MEDISTIM

Intui

CABG Guidebook

Intraoperative guidance and quality assessment using TTFM & HFUS

VOLUME 1, SEPTEMBER 2025


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US Assessment
Cross clamp off
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Q1
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ECG
5 s
Imaging
Flow
Save

“

TTFM should be used in every CABG case.

- Gaudino M, Sandner S, Di Giammarco G, Di Franco A, Arai H, Asai T, Bakaeen F, Doenst T, Fremes SE, Glineur D, Kieser TM, Lawton JS, Lorusso R, Patel N, Puskas JD, Tatoulis J, Taggart DP, Vallely M & Ruel M. 2021 [1]

CONTENTS

1. INTRODUCTION

Medistim launched its first TTFM-based flowmeter (CardioMed) in 1994 and has since developed several generations of quality assurance systems.

In 2009, Medistim introduced the first ultrasound imaging probe approved for direct cardiac contact and remains the only company offering an integrated, user-friendly TTFM and intraoperative high-frequency ultrasound (HFUS) imaging system.

Medistim MIraQ™ Cardiac System

With the introduction of **INTUI**, Medistim's next-generation cardiac software, the MiraQ Cardiac system now offers clearer visualization, more intuitive workflows, and smarter reporting tools. Developed in close collaboration with surgical teams, **INTUI** improves intraoperative guidance and graft assessment by providing real-time insight, streamlined navigation, and stronger documentation, ensuring a higher standard of care.

TTFM is standard clinical practice in many countries. It was included in the European coronary revascularization guidelines in 2010, followed by NICE recommendations in 2011, which were updated in 2018 and 2022 to include MiraQ. Intraoperative ultrasound imaging is also endorsed by the American Heart Association.

OBJECTIVE

The objective of this guidebook is to provide a comprehensive overview of the Medistim Cardiac INTUI system 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 (eduq.medistim.com).

Medistim Vascular TTFM Probes

Medistim Imaging Probe

Medistim QuickFit™ TTFM Probes

2. WHY PERFORM TTFM AND HFUS?

Already in 2000, D'Ancona et al. concluded in a publication on TTFM: "Evaluation of TTFM is valuable in determining the status of a coronary graft after CABG. Correct interpretation of flow patterns allows for correction of abnormalities prior to chest closure." [2]

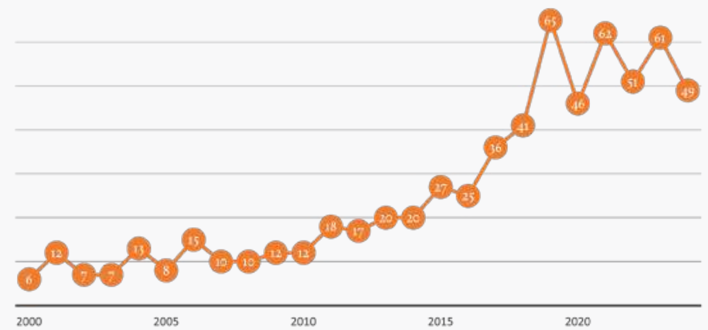
In 2018, Kieser and Taggart published their perspective on the use of intraoperative graft assessment in guiding graft revision: [3] They wrote: "Quality assurance of the CABG procedure is receiving attention for multiple reasons:

1. Failed bypass grafts may exist without any intraoperative sign, including hemodynamic instability, electrocardiographic signs of myocardial infarction and/or new regional wall abnormalities seen on transesophageal echocardiography. [4]
2. Transit-time flow measurement (TTFM) and epicardial ultrasound (ECUS) are reliable intra-operative graft patency validation techniques. [5]
3. It is prudent to verify connections between two 1–2 mm vessels. [5]
4. Intraoperative quality assurance techniques have long existed for other cardiac operations, such as intraoperative transesophageal echocardiography for mitral valve repair." [6]

Kieser and Taggart state that these two intraoperative techniques should be used to improve patient outcomes. However, change may not always be readily embraced. In spite of guidelines provided both in USA and Europe, graft verification techniques are still not universal.

The adoption of TTFM and HFUS for surgical guidance and quality control is increasing. However, there are still surgeons who rely on palpation for graft patency assessment even though feeling a pulse does not indicate that there is actually flow passing through the vessel. [6] Increasing demands by hospitals and payers for documentation of performance and quality control during surgery make the Medistim system an ideal fit for practice.

The number of publications on this technique continues to grow, with more articles published each year. Medistim actively monitors the field and has identified over 675 clinical publications involving surgeries performed with our TTFM and HFUS systems.



3. COMPARATIVE DATA

TTFM vs no TTFM and PI < 5 vs PI > 5

Kieser and Taggart cite four studies demonstrating a correlation between the use of TTFM and a decrease in adverse patient outcomes.[13, 14, 4, 12] Since 2018, three more comparative studies have been published.[9, 10, 11]

Two authors estimate that TTFM adds just 10-30 seconds per measurement, depending on the level of experience [9, 6] With three measurements on three grafts, the added OR time would be 1.5-3 minutes. The table below presents the reduction in adverse events by adding TTFM during CABG.

Ref.	TTFM	n=	Revision*	MACE	Periop. MI	Re-op.	Morbidity	Mortality	Post-op angio ITA patency
Laali 2022 [9]	No	480	0.0%	6.9%					
	Yes	430	1.4%	3.3%					
Quan 2022 [10]	No	66			32%**				
	Yes	80			14%*				
Kim 2019 [11]	No	221	-			7.2%			97.1%
	Yes	2599	5.6%			2.3%			99.4%
Kieser 2010 [6]	PI > 5	59	4.2%	17%				9%	
	PI ≤ 5	277		5.4%				2%	
Herman 2008 [12]	PI > 5	184	2.0%		1.0%	0.5%	31%		
	PI ≤ 5	761			0.7%	0%	17%		
Becit 2007 [13]	No	100	0.0%		5.0%		16%	4%	
	Yes	100	9.0%		0.0%		6%	0%	
Bauer 2005 [14]	No	4321	0.3%		1.6%			1.5%	
	Yes	3484	3.2%		0.7%			1.2%	

* Patients with graft revision

** Perioperative MI defined as Troponin I > 2380 ng/L

MI: Perioperative or postoperative Myocardial Infarction

MACE: Major Adverse Cardiac Events

PI: Pulsatility index

Re-op.: Re-intervention

4. GUIDELINES & CONSENSUS

2018 ESC/EACTS GUIDELINES ON MYOCARDIAL REVASCULARIZATION

The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS) recommend graft assessment by TTFM and epiaortic HFUS prior to manipulation. [15]

"Transit-time flow measurement is the most frequently used technique for graft assessment and has been able to detect 2 - 4% of grafts that require revision. In observational studies, the use of intraoperative graft assessment has been shown to reduce the rate of adverse events and graft failure, although interpretation can be challenging in sequential and T-graft configurations."

ESC
European Society of Cardiology
EACTS
European Association for Cardio-Thoracic Surgery

RECOMMENDATIONS

TTFM:
Routine intraoperative graft flow measurement should be considered

Recommendation class IIa
Evidence level B

HFUS:
Epiaortic scanning should be considered prior to aortic manipulation

Recommendation class IIa
Evidence level C

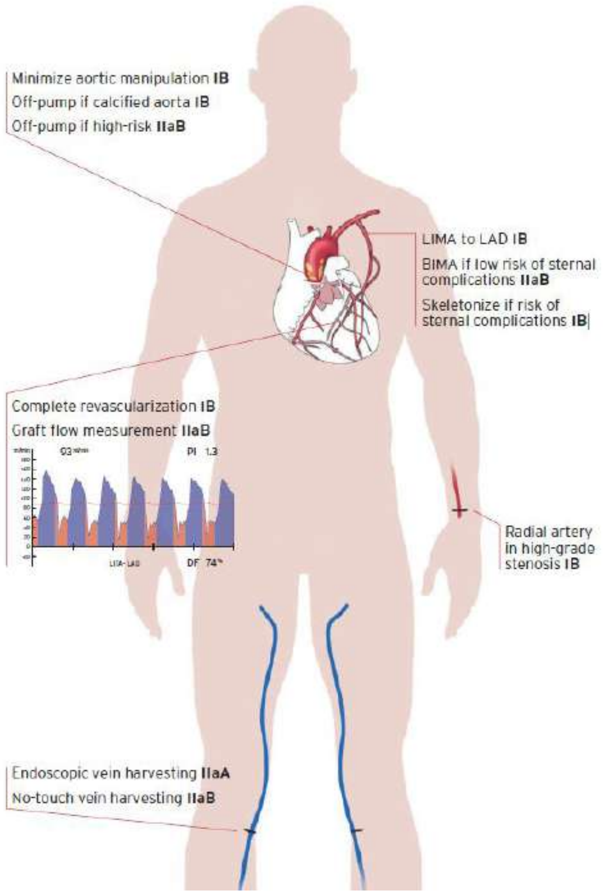


Illustration from the 2018 ESC/EACTS guidelines including TTFM

2022 NICE - NATIONAL INSTITUTE FOR HEALTH AND CARE EXCELLENCE

“The MiraQ system is recommended as a cost saving option for assessing graft flow during coronary artery bypass graft surgery. Clinical evidence shows that the MiraQ system is effective for assessing coronary artery bypass grafts and allows for grafts to be revised during surgery.

This may reduce the frequency of graft occlusion and may reduce perioperative morbidity and mortality. The MiraQ system can lead to an estimated cost saving of £80.27 per person compared with clinical assessment.” [16]

NICE
National Institute for Health and Care Excellence

2015 ASE AND EACVI GUIDANCE ON IMAGING OF THORACIC AORTA

The American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI) recommend epiaortic ultrasound to reduce risk for perioperative stroke. [17]

“Several investigators have demonstrated that Epiaortic Ultrasound (EAU) is superior to both manual palpation and TEE for detecting atheroma in the ascending aorta and arch. Compared with TEE, EAU has better resolution, less artifacts, no blind spot, and has superior detection of disease in the mid and distal ascending aorta. Furthermore, EAU also appears to be superior to preoperative CT for this purpose.”

ASE
American Society of Echocardiography

EACVI
European Association of Cardiovascular Imaging

2021 ACC/AHA/SCAI GUIDELINE FOR CORONARY ARTERY REVASCULARIZATION

A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. [18]

”In patients undergoing CABG, the routine use of epiaortic ultrasound scanning can be useful to evaluate the presence, location, and severity of plaque in the ascending aorta to reduce the incidence of atheroembolic complications”
(Class IIa, level B-NR)

Comment: “Epiaortic ultrasound has been demonstrated to be far superior to either surgical digital palpation or transesophageal echocardiography (TEE) for defining the presence and extent of disease and has come to be recognized as the “gold standard” for the detection of aortic atherosclerosis.”

ACC
American College of Cardiology

AHA
American Heart Association

SCAI
Society for Cardiovascular Angiography and Interventions

The Use of Intraoperative Transit Time Flow Measurement for Coronary Artery Bypass Surgery - Systematic Review of the Evidence and Expert Opinion Statements

Authors: Gaudino M, Sandner S, Di Giammarco G, Di Franco A, Arai H, Asai T, Bakaeen F, Doenst T, Fremes SE, Glineur D, Kieser TM, Lawton JS, Lorusso R, Patel N, Puskas JD, Tatoulis J, Taggart DP, Vallely M & Ruel M. | Circulation. 2021;144:1160–1171.

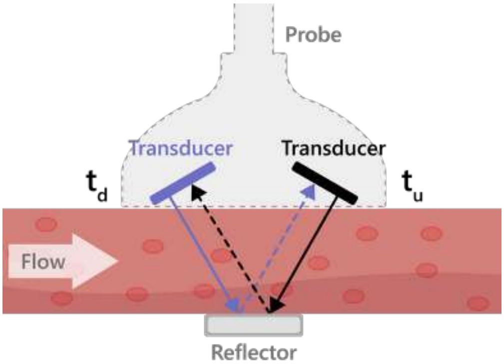
This group of 19 cardiothoracic surgeons performed a systematic review of the evidence on TTFM and other methods for quality control in coronary artery bypass grafting and elaborated expert recommendations by using a structured process. The consensus process consisted of two rounds of electronic voting and a final face-to-face virtual meeting. Eighty percent agreement was required for acceptance of the statements. Ten expert statements for TTFM use in clinical practice were formulated. These consensus statements will help to standardize the use of TTFM in clinical practice and provide guidance in clinical decision-making.

#	CONSENSUS STATEMENT	AGREEMENT
1	TTFM should be used in every CABG case.	83.3 %
2	The size of the TTFM probe must perfectly fit the explored conduit. In particular, the probe should neither be too small so that it compresses the conduit, nor too large so that the contact is poor.	88.9%
3	The TTFM probe should be positioned in the mid or distal part of the graft, if this is possible without risk of hemodynamic compromise or excessive traction on the graft.	83.3 %
4	TTFM measurements should be performed at least immediately before and after protamine administration and immediately before chest closure. Additional measurements during cardiopulmonary bypass or after the completion of each anastomosis (for off-pump cases) may be useful especially if competitive coronary flow is anticipated.	83.3 %
5	If TTFM measurements are questionable at lower mean arterial pressure (MAP), they should be repeated at MAP ≥80 mm Hg.	100%
6	At least one TTFM measurement per graft taken before sternal closure should be recorded.	94.4%
7	A mean flow <15 to 20 mL/min or a PI >3 to 3.5 (5 for the right coronary artery distribution) should elicit the suspicion of graft malfunction and prompt further evaluation of the anastomosis and the conduit.	88.9%
8	A percentage of backward flow (%BF) >3% in conjunction with MGF and PI outside the described cutoffs should elicit the suspicion of graft malfunction and prompt further evaluation of the graft.	83.3 %
9	Functional test using inotropic or vasodilatory challenges or proximal snaring of the target vessel may be useful in case of suspicion of graft malfunction attributable to competitive flow.	100%
10	The decision to revise the anastomosis should be based not only on TTFM reading, but also on the clinical scenario and the surgeon's assessment of the conduit and the target vessel.	94.4%

5. TTFM AND DOPPLER PRINCIPLES

Doppler and TTFM are different in several ways. With TTFM, ultrasound is used to measure blood flow volume directly. This differs from the Doppler principle that measures flow velocity.

TTFM

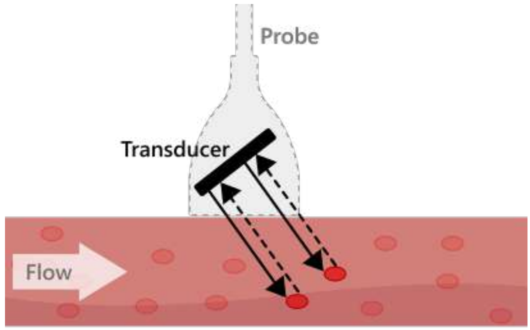


TTFM is based on the fact that the time required for ultrasound to pass through blood is slightly longer upstream (t_u) than downstream (t_d). The mean flow is calculated by using a constant from the calibration: Flow (Q) = Constant x $(t_u - t_d)$

TTFM probes are designed to fit around the vessel, and selecting the correct size ensures optimal measurement conditions. Two ultrasound transducers emit pulses in opposite directions through the bloodstream. Although both pulses travel the same distance, the flow of blood causes a difference in transit time, which the system records.

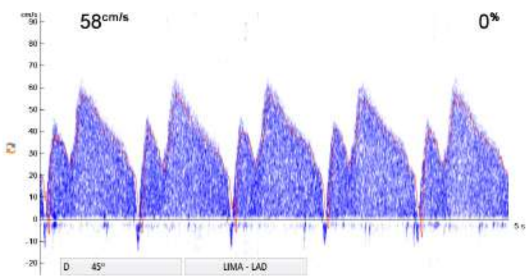
This difference is directly proportional to the blood volume in mL/min. Each probe has a unique Constant used during calibration. By applying the wide-beam ultrasound principle, flow volume is measured accurately when the properly sized probe is placed around the vessel.

DOPPLER



Doppler technology estimates velocities from the Doppler shift of the reflected waves (backscattering) from particles (blood cells) within the vessel.

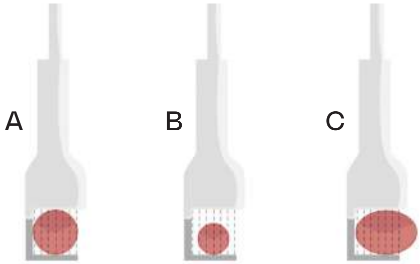
Doppler measurements provide a spectrogram showing the velocity distribution of the blood within the range gate. The spectrogram can be used to calculate the bloodflow volume in the vessel, but the result will rarely be as accurate as with TTFM. This is due to the varieties in intraluminal shape and diameter as well as angle sensitivity.



Doppler is useful when searching for deep/intramural vessels, and to distinguish between arteries and veins. Doppler provides information on type of flow (e.g. detect turbulent flow) and can be used to locate and quantify stenoses.

6. SELECTING THE CORRECT PROBE SIZE

Accurate measurements depend on selecting the correct probe size. The probe should wrap around the vessel without compressing, bending, or twisting it. Various sizes are available to ensure optimal contact, with 2–5 mm probes most commonly used for coronary flow measurements.



A. Correct probe size will provide a reliable measurement.

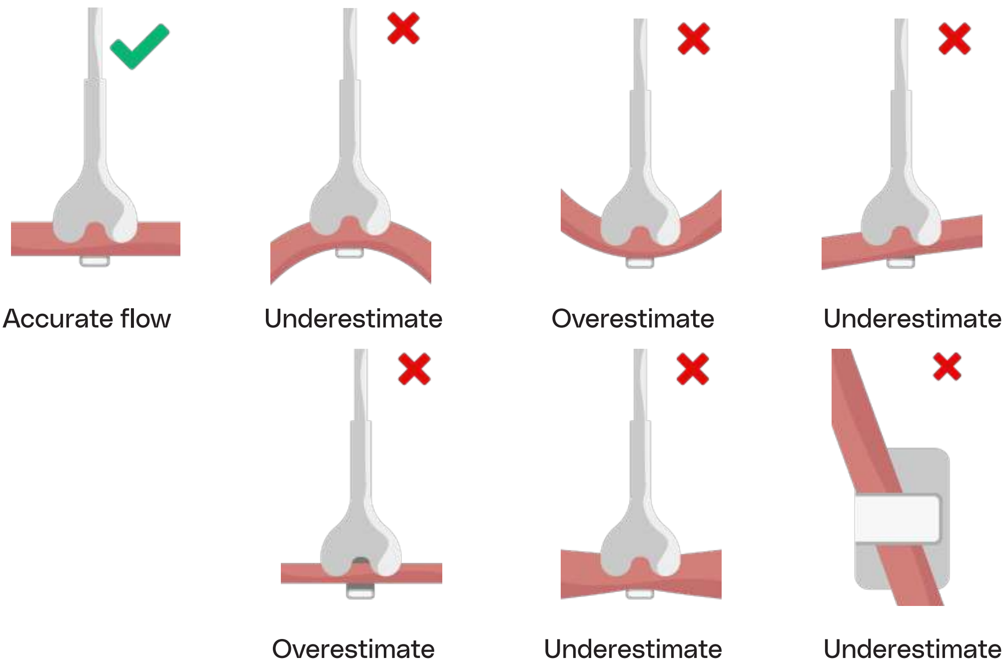
B. An oversized probe may result in poor vessel contact and make proper graft alignment more difficult.

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

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

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 correct placement of the vessel. Situations that may provide inaccurate measurements. Figure partly derived from Amin S. [27]



7. PERFORM FUNCTIONALITY TEST

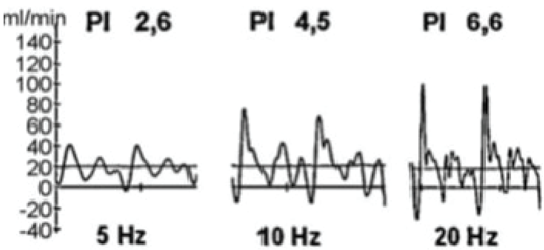
Before using a TTFM probe, a functionality test must be performed to ensure that the probe and system are functioning optimally.

1. Connect the probe to the MiraQ™. A measurement trace will appear on screen.
2. Place the probe in a container, preferably plastic, with sterile saline solution. If a metal container is used, cover the bottom with gauze or cotton to avoid disturbances in the measurement.
3. Verify good ACI (Acoustic Coupling Index). If ACI is below 90%, try stirring the liquid with the probe to dislodge air bubbles.
4. Check that the offset in mean flow (red line) is close to zero.
5. If the ACI is less than 90% and/or the offset is large, the probe is not working properly and should be replaced (refer to the MiraQ IFU for troubleshooting tips).

FILTER SETTING

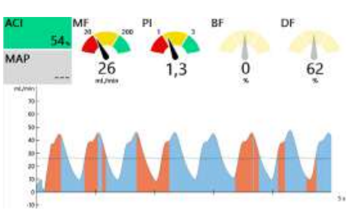
The default and recommended filter setting for Medistim systems is 20Hz. Using a lower setting results in a smoother TTFM curve and lower PI, so PI expectations should be adjusted accordingly. The reference values in this guide are based on the 20Hz setting.

Nordgaard et al. have studied the effect on PI from different filter settings.[20] The curves below illustrate the effect on tracings measured with different filter settings:

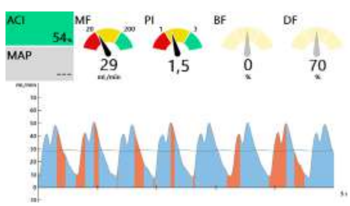


A lower filter setting may camouflage important information while a too high filter setting may include too much noise.

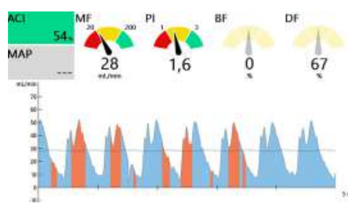
The screenshots from MiraQ below illustrate how this might look on the screen. Note that the PI increases as the filter setting is increased.



