Reduce Early Graft Failure Following CABG Surgery

Accurate Flow Measurements Help You Identify and Repair Flow Restrictions to Assure Graft Patency Prior to Closure

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CE 2797

Coronary Flowprobes take the guesswork out of knowing bypass flow

Transonic® Cardiovascular Flowprobes work with the Transonic® Flowmeters to measure volume flow in vessels or grafts from 1.5 - 36 mm diameter. The non-constrictive perivascular Flowprobes use transit- time ultrasound technology to measure volume blood flow directly, quickly and easily, even in the low-flow range.

The surgeon now has a quantitative tool with which to objectively assess the quality of the anastomosis. Unseen blood flow obstructions can be detected intraoperatively and repaired before closing the patient. This ability to correct otherwise undetectable flow restrictions gives the surgeon with a unique opportunity to improve patient outcomes.

European Revascularization Guidelines

"Graft flow measurement, related to graft type, vessel size, degree of stenosis, quality of anastomosis, and outflow area, is useful at the end of surgery. Flow <20 mL/min and pulsatility index >5 predict technically inadequate grafts, mandating graft revision before leaving the operating theatre."[1]

1 The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS) "Guidelines on Myocardial Revascularization," Eur J CardiothoracSurg 2010; 38, S1 S52

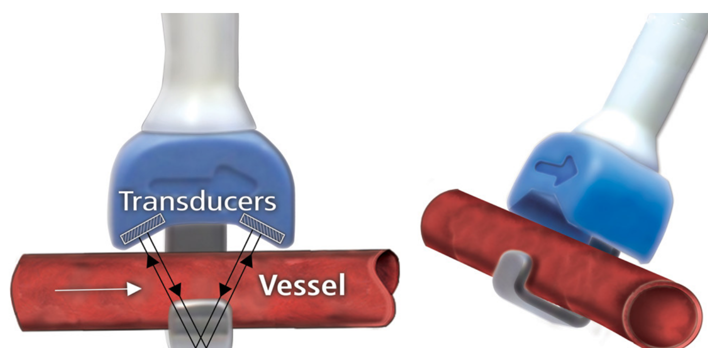
"...TTFM predicts graft failure within six months after CABG."
Jokinen et al,"Clinical value of intra-operative transit-time flow measurement for coronary artery bypass grafting: a prospective angiography-controlled study", Eur J Cardiothorac Surg 2011;39(6):918-23.

"TTFM is a reliable method to verify intraoperative graft patency."
Di Giammarco et al, "Can transit-time flow measurement improve graft patency and clinical outcome in patients undergoing coronary artery bypass grafting?" Interact Cardiovasc Thorac Surg 2010; 11(5): 635-40.

"Routinely, the use of TTFD significantly reduced the incidence of post operative VFib, post-operative CK/CK-MB fraction and angiographically detected bypass malfunction." Bauer SF et al, "Intraoperative bypass flow measurement reduces the incidence of postoperative ventricular fibrillation and myocardial markers after coronary revascularisation," Thorac Cardiovasc Surg 2005; 53(4): 217-22.

"The intraoperative use of flow measurements provide invaluable information in a timely, accurate, cost-effective manner allowing for the surgical correction of a surgical problem. This has signficantly reduced the complication related to early technically induced graft failure." *Mindich B, MD*

TRANSIT-TIME ULTRASOUND TECHNOLOGY
MEASURES VOLUME FLOW, NOT VELOCITY



Two transducers pass ultrasonic signals, alternately intersecting the vessel in upstream and downstream directions. The difference between the two transit times yields a measure of volume flow.

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Flow-based Patency Assurance: Illustrative CABG Case Reports

"The intraoperative use of flow measurements provides invaluable information in a timely, accurate, cost-effective manner allowing for the surgical correction of a surgical problem. This has significantly reduced the complications related to early technically induced graft failure ... and provides documentation of the *sine qua non* of the operation: patency."

Mindich BP et al, "Reduction of Technical Graft Problems Utilizing Ultrasonic Flow Measurements," NY Thoracic Society, 2001.

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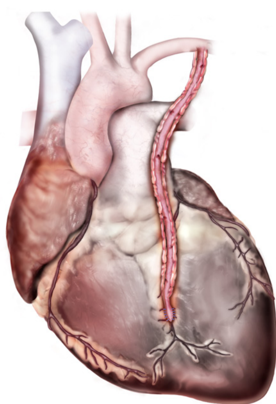
Flow-Based Patency Assurance

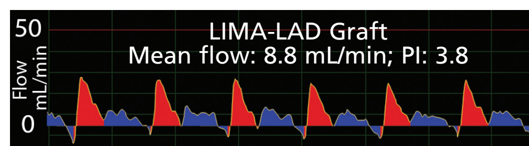
Two LIMA-LAD Cases Demonstrate that PIs <5 Can Be Misleading; Acceptable Mean Flow Is Key

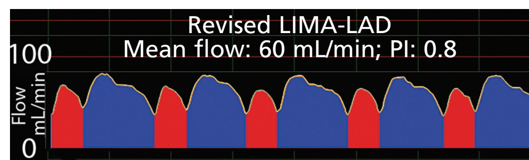


These two cases demonstrate that a PI < 5 doesn't always mean that the graft has good flow. Acceptable mean flow is critical for graft patency assurance and decision making.

