Medistim USA Inc.
14000 25th Ave N. Ste.108
Plymouth, MN 55447
USA
Phone +1 763 208 9852

Medistim Deutschland GmbH
Bahnhofstr. 32
82041 Deisenhofen
Germany
Phone +49 (0) 89 62 81 90 33

Medistim Spain S.L.
Calle Balmes 173, 4º, 2
08006 Barcelona
Spain
Phone +34 911 238 318

Medistim UK Limited
34 Nottingham South Ind Est
Ruddington Lane Wilford
NG11 7EP Nottingham
United Kingdom
Phone +44 (0) 115 981 0871

Medistim Canada, Inc.
130 King Street West,
Suite 1900
Toronto, Ontario M5X 1E3
Canada
Phone: +1 844 819 9636

Medistim (Guangzhou) Medical Technology Co., Ltd
KB Dongzhao Building,
515 Dongfeng Middle Road
Yuexiu District, Guangzhou
China
Phone +86 188 1683 0702

GBTXINen 1.0.0 09/23