Filter set at 5Hz



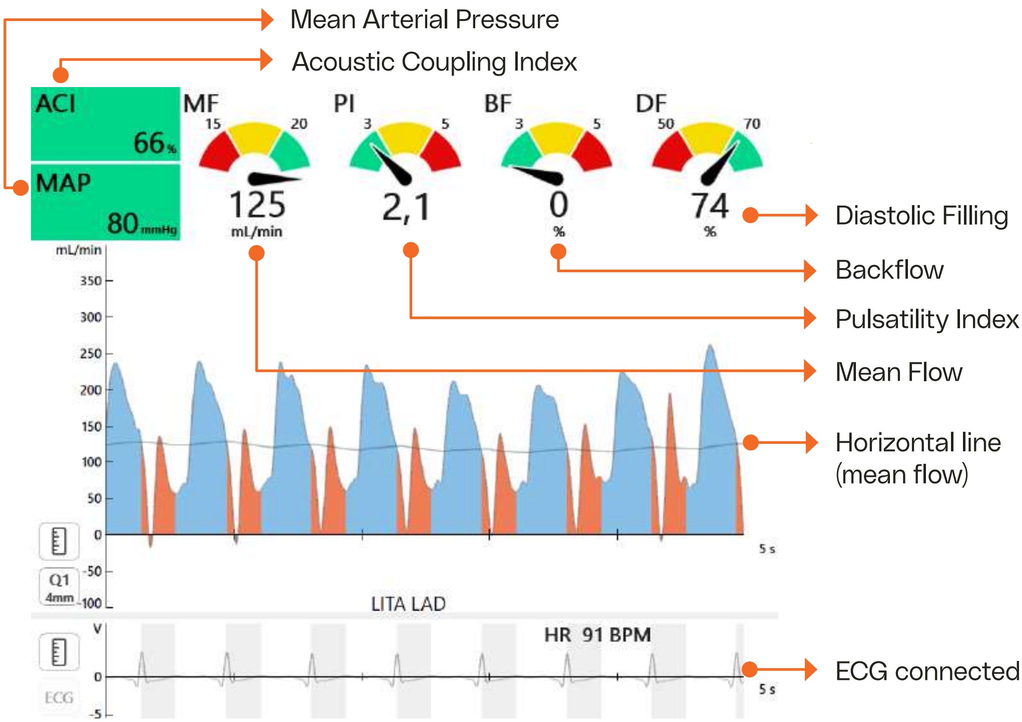
Filter set at 10Hz



Filter set at 20Hz

8. WHAT DO THE NUMBERS MEAN?

The following sections outline key factors for performing TTFM. The INTUI interface presents the same information as earlier versions, but in a new layout. You can choose to view the screen with both colored tiles and gauges, or just colored tiles. ACI and MAP indicate whether measurement conditions are satisfactory.



ACOUSTIC COUPLING INDEX (ACI)

ACI	50-100 %	Good
ACI	30-50%	Acceptable
ACI	0-30 %	Unacceptable

ACI reflects proper contact between the probe and the vessel. For reliable TTFM, ACI should be above 30%, showing green or yellow. Red ACI may result in inaccurate or inconsistent readings. For example, the ITA pedicle can cause low ACI due to high ultrasound attenuation. Skeletonizing a small segment (~15 mm) can improve contact. If ACI drops below 10%, no measurement will be displayed.

MAP (MEAN ARTERIAL PRESSURE)

MAP	70-90 mmHg	Good
MAP	< 70 or > 90 mmHg	Acceptable

MAP can be entered manually or via the pressure channel. It helps interpret TTFM results, as lower pressures typically lead to lower flows. Ideally, flow should be assessed at the patient's normal blood pressure, but since this can be difficult, an MAP of 70–90 mmHg is recommended, aligned with most studies referenced in this booklet. 80 mmHg was used in the **REQUEST** trial. Preferred MAP range can be stored in the system so that the color-coded tile signals whether the value is within range.

MEAN FLOW (MF)

Mean flow is the numerical value of the red horizontal line. Factors influencing mean flow are: mean arterial pressure (MAP), the size of the vessel, the quality of the coronary bed, the size of the native coronary artery and possible spasm in arterial grafts or the native coronary artery. Mean flow should be evaluated against what you expect based on these factors. A low mean flow value in itself is not an indication of a compromised graft, but only part of the diagnostic information. Mean flow will often increase for a while after the procedure, so waiting and measuring again is recommended if mean flow is the only parameter that is out of range.

The **horizontal line** on the screen is the average mean flow over the last 7 seconds. This setting can be adjusted in the system preferences. After positioning the probe, wait 7–10 seconds for the line to stabilize before saving. If the probe is repositioned, wait another 7 seconds. Pressing **SAVE** stores up to the last 60 seconds of data.

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.

Turbulence results in elevated PI and spikes in the flow tracing. If the probe is positioned over an internal valve of a saphenous vein graft, the PI may be elevated due to turbulent flow. Reposition the probe to see if PI improves. Before making the final decision to undo the anastomosis to correct for technical error, make sure to do a second measurement. Wait a few minutes to allow the flow to normalize and measure again. Spasm in an arterial graft or the perfused bed can cause a decrease in flow with an increase in PI.

BACKFLOW (BF%)

The amount of retrograde flow in the graft, expressed as a percentage of the total flow. Backflow is blood flowing backwards from the native coronary through the anastomosis into the conduit. This is represented by the trace located below the zero line. Backflow can be caused by competitive flow in the native artery or by steal from other vessels. For more information on how to view and understand backflow/insufficiency %, see Chapter 16. Backflow.

DIASTOLIC FILLING PERCENTAGE (DF)

DF is the flow volume during diastole and is calculated while the system is connected to the ECG monitor. The cardiac muscle is usually perfused with diastolic dominance during the resting phase of the heart cycle. The rest of the body is perfused during systole. Expected DF% differ for the right side and the left side of the heart since the right ventricle, being less muscular, pumps blood to the lungs, while the left ventricle, supplies blood to the entire body.

Diastolic filling should be ≥50% on the right side of the heart and >60–70% on the left side.[6] A lower value may indicate resistance to blood flow, even when the heart muscle is normally perfused. DF% is particularly important in low-flow situations (Q < 10 ml/min).

REFERENCE VALUES

Relying on one or two TTFM parameters is not enough to accurately assess graft patency. A complete evaluation requires consideration of the full clinical picture. All relevant factors must be reviewed before concluding there is a problem with the bypass graft.[1]

Medistim refers to published and peer-reviewed literature to recommend reference values.[6, 21-28] Abstracts and workflows from two such studies are included in Chapter 25. Published Workflows [6, 28]

When configuring the Medistim MiraQ Cardiac INTUI system, customized reference ranges can be applied to the gauges to indicate red, yellow, or green readings. Without this configuration, the gauges will remain gray.

The table below outlines the TTFM parameters along with commonly used reference values. In addition to these, mean arterial pressure (MAP) should be sufficiently high, and the Acoustic Coupling Index (ACI) should be 30% or higher.

PARAMETER				
DEFINITION	Mean graft flow; Calculation: Average mean flow over the last 7 seconds	Pulsatility Index Calculation: (Qmax – Qmin) / Qmean	Diastolic Filling Calculation: Qdiastole/ Qtotal	Backflow Calculation: Percentage of the area below zero-line
REFERENCE VALUES	> 15-20 mL/min for arteries > 40 mL/min for SVG	Right side: < 5.0 Left side: < 3.0 On pump: < 0.3-0.4 [3]	> 50% > 60-70% on the left side	< 3% on left side < 5% on right side
AFFECTED BY	• Blood pressure (MAP) • Size/quality of graft • Quality of native coronary artery • Distal run-off/ resistance • Spasm • Blood velocity • Air bubbles	• Anastomotic narrowing • Distal stenosis • Distal occlusion (thrombus) • Twist or kink • Misplaced stitch • Poor run-off • Competitive flow	Higher on left side due to myocardial pressure	• Increases with less severe native coronary artery stenosis (competitive flow) • Steal flow from other vessels (e.g. Subclavian steal)

WHAT IF THE FLOW PARAMETERS ARE SUBOPTIMAL?

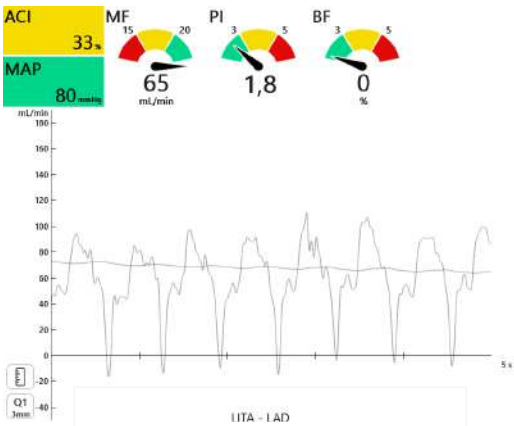
If the TTFM parameters do not meet the suggested reference values, there are several steps that can be taken to confirm if there is any issue with the graft:

- Wait for a while and re-measure with MAP stabilized at 80 mmHg
- Use ultrasound to assess graft integrity
- Check proximal and distal anastomotic patency with ultrasound
- Perform a stress test using dobutamine
- Compress the native coronary artery to evaluate competitive flow
- Consider revising the anastomosis
- Consider rearranging the grafts

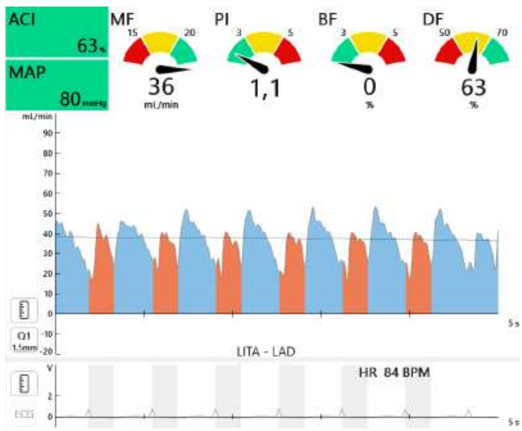
CONNECT ECG

Connect the monitor device to the AUX port on the MiraQ using an interconnect cable.

The ECG must be connected to get a visual illustration of systolic (orange) and diastolic (blue) flow and calculation of diastolic filling (DF%). D'Ancona et al. state that ECG should always be coupled to the TTFM system.[2] A low DF% may be an indication of a problem with the graft. Without an ECG connection, the waveform will not be filled in with blue and orange and no DF% will be displayed as demonstrated in the examples below.



Without ECG connected



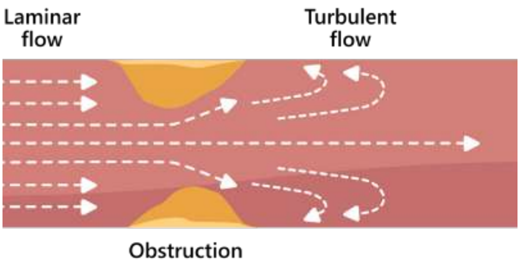
With ECG connected

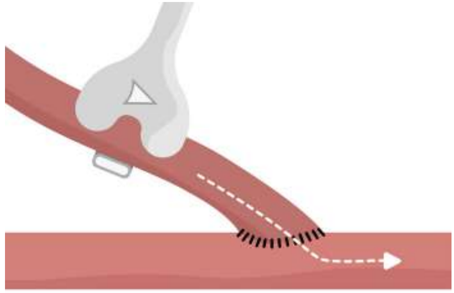
TIPS IN CASE ECG CONNECTION DOES NOT WORK

- Check ECG cable connection: one end to A1/A2 on MiraQ, the other end to "ECG Out" on the anesthesia monitor
- Inspect the cable for damage
- Ensure the system is set to the correct channel
- Calibrate the AUX channel for ECG
- If the issue persists, replace the cable

9. OPTIMAL PROBE PLACEMENT

Place the probe approximately 1.5 cm proximal to the anastomosis you want to examine, as turbulence is more easily detected when the probe is positioned near any narrowing in the vessel.

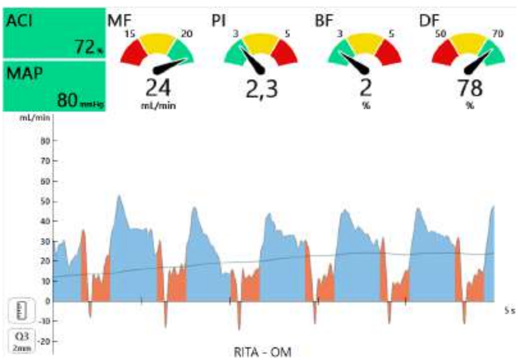




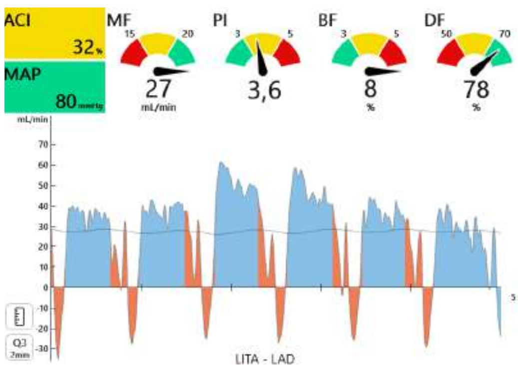
PROBE PLACEMENT

In some cases, the probe needs to be placed more proximally to avoid displacement of the heart. Note that the mean flow may remain the same, but the flow curve and PI may differ with a more proximal placement of the probe. A case published by Jelenc et al. in 2013, illustrates how placement of the probe affects TTFM parameters.[21] The mean flow is approximately the same for both measurements, but the PI and backflow are different.

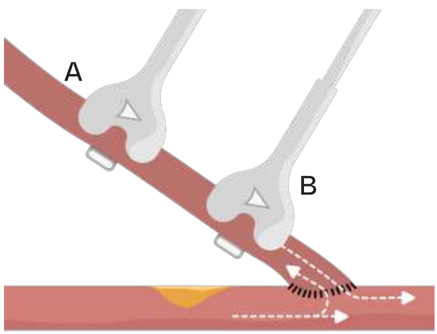
The example below from MiraQ INTUI illustrates how probe placement might affect the TTFM parameters. Note how the PI and BF values are higher on the more distal measurement.



A. Probe placed proximally on LIMA-LAD



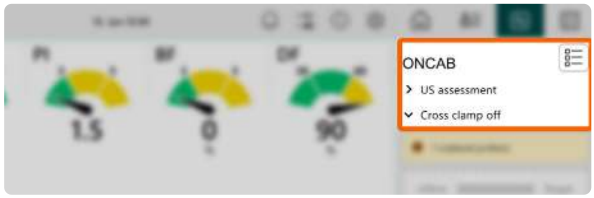
B. Probe placed distally on LIMA-LAD.



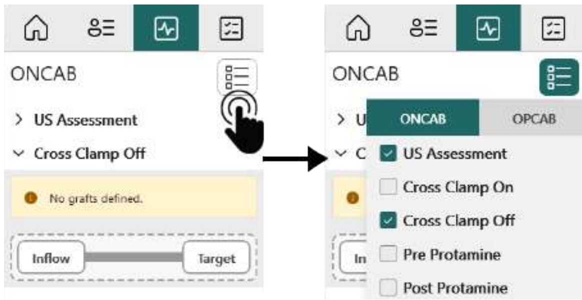
10. DEFINE MEASUREMENT LOCATION

PROCEDURE WORKLIST

Prior to starting flow measurements or imaging, a worklist may be set up on the system. Predefined suggested worklist items change depending on the type of procedure you choose (ONCAB / OPCAB) and can be setup before the operation, or adapted during the procedure.

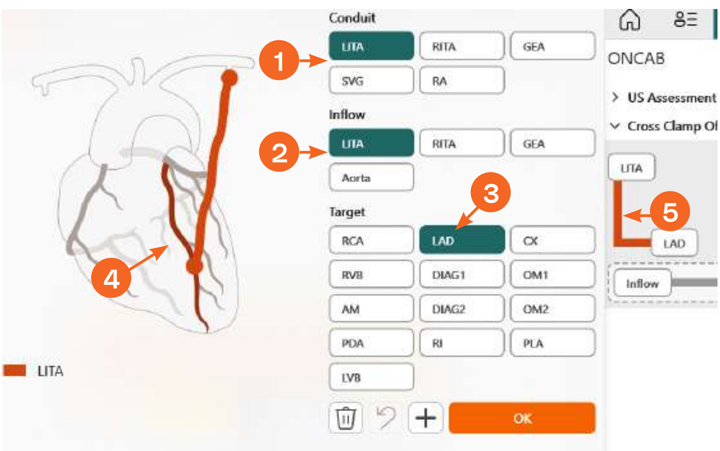


Tap the TimeStep button to override the suggested presets and match your procedure workflow.



Before performing a flow measurement, the graft should be defined in the system. This will provide a much better report after completing the procedure (see Chapter 12. Procedure outcome report for more details). Start by setting up a worklist (different for ONCAB and OPCAB) either before or during the procedure. Tap the Inflow - Target button to create a new graft. The Edit button will appear and this will open the Anatomical Location dialog. The Anatomical Location dialog contains a list of most commonly used locations used for the corresponding measurement type and currently selected application.

Follow the steps in the menu to create a SubwayMap representation of the grafts.

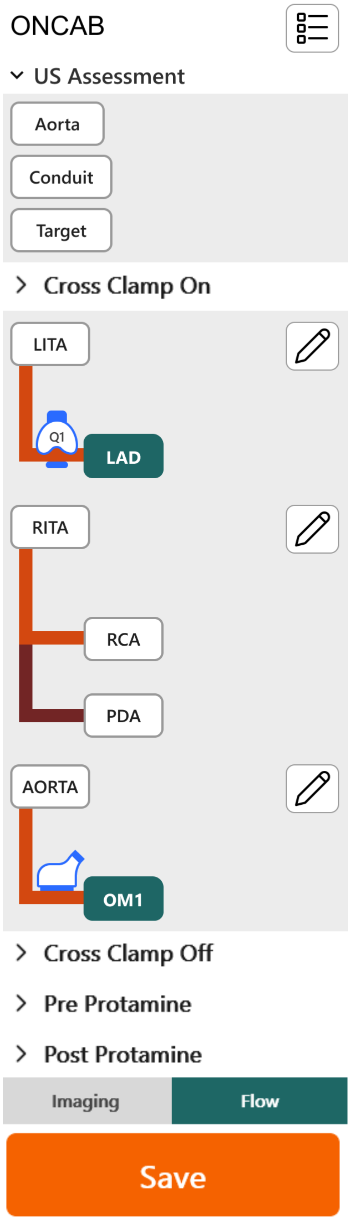


#	ANATOMIC LOCATION STEPS
1	Select graft conduit
2	Select graft inflow
3	Select graft target
4	Graphical representation
5	Result: SubwayMap representation

11. WHEN TO USE MiraQ

Performing ultrasound and flow measurements at key stages of the bypass procedure helps identify suboptimal grafts allowing for revisions with minimal impact on operative time, patient morbidity, and surgeon frustration.

Planning ahead and creating a worklist in MiraQ Cardiac with INTUI software helps streamline the workflow and save valuable time during surgery. Below is an overview of HFUS and TTFM steps for On-Pump CABG (ONCAB). Begin by selecting ONCAB or OPCAB, then choose the HFUS and TTFM steps you want to perform. Refer to Chapter 10. Define measurement location for guidance on what to evaluate at each measurement step.



HFUS

Check aortic clamping and cannulation sites

Check integrity of IMA in situ

Guide anastomotic target

TTFM

Check conduit integrity during / after harvest

Check graft patency at the following possible steps

- Cross Clamp On
- Cross Clamp Off
- Pre Protamine
- Post Protamine

Verify flow parameters: MF, PI, DF and BF

HFUS

Scan transversely and longitudinally to check that the anastomoses are patent

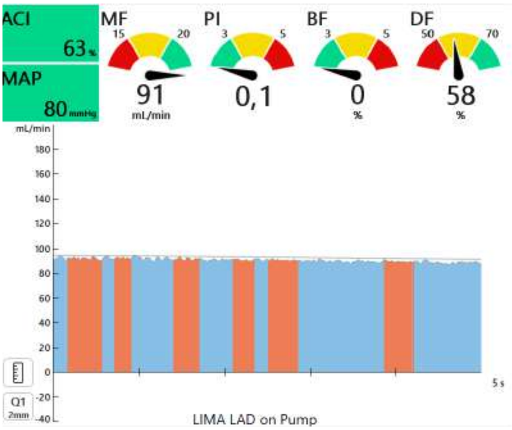
POSSIBLE TTFM STEPS FOR ON-PUMP CABG (ONCAB)

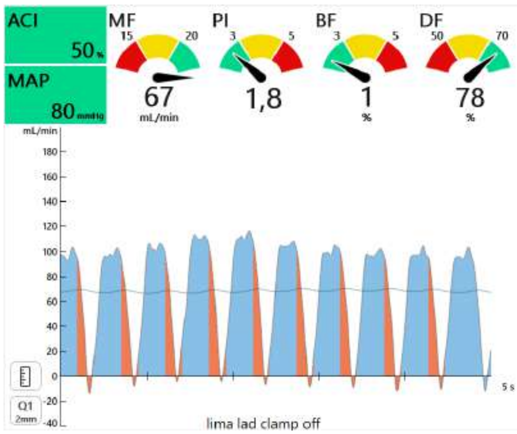
PUMP ON & CLAMP ON

To confirm a patent distal anastomosis, check graft flow and PI while on pump. If flow is low or PI over 0.3-0.4, consider revision. Most relevant for ITAs, but also relevant for other grafts during injection of cardioplegia. Mean flow is related to the flow from the pump.

PUMP ON & CLAMP OFF

Repeat the measurement with the cross clamp off, before decannulation. The heart starts beating and the flow is pulsatile, reflecting a mix of pump and heart flow. The flow curve should be repetitive. Verify the expected parameters and look for backflow.



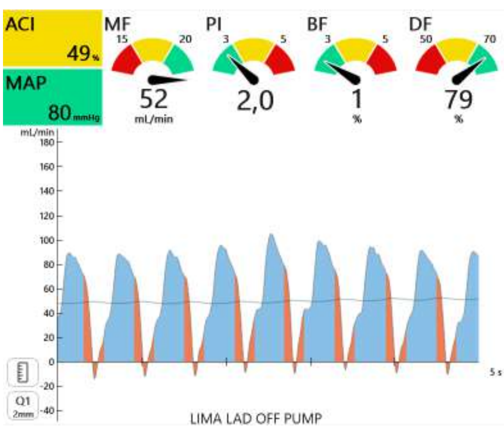


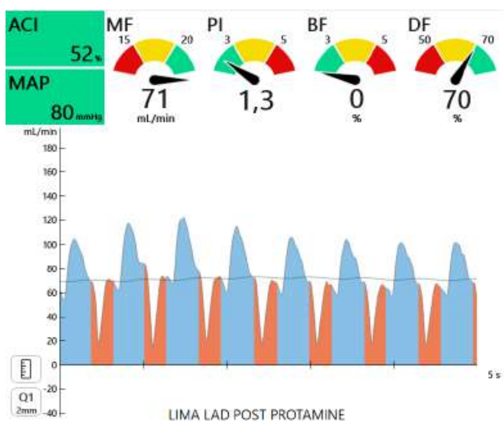
PRE PROTAMINE

After weaning off CPB, evaluate the graft pre protamine. The flow curve should be repetitive with no sharp peaks, and the backflow should not be more than expected. The diastolic filling and the flow quantity should be as expected.