A 76-year-old male patient underwent coronary artery bypass grafting (CABG) surgery to bypass a lesion in the left anterior descending (LAD) artery utilizing a left internal mammary artery (LIMA) graft. Initial LIMA-LAD mean flow measured 8.8 mL/min (PI: 3.8) (top waveform).

The graft was revised. Following revision, LIMA-LAD mean flow improved to 60 mL/min (PI: 0.8) and was accompanied by a classic, diastolic dominant waveform profile (bottom waveform).

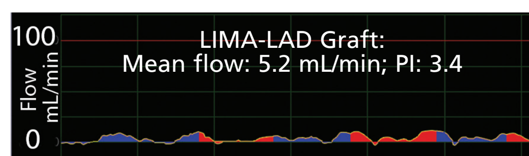


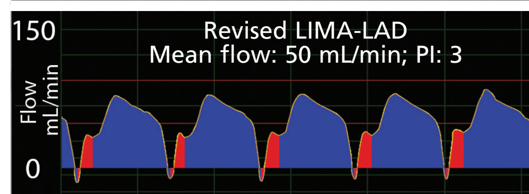


The top LIMA-LAD graft waveform with a spiky systolic profile shows an initial graft flow of 8.8 mL/min (PI: 3.8). Following revision of the graft, flow increased to 60 mL/min (PI: 0.8) and was accompanied by a diastolic dominant waveform profile (bottom waveform).

In the second case, a 67-year-old male patient with single-vessel coronary artery disease underwent off-pump CABG. LIMA-LAD graft flow first measured 5.2 mL/min (PI: 3.4). The patient's pulse and pressure appeared normal and the graft appeared functional, but the waveform exhibited a damped profile and atypical diastolization (top waveform). The surgeon decided to revise the graft.

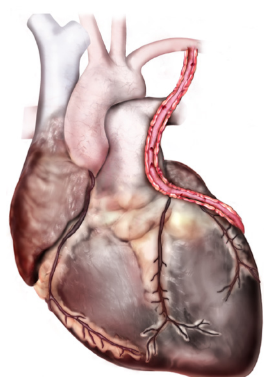
After revision, LIMA-LAD graft flow improved to 50 mL/min (PI: 3). The flow waveform (bottom) exhibited a classic LIMA-LAD profile. Note that the first PI was 3.4, the revised PI was 3.





The top waveform demonstrated a damped profile and an atypical diastolization, and was accompanied by the 5.2 mL/min flow. This supported the surgeon's decision to revise the LIMA-LAD graft. Flow improved dramatically after revision and the waveform exhibited a classic LIMA-LAD profile (bottom waveform).

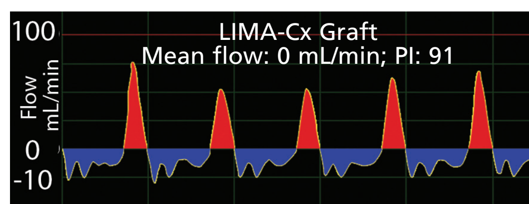
Zero Mean Flow Demands Revision of LIMA-Cx Graft

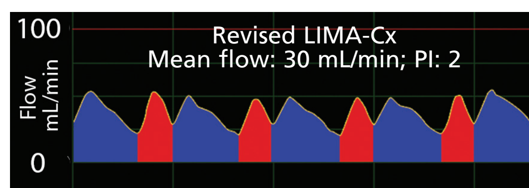


Case demonstrates serious problem with a graft when flow measures 0 mL/min.

A 78-year-old female patient underwent single coronary bypass grafting to bypass a blocked circumflex (Cx) coronary artery with the LIMA. Flow first measured 0 mL/min (PI: 91) following anastomosis of the LIMA to the Cx. The flow waveform had a spiky systolic profile (top waveform). Revision was demanded.

Following revision of the graft, mean graft flow improved to 30 mL/min (PI: 2), and the waveform exhibited a balanced systolic/diastolic profile (bottom waveform). Zero mean flow was the determining factor in the decision to revise the graft.

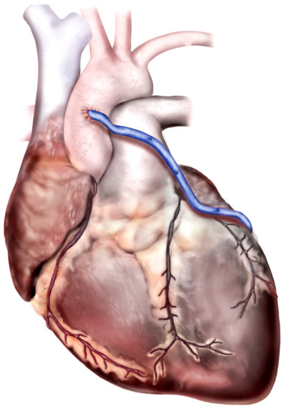




The top waveform exhibited a spiky systolic profile, which, accompanied by zero mean flow, called for the surgeon to revise the LIMA-Cx graft without hesitation. Flow improved to 30 mL/min after revision and the waveform exhibited a balanced LIMA-Cx profile (bottom waveform).

Flow-Based Patency Assurance

Zero Flow in SVG-Cx Graft Reveals Clot

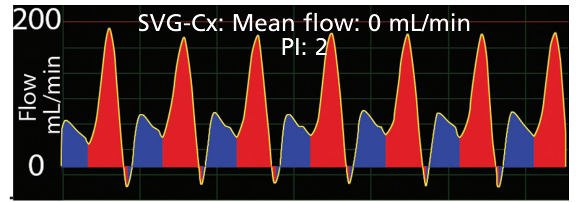


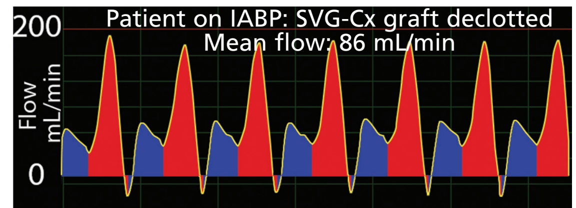
Case demonstrates that IABP support does not significantly influence flow.

