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.

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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.

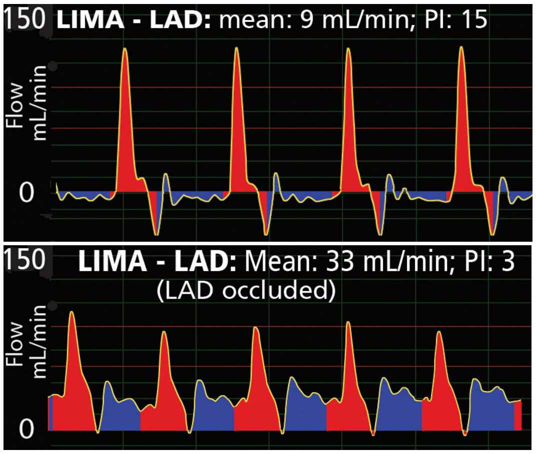
PI can also be influenced by factors other than graft obstruction, including competitive native coronary flow, heart rate, arterial pressure, distal coronary runoff quality, downstream vascular resistance, and other hemodynamic conditions. As a result, an elevated PI may occur in a technically satisfactory 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.

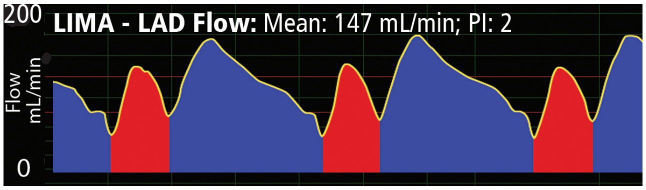
In general clinical use:

- 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.



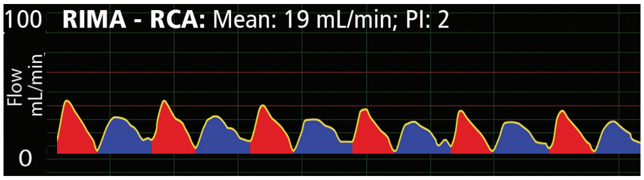
Competitive Flow in LIMA-LAD Graft

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.

References:

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.

3 The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS) Kohl G (Chair),"Guidelines on Myocardial Revascularization," Eur J Cardiothorac Surg 2010; 38: S1 S52.

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.

5 Jelenc M *et al,* "Understanding coronary artery bypass transit time flow curves: role of bypass graft compliance," Interact Cardiovasc Thorac Surg. 2014 Feb; 18(2): 164-8.

6 Morota T *et al,* "Intraoperative evaluation of coronary anastomosis by transit-time ultrasonic flow measurement,"Ann Thorac Surg. 2002 May; 73(5): 1446-50.

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Measure Graft Flow
Temporarily occlude native coronary; assess for competitive flow

Evaluate Mean Flow Reading

0 mL/min - 25 mL/min

May warrant further assessment

Examine Graft
(spasm/kinks/twists/soft BP)

>25 mL/min or >20 mL/min depending on a patient size & clinical conditions

Flow findings generally consistent with satisfactory graft performance

Re-evaluate Mean Flow
Temporarily occlude native coronary; assess for competitive flow

5 mL/min - 25 mL/min, further assessment may be warranted

<5 mL/min prompt technical assessment may be warranted

Flow Waveform Analysis
- Diastolic Dominant (left ventricle)
- Systolic/Diastolic balanced (right ventricle)

If Clinical Concerns are Satisfied

If Clinical Concerns Remain

Analyze Other Factors
- Small patient/small target vessel
- Physiologic factors (MI, vasospasm, low MAP)
- Poor run-off
- Quality of myocardium
- Conduit prep/ graft quality concerns
- Size and quality of the graft

Flow measurements consistent with published flow ranges
Proceed to the next graft

Revise as clinically indicated