POST PROTAMINE

Check the graft post heparin reversal, before chest closure. If the parameters are off, wait and measure again. This step may detect any newly developed thrombi. When the heart is in its normal position, check one final time to check for twists or kinks on the graft.





POSSIBLE TTFM STEPS FOR OFF-PUMP CABG (OPCAB)

PRE PROTAMINE

Start with a measurement before heparin reversal. During an OPCAB, generally lower flow values should be expected.

POST PROTAMINE

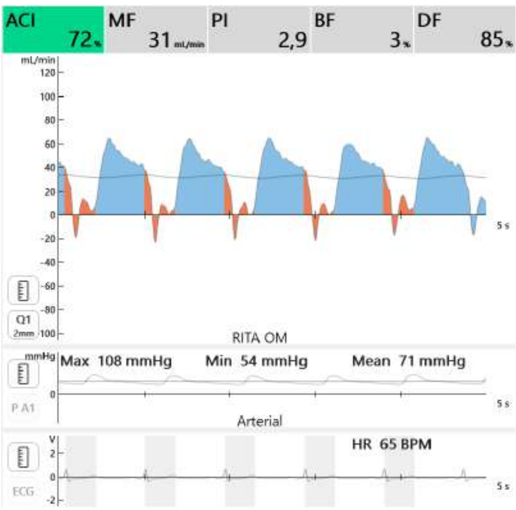
Perform TTFM post protamine and repeat before chest closure. When the heart is in its normal position, check one final time to make sure there are no twists or kinks on the grafts.

ADDITIONAL MEASUREMENTS

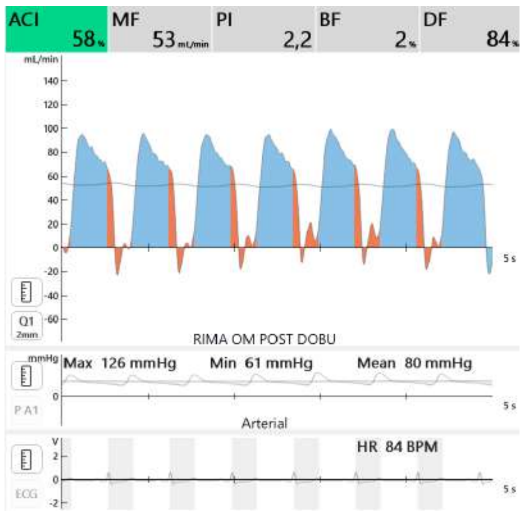
STRESS TEST TO ASSESS GRAFT FLOW RESERVE

In case of suboptimal TTFM parameters, a dobutamine test may be performed to evaluate the graft flow reserve. Injecting dobutamine increases heart rate and blood pressure. Measure when systolic blood pressure multiplied with heart rate (SxHR) exceeds 10,000. Flow should increase while PI and backflow should decrease. Reduced flow during the test may be a sign of a restrictive anastomosis. [20]

RIMA-OM pre dobutamine. Note that the gauges are not visible when more than two signal inputs are visualized on the screen.

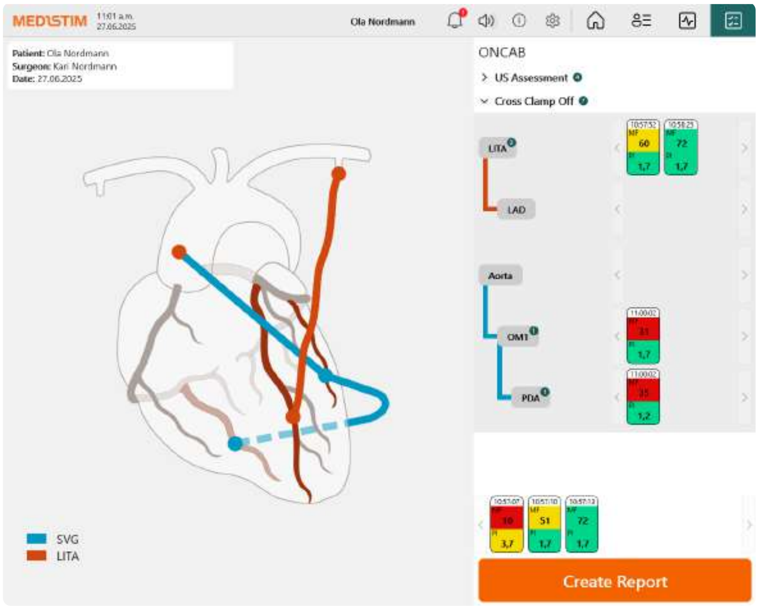


RIMA-OM post dobutamine with higher mean flow, reduced PI and reduced backflow.

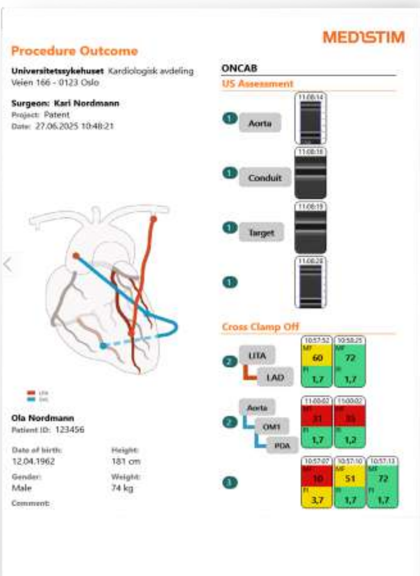


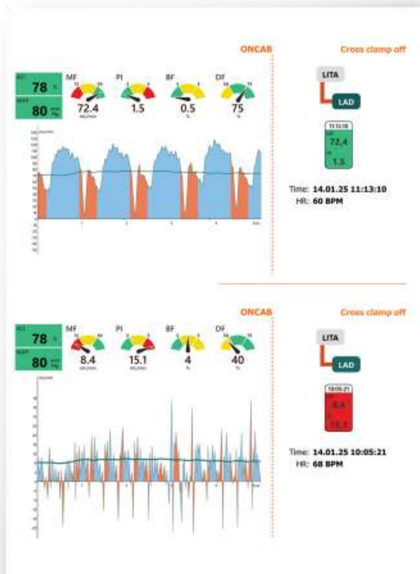
12. PROCEDURE OUTCOME REPORT

If the grafts have been defined in the MiraQ system before measuring flow and performing ultrasound imaging, the system will generate a visual report. This procedure report consolidates key data into a comprehensive view, allowing surgical teams to assess the procedure outcome and makes the data easy to interpret and share across the care team.



The procedure report provides a summary of the entire surgical procedure, including "subway maps" of all grafts, thumbnails of all measurements, and a detailed visualization of the procedure on the heart. This report is useful for communicating with the patient as well as the referring cardiologist.





13. GRAFT AND CORONARY TARGET ABBREVIATIONS

Below is an overview of the standardized nomenclature used throughout this guidebook.

CONDUITS

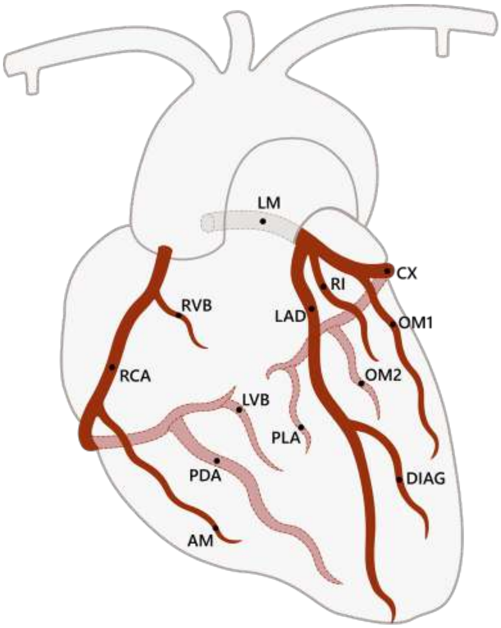
LITA/LIMA	Left Internal Thoracic/Mammary Artery	RITA/RIMA	Right Internal Thoracic/ Mammary Artery
GEA	Gastroepiploic artery	RA	Radial Artery
SVG	Saphenous Vein Graft		

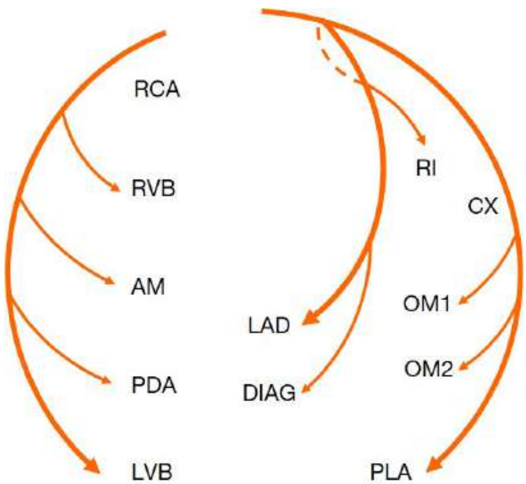
TARGETS ON RIGHT VENTRICLE

RCA	Right Coronary Artery
RVB	Right Ventricular Branch
AM	Acute Marginal Artery
PDA	Posterior Descending Artery
LVB	Left Ventricular Branch

TARGETS ON LEFT VENTRICLE

LAD	Left Anterior Descending
DIAG	Diagonal Artery
RI	Ramus Intermedius
CX	Circumflex Artery
OM1	Obtuse Marginal first branch
OM2	Obtuse Marginal second branch
PLA	Posterior Lateral Artery





FREE VS IN SITU

ITAs are used as either in situ or free grafts. In situ grafts typically show slightly different flow curves compared to free ITAs connected directly to the aorta, which resemble the flow patterns of RA or GEA grafts.

MAP

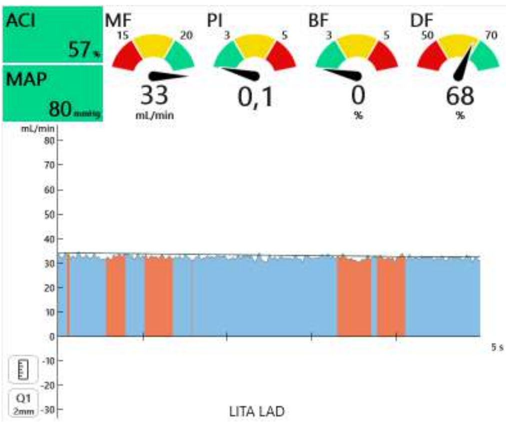
In this Guidebook, case examples without registered MAP have been assigned a default of 80 mmHg.

14. TTFM EXAMPLES - NORMAL VS QUESTIONABLE

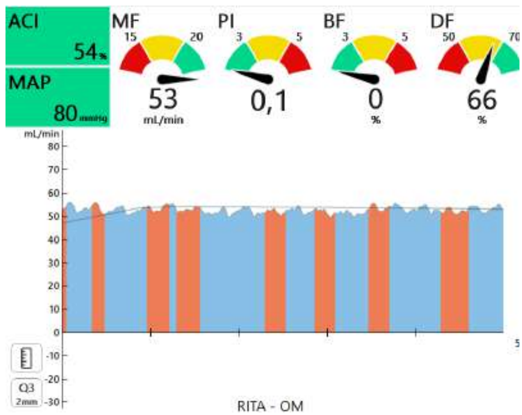
ON-PUMP & CLAMP ON

To verify that the distal anastomosis is open and that there is no occlusion of the graft, check the flow while the clamp is on. Expect higher mean flow and lower PI than when measuring off-pump. According to Kieser et al., PI should be below 0,3-0,4 at this point. High flows on-pump might indicate competitive flow if the stenosis is <70%.[6] For on-pump measurements, DF% is not relevant.

NORMAL MEASUREMENTS

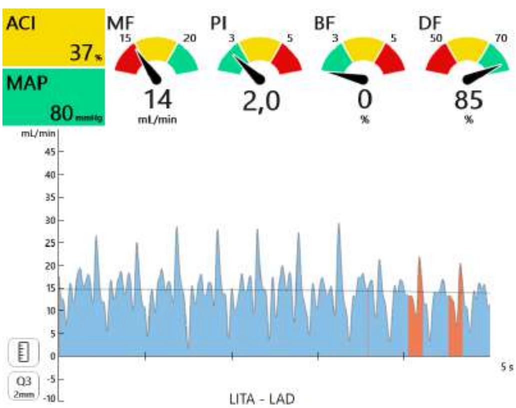


Normal LIMA-LAD on-pump TTFM with clamp on. PI well below 0.4 and a smooth, flat line showing flow of 33 ml/min.

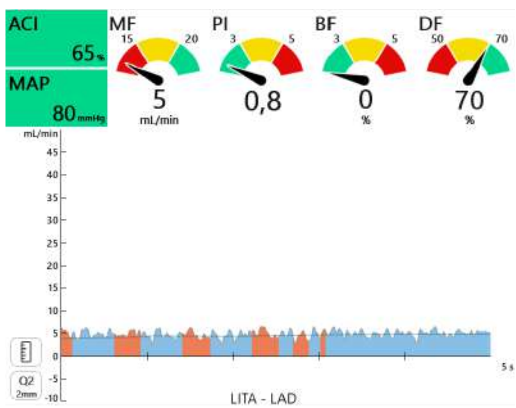


RITA-OM on-pump, clamp-on measurement shows good flow and low PI. Flows are expected to be higher during clamp-on measurements due to myocardial ischemia.

QUESTIONABLE MEASUREMENTS



Clamp-on LITA-LAD with jagged curve and high PI suggests that there is some obstruction in the anastomosis or the graft.

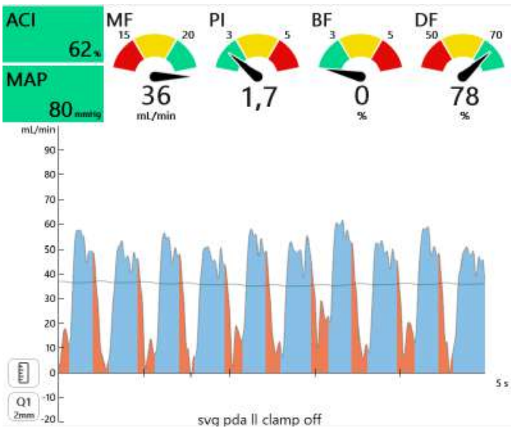


Clamp-on measurement of the LITA-LAD shows very low flow and a high PI. The low flow may be caused by the pump or by an obstruction in the anastomosis or graft.

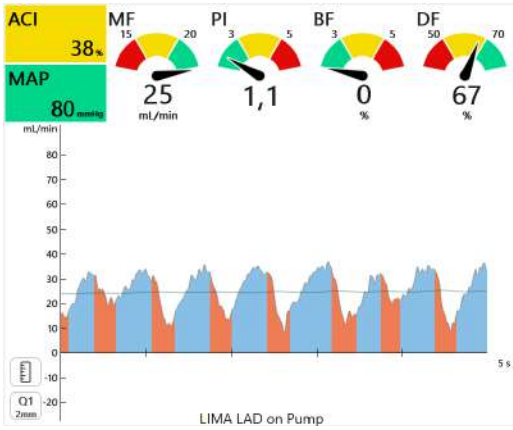
ON-PUMP & CLAMP OFF

Once the clamp is removed and the heart begins to beat again, pulsatile flow should return in the graft. The waveform should appear regular and consistent. Ensure that all expected flow parameters fall within their normal ranges, and examine the flow curve for any signs of backflow. If backflow is observed, repeat TTFM while temporarily compressing the native coronary artery proximal to the anastomosis to identify any competitive flow.

NORMAL MEASUREMENTS

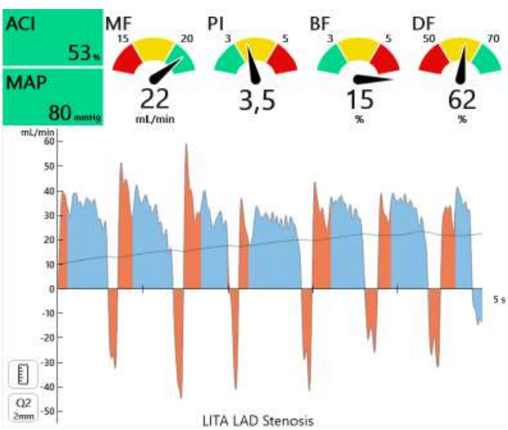


Normal TTFM findings for an on-pump SVG-PDA graft after clamp removal. The flow is adequate, PI is low, and the flow curve is repetitive and normal.

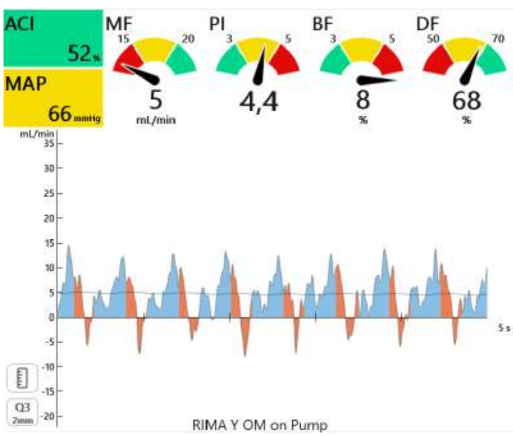


Normal TTFM results for an on-pump LIMA-LAD graft following clamp removal. The flow is adequate, PI is low, and the flow curve is repetitive and normal.

QUESTIONABLE MEASUREMENTS



Borderline TTFM parameters with good flow, but relatively high PI. Backflow of 15% is higher than recommended and suggests competitive flow or steal phenomenon.

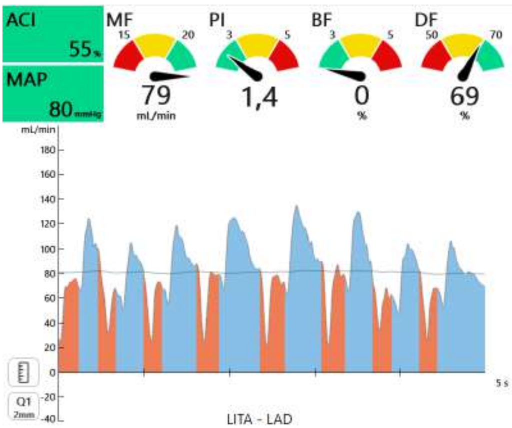


In this case, the flow is very low and both PI and BF quite high. After waiting for a while and administering protamine, the flow parameters improved to acceptable levels.

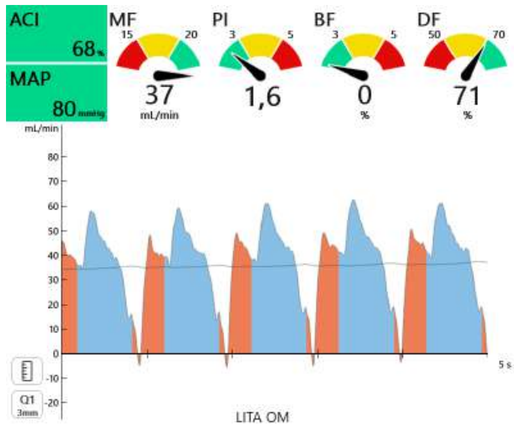
OFF-PUMP MEASUREMENTS - ARTERIAL GRAFTS TO THE LEFT VENTRICLE

On the left side of the heart, diastolic dominance is expected, with diastolic filling accounting for 60–70% or more of total flow, and lower systolic peaks. In arterial grafts, retrograde flow during early systole is common. These grafts often produce M-shaped flow curves and are more prone to vasospasm compared to vein grafts.

NORMAL MEASUREMENTS

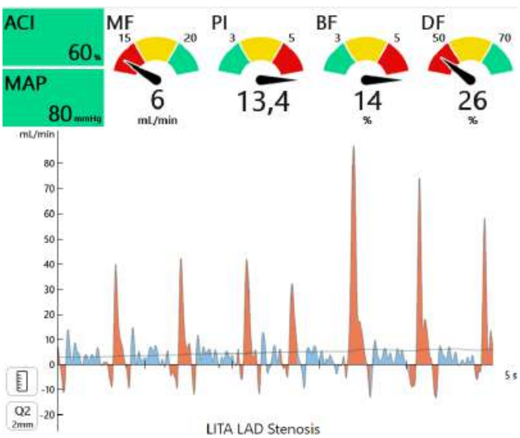


Normal TTFM findings for a LIMA-LAD graft: high flow, low PI, and a diastolic filling (DF) of 69%, with a repetitive flow curve.

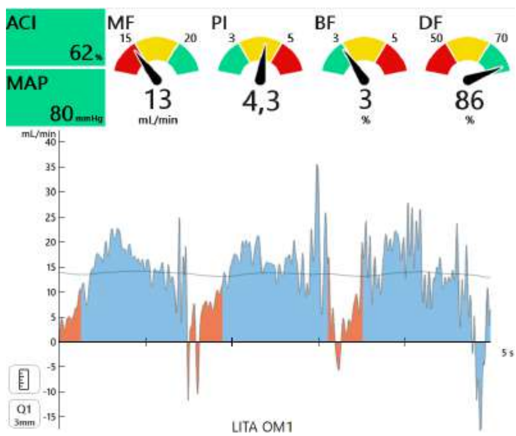


Normal TTFM in LIMA–OM, showing a diastolic filling (DF) over 70% and a slight but acceptable backflow of 0.2%. Note the characteristic M-shaped flow curve.

QUESTIONABLE MEASUREMENTS



LIMA-LAD TTFM pre protamine with low flow and high PI. DF is also low. The systolic spikes indicate flow obstruction. The graft was shortened by approximately 1 cm and the incision in the LAD was extended. Flow improved after revision.