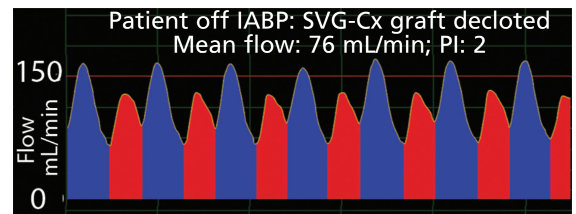
An 81-year-old male patient underwent CABG surgery to bypass a blocked circumflex (Cx) coronary artery. A harvested saphenous vein graft (SVG) was used to connect the aorta to the Cx distal to the lesion (top waveform).

Following anastomosis of the SVG to the Cx, graft flow measured 0 mL/min, clearly indicating that there was a problem. Investigation revealed a clot in the graft. The patient was placed on IABP support. The graft was declotted and flow was remeasured with the patient still on IABP support. Flow measured 86 mL/min (middle waveform).

When the IABP support was removed, graft flow measured 76 mL/min (PI: 2) indicating that the presence of an IABP did not significantly affect graft flow (bottom waveform).

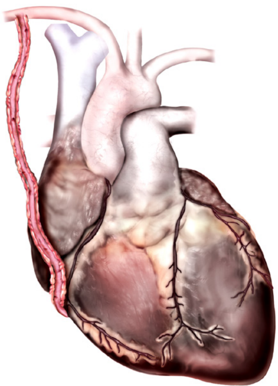






Three waveforms above show a progression from a clotted graft with zero mean flow (top waveform) to a declotted graft on IABP (mean flow, 86 mL/min) to the declotted graft with IABP removed (mean flow, 76 mL/min, bottom waveform).

RIMA-RCA Graft Flow Suppressed by Competitive RCA Flow



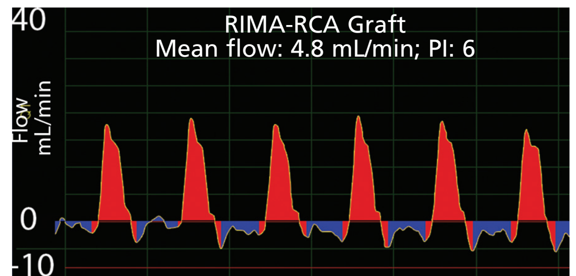
Case demonstrates that competitive flow from a native coronary can suppress graft flow.

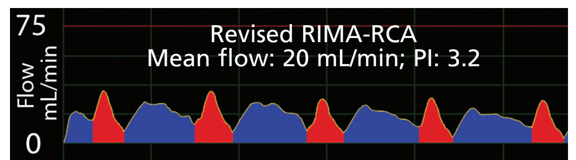
A 60-year-old male underwent CABG to bypass a blockage in his right coronary artery (RCA) with a right internal mammary artery graft (RIMA).

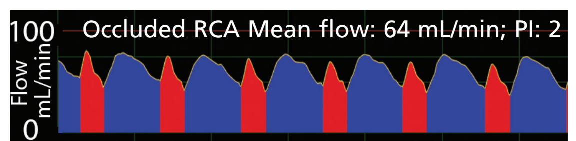
Following the RIMA-RCA anastomosis distal to the blockage, flow measured 4.8 mL/min (PI: 6). Low mean flow, a high PI and a systolic dominant waveform profile indicated the need for graft revision.

After revision, flow improved to 20 mL/min (PI: 3.2), but this flow was not as high as the surgeon expected given the size of the patient. Suspecting the presence of competitive flow from the native RCA, the surgeon occluded the native RCA proximal to the anastomosis of the graft. Mean graft flow increased to 64 mL/min (PI: 2). Another graft was added, placed more distally on the RCA. Runoff improved, competitive flow decreased and graft flow was > 40 mL/min

The significant increase in mean graft flow supported the surgeon's suspicion that competitive flow was suppressing graft flow.





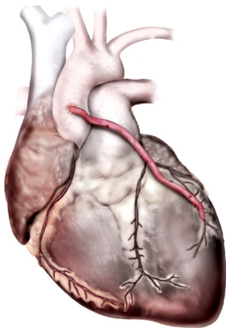


The three waveforms show the systolic dominant profile of the RIMA-RCA graft before revision (top), the systolic/diastolic flow waveform profile following revision of the graft (middle), and the similar graft waveform with the proximal RCA occluded (bottom).

Cases courtesy of B. Mindich, MD

Flow-Based Patency Assurance

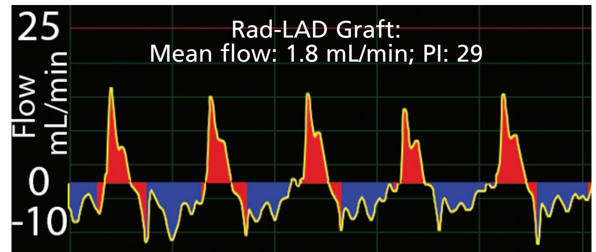
Poor Rad-LAD Graft Flow Triggers Graft Revision

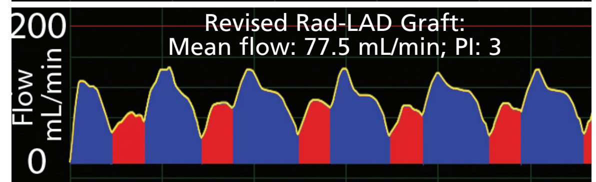


Case demonstrates that poor flow signals need for graft revision.

