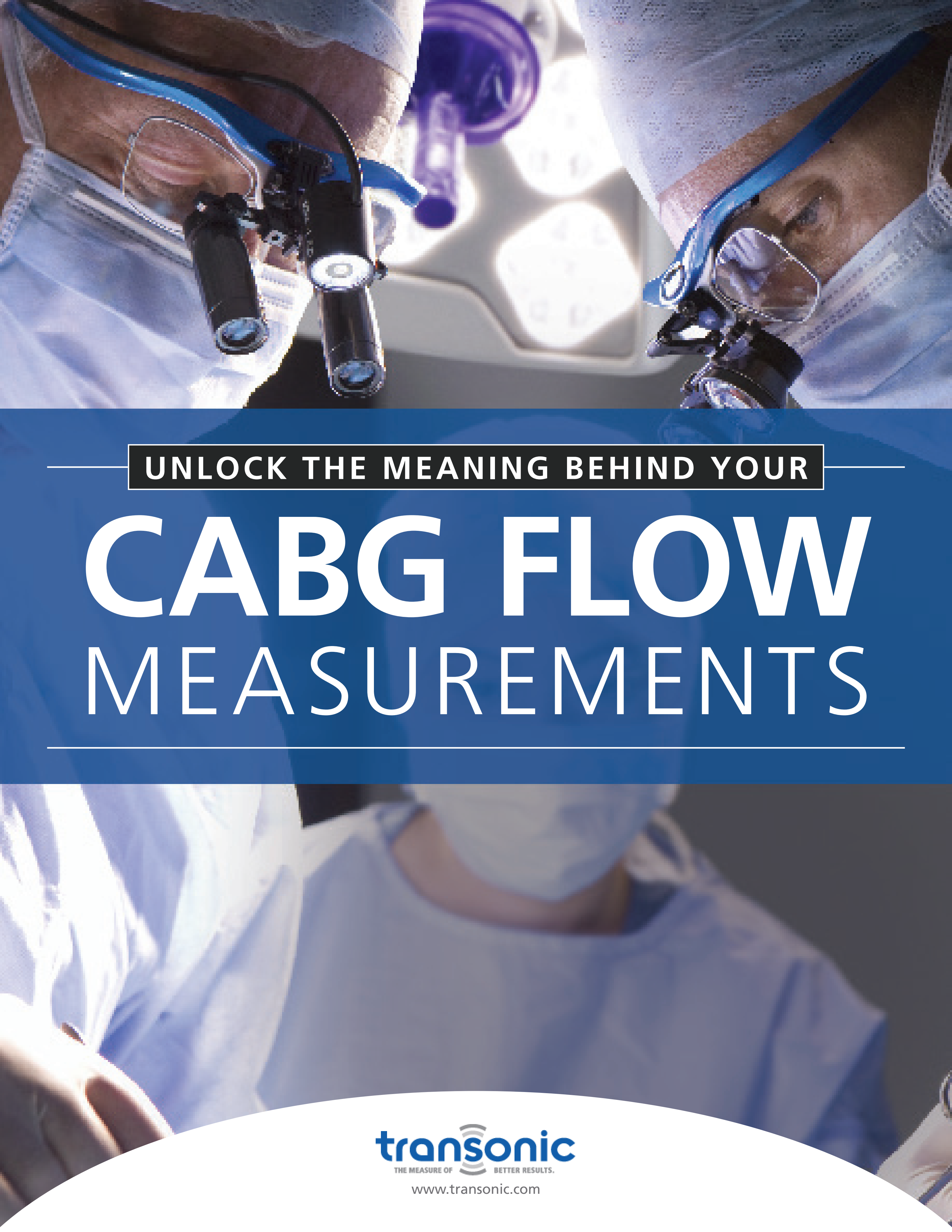

UNLOCK THE MEANING BEHIND YOUR

CABG FLOW MEASUREMENTS

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Patent, functioning bypass grafts are fundamental to successful coronary artery bypass grafting (CABG) surgery. Verification of patent grafts by intraoperative flow measurements sets the stage for surgical success. Knowing graft flows either assures the surgeon that the bypass grafts are delivering life-giving blood to the heart or they alert the surgeon to a problem at a time when it can be easily corrected. The graft can be reexamined and, if necessary, revised to avert complications and extend graft patency.