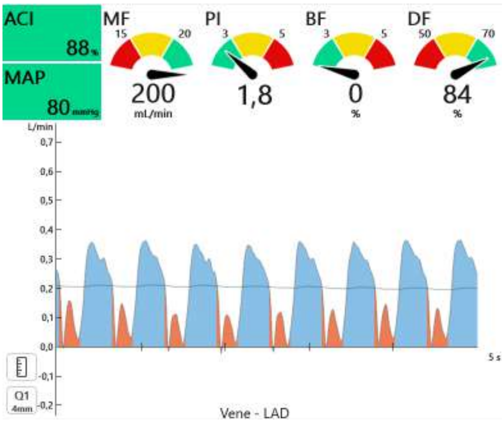


LIMA-OM TTFM showed a graft in spasm with low flow and a jagged curve. To relax a spasm, either leave the graft for a while or administer vasodilator.

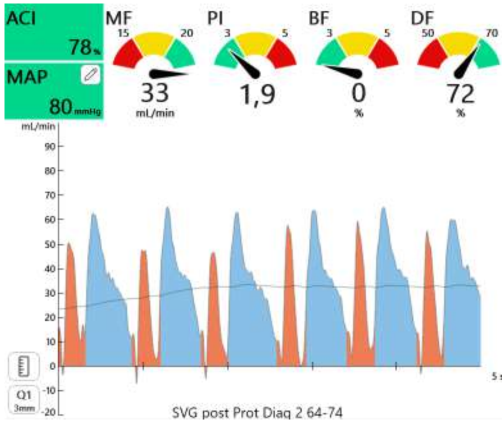
OFF-PUMP MEASUREMENTS - VEIN GRAFTS TO THE LEFT VENTRICLE

On grafts to the left side of the heart we expect diastolic filling to be over 60-70% due to the stronger muscle restricting flow in systolic phase. Vein grafts to the left ventricle usually have a dual beat filling. This means that we see two peaks (beats) caused by the hemostatic pressure in aorta in diastole making a second peak. The maximum flow during diastole should be higher than the maximum systolic value.

NORMAL MEASUREMENTS

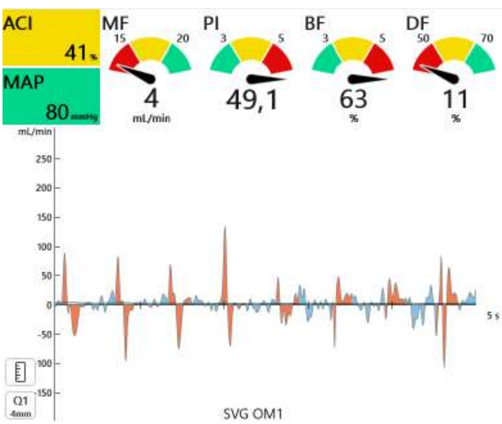


Excellent SVG-LAD TTFM with mean flow at 201 mL/min and DF at 84%. The diastolic flow is much higher than the systolic flow.

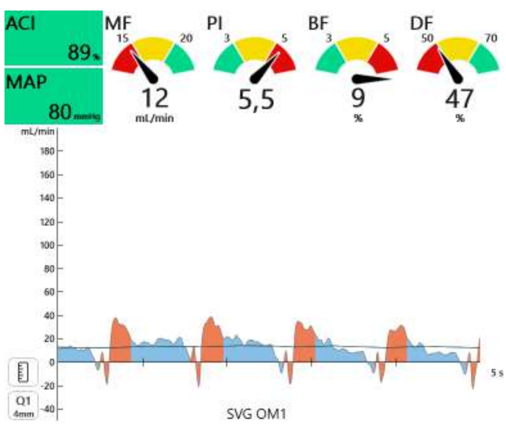


Normal SVG-DIAG TTFM with mean flow at 33 mL/min and DF at 72%. Clear diastolic peaks and dual beat filling pattern.

QUESTIONABLE MEASUREMENTS



Poor TTFM due to SVG-OM1 was twisted at proximal anastomosis. The graft was revised and the TTFM parameters improved.

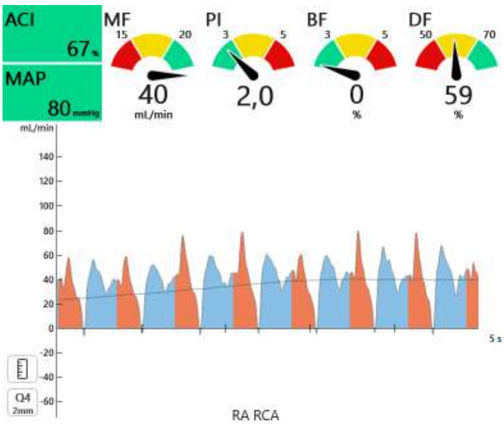


SVG-OM post protamine shows low flow, high PI and high backflow. The flow parameters improved after waiting a couple of minutes, probably due to light spasm that was relieved.

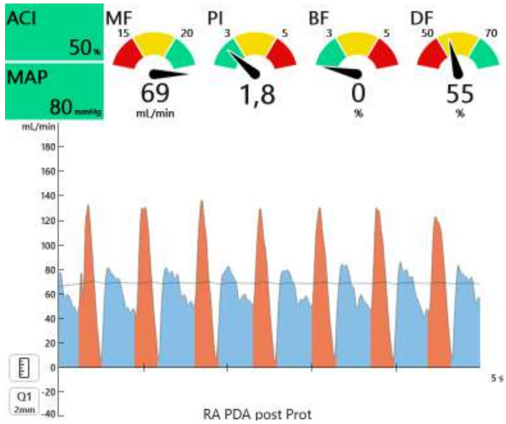
OFF-PUMP MEASUREMENTS - ARTERIAL GRAFTS TO THE RIGHT VENTRICLE

The expected diastolic filling is lower, but should be over 50%. The systolic spike is expected to be higher, but should never be more than double the maximum diastolic value.

NORMAL MEASUREMENTS

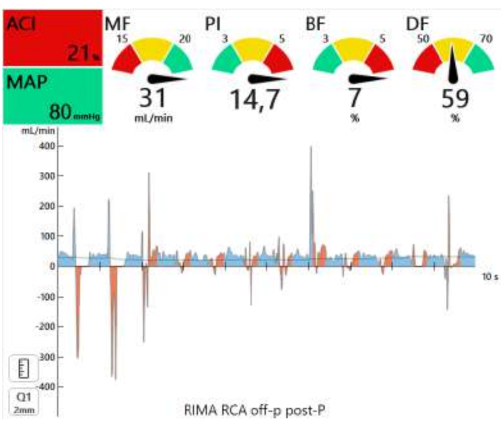


Normal RA-RCA TTFM with mean flow of 39 mL/min and DF at 58%. The flow curve shows the typical higher systolic spikes compared to grafts to the left ventricle.

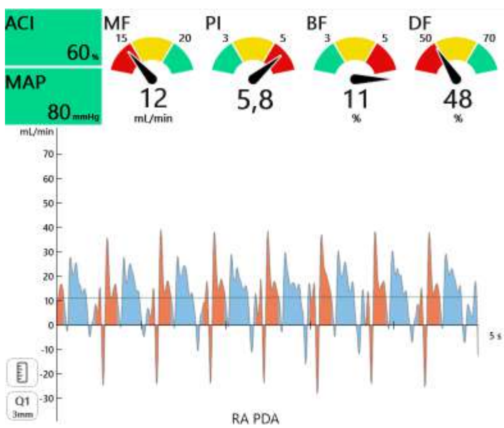


Normal RA-PDA TTFM with DF over 50% and high systolic spikes.

QUESTIONABLE MEASUREMENTS



The RITA-RCA graft shows signs of potential trouble. Although the mean flow is acceptable, the elevated PI and increased backflow are concerning

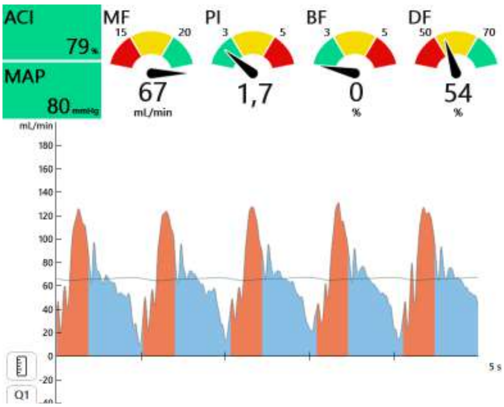


RA-PDA showed a PDA in spasm. The measurement improved after waiting 10 minutes for the native vessel to relax.

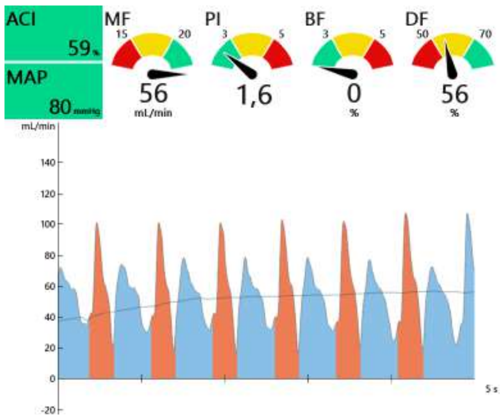
OFF-PUMP MEASUREMENTS - VEIN GRAFTS TO THE RIGHT VENTRICLE

Due to lower operating pressures in the right ventricular wall, patent grafts to the RCA or PDA often exhibit TTFM waveforms with systolic peaks. Dual-phase (systolic and diastolic) filling is a normal finding in these grafts.

NORMAL MEASUREMENTS

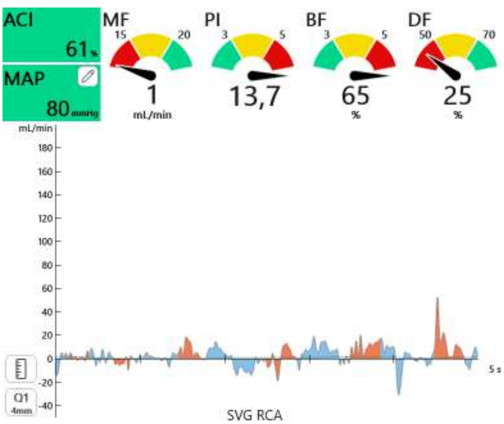


Normal SVG-RCA TTFM with mean flow 67 mL/min, low PI and DF at 54%.

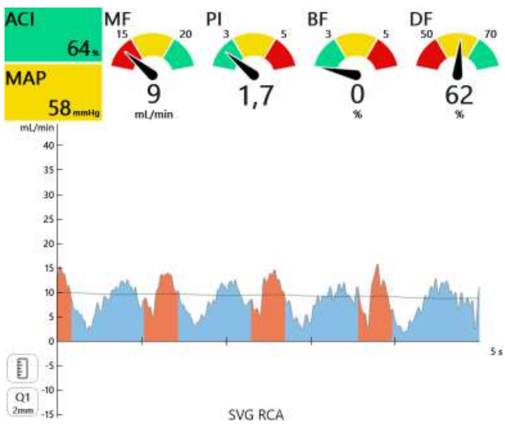


Normal SVG-PDA TTFM with mean flow at 56 mL/min, low PI, DF at 56% and dual beat filling.

QUESTIONABLE MEASUREMENTS



SVG-RCA with low flow and high PI on TTFM. Imaging showed that the anastomosis was tight (purse string effect). Revision led to flow of 73 mL/min and PI of 0.9.



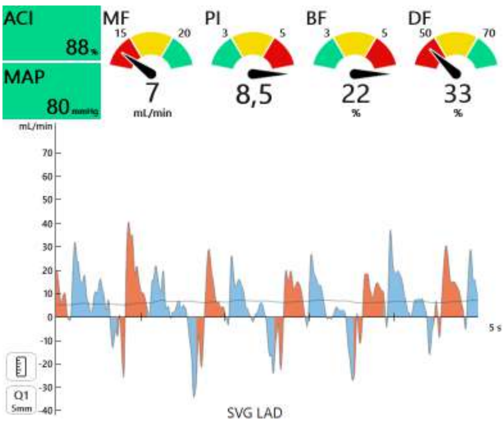
This SVG-RCA graft has a repetitive curve pattern, but the flow is low. Later measurements with higher MAP showed improved flow of 24 mL/min.

15. TTFM IN GRAFTS WITH FLOW ISSUES

GRAFT ISSUES

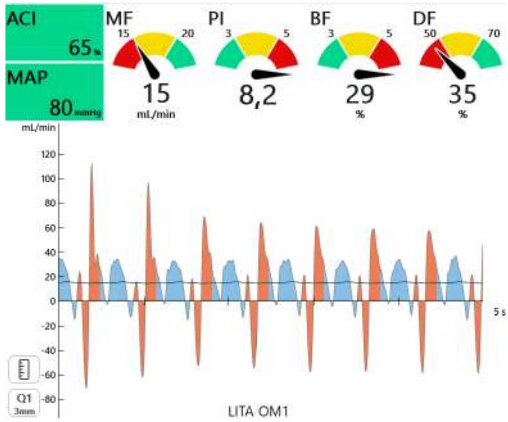
Twisted, kinked, or stretched grafts often result in disorganized TTFM waveforms characterized by low flow, high-frequency spikes, and an elevated pulsatility index (PI).

KINKED GRAFT



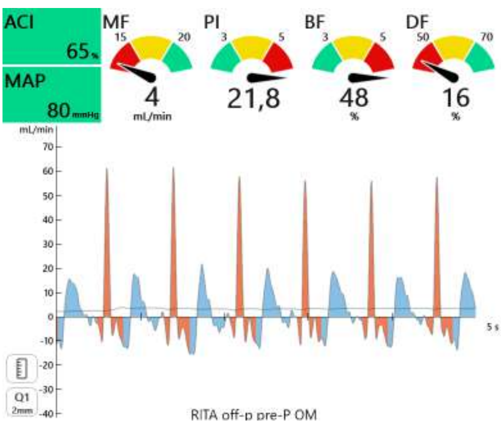
TTFM was suboptimal due to a kinked graft. Native coronaries went in and out of spasm, probably affecting the TTFM parameters. The graft was shortened and TTFM improved.

TWISTED GRAFT



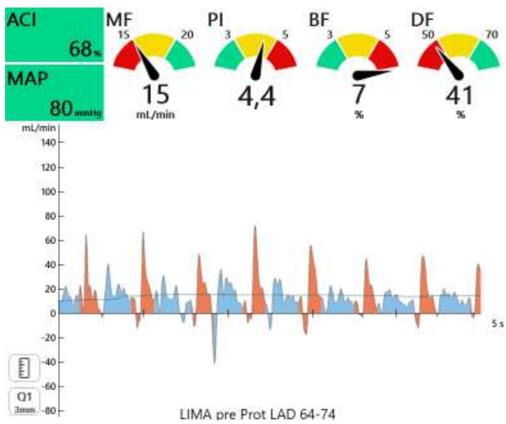
This sequential graft LITA-LAD-OM1 was revised due to a twist that resulted in low flow and high PI and BF. Revision improved the flow.

STRETCHED GRAFT



RIMA-OM2 TTFM with low flow and high PI. The graft appeared thinned out and stretched for the last 3 mm near the distal anastomosis. RIMA was detached from subclavea and used as a free graft to OM2. TTFM post revision was improved.

STRETCHED GRAFT

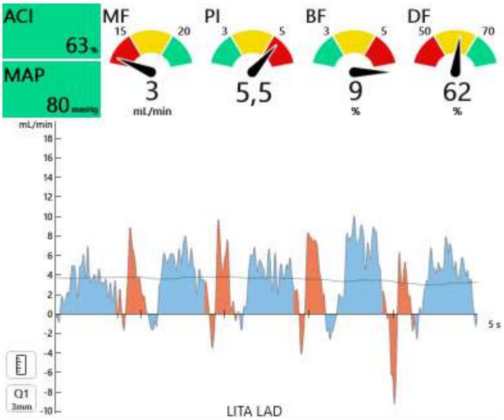


Low flow, borderline PI and systolic spikes more than twice as high as the diastolic peaks indicated a problem. The surgeon suspected graft stretching and extended LIMA with an SVG segment. This led to a slight improvement of TTFM post revision.

OBSTRUCTIONS

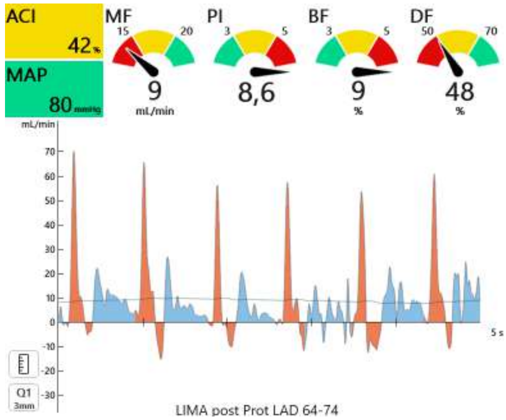
Flow can be obstructed by objects in the graft, native vessel, or anastomosis. An intimal flap or thrombus can reduce flow and cause spikes in the flow curve. A jagged, spiky waveform may indicate spasm in the graft or target artery. Repeating the measurement after a short wait may allow the spasm to subside, or a vasodilator can be used to relax the vessel.

INTIMAL FLAP



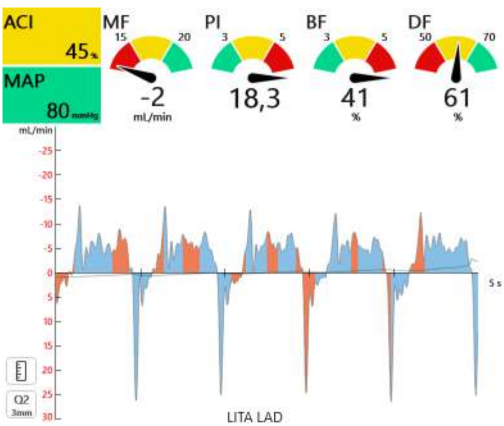
Post-protamine LIMA-LAD TTFM was suboptimal. Imaging revealed an intimal flap at the anastomosis, likely residual plaque from endarterectomy. Flow was satisfactory pre-protamine but dropped after heparin reversal. Flap removal led to improved TTFM.

THROMBUS



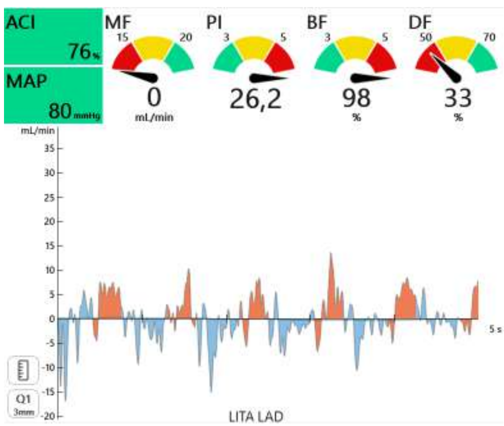
LIMA-LAD flow was good on-pump but declined post-protamine. Imaging suggested a possible thrombus distal to the anastomosis. Post-revision TTFM and imaging showed improvement.

OBSTRUCTION



Suboptimal TTFM with minimal flow and high PI. Imaging revealed an obstruction at the distal anastomosis. Although the cause was unclear, revision improved flow and PI.

DISSECTION

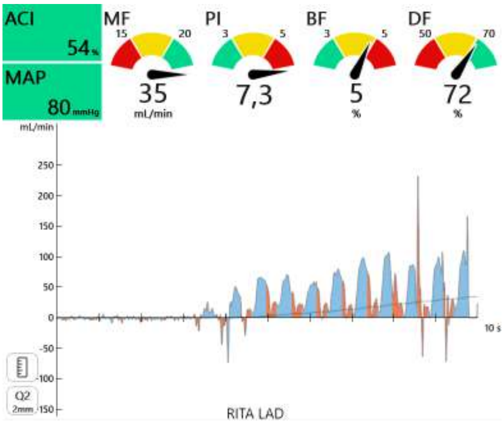


Initial LIMA-LAD TTFM was suboptimal. HFUS imaging revealed a LIMA dissection, and the distal segment was replaced with SVG. Post-revision TTFM showed marked improvement.

MISTAKES TO AVOID

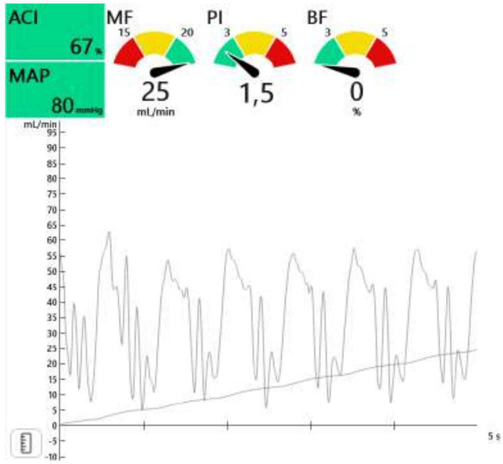
To ensure reliable transit time measurements, the ACI must be yellow or green and the red line must be flat. When ECG is connected, diastolic flow appears blue, systolic flow orange, and the diastolic filling percentage (DF%) is automatically calculated.

SAVING TOO SOON



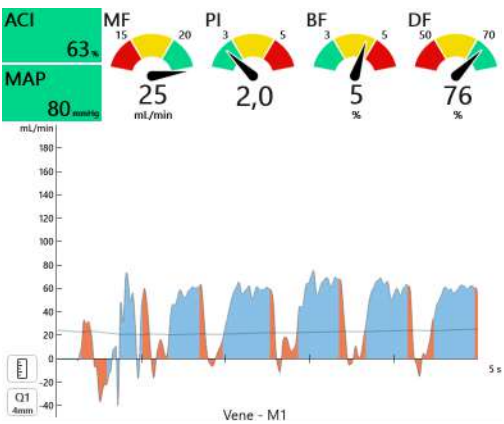
In this case, the measurement was saved prematurely, before the horizontal line had stabilized. As a result, the measurement should be disregarded.

UNSTABLE HORIZONTAL LINE



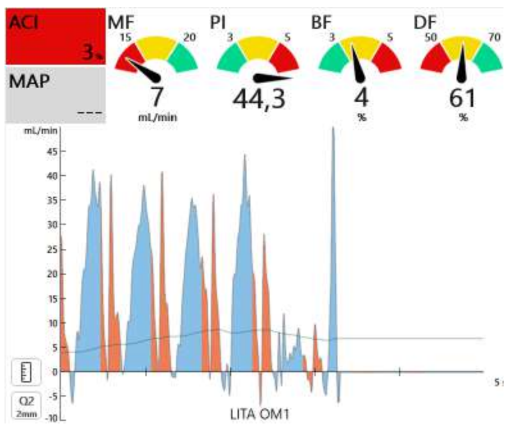
In this measurement, the red line has not yet stabilized, resulting in a mean flow (MF) that is lower than expected. Additionally, the DF% value is unavailable because the ECG is not connected to the system.