A 71-year-old male with single-vessel coronary artery disease underwent CABG surgery. A segment of the radial artery (Rad) was harvested and grafted proximally to the aorta and distally to the LAD. Initial Rad-LAD mean flow measured 1.8 mL/min (PI: 29) indicating that revision of the graft was warranted (top waveform).

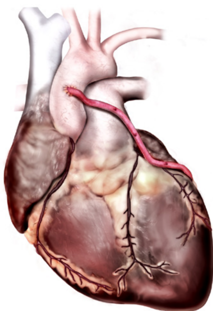
After revision, graft flow improved to 77.5 mL/min (PI: 3). The flow was accompanied by a repetitive systolic/diastolic waveform profile (bottom waveform).





The top Rad-LAD waveform exhibits a spiky systolic profile and is coupled with an initial graft flow of 1.8 mL/min. Following revision of the graft, flow increased to 77.5 mL/min and was accompanied by a diastolic dominant waveform (bottom).

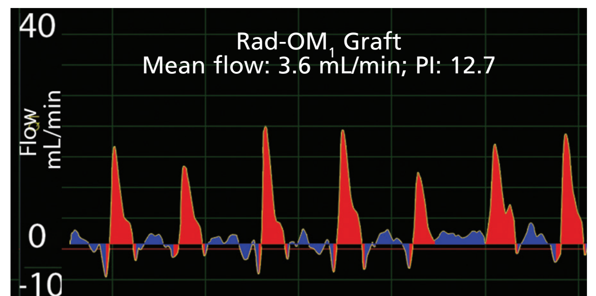
Low Mean Flow Spurs Rad-OM_1 Graft Revision

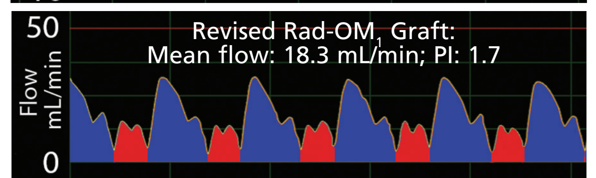


Case demonstrates that poor flow in one out of four grafts signals need for need for graft revision in that one graft.

A 48-year old male patient with multi-vessel coronary artery disease underwent quadruple CABG. Four grafts including a LIMA-LAD, SVG-OM, SVG-Dx and Rad-OM_1 were constructed to deliver flow to the distal myocardium. Mean flows in the LIMA-LAD, SVG-OM and SVG-Dx grafts were acceptable.

However, mean Rad-OM_1 graft flow measured 3.6 mL/min (PI: 12.7) signaling the need for revision of the graft. Following Rad-OM_1 graft revision, mean graft flow improved to 18.3 mL/min (PI, 1.7) and was accompanied by a systolic/diastolic waveform.





The top waveform with a spiky systolic profile shows initial Rad-OM_1 graft flow of 3.6 mL/min. Following revision of the graft, flow increased to 18.3 mL/min and was accompanied by a diastolic dominant waveform profile (bottom waveform).

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FAST - Flow-assisted Surgical Techniques during Coronary Artery Bypass Grafting

Why Measure Coronary Bypass Blood Flow?

During coronary artery bypass grafting (CABG) surgery, coronary Flowprobes may be used as a quantitative tool to measure blood flow through a bypass graft and to provide objective intraoperative flow information. This information may assist the surgeon in evaluating graft flow characteristics while the patient remains in the operating room.

Measuring CABG Blood Flow

The following techniques reflect reported user practices intended to support flow measurement consistency. Flow-assisted graft assessments are typically performed once the patient is off-pump.

1. If using an internal mammary artery graft, skeletonize a 1.0cm segment of its distal end before performing the anastomosis. For flow measurement purposes, unlike IMA grafts, no additional local dissection/skeletonization is typically needed for saphenous vein grafts before placing the Flowprobe.
2. Select a Flowprobe size such that the graft fills at least approximately 75% of the Flowprobe sensing window. Avoid selecting a probe that is unnecessarily small for the graft, as the vessel should fit comfortably within the sensing window to support proper placement and measurement performance.
3. Inspect each flowprobe prior to use. Do not use in any of the following cases:

- Sharp edges or burrs on the device
- Cracks or chips on the Probe head, reflector, handle, or connector
- Nicks in the Probe cable
- Damage to the silicone seal (if integrity of the silicone is compromised).
- Damage to the sterile packaging:
    - For reusable Flowprobes, return the Flowprobe to central processing to be cleaned and sterilized following the appropriate instructions for use in your country supplied with your Flowprobes
    - For single use Flowprobes discard Flowprobe after use.