But what is a good flow for a graft, such as a LIMA– LAD or a RIMA – RCA, or, for that matter, any of the myriad bypass grafts that are placed? How should a surgeon interpret the flow values? How important is Pulsatility Index or Diastolic Fraction Percentage? Should a surgeon examine every graft flow waveform for clues to its patency? When Mean Flow, Maximum Flow, Minimum Flow, PI, DF% or D/S Ratio all show up on the flow monitor display, what should the surgeon consider first in interpreting the patency of a bypass graft?

Mean Flow is Paramount

Mean flow is the primary indicator of graft patency. It can confirm the patency of a good graft or, conversely, signal an inadequate graft. While flows greater than 20 to 30 mL/min indicate a good graft, flows under 5 mL/min always indicate that there is a problem with the graft. Experience supports a mean flow of 30 mL/min to indicate acceptable patency. For small patients or small target vessels, this number can be reduced to 20 mL/min. European Guidelines state: "Flow < 20 mL/min and pulsatility index >5 predict technically inadequate grafts, mandating graft revision before leaving the operating theatre."

Mean flow alerts the surgeon to one of three graft conditions: Mean flow > 20 mL/min: the graft provides adequate flow and may be considered patent; Mean flow ≤ 5 mL/min is unacceptably low: the graft is compromised and requires further examination; mean flow between 5 mL/min and 20 mL/min signals a questionable graft that should be analyzed further.

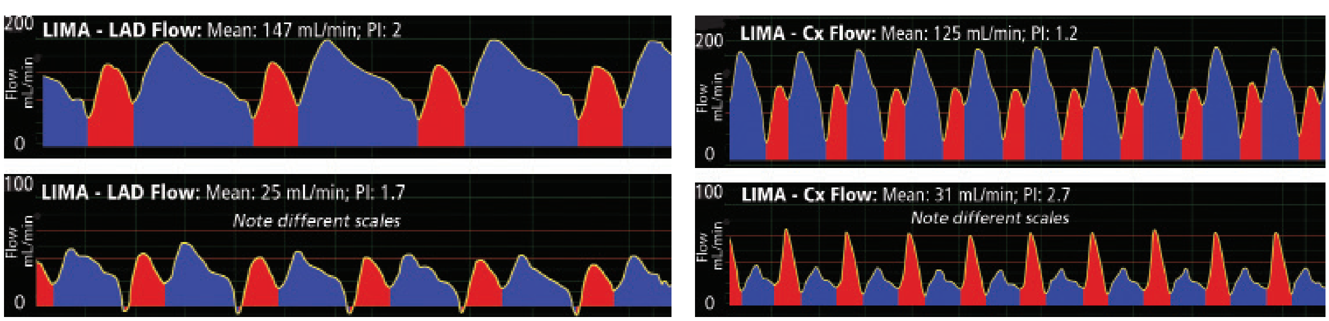


Figure 1
Example of mean flows of LIMA-LAD and LIMA-Cx graphs that demonstrate the wide disparity in accceptable flows.

Mean graft flow can vary over a wide range as demonstrated by the examples of LIMA – LAD and LIMA – Cx grafts above. Mean flow can also be influenced by and should be evaluated with respect to:

- The size and quality of the graft;
- Mean arterial pressure;
- The size and quality of the target vessel;
- Run-off quality of the coronary bed.

Competitive Flow

What if the mean flow of a graft is not as high as one would expect? Is the graft bad? Where would you look if the graft flow is less than one would anticipate given the health and size of the conduit and the physiology of the patient? The response is to first check for competitive flow from the native coronary. Competitive flow will reduce graft flow. It, therefore, reduces the predictive value of graft flow as a measure of graft patency. If the native coronary artery is not fully stenosed and a bypass graft is placed, blood flow from the native coronary artery literally "competes" with and reduces bypass flow. Assessing competitive flow during CABG informs the surgeon and facilitates subsequent graft patency decision making.

Although it is optimal to assess competitive flow immediately when bypass graft flow is measured, it is more practical to check for competitive flow only if mean bypass flow is less than expected or in the questionable range.