PROBE MOVEMENT



TTFM of SVG-OM with probe movement during measurement. After repositioning the probe, wait at least 7 seconds for the red line to stabilize. The flow curve should appear repetitive and steady.

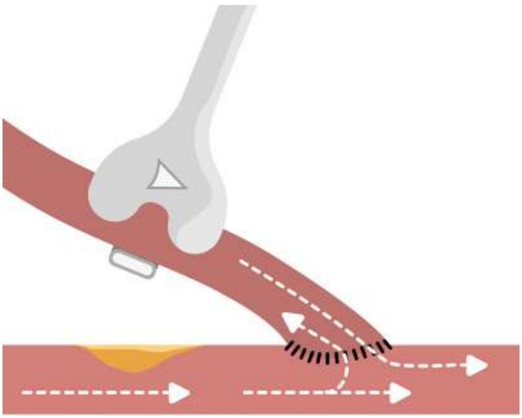
SAVING AFTER PROBE REMOVAL



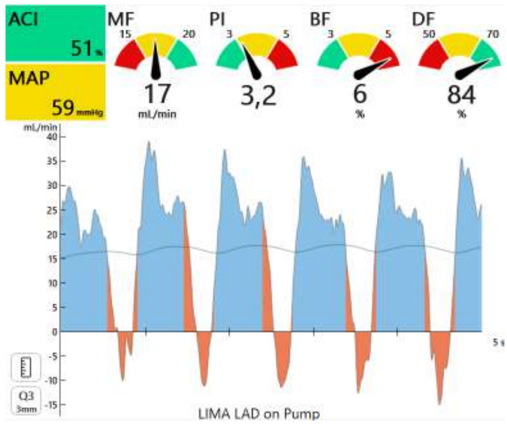
This measurement was saved after the probe was removed, leading to an abnormally low ACI and inaccurate mean flow. For accurate results, ensure the ACI is above 30% and save while the probe is steady on the vessel.

16. BACKFLOW

Backflow is blood flowing backwards from the native coronary through the anastomosis into the conduit. Backflow is a normal phenomenon that appears more frequently in arterial grafts than in venous grafts.



Visualization of backflow



Example of flow curve displaying backflow

Backflow is most commonly caused by competitive flow in the native coronary artery due to a non-critical stenosis (<70%), typically observed in early systole. To confirm, compress the native vessel with a blunt instrument or finger. If mean flow increases, competitive flow is likely the cause. If flow does not improve and backflow remains significant, consider steal phenomenon or a compromised graft.

Note: competitive flow can occur without graft backflow.

Backflow can also indicate flow obstruction, and may present together with suboptimal TTFM parameters such as low flow and high PI.

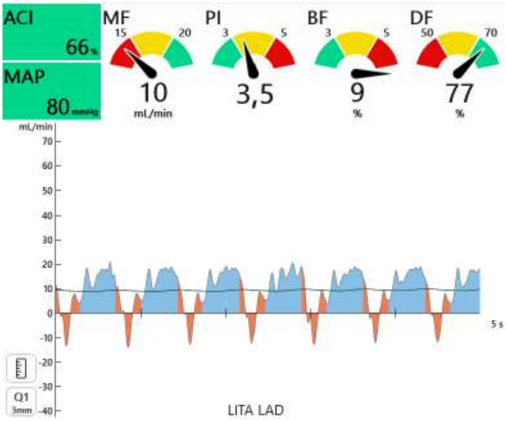
Susceptibility to backflow varies by graft type: in situ ITAs have lower pressure than free ITAs and show more backflow. Right-side native coronaries have lower resistance than left-side, leading to higher flow and more backflow. Vein grafts, being larger, are less prone to backflow.

GRAFTS THAT ARE MORE OR LESS SUSCEPTIBLE TO BACKFLOW

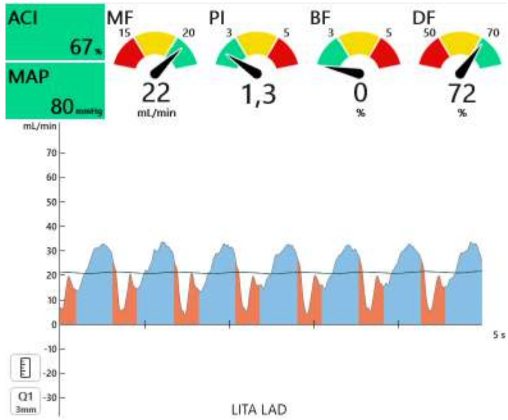
Vein graft to any side of the heart	>	Free arterial grafts to left side of the heart	>	Free arterial grafts to right side of the heart	>	In situ ITA's to left side of the heart	>	In situ ITA's to right side of the heart

COMPETITIVE FLOW FROM NATIVE VESSEL

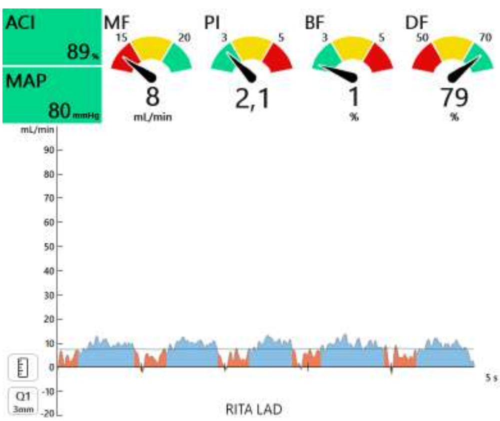
If the stenosis in the native coronary artery is non-critical, there is a likelihood that there will be some backflow into the graft during systole. The following examples show the effect of compressing the native coronary to confirm whether there is competitive flow.



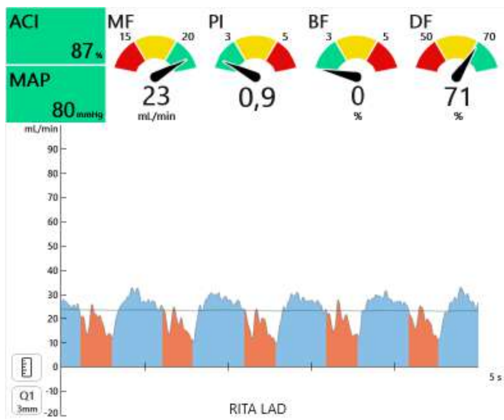
Y-graft with LITA-OM1 and RITA-LAD. TTFM showed low flow and a backflow of 10.2%. This is calculated by the system and is visible when pressing "Calculate" on the side menu.



Compression:
TTFM during native vessel compression showed increased flow, lower PI, and no backflow, confirming competitive flow. The graft was left unchanged.

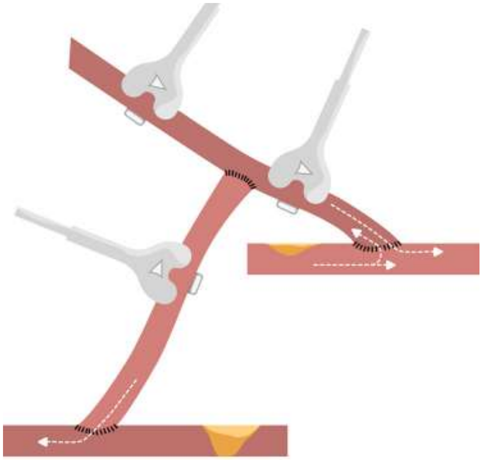


TTFM showed unexpectedly low flow, The surgeon suspected competitive flow and compressed the LAD proximal to the anastomosis.



Compression:
TTFM during compression of LAD showed greatly improved flow. Competitive flow was confirmed and the graft was left alone.

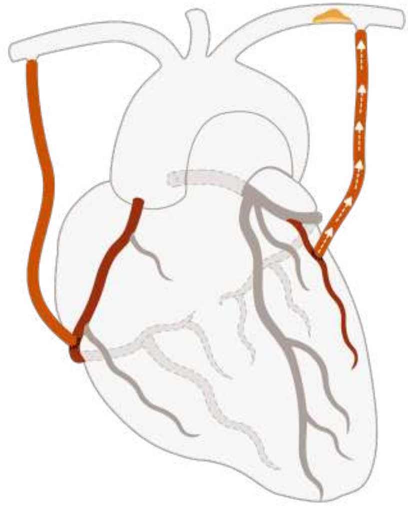
COMPETITIVE FLOW IN COMPOSITE GRAFTS



TTFM is straightforward for single grafts but harder to interpret for sequential or composite grafts. All segments of a composite graft should be measured.

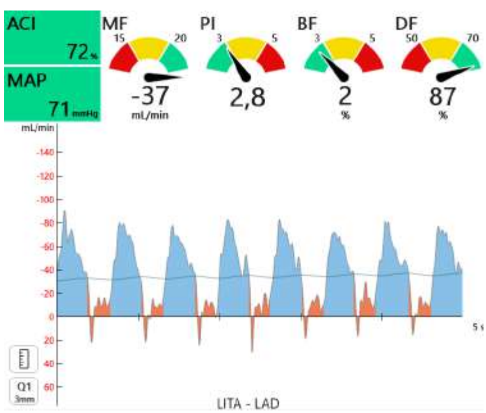
Backflow may indicate competitive flow, as blood moves toward lower pressure. Repeating measurements while compressing different graft segments can help confirm this.

SUBCLAVIAN STEAL

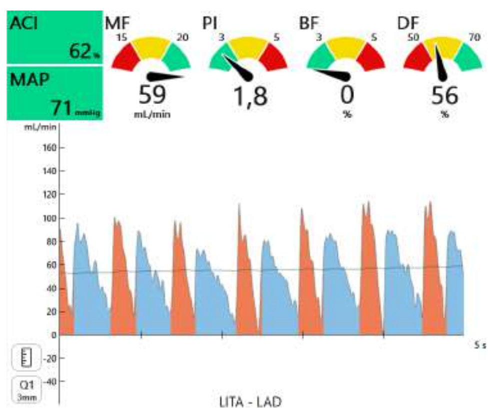


A proximal subclavian stenosis can cause low pressure, reversing graft flow as blood moves from the vertebral artery and ITA. If compressing the native vessel doesn't improve flow, subclavian steal is confirmed.

EXAMPLE OF SUBCLAVIAN STEAL



LIMA-LAD TTFM showed systolic backflow, suggesting subclavian steal. Native vessel compression did not reduce flow, confirming the phenomenon.



The graft was revised by freeing the LIMA from subclavia and attaching it directly to aorta. TTFM post revision showed improved parameters.

17. PRINCIPLES OF HFUS

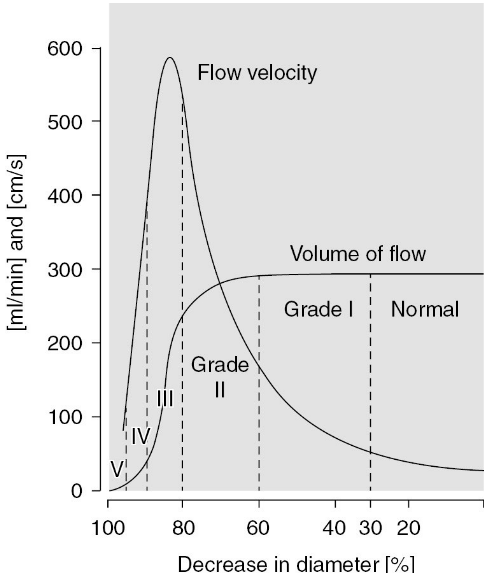
BACKGROUND

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

A paper by Head et al. covers intraoperative graft assessment and states the following: [8]

"Although TTFM is valuable to identify truly poor and truly good grafts, its value is limited in identifying grafts with minor abnormalities that may present false-negative values of pulsatility index and flow. As a result, recent studies have suggested that 2 parameters, graft flow and anastomotic patency, are required for the complete assessment of bypass grafts. TTFM combined with epicardial echocardiography is an approach that provides both a functional and an anatomic assessment of bypass grafts. The need for technique modifications based on epiaortic ultrasonography ranges between 4% and 31%, depending on the type of modification and the definitions used. On the basis of these findings, intraoperative epiaortic scanning should be considered before aortic manipulation."

"TTFM alone, although useful for intraoperative bypass graft assessment, is not enough; 10–15% of graft values are ambiguous as to the efficacy of graft function. Therefore, although newer, ECUS is already being established as an indispensable tool for quality assessment in coronary surgery. The two modalities combined are vital for 'state of the art' intraoperative bypass graft assessment."



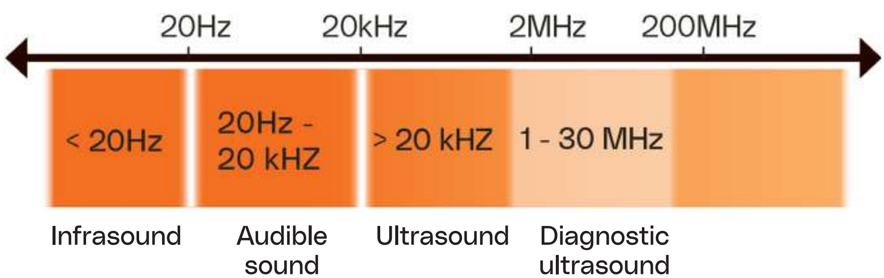
A limitation of TTFM is that only stenoses that obstruct over 70-75% of the vessel lumen will impact flow, hence, lower grade stenoses with no flow limitation will not be detected. This can be explained by the Spencer's curve:

Figure: Spencer's curve. The flow volume stays stable until the narrowing exceeds 70-75%.[30]

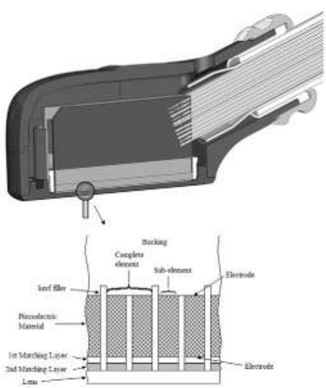
The Doppler modality is more sensitive when it comes to detecting low-grade stenoses by measuring increased flow velocity. This detection can be performed using the imaging probe that also has pulsed wave Doppler technology.

ULTRASOUND

Ultrasound consists of soundwaves with frequencies/wavelengths higher than 20 kHz. Diagnostic ultrasound has frequencies between 1 and 30 MHz.



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

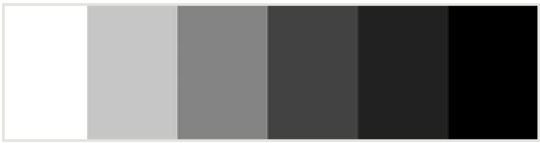


The L15 imaging probe contains 128 piezoelectric elements. It has a frequency range from 11 to 18 MHz, with a center frequency of 15MHz. The probe is designed to provide high resolution images in the extreme near field (0-20 mm).

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.



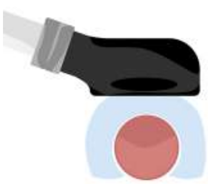
When a sound wave hits a boundary, some of the energy of the wave will be reflected back to the probe. How much of the wave that is reflected depends on the type of boundary. High reflection will appear white, while low reflection will appear black on the image created.

Muscle/blood	0.07 %
Soft tissue/water	0.23 %
Fat/muscle	1.08 %
Bone/fat	48.91 %
Soft tissue/air	99.9 %

Percentage of energy reflected at tissue interfaces [29]

COUPLING AGENTS

Ultrasound does not penetrate air, making adequate acoustic coupling essential for clear imaging. For imaging the aorta or native coronaries, surface moisture is often enough. But when scanning grafts and anastomoses, adding saline, blood, or ultrasound gel made for intraoperative use gives a clearer image. As shown below, using enough gel also helps avoid compressing the vessel.



The left image shows the right amount of gel between the probe and vessel. The right image shows how too little gel can compress the vessel.

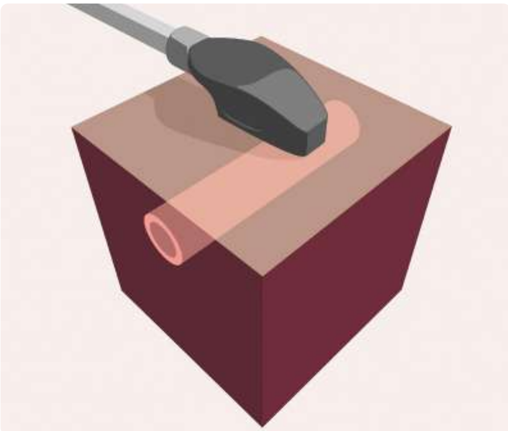
Another technique is to fill the pericardium with saline during imaging. This is especially useful when imaging an anastomosis on the back side of the heart.

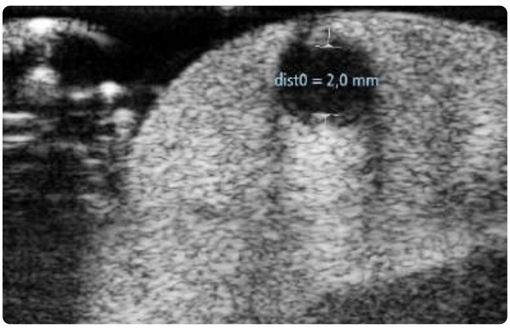
18. IMAGING VIEWS

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.

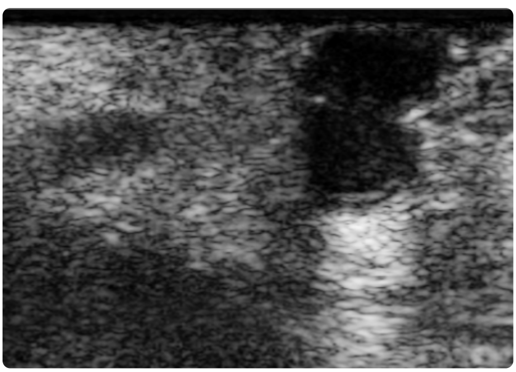
TRANSVERSE / CROSS SECTION

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





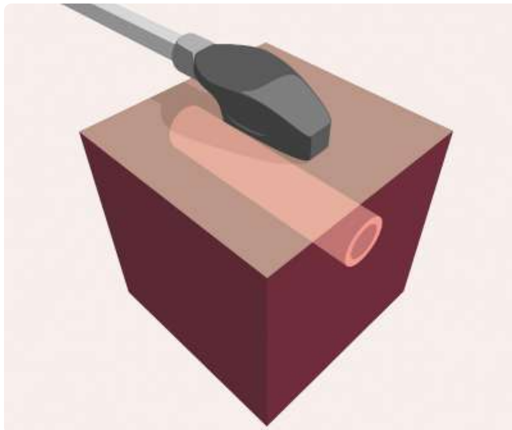
Transverse view of a vessel.

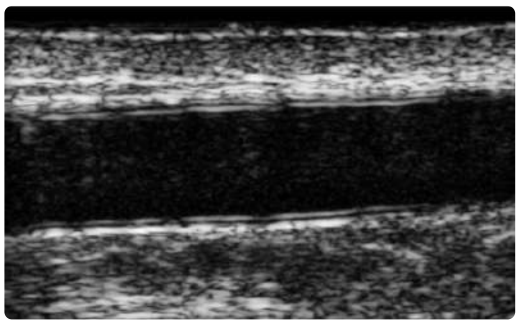


Transverse view of an anastomosis.

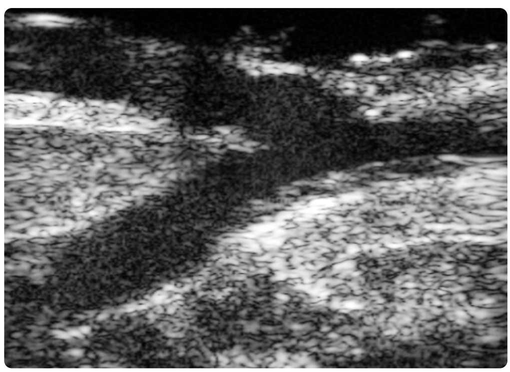
LONGITUDINAL

View to evaluate calcifications or obstructions and to check anastomosis.





Longitudinal view of a vessel.

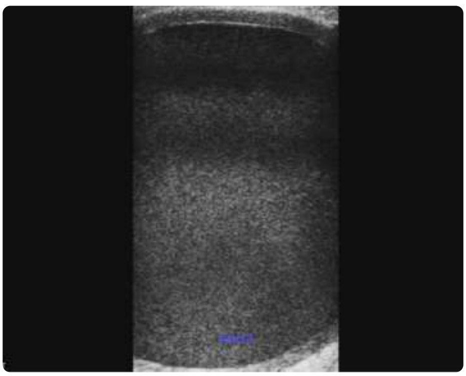


Longitudinal view of an anastomosis

19. HFUS DURING CABG

EPIAORTIC ULTRASOUND

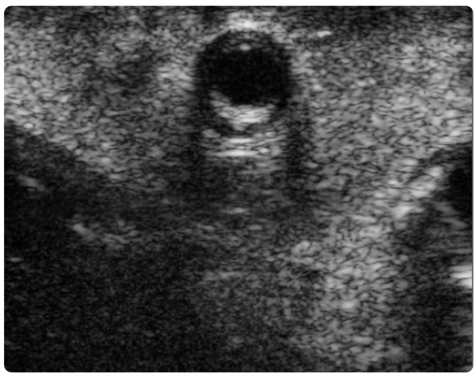
Epiaortic imaging allows a sensitive, direct diagnosis of aortic disease, which can lead to modifications in intraoperative surgical management. Scanning of aorta prior to manipulation reduces the chance of stroke by evaluating the clamp site, cannulation site and the site for the proximal anastomosis.



During aortic scanning the maximum depth of 45 mm should be chosen. This is a part of the aorta imaging preset.

EPICARDIAL ULTRASOUND

Epicardial imaging can be used intraoperatively to assess coronary quality, strategize graft placement and visualize constructed anastomoses. Epicardial scanning can also assist in locating intramural coronaries.



During coronary scanning a depth of 15 mm should be chosen. This is a part of the coronary imaging preset.