4. Prior to use verify Flowprobe connection and signal strength. Plug in the Flowprobe then immerse (couple) the Flowprobe in still, sterile saline or use sterile acoustic gel couplant in the probe's window to establish a zero-flow condition.
    - Once coupling is achieved, the Signal Strength Indicator icon will fill with the appropriate number of bars to indicate the quality of coupling. Confirm that signal strength is adequate (≥15%). If the probe is properly coupled, a moderate signal strength does not have any impact on flow accuracy.
    - Confirm that the waveform in the meter's display window is stable, offset is within specification and no environmental interference is evident.
5. Apply sterile ultrasonic couplant in the Flowprobe's sensing window and turn on FlowSound. A low-pitched hum generally indicates that the Flowprobe is properly connected and that adequate ultrasound couplant is present within the sensing window.
6. Place the Flowprobe on the graft so that it is positioned perpendicular to the graft. Avoid stretching, compressing, or kinking the graft. Do not place the Flowprobe over surgical clips or sutures. The ultrasound's signal quality is indicated on the meter's display.
7. Observe the contraction of the heart while listening to FlowSound. In CABG grafts, a lower pitch generally corresponds to lower-flow systolic phases and a higher pitch to higher-flow diastolic phases. Listen to the relative systolic and diastolic FlowSound characteristics to help assess graft flow balance.
    - FlowSound in Diastolic-dominant Left Heart Grafts: Because myocardial contraction can

Pictured, from left to right, are 1.5 mm, 2 mm, 3 mm and 4 mm Coronary Flowprobes showing their blue Probe bodies, J-style reflectors and ultrasonic sensing windows.

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reduce inflow during systole, grafts supplying the left heart often demonstrate a stronger diastolic flow component. This may be heard as a lower pitch during systole, and relatively greater diastolic flow, which may be heard as a higher pitch during diastole.

- FlowSound in Systolic/Diastolic Balanced Right Heart Grafts: Because the right side of the heart generally contracts less forcefully than the left heart, graft flow to a right heart coronary graft may be less impeded during systole and thus may demonstrate more balanced systolic and diastolic flow components. In these grafts, the FlowSound pitch during systole and diastole may be more similar and balanced.

8. The average (mean) flow will display on the Flowmeter screen or the front panel of the Flowmeter.
9. Assess for competitive flow if graft flow appears lower than expected or when waveform findings are uncertain. Temporarily occlude the native coronary artery proximal to the anastomosis, in accordance with surgical judgment, and observe any changes in FlowSound, mean flow, or waveform pattern. An increase in mean flow, corresponding rise in FlowSound pitch, and a more favorable waveform profile during occlusion may be consistent with competitive native coronary flow. Competitive flow may also be associated with brief reversed or negative flow components. Measurements obtained with temporarily reduced competitive native flow may provide additional insight into graft flow capacity. However, waveform findings should be interpreted together with mean flow and overall clinical context.
10. When flow waveform and mean flow have stabilized, press Snapshot, Print, or Export to the USB v2.0 Type A on the Flowmeter.

Mean Flow as a Primary Clinical Indicator

Transonic's FAST Assessment for CABG places primary emphasis on mean graft flow interpreted together with waveform characteristics and overall clinical context. Mean flow is generally the primary parameter used to support a surgeon's assessment of graft flow adequacy and to identify findings that may warrant further clinical evaluation.
Mean Flow assessment includes the following range guidance:

1. Mean Flow ≥ 25 mL/min (small patients, >20 mL/min) is often consistent with favorable graft flow when interpreted in clinical context. If mean flow is lower than expected, first assess for the presence of competitive flow by temporarily occluding the native coronary artery proximal to the anastomosis to assess the graft flow's capacity.
2. Mean Flow < 5 mL/min may indicate the need for evaluation of technical, physiologic, or graft-related factors

If competitive flow is reasonably excluded as a contributor to lower flow, consider that mean graft flow can vary over a wide range and should be interpreted with consideration of:

- patient size, weight, and overall condition;
- graft size and quality;
- target vessel size and quality;
- Mean Arterial Pressure (MAP);
- myocardial runoff and distal vascular bed condition.

FlowSound may provide supplemental information when evaluating lower flow. With the probe on the graft, activate FlowSound and listen for pitch changes as the graft or surrounding tissue is gently manipulated and assessed. Evaluate for potential kinks or twists in the graft, low MAP, or diminished pulsatility on the displayed waveform. If technical concerns remain after evaluation, further surgical assessment or revision may be considered.

FAST during CABG

Derived Parameters

1. If mean graft flow is lower than expected and competitive flow has already been assessed, the next step is assessment of the systolic/diastolic waveform characteristics. Waveforms should first be evaluated for a repetitive flow pattern generally expected for the ventricle supplied (left ventricle grafts are typically diastolic dominant; while right ventricle grafts typically display a more balanced systolic/diastolic distribution).
2. If the Flowmeter is connected to the patient's ECG for systolic-diastolic phase detection, D/S Ratio (or DF%) may be calculated to further characterize the flow waveform through the bypass graft. D/S Ratio compares diastolic flow to systolic flow. DF% compares diastolic flow to total flow. Either derived parameter can be selected in the Settings screen.
3. If ECG-based systolic-diastolic detection is unavailable, Pulsatility Index (PI) may be reviewed. If competitive flow is not present, analysis of diastolic/systolic waveform properties can shed light on a possible problem. Waveforms should be examined first to see if they exhibit a repetitive flow pattern characteristic for the ventricle it is supplying (left ventricle: diastolic dominant pattern; right ventricle: systolic/diastolic balanced waveform.