To check for competitive flow, two consecutive flow measurements are recommended: one without occlusion of the native coronary artery; a second with occlusion. If occlusion fails to increase graft flow, a 100% native coronary artery stenosis is present. Subsequent graft flow measurements can then be made without further coronary occlusion. If occlusion of the native coronary produces a higher graft flow reading, competitive flow from the native coronary is present. In such instances, the analysis of graft patency should be based only on flow observations taken with full coronary occlusion.

One clue for the presence of competitive flow is a short negative pulse in the systolic phase of the flow waveform (retrograde flow). Such a negative flow pulse will occur, typically, at the onset of systole, but may occur at the end of systole as well. The absence of a negative pulse does not rule out the presence of competitive flow. Sub acute lesions will permit larger amounts of blood to flow through the native coronary, and compete with the augmented flow from the graft.

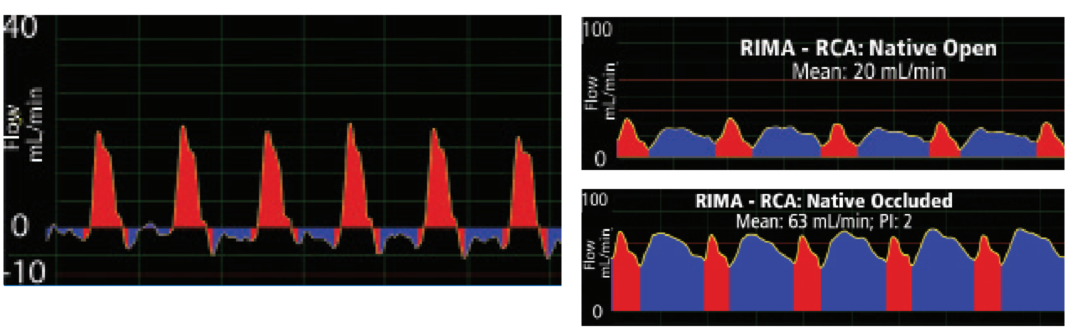


Figure 2
The three waveforms show the RIMA-RCA graft before revision (left), following the first revision of the graft (top right) when competitive flow was suspected, and the graft profile with the proximal RCA occluded (bottom right) to exclude competitive flow.

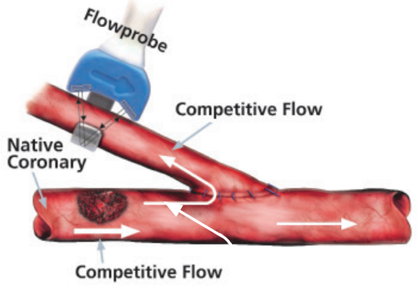


Figure 3
When the native coronary is partially stenosed, competitive flow from the native coronary artery reduces or, if strong enough, actually reverses the blood flow through the bypass graft. Technical errors can be masked.

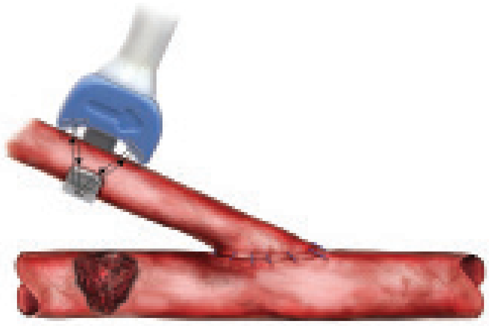


Figure 4
Competitive flow does not occur when the native coronary is fully stenosed. Flow through the bypass graft is at its maximum and technical errors become more apparent.

Poor Graft Mean Flow

If graft mean flow is poor (≤ 5 mL/min) the graft is compromised. The myocardial territories will not receive the blood flow they need. Further examination of the graft is necessary. The surgeon might consider the numerous factors that diminish or can lower mean flow. Physiologic factors to consider include vasospasm in arterial grafts, low mean arterial pressure, poor myocardial runoff, size of target coronary, small graft capacity, and the size and health of the patient. Technical problems could include the presence of thrombus, kinks or twists in the graft, or a mislocated stitch at the anastomosis. If indications point to technical error, the anastomosis can be resewn and the graft rescued before the chest is closed and the patient leaves the operating room.