IMAGING PRESETS

The Medistim MiraQ™ System includes a range of imaging presets, each optimized with ultrasound acquisition parameters for specific applications. For example, the settings used to scan the aorta differ from those used for coronary arteries. When following the predefined worklist, the appropriate preset is automatically selected for each imaging step.

20. HFUS SETTINGS

IMAGING MODALITIES

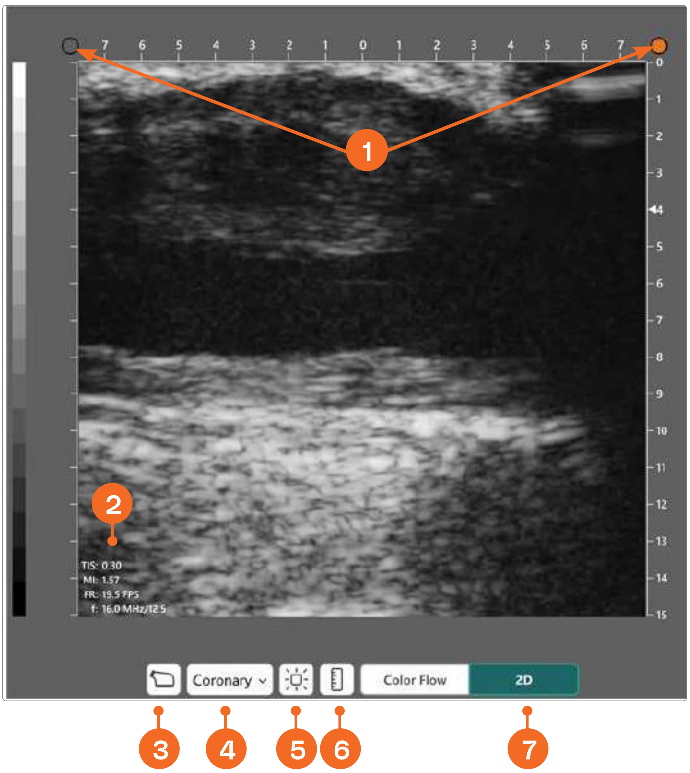
There are two imaging modalities available, 2D mode (B-mode, gray scale imaging) and Color Mode.

2D MODE

2D-mode (B-mode) offers the highest frame rate, making it ideal for viewing anatomy, assessing structures, and detecting defects. In this mode, you can also adjust the gain and persistence settings. Gain controls the image brightness, while persistence applies a temporal averaging filter to reduce random noise and create a smoother image.

Focal Points make the image sharper at the defined depth. Pressing the 2D tab will change the imaging mode to 2D (gray scale only). If the system was already in 2D, then a menu appears with more advanced controls for optimizing the 2D image.

SCREEN ELEMENTS IN 2D MODE



1 Probe orientation
2 Exposure statistics
3 Imaging probe properties
4 Current imaging preset
5 Imaging controls (gain & persistence)
6 Depth control
7 2D mode tab

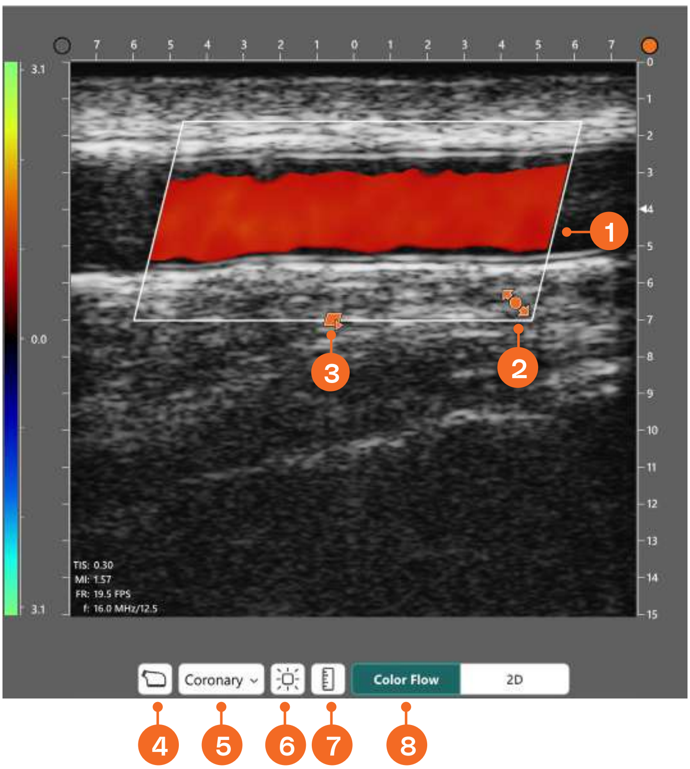
COLOR MODE

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:

1. **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.
2. **Velocity mode** uses the Doppler shift to detect flow and provides information about flow direction relative to the probe and flow velocity.

Aliasing may occur when the blood flow velocity is higher than what the system is configured 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 and 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.

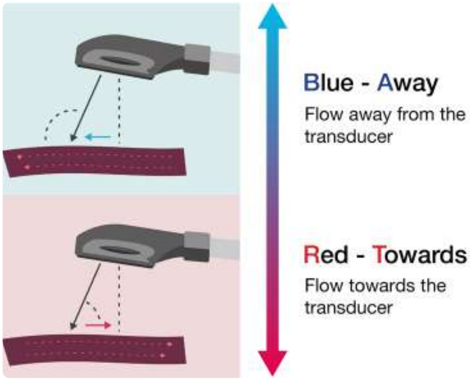
SCREEN ELEMENTS IN COLOR MODE



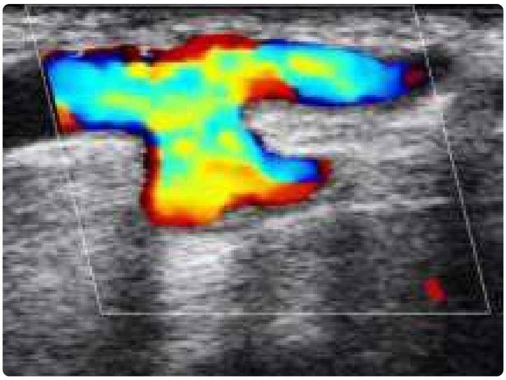
1 Region of interest (ROI)
2 Size
3 Steering angle
4 Imaging probe properties
5 Current imaging preset
6 Imaging controls (velocity & power mode)
7 Depth scale
8 Color mode tab

FLOW DIRECTION AND VELOCITY

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



Blood moving away from the probe is colored blue and blood moving towards the probe gives a red color on the screen.



CFM image with suboptimal velocity setting.

Aliasing may occur if the blood flow velocity is higher than what the system is configured to measure.

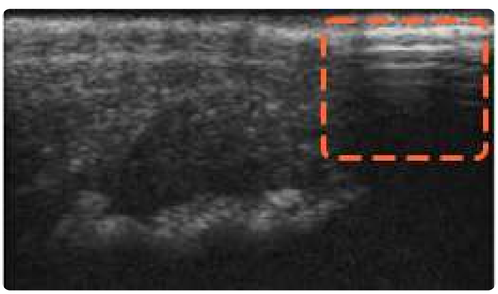
The peaks of the velocity spectrum will exceed the highest values of the velocity scale and reappear at the bottom of the scale, now represented as negative values.

Aliasing can be corrected by adjusting the velocity scale.

21. IMAGING ARTIFACTS

Imaging artifacts are elements in the image that are effects of the ultrasound technology, not the actual tissue. How to identify an artifact? Move the probe and observe whether the artifact changes or disappears with a different angle. This can help distinguish artifacts from real tissue. Common types of artifacts are outlined below.

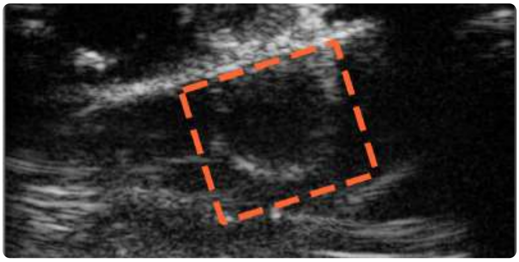
REVERBERATION



Reverberation at the top right of the image.

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.

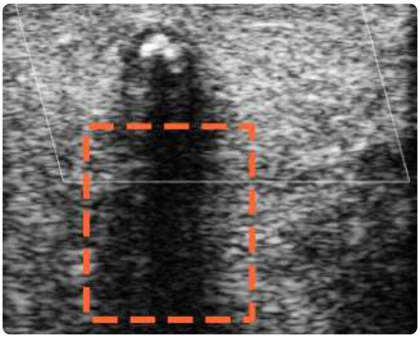
MIRRORING



A mirror image artifact occurs when ultrasound waves encounter a highly reflective surface, such as a gloved finger beneath the internal thoracic artery (ITA), causing the ITA to appear duplicated below the reflective interface.

ITA shown over the white line and the mirroring underneath.

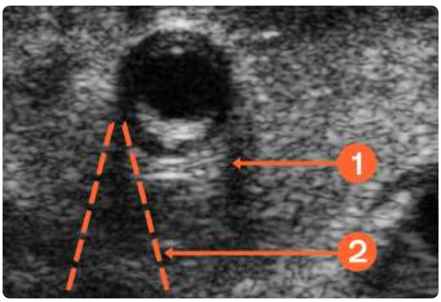
SHADOWING



When the ultrasound waves hit hard tissue like calcified plaque, a shadow is formed on the image below this area.

Shadow under a calcified area (white).

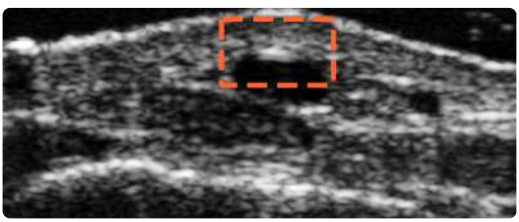
ENHANCEMENT AND WALL SHADOW



When ultrasound waves pass through a region of low attenuation and encounter tissue, the resulting difference in attenuation enhances the signal, producing a brighter (white) area on the image. Unlike calcified plaque, which causes acoustic shadowing beneath it, this enhancement does not create a shadow.

Enhancement (1) and dark wall shadow (2)

SPECULAR REFLECTION

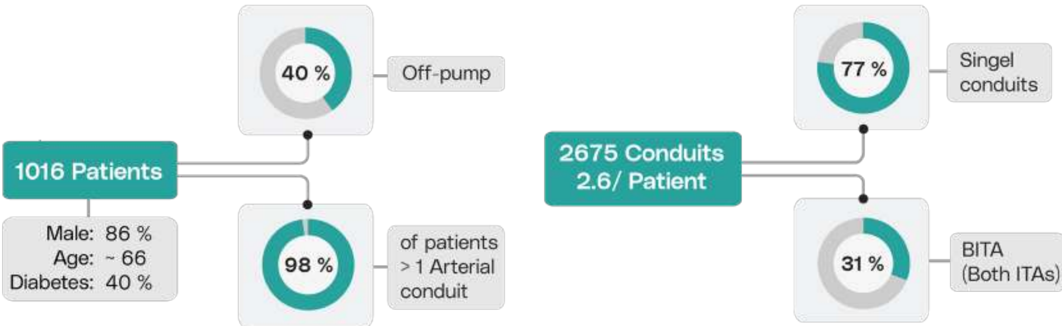


This artifact appears when a smooth surface reflects the sound waves. In the example, the top side of a blood vessel reflects the ultrasound, creating a white area above, as seen here in the upper part of the vessel.

Specular reflection in the upper part of the vessel.

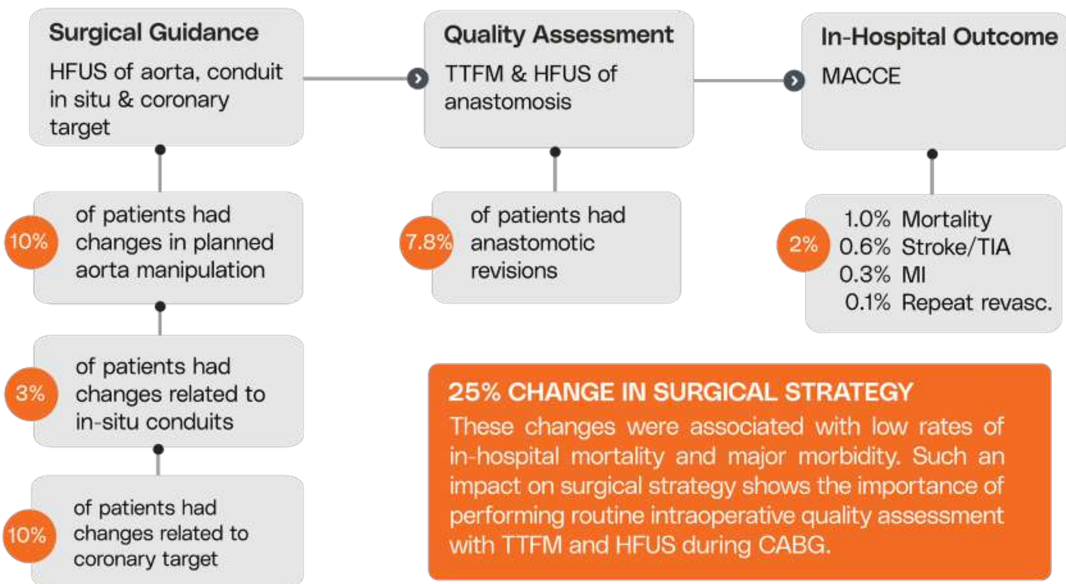
22. REQUEST PROTOCOL AND RESULTS

The combination of intraoperative high-frequency ultrasound (HFUS) imaging and transit time flow measurement (TTFM) was demonstrated and documented in a large group of patients for the first time with the REQUEST study. [31] In this prospective study, Medistim's MiraQ™ or VeriQ C™ devices were used. Patient population: patients scheduled for isolated CABG with multivessel disease.



PROTOCOL AND RESULTS

Surgical strategy changes took place in 25% of patients. More than three out of four of these changes were due to TTFM and/or HFUS.



Intraoperative Transit-Time Flow Measurement and High-Frequency Ultrasound Assessment in Coronary Artery Bypass Grafting (REQUEST)

Authors: Taggart DP (Oxford), Thuijs DJFM (Rotterdam), Di Giammarco G (Chieti), Puskas JD (New York), Wendt D (Essen), Trachiotis GD (Washington), Kieser TM (Calgary), Kappetein AP (Rotterdam) and Head SJ (Rotterdam).

ABSTRACT

Objectives

We evaluated the impact of transit-time flow measurement (TTFM) with epicardial and epiaortic high frequency ultrasound (HFUS) in patients undergoing coronary artery bypass grafting (CABG).

Methods

The REQUEST study is a multicenter, prospective study among 7 international centers performing CABG. The primary endpoint was any change in the planned surgical procedure. Major secondary endpoints consisted of i) the rate and reason for surgical changes related to the aorta, in-situ conduits, coronary targets, and completed grafts, and ii) the rate of in-hospital mortality and major morbidity.

Results

Between April 2015 and December 2017, 1046 patients were enrolled. Of those, 1016 were included in the final analyses. Mean age was 65,9 years, 14,0% were female and diabetes was present in 39,6%.

Off-pump procedures were performed in 39,6% and bilateral internal thoracic arteries in 30,5%.

The primary endpoint occurred in 25,2% of patients (n=256) and in 77% (197/256) this was based on TTFM and/or HFUS. Surgical changes were related to the aorta in 9,9%, to in-situ conduits in 2,7%, and the coronary targets in 22,4%. Graft revision occurred in 7,8%, including revisions of the proximal and/or distal anastomosis in 6,6%. In-hospital adverse event rates were 0,6% for mortality, 1,0% for cerebrovascular events and 0,3% for myocardial infarction.

Conclusion

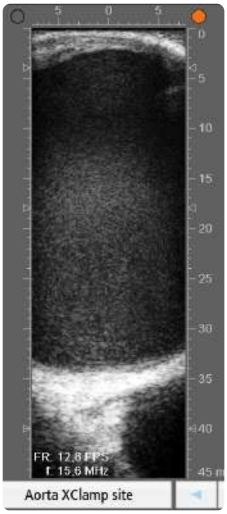
Surgical changes related to the aorta, conduits, coronary targets, and anastomosis were made in 25% of patients. This was associated with low operative mortality and low major morbidity. TTFM and HFUS may improve the quality, safety and efficacy of CABG and should be considered as a routine procedural aspect.

23. REQUEST WORKFLOW

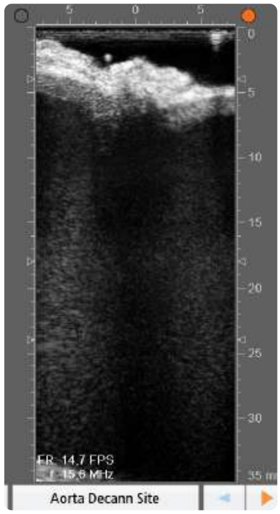
The REQUEST protocol advised to standardize and optimize TTFM assessment. A MAP (mean arterial pressure) of 80 mm Hg was recommended. ACI (Acoustic Coupling Index) should be green or yellow. The mean flow, shown by the red line, should be stable and horizontal. Target values included a pulsatility index < 5, diastolic filling > 70% for left-sided and > 50% for right-sided coronary vessels.

Graft revision was left to the discretion of the operating surgeon. Adherence to the protocol was strongly encouraged but it was not mandatory.

HFUS OF AORTA | HFUS OF CONDUIT | TTFM ASSESSMENT | HFUS OF ANASTOMOSIS

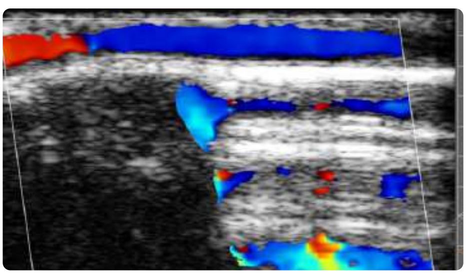


For safer clamping and/or cannulation of the aorta

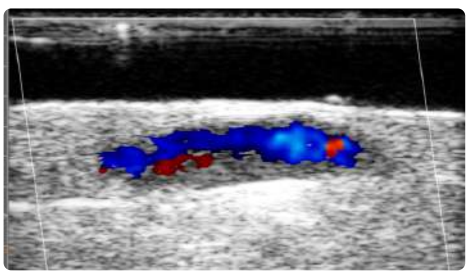


A final scan of the aorta after decannulation allows one to assess any potential damage to the aorta before chest closure

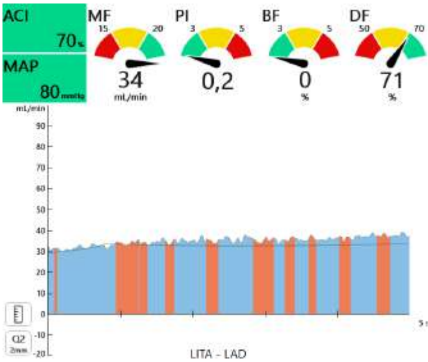
HFUS OF AORTA | **HFUS OF CONDUIT** | TTFM ASSESSMENT | HFUS OF ANASTOMOSIS



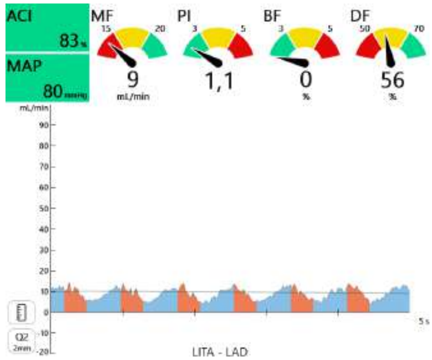
Scan of LITA in situ to make sure the conduit is undamaged after harvest



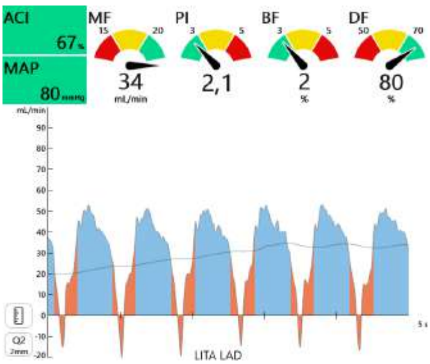
Scan of LAD to find the best anastomotic site



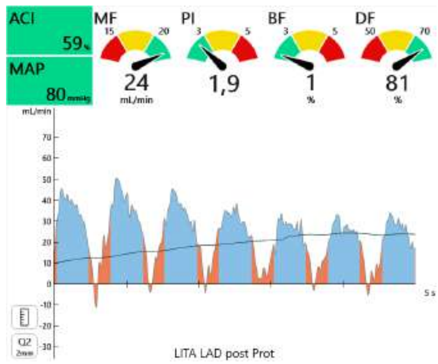
LITA-LAD on-pump with clamp-on



LITA-LAD on-pump with clamp-off

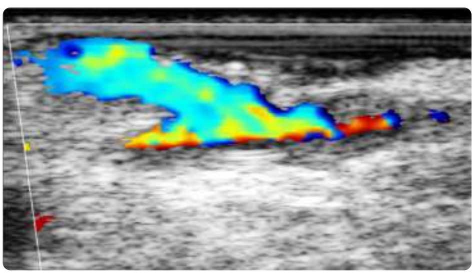


LITA-LAD off-pump pre-protamine

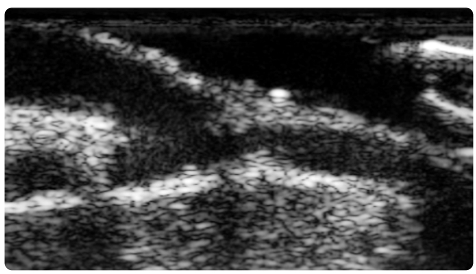


LITA-LAD off-pump post-protamine

HFUS OF AORTA | HFUS OF CONDUIT | TTFM ASSESSMENT | HFUS OF ANASTOMOSIS



Scan of LITA-LAD anastomosis to check patency in color mode



Scan of LITA-LAD anastomosis to check patency in 2D mode

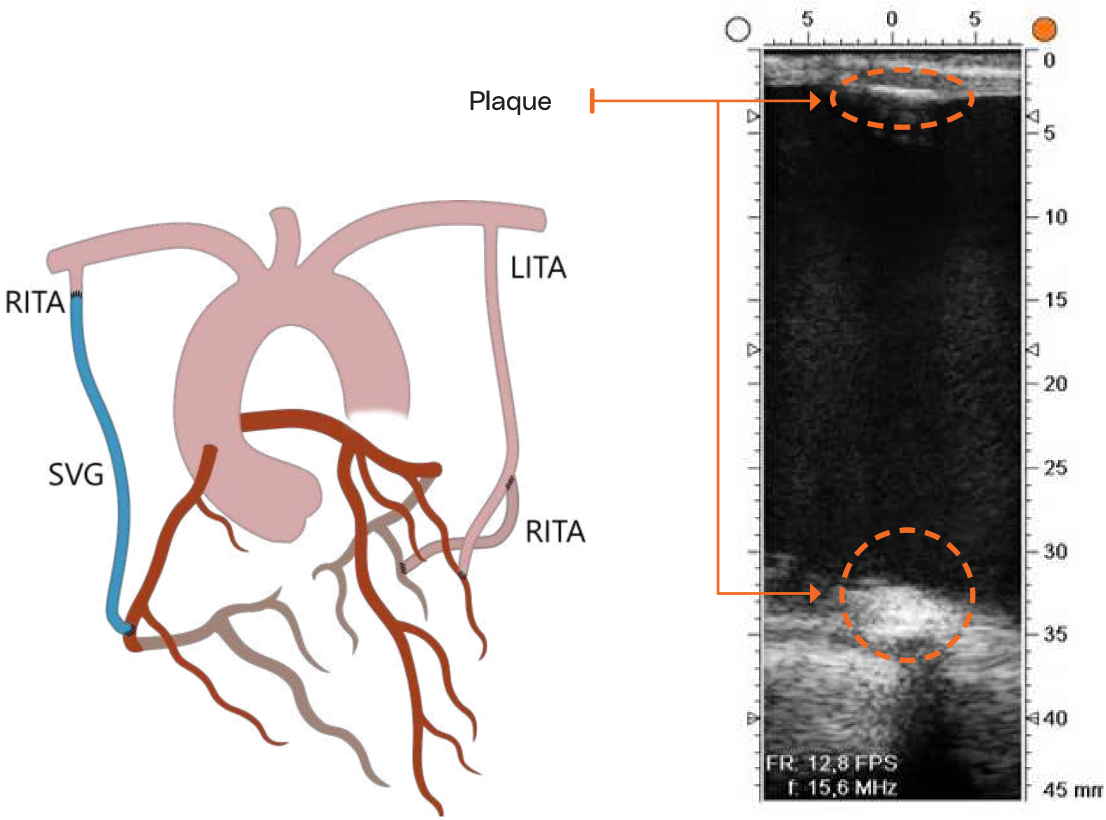
The REQUEST study provided several interesting case examples that illustrate the usefulness of TTFM and HFUS. This chapter presents a collection of these cases.