The derived parameters depend on the quality of the waveform and no flow-derived parameter is intended to be relied on as a sole diagnostic indicator. All flow-related assessments should be performed within the clinical context of the patient. If waveform appearance is unstable or inconsistent with expected physiology, refer to Appendix G of the FlowXL Operator's Manual before relying on derived parameters.

DIASTOLIC SYSTOLIC RATIO (D/S)

D/S ratio compares the diastolic flow to systolic flow. Expressed mathematically:

$$\text{D/S Ratio} = \frac{\text{Total Diastolic Flow}}{\text{Total Systolic Flow}}$$

- D/S Ratio >2 is generally more consistent with a diastolic-dominant profile;
- D/S Ratio between 1 and 2 is generally more consistent with a balanced systolic/diastolic profile, often seen in right-heart grafts;
- D/S Ratio <1 may indicate a relatively systolic-dominant profile and may warrant further evaluation.

DIASTOLIC FRACTION (DF%)

Diastolic Fraction compares diastolic flow to flow occurring during both systole and diastole as a percentage. Expressed mathematically:

$$\text{DF\%} = \frac{\text{Average Diastolic Flow}}{\text{Total (Diastolic + Systolic) Flow}} \times 100$$

- DF% greater than 50% is generally more consistent with a diastolic-dominant flow profile;
- DF% approximating 50% is generally more consistent with a balanced systolic/diastolic profile;
- DF% less than 50% is generally more consistent with a systolic-dominant flow profile.

NOTE: D/S Ratio and DF% are two methods of evaluating similar waveform characteristics.

In general:

- D/S of greater than 2 corresponds to DF% greater than 67%;
- D/S between 1 and 2 corresponds to DF% between 50% and 67%;
- D/S less than 1 corresponds to DF% less than 50%.

PULSATILITY INDEX (PI)

Pulsatility Index (PI) is a derived parameter that reflects the relationship between waveform amplitude and mean flow. Expressed mathematically:

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

While PI may provide useful supplemental information, it should not be used alone to determine graft patency or graft quality. In some clinical practices, a PI >5 has been used as a potential indicator of technical concern; however, **Transonic has long recommended that PI be used only as a supplementary parameter with an understanding of its limitations.**

Publications such as Jelenc M, et al. in Understanding Coronary Artery Bypass Transit-Time Flow Curves: Role of Bypass Graft Compliance, have noted important limitations of PI when used in isolation. These authors

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reported that PI may be significantly influenced by factors such as graft compliance, measurement location, pulse pressure, and mean flow, which may reduce specificity when used for graft patency assessment.

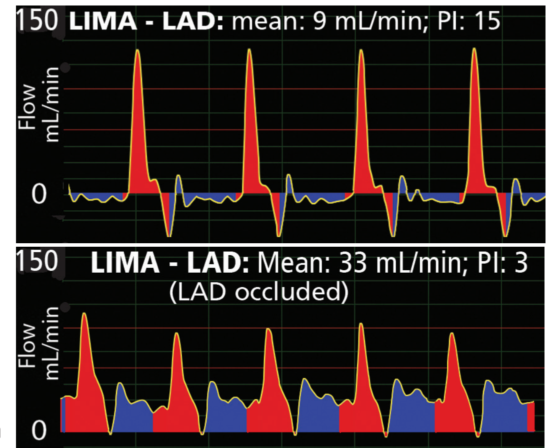
PI can also be influenced by factors other than graft obstruction, including competitive native coronary flow, heart rate, arterial pressure, distal coronary runoff quality, downstream vascular resistance, and other hemodynamic conditions. As a result, an elevated PI may occur in a technically satisfactory graft, while an unfavorable graft condition may at times present with a PI within commonly accepted ranges.

Published literature has also reported that mean flow and diastolic flow metrics (such as D/S Ratio) may provide greater sensitivity than PI alone for indicating certain graft abnormalities, particularly less severe or subcritical stenoses.

For these reasons, PI is best interpreted together with mean flow, waveform appearance, D/S Ratio or DF% (when available), and the overall clinical context. Mean flow and direct waveform assessment should remain the primary considerations.

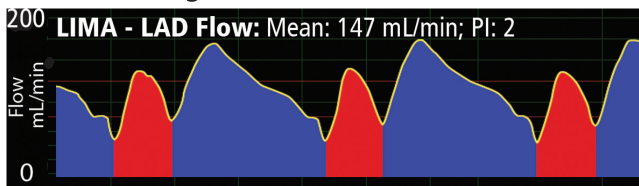
In general clinical use:

- PI >5 has been associated with certain low-flow, restrictive, or competitive flow conditions and may warrant further clinical assessment.
- PI between 1 and 5 may be acceptable when interpreted together with mean flow, waveform appearance, and other clinical findings.



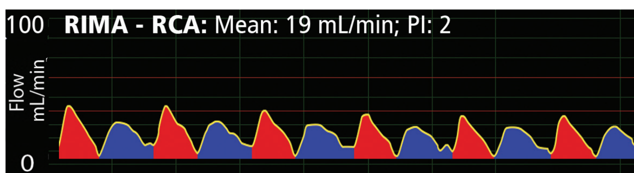
Competitive Flow in LIMA-LAD Graft

Flow increased from 9 mL/min to 33 mL/min when the LAD was temporarily occluded. The presence of competitive flow (top waveform) was associated with a spiky systolic profile and PI of 15. When the LAD was occluded (bottom waveform), the waveform shifted toward a more diastolic-dominant profile with PI of 3.