WAVEFORM ANALYSIS FOR QUESTIONABLE FLOWS

Graft Flows Between 5 mL/min and 20 mL/min to 30 mL/min

When the mean flow of a graft lies in an intermediate range between clearly poor graft flow (0 - 5 mL/min) and reasonably good mean graft flow of 20 ml/min- 30 mL/min, analysis of the graft waveform can provide valuable clues to the viability of the graft. This is the appropriate moment for waveform analysis.

Waveforms can vary widely. Unfortunately, there is no universal waveform profile for a specific graft or patient. If good technique has been used during flow measurement, the waveform should always exhibit a smooth repetitive profile. CABG waveforms are biphasic. Each heart beat depicted by the waveform is divided into systole as the heart contracts and pumps blood into the ascending aorta and pulmonary artery and diastole when the heart relaxes and coronary arteries are filled.

Diastolic-Dominant Pattern

Bypass grafts to left side coronaries characteristically exhibit a disparity between the systolic and diastolic flow profile due to the combined effect of pressure and resistance. The volume of blood delivered by the graft during diastole usually exceeds the volume delivered during systole. The shorter waveform peak is usually systolic, and the higher, broader peak diastolic (Fig. 5) except in the presence of severe tachycardia where diastole is shortened. An acceptable left ventricular waveform is “diastolic dominant” where the delivered diastolic blood volume (i.e., area under diastolic curve) exceeds delivered systolic blood volume. A biphasic 1/3 systolic to 2/3 diastolic waveform profile is typically exhibited.

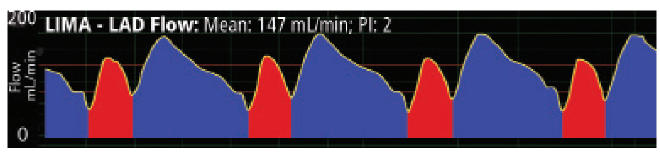


Figure 5
LIMA-LAD: mean = 147 mL/min; diastolic dominant; PI =2.

Balanced Systolic/Diastolic Pattern

In right-sided coronary grafts such as the RCA, flow is more equally distributed between the systolic and diastolic phases. This produces a flow waveform where the systolic peak may dominate, but is followed by a proportionately strong diastolic flow producing a biphasic balanced systolic/diastolic waveform (Fig. 6).