CASE 1 HFUS OF AORTA PRIOR TO MANIPULATION

For safer clamping or and/or cannulation of the aorta, the investigators were recommended to scan the aorta before manipulation. Some of these scans showed soft, non-palpable plaque that can potentially embolize and create obstructions.

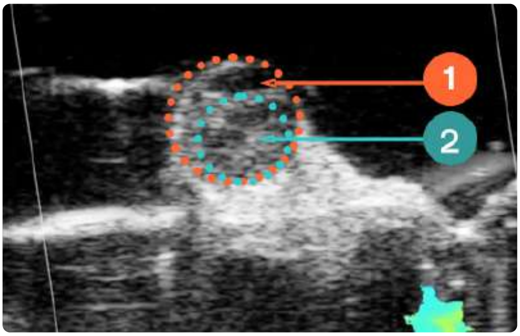
PLAQUE IN AORTA LED TO CHANGE OF SURGICAL STRATEGY

In this case, the surgeon changed the surgical strategy after scanning of the aorta. The aorta was calcified, so the initially planned on-pump LITA-LAD, SVG-OM and SVG-RCA strategy was changed to an off-pump LITA-Y-RITA-OM and RITA-SVG-RCA to avoid clamping and cannulation. A potential problem caused by manipulation of a severely calcified aorta was avoided.



CASE 2 HFUS OF CONDUIT IN-SITU AND CORONARY TARGET

To check for dissections or other issues with the conduit, a HFUS scan during or after harvest was sometimes performed. HFUS also proved helpful in locating intramural coronaries and for optimal placement of anastomoses.

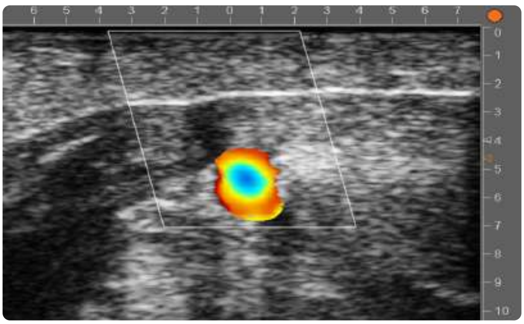


False lumen (1), true lumen (2)

HFUS imaging of LITA in situ showed a dissection that could have led to graft failure.

Imaging clearly showed dissection of the LITA, enabling the surgeon to change the strategy from LITA-LAD to SVG to OM, PDA and LAD.

To avoid compressing the graft, the pericardium can be filled with saline solution or warm water, enabling imaging without compressing the LITA.



HFUS of coronary target

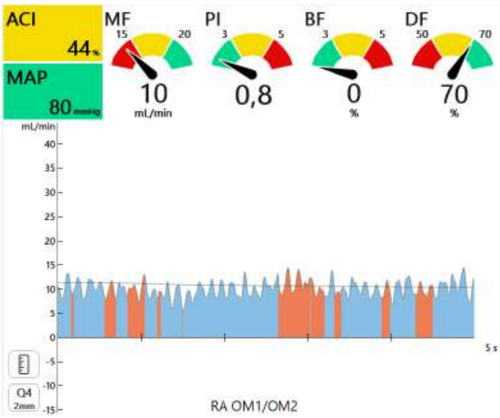
This image shows an LAD that is deeply embedded (5-6 mm) into the myocardium. HFUS can assist in myocardial bridge myotomy (split) and in bypass grafting to intramural coronaries. It is also useful in locating plaque in the native coronary and selecting the optimal anastomosis site.

CASE 3 TTFM FOR GRAFT ASSESSMENT

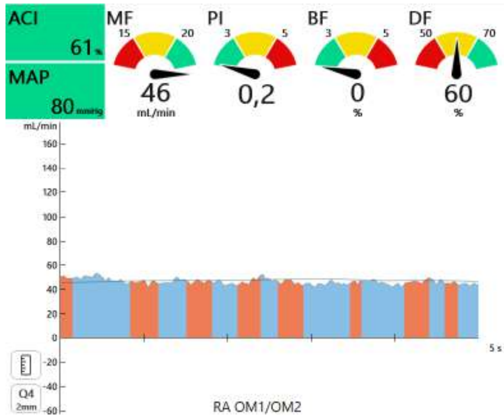
TTFM may be performed at several steps during the procedure to assess graft patency. On-pump measurements will reveal if the anastomosis is open. Later measurements will detect if there are other problems with the graft.

TWISTED GRAFT

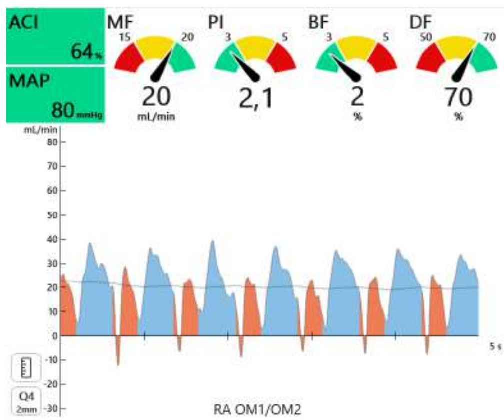
This patient had a bad TTFM for RADIAL-OM/OM2. Closer inspection led to the finding of a 360 degree twist. TTFM improved after revision.



On-pump TTFM with slightly elevated PI *(recommended by Kieser to be below 0,4)* indicated a potential problem with the graft



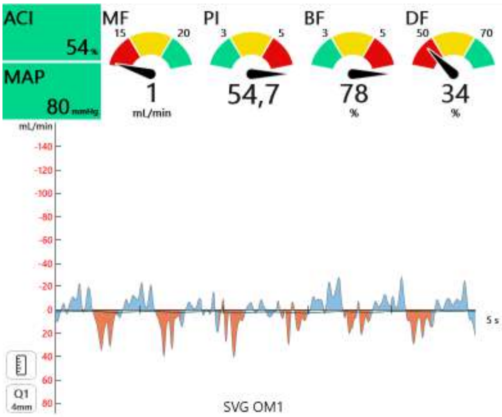
TTFM post revision greatly improved



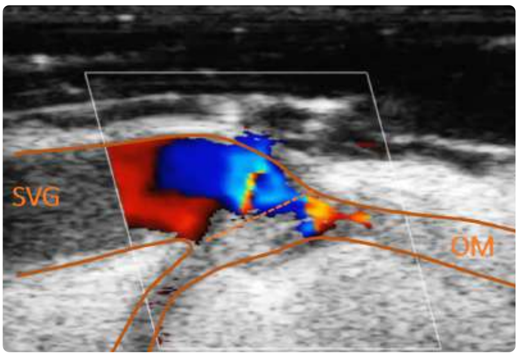
TTFM post protamine was normal

CASE 4 REVISION DUE TO AN OCCLUDING CLIP

After the completion of an SVG-OM anastomosis, the TTFM assessment showed unexpected numbers when the patient came off bypass. HFUS of the anastomosis showed an obstruction and the surgeon decided to revise the graft.

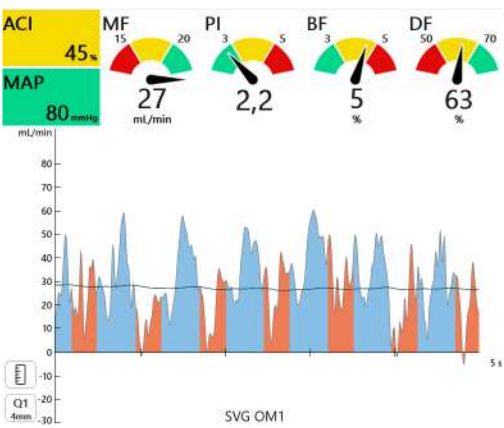


TTFM showed low flow, high PI and low DF% which indicated a problem. The surgeon decided to do a revision of the anastomosis.



Upon initiation of revision, the surgeon found a clip that was partially occluding the SVG lumen. The clip was removed and further revision deemed unnecessary.

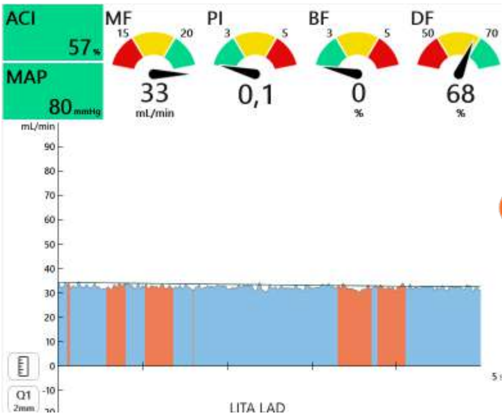
The surgeon reported that he would not have been able to see this obstruction without using the imaging probe.



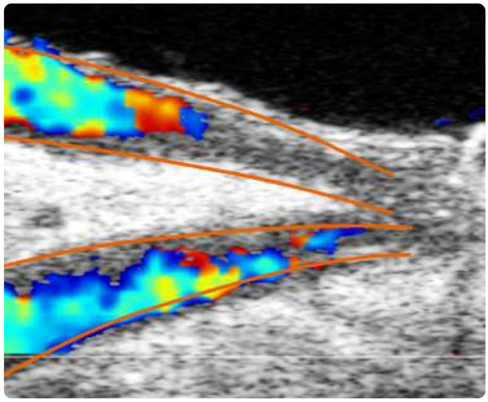
All TTFM parameters were greatly improved after removal of the clip. The flow curve is still not fully repetitive, but acceptable.

HFUS OF ANASTOMOSIS REVEALING ISSUE

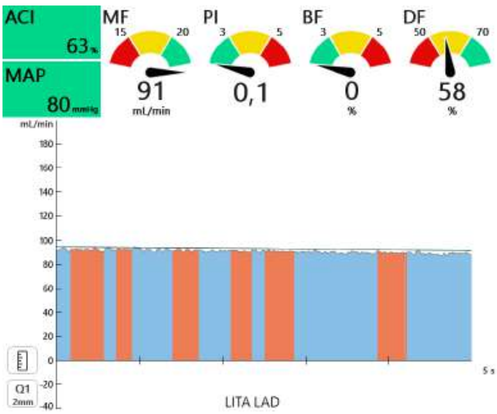
In this case, the on-pump TTFM did not reveal any issues with the anastomosis. The flow was normal and the PI was low. Imaging, however, showed a tapering that reduced the flow. The anastomosis was redone, resulting in almost three times higher flow.



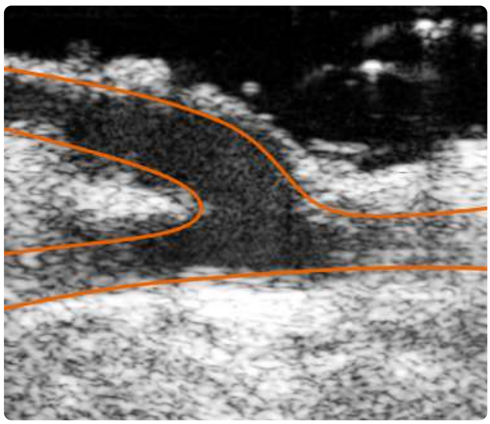
TTFM before revision. PI is fine, but flow a little lower than expected.



HFUS pre revision shows the tapering



TTFM post revision. PI unchanged, but flow is three times higher.

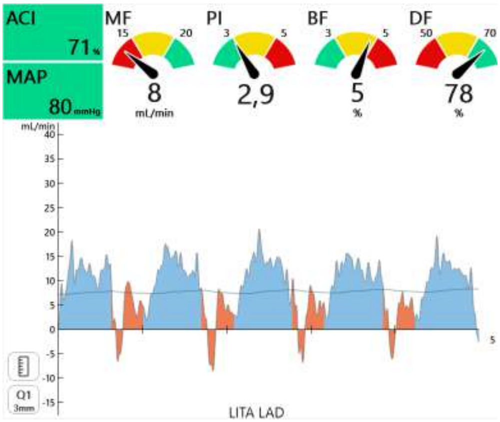


HFUS post revision shows an open anastomosis

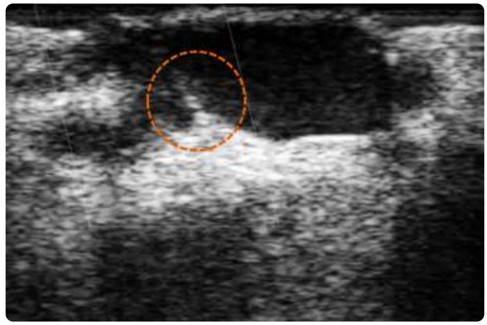
This example shows the usefulness of evaluating graft flows at several steps during the procedure.

CASE 6 ENDARTERECTOMY OF DIFFUSELY DISEASED LAD

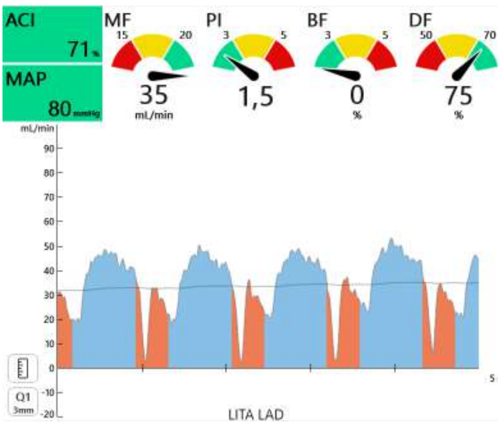
An endarterectomy of the posterior wall was performed to prepare the best target option. After administration of protamine, the TTFM showed a low flow and a borderline PI on LIMA-LAD. The flow curve looks rugged, implying that something might be obstructing the flow. HFUS revealed a flap in the anastomosis. Removing the flap improved the flow parameters.



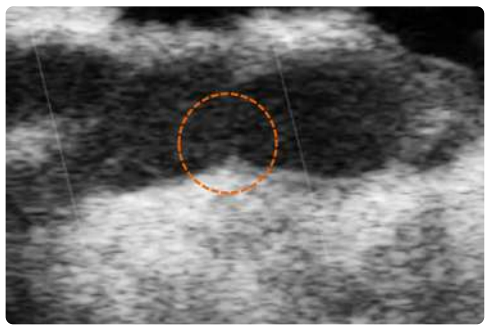
Low flow in LAD examined by HFUS imaging



Intima flap observed which led to revision



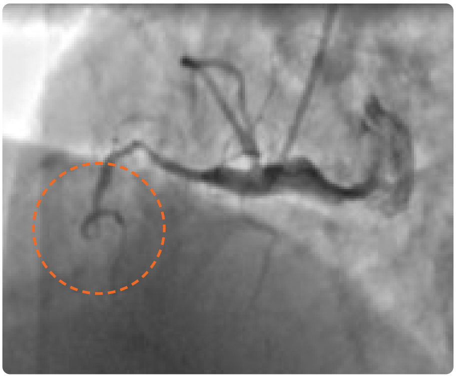
Improved flow parameters



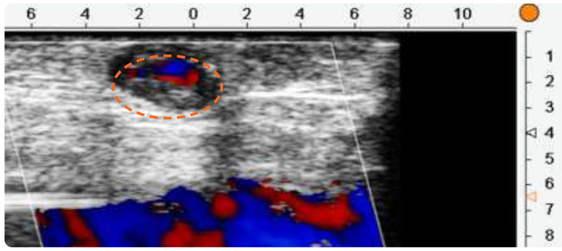
Flap removed during revision

CASE 7 HFUS ASSISTED IN LOCATING BEST ANASTOMOTIC TARGET

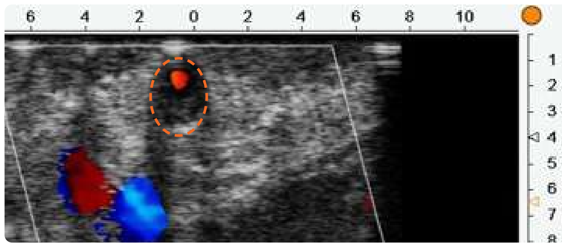
Angio showed a completely occluded RCA, leading to a planned SVG-RPD (Ramus Descendens Posterior). However, epicardial imaging showed a more occluded RPD than RCA, so the target was changed to RCA.



RCA on angio seems 100% occluded and the plan was to avoid performing any grafts to this vessel.



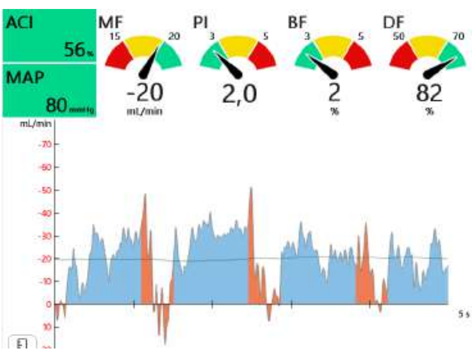
Slight opening in RCA found with HFUS



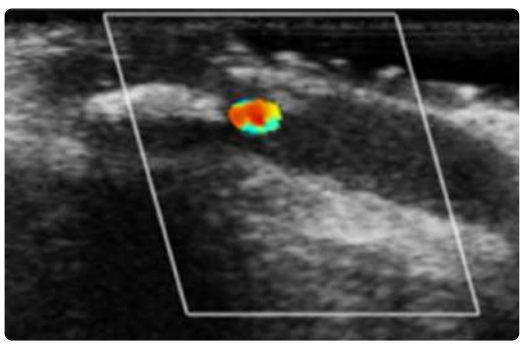
HFUS of PDA shows a near complete occlusion

CASE 8 ANASTOMOSIS ON TOP OF STENOSIS

TTFM for the RIMA–IM indicates acceptable but borderline flow. Imaging confirms that the anastomosis has been positioned directly over the stenosis.



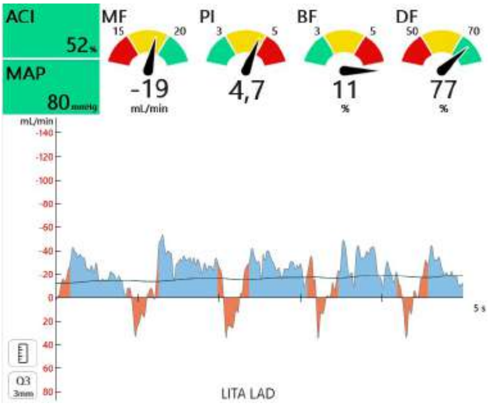
TTFM of RIMA-IM with jagged curve shape but acceptable values



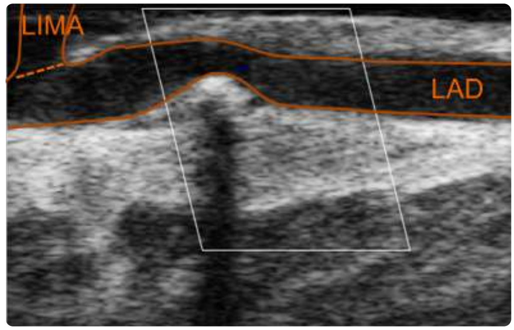
HFUS shows the anastomosis placed over a stenosis

CASE 9 STENOSIS DISTAL TO ANASTOMOSIS

Suboptimal TTFM result on LIMA - LAD and HFUS shows a stenosis distal to the anastomosis.