Diastolic Dominant Pattern (Left-Heart Grafts)

For grafts to the left ventricle, the shorter waveform peak is often systolic and the broader higher peak is often diastolic, except in conditions such as marked tachycardia where diastole may be shortened. A typical left-heart graft waveform is diastolic dominant, where delivered diastolic blood volume exceeds systolic blood volume.



Balanced Systolic Diastolic Pattern (Right-Heart Grafts)

In grafts to the right ventricle, flow may be more evenly distributed between systolic and diastolic phases. This may produce a waveform in which the systolic peak is prominent and is followed by a proportionally strong diastolic component.

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1 Mindich BP *et al,* "Reduction of Technical Graft Problems Utilizing Ultrasonic Flow Measurements,"NY Thoracic Society, 2001.
2 Di Giammarco G, Rabozzi R, "Can transit-time flow measurement improve graft patency and clinical outcome in patients undergoing coronary artery bypass grafting?" Interact Cardiovasc Thorac Surg. 2010 Nov; 11(5): 635-40.
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4 Tokuda Y *et al,* "Predicting midterm coronary artery bypass graft failure by intraoperative transit time flow measurement," Ann Thorac Surg 2008 Aug;86(2):532-6.
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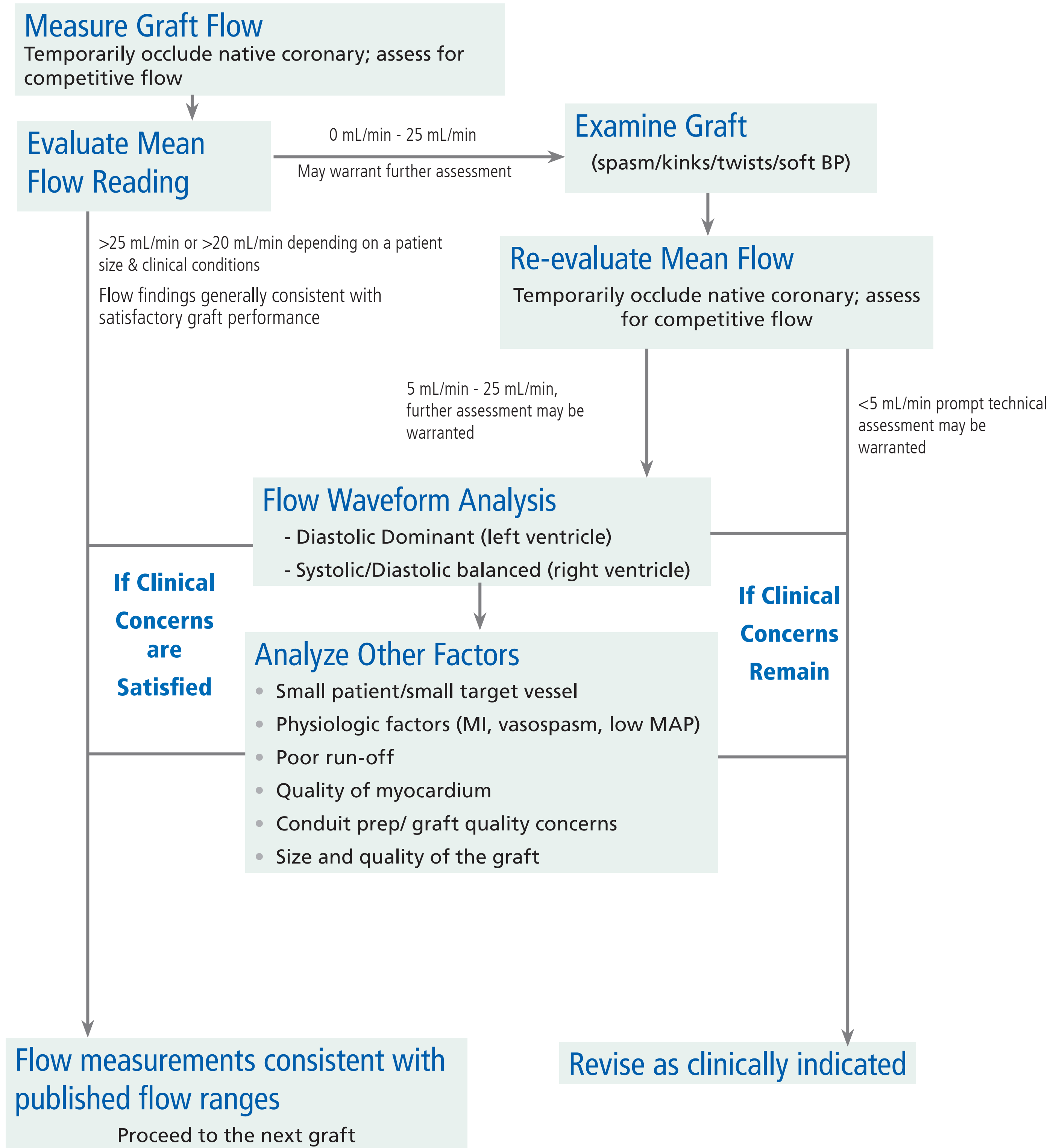
FAST during CABG



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Signature Transit-time Ultrasound CABG References