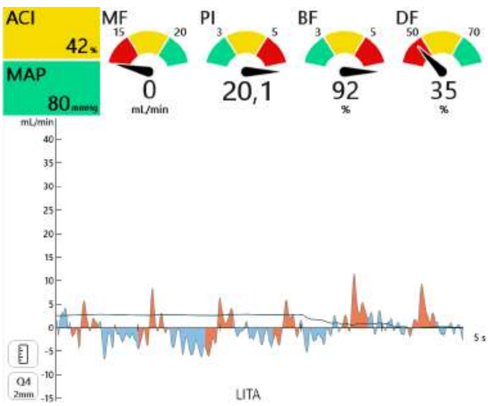


TTFM of LITA–LAD: backflow, elevated PI

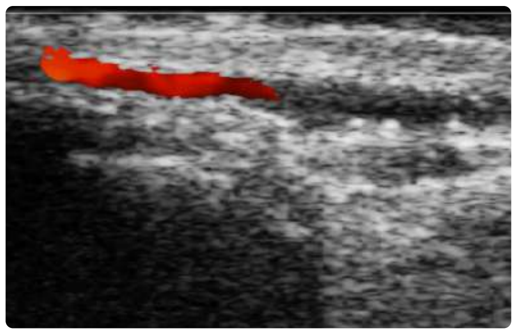


HFUS shows a stenosis distal to the anastomosis

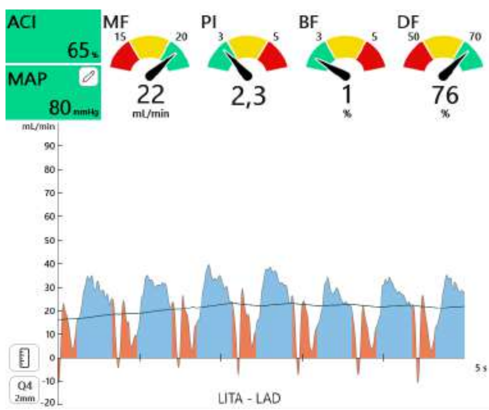
CASE 10 HEMATOMA IN LITA



LIMA in situ during harvest



LIMA narrowed by hematoma - not dissection



TTFM LIMA-LAD post protamine

Transit-time flow predicts outcomes in coronary artery bypass graft patient: a series of 1000 consecutive arterial grafts

Kieser TM, Rose S, Kowalewski R and Belenkie I | Calgary, Canada | *European Journal of Cardio-thoracic Surgery 38 (2010) 155–162*

ABSTRACT

Objective

This study was undertaken to evaluate transit-time flow (TTF) as a tool to detect technical errors in arterial bypass grafts intra-operatively and predict outcomes.

Methods

TTF's three parameters, pulsatility index (PI, index of resistance), flow (cc min(-1) and diastolic filling (DF, proportion of diastole with coronary flow), were measured in 990/1000 (99%) of arterial grafts in 336 consecutive patients, prospectively enrolled in a database. Grafts were revised when TTF findings supported the otherwise suspected graft malfunction. If no other signs/suspicion of graft malfunction existed (normal electrocardiogram (EKG), stable haemodynamics and unchanged ventricular function on transoesophageal echocardiography (TEE)), and the PI was >5, grafts were not revised. Major adverse cardiac events (MACEs: recurrent angina, perioperative myocardial infarction, postoperative angioplasty, re-operation and/or perioperative death) were related to TTFM measurements.

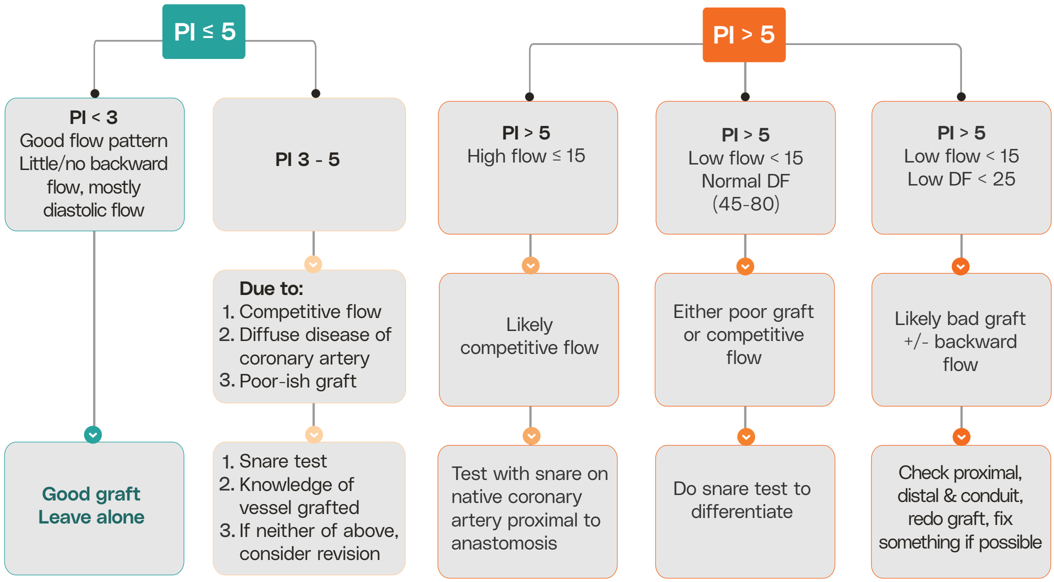
Results

The average number of grafts per patient was 3,02, of which 99% were arterial. Satisfactory grafts were achieved in 916/990 (93%) of the grafts, with flows from 34 to 61 cc min(-1), PI < or =5 and DF of 62-85%. Fourteen conduits, 20 grafts (2%) suspected to be problematic, were revised. Patients were divided into two groups: 277 (82%) with at least one graft with PI < or =5 and 59 (18%) with a PI >5. MACE occurred in 25 (7,4%) patients -15/277 patients with a PI < or =5 (5,4%) and 10/59 with a PI >5 (17%, p=0,005). Mortality following non-emergent surgery was significantly higher in patients with a PI >5 (5/54, 9%) than in patients with a PI < or =5 (5/250, 2%, p=0,02). Flow and DF were not predictive of outcomes.

Conclusions

A high PI predicts technically inadequate arterial grafts during surgery - even if all other intra-operative assessments indicate good grafts; it also predicts outcomes, particularly mortality.

KIESER'S WORKFLOW FOR TTFM DURING CABG



**Kieser et al. Eur. Journal Cardio-thoracic Sur. 38 (2010) 155–162 (Medistim systems)*

Intraoperative graft verification in coronary surgery

Di Giammarco G, Marinelli D, Foschi M and Di Mauro M. | Chieti, Italy | *J Cardiovasc Med 2017, May;18(5): 295-304*

ABSTRACT

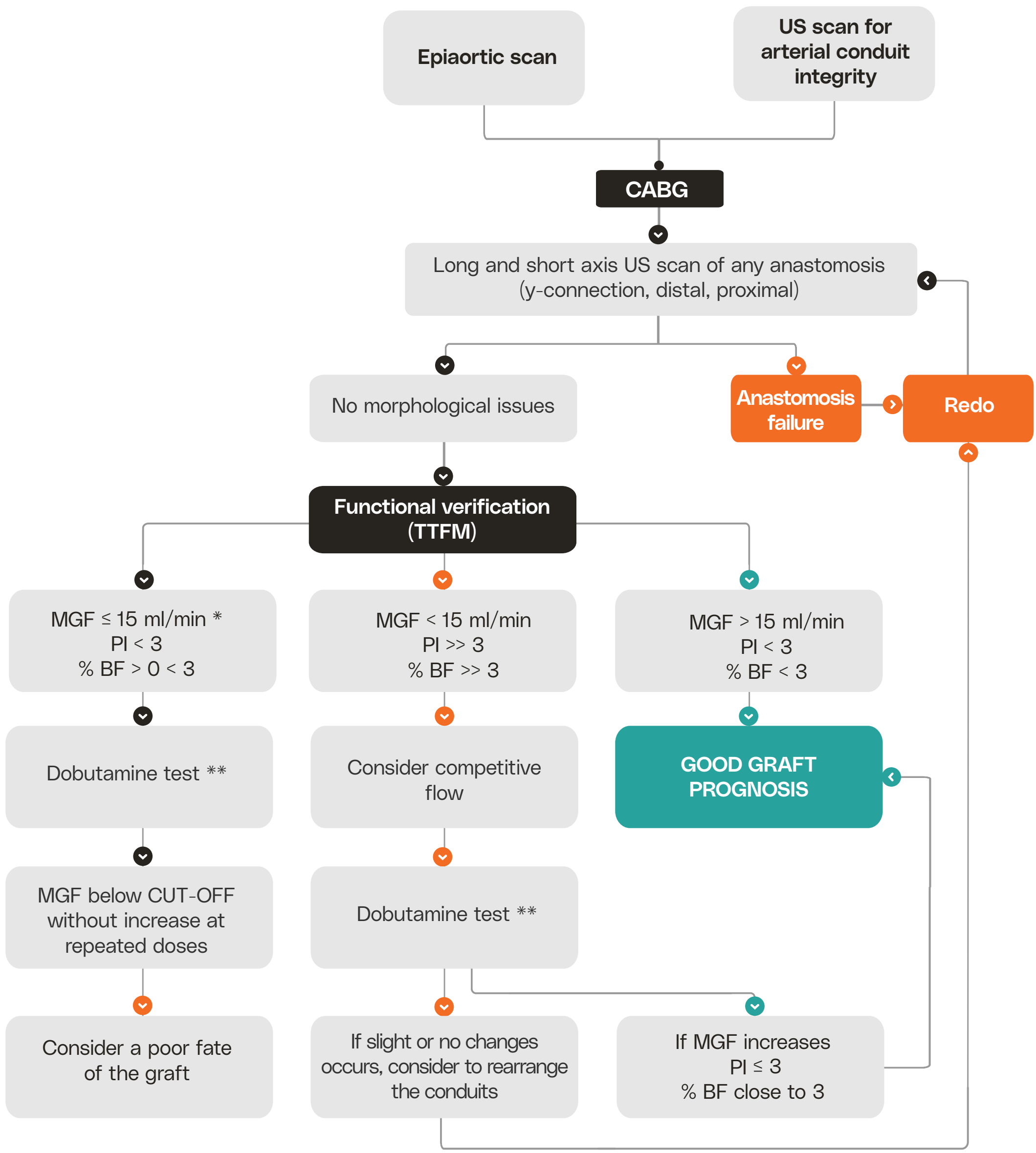
Transit-time flow measurement (TTFM) is a reliable method to check the graft function intraoperatively in coronary surgery. The given parameters are Mean Graft Flow (MGF); Pulsatility Index (PI) and Insufficiency Ratio (%BF).

Some cutoffs of these parameters have been identified as predictors for unfair 1-y clinical outcome: mean graft flow (MGF) less than 20 ml/min and high pulsatility index greater than 5. Other cutoffs have been found as related to postoperative angiography: MGF 15 ml/min or less and pulsatility index at least 3 (sensitivity 94%; specificity 61%); MGF less than 15 ml/min and pulsatility index greater than 3 for left coronary artery. Pulsatility index greater than 5 for right coronary artery (sensitivity 96%; specificity 77%); MGF 15 ml/min or less and pulsatility index at least 5,1 left coronary artery (sensitivity 98%; specificity 26%).

Hence, with the need to improve the diagnostic accuracy of TTFM, a high-resolution epicardic coronary ultrasound module has been added to graft flow evaluation providing 2D ultrasound imaging (either in short-axis or long-axis) and color-flow mapping, allowing an accurate morphological evaluation of body graft and anastomosis. An intraoperative method aimed to verify coronary grafts should be easy to handle, not time consuming, minimally invasive, easily meaningful and relatively cheap; in addition, it should offer objective parameters more than qualitative criteria.

We herein report the results of our experience with intraoperative graft verification with TTFM and high resolution imaging along with a systematic review of the literature in this field with the aim to provide a road map to be followed.

DI GIAMMARCO'S WORKFLOW FOR TTFM & HFUS DURING CABG



* OR = 21.2 for mid term failure
JTVC 2006, 132(3):486-74

** JTVC 2003, 126(4):1076-9

26. CHECKLISTS AND SCREEN CAPTURE

TTFM CHECKLIST

1. Insert the TTFM probe holding the widest part of the connector.*
2. Enter patient information
3. Connect the ECG
4. Perform functionality test
5. Define worklist
6. Annotate if relevant
7. ACI should be green or yellow
8. Mean flow red line should be flat
9. 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. Press the "Live Imaging" tab
3. Press "Imaging Preset" to open the Imaging Preset dialog
4. Choose the desired preset optimized for your application
5. Label the measurement for future reference
6. Press SAVE once the desired object is in frame

SCREEN CAPTURE STEPS

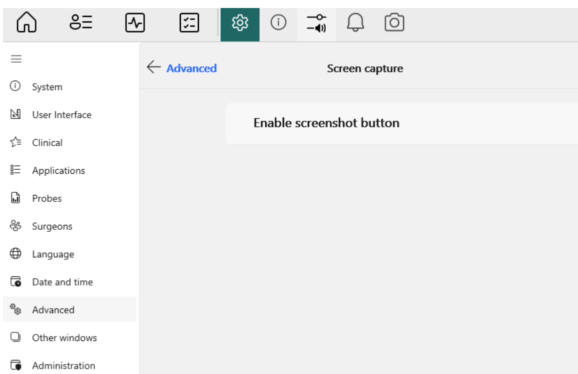
The screen capture feature allows you to take snapshots of the MiraQ display for use in presentations or as illustrations in patient records. Captures can be stored locally on the MiraQ or saved to a USB stick.

Enabling screen capture:
- Go to Settings → Advanced Settings.
- Select Screen capture and enable the screenshot button.

Once enabled, a camera-shaped icon will appear next to the notification icon.

Taking a screen capture:
When relevant data is displayed, press the screen capture icon. You will be prompted to select where to save the image.

The media panel has 2 USB ports



Advanced settings screen

27. ABBREVIATIONS & DEFINITIONS

2D	B-mode/ gray scale (no color) ultrasound
ACI	Acoustic Coupling Index
AM	Acute Marginal Artery
BF%	Backflow
CABG	Coronary Artery Bypass Graft
CX	Circumflex Artery
CFM	Color Flow Mapping (color mode)
CPB	Cardiopulmonary bypass
DF	Diastolic filling
DIAG	Diagonal Artery
EAU	Epiaortic ultrasound
ECG	Electrocardiography
ECUS	Epicardial ultrasound
GEA	Gastroepiploic artery
LAD	Left Anterior Descending Artery
LITA/ LIMA	Left Internal Thoracic / Mammary Artery
LVB	Left Ventricular Branch
MACCE	Major adverse cardiocerebrovascular event
MACE	Major adverse cardiac event
MAP	Mean Arterial Pressure
MGF	Mean graft flow
MF	Mean flow
MI	Myocardial Infarction
OM1 & OM2	Obtuse Marginal first and second branch
OR	Operating room
PDA	Posterior Descending Artery
PI	Pulsatility Index
PLA	Posterior Lateral Artery
PW	Pulsed Wave
RA	Radial Artery
RCA	Right coronary artery
RI	Ramus Intermedius
RITA/ RIMA	Right Internal Thoracic / Mammary Artery
ROI	Region Of Interest
RVB	Right Ventricular Branch
SVG	Saphenous Vein Graft
TGC	Time gain compensation
TIA	Transitoric Ischemic Attack
TTFM	Transit Time Flow Measurement

28. REFERENCES

1. **Gaudino** M, Sandner S, Di Giammarco G, Di Franco A, Arai H, Asai T, Bakaeen F, Doenst T, Fremes SE, Glineur D, Kieser TM, Lawton JS, Lorusso R, Patel N, Puskas JD, Tatoulis J, Taggart DP, Vallely M & Ruel M. The Use of Intraoperative Transit Time Flow Measurement for Coronary Artery Bypass Surgery - Systematic Review of the Evidence and Expert Opinion Statements. Circulation. 2021;144:1160–1171.
2. **D'Ancona** G, Karamanoukian HL, Ricci M, Schmid S, Bergsland J and Salerno TA. Graft revision after transit time flow measurement in off-pump coronary artery bypass grafting. European Journal of Cardio-thoracic Surgery 17 (2000) 287±293.
3. **Kieser** TM, Taggart DP. The use of intraoperative graft assessment in guiding graft revision. Ann Cardiothorac Surg 2018;7(5):652-662.
4. **Kieser** TM, Rose S, Kowalewski R and Belenkie I. Transit-time flow predicts outcomes in coronary artery bypass graft patient: a series of 1000 consecutive arterial grafts. European Journal of Cardio-thoracic Surgery 38 (2010) 155–162.
5. **Kieser** TM, Taggart DP. Current status of intra-operative graft assessment: Should I be the standard of care for coronary artery bypass graft surgery? J Card Surg 2018;33:219-28.
6. **Kieser** TM. Graft quality verification in coronary artery bypass graft surgery: how, when and why? Curr Opin Cardiol 2017;32:722-36.
7. **Mujanovic** E, Kabil E, Bergsland J. Transit time flowmetry in coronary surgery–an important tool in graft verification. Bosn J Basic Med Sci2007;7:275–8
8. **Head** SJ, Milojevic M, Taggart DP and Puskas JD. Current Practice of State-of-the-Art Surgical Coronary Revascularization. Circulation. 2017;136:1331–1345.
9. **Laali** M, Nardone N, Demondion P, D'Alessandro C, Guedeney P, Barreda E, Lebreton G & Leprince P. Impact of transit-time flow measurement on early postoperative outcomes in total arterial coronary revascularization with internal thoracic arteries: a propensity score analysis on 910 patients. Interact Cardiovasc Thorac Surg. 2022 Jul 9;35(2)
10. **Quan** Z, Zhang X, Song X, Chen P & Wu Q. The use of intraoperative transit time flow measurement can reduce postoperative myocardial injury. J Card Surg. 2022;1–8.
11. **Kim** K-B, Choi JW, Oh SJ, Hwang HY, Kim SJ, Choi J-S & Lim C. Twenty-year experience with off-pump coronary artery bypass grafting and early postoperative angiography. The Annals of Thoracic Surgery 2019
12. **Herman** C, Sullivan JA, Buth K & Legare J-F. Intraoperative graft flow measurements during coronary artery bypass surgery predict in-hospital outcomes. Interact CardioVasc Thorac Surg 2008;7:582-585.
13. **Becit** N, Erkut B, Ceviz M, Unlu Y, Colak A & Kocak H. The impact of intraoperative transit time flow measurement on the results of on-pump coronary surgery, Eur J Cardiothorac Surg. 2007 Aug;32(2):313-8.
14. **Bauer** SF, Bauer K, Ennker C, Rosendahl U & Ennker J. Intraoperative Bypass Flow Measurement Reduces the Incidence of Post-operative Ventricular Fibrillation and Myocardial Markers After Coronary Revascularisation. Thorac Cardiov Surg 2005; 53: 217–222.
15. **ESC/EACTS 2018**. The Task Force on myocardial revascularization of the European Society of Cardiology (ESC) and European Association for Cardio-Thoracic Surgery (EACTS). 2018 ESC/EACTS Guidelines on myocardial revascularization. European Heart Journal (2018) 00, 1–96
16. **NICE 2022**. MiraQ for assessing graft flow during coronary artery bypass graft surgery. www.nice.org.uk/guidance/mtg8.

17. **ASE & EACVI 2015**. Multimodality Imaging of Diseases of the Thoracic Aorta in Adults: From the American Society of Echocardiography and the European Association of Cardiovascular Imaging. Journal of the American Society of Echocardiography 2015;28:119-82.

18. **2021 ACC/AHA/SCAI Guideline** for Coronary Artery Revascularization Lawton J, Tamis-Holland J, et al. J Am Coll Cardiol. 2022 Jan, 79 (2) e21–e129.

19. **Drost** C. Vessel diameter-independent volume flow measurements using ultrasound. 1978, Proc. San Diego Biomed Symposium.

20. **Nordgaard** H, Vitale N, Astudillo R, Renzulli A, Romundstad P and Haaverstad R. Pulsatility index variations using two different transit-time flowmeters in coronary artery bypass surgery. European Journal of Cardio-thoracic Surgery 37 (2010) 1063–1067

21. **Jelenc** M, Juvan KA, Medvešček NTR and Geršak B. Influence of Type of Aortic Valve Prosthesis on Coronary Blood Flow Velocity. The Heart Surgery Forum #2012-1073, 16 (1), 2013.

22. **Kim** KB, Kang CH, Lim C. Prediction of graft flow impairment by intraoperative transit time flow measurement in off-pump coronary artery bypass using arterial grafts. Ann Thorac Surg. 2005;80:594–8.

23. **Tokuda** Y, Song M, Ueda Y, Usui A, Akita T. Predicting early coronary artery bypass graft failure by intraoperative transit time flow measurement. Ann Thorac Surg. 2007;84:1928–33.

24. **Di Giammarco** G, Pano M, Cirmeni S, Pelini P, Vitolla G, DiMauro M. Predictive value of intraoperative transit-time flowmeasurement for short-term graft patency in coronary surgery. J Thorac Cardiovasc Surg. 2006;132:468–74.

25. **Trachiotis** GD. Value of diastolic flow with transit-time flow meters in coronary artery bypass surgery. Eur J Cardiothorac Surg 2011;39(03):431, author reply 431–432.

26. **Leong** DK, Ashok V, Nishkantha A, Shan YH, Sim EK. Transit-time flow measurement is essential in coronary artery bypass grafting. Ann Thorac Surg. 2005;79:854-77; discussion 857-8.

27. **Amin** S. An Investigation of Transit-time Flowmetry Parameters in Coronary Artery By-pass Grafting, A dissertation for the degree of Doctor of Philosophy. Wolfson College, University of Oxford.

28. **Di Giammarco*** G, Marinelli D, Foschi M and Di Mauro M. Intraoperative graft verification in coronary surgery. J Cardiovasc Med 2017, May;18(5): 295-304.

29. **McDicken** WN, Anderson T, Chapter 1 in Clinical Ultrasound (Third Edition), (Ed: Weston), Churchill Livingstone, Edinburgh 2011.

30. **Spencer** M P and Reid J M. Quantitation of carotid stenosis with continuous-wave (C-W) Doppler ultrasound. Stroke (1979);10:326-330.

31. **Taggart** DP, Thuijs DJFM, Di Giammarco G, Puskas JD, Wendt D, Trachiotis GD, Kieser TM, Kappetein AP, Head SJ, Intraoperative Transit-Time Flow Measurement and High Frequency Ultrasound Assessment in Coronary Artery Bypass Grafting. J Thorac Cardiovasc Surg. 2020 Apr;159(4):1283-1292.e2..

32. **Taggart** DP & Puskas JD, State of the Art Surgical Coronary Revascularization (Textbook), 2021

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Given that graft failure is often silent in the operating room and strongly associated with later adverse clinical events, we feel that TTFM should be used for all surgical revascularization, particularly OPCAB.

- David P Taggart & John D Puskas [32]

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