Neumann FJ *et al*, **"2018 ESC/EACTS Guidelines on myocardial revascularization,"** Eur Heart J. 2019 Jan 7;40(2):87-165. *"5.1.7 INTRAOPERATIVE QUALITY CONTROL: Besides continuous ECG monitoring and transoesophageal echocardiography immediately after revascularization, intraoperative quality control may also include graft flow measurement to™ confirm or exclude a technical graft problem.513 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.513,514 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."*

Thuijs DJFM, Bekker MWA, Taggart DP, Puskas JD, Head SJ*et al*, "**Improving coronary artery bypass grafting: a systematic review and meta-analysis on the impact of adopting transit-time flow measurement,"** Eur J Cardiothorac Surg. 2019 Oct 1;56(4):654-663. *A comprehensive literature review and meta-analysis of 66 publications, 8,943 patients and 15,673 grafts, showed that a mean graft flow of 20mL/min was a commonly used threshold for flow. The PI threshold used was more variable. Some studies use a threshold PI value < 5 to indicate an acceptable graft while other studies suggest that a PI threshold of < 3 may be a more appropriate threshold. Overall reported sensitivity of TTFM for predicting a failing graft was as low as 20-30%, the specificity of TTFM was more often in the 90% range.*

Caliskan E, de Souza DR, Böning A, Liakopoulos OJ, Choi YH, Pepper J, Gibson CM, Perrault LP, Wolf RK, Kim KB, Emmert MY, **"Saphenous vein grafts "in contemporary coronary artery bypass graft surgery,** Nat Rev Cardiol. 2020 Mar;17(3):155-169. (Transonic Reference # 118902AHR) *To improve long-term SVG patency rates, a systematic, step-by-step, best practice approach should include intraoperative graft assessment to help identify grafts that might fail early and lead to revision of the low-flow graft, thereby improving graft patency.*

Kim KB, Choi JW, Oh SJ *et al*, **"Twenty-Year Experience with Off-Pump Coronary Artery Bypass Grafting and Early Postoperative Angiography,"** Ann Thorac Surg. 2020;109(4):1112-1119. (Transonic Reference # 115882AHM) *Twenty-year single center study reported a TTFM-based intraoperative revision rate of 5.6%. TTFM adoption was associated with a higher LIMA patency rate (99.4%) compared pre-TTFM (97.1%,p=0.009). They compared outcomes before and after TTFM introduction and found that the postoperative reintervention rate decreased from 7.2% (16/221) prior to TTFM adoption to 2.3% (60/2599) after TTFM adoption; p<0.001. Of the 76 patients who underwent re-intervention, most (73/76) underwe*nt reoperation; three patients were treated using PCI.

Quin JA, Noubani M, Rove JY, Krstacic JE, Hattler B, Collins JF, Grover FL, Almassi GH, Shroyer AL, **"Veterans Affairs Randomized On/Off Bypass Follow-up Study (ROOBY-FS) Group. Coronary Artery Bypass Grafting Transit-Time Flow Measurement: Graft Patency and Clinical Outcomes,"** Ann Thorac Surg. 2020 Dec 22:S0003-4975(20)32150-0. (Transonic Reference # 11879AH) *The investigation suggests that intraoperative TTFM assessment, however used, may be associated with higher 1-year angiographic graft patency.*

Di Giammarco G, Rabozzi R, **"Can transit-time flow measurement improve graft patency and clinical outcome in patients undergoing coronary artery bypass grafting?"** Interact Cardiovasc Thorac Surg. 2010 Nov;11(5):635-40. (Transonic Reference # 1705V) *"We conclude that TTFM is a reliable method to verify intraoperative graft patency. There is some evidence that checking graft patency intraoperatively may improve mid-term outcomes."*

Bauer SF *et al*, "**Intraoperative Bypass Flow Measurement Reduces the Incidence of Postoperative Ventricular Fibrillation and Myocardial Markers after Coronary Revascularization,"** Thorac Cardio Surg 2005; 53: 217-22. (Transonic Reference # 6997AH) *"Routine use of intraoperative transit-time flow measurements reduces the incidence of postoperative anastomosis failure and related technical complications of bypass surgery and leads to a significant reduction of postoperative mortality in CABG."*

Mindich BP *et al*, **"Reduction of Technical Graft Problems Utilizing Ultrasonic Flow Measurements,"**NY Thoracic Society, 2001. "*The intraoperative use of flow measurements provide invaluable information in a timely, accurate, cost-effective manner allowing for the surgical correction of a surgical problem. This has significantly reduced the complications related to early technically induced graft failure. In an era of rapidly changing surgical techniques this provides documentation of the sine-qua-non of the operation: patency."*

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Signature Transit-time Ultrasound CABG References cont.

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*Herman C *et al*, **"Intraoperative Graft Flow Measurements during Coronary Artery Bypass Surgery Predict In-hospital Outcomes,"** Interact CardioVasc Thorac Surg 2008;7:582-585. (Transonic Reference # 7626AHM) *"Our findings suggest that abnormal flows measured intraoperatively are independently associated with short-term in-hospital adverse outcome."*

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Validations

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Canver CC, Dame, N, **"Ultrasonic Assessment of Internal Thoracic Artery Graft Flow in the Revascularized Heart,"** Ann Thorac Surg 1994; 58:135-8. J. Cardiovasc Surg (Torino)1997;38:211-5. (Transonic Reference # 51V) *"Transit-time ultrasound can accurately quantify physiologic blood flow through an ITA graft immediately after CABG and provides the surgeon with valuable information."*

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