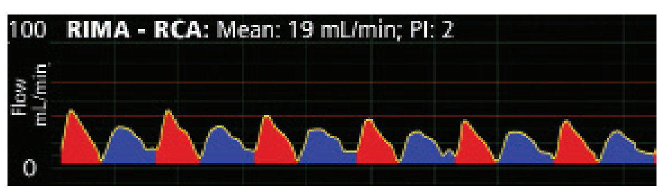
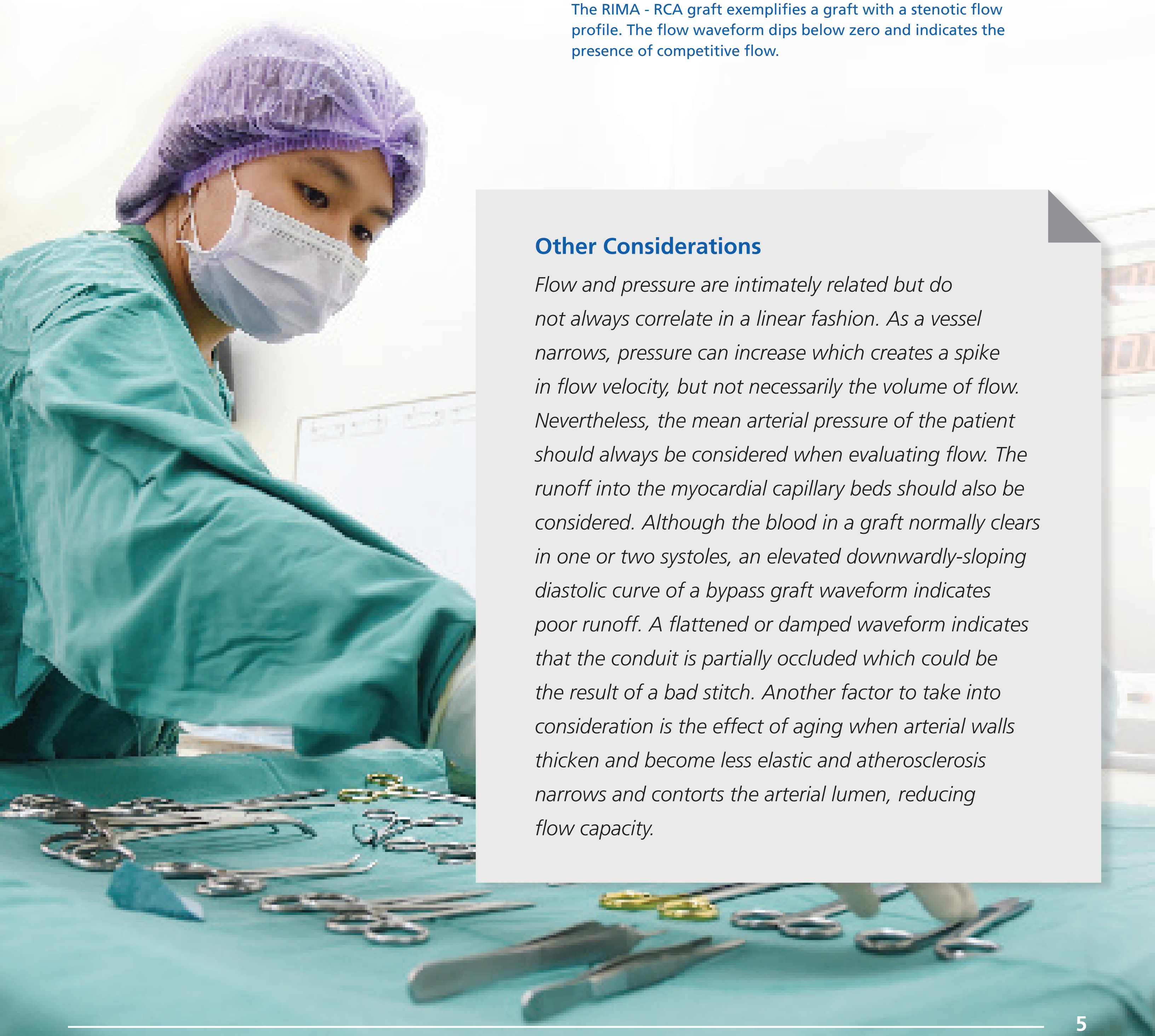


Figure 6
RIMA - RCA: mean is 19 mL/min; systolic/diastolic balanced; PI=2.

Stenotic Pattern

In the presence of sub acute stenoses, the systolic peak dominates the flow profile and is associated with low or zero mean flow. Often, systolic charge flow flows backwards as a negative flow during diastole (Fig. 7).

Figure 7
The RIMA - RCA graft exemplifies a graft with a stenotic flow profile. The flow waveform dips below zero and indicates the presence of competitive flow.



Other Considerations

Flow and pressure are intimately related but do not always correlate in a linear fashion. As a vessel narrows, pressure can increase which creates a spike in flow velocity, but not necessarily the volume of flow. Nevertheless, the mean arterial pressure of the patient should always be considered when evaluating flow. The runoff into the myocardial capillary beds should also be considered. Although the blood in a graft normally clears in one or two systoles, an elevated downwardly-sloping diastolic curve of a bypass graft waveform indicates poor runoff. A flattened or damped waveform indicates that the conduit is partially occluded which could be the result of a bad stitch. Another factor to take into consideration is the effect of aging when arterial walls thicken and become less elastic and atherosclerosis narrows and contorts the arterial lumen, reducing flow capacity.

Secondary Indicators of Bypass Patency

Pulsatility Index

Pulsatility Index is calculated by subtracting the minimum recorded flow from the maximum recorded flow and dividing the difference by the mean flow. A PI between 1 and 5 should indicate a good graft, while a PI greater than 5 should indicate a suspect graft. However, surgeons beware! False negatives can occur. PI does not apply well to every graft in each and every condition. An acceptable PI of below 5 doesn't always indicate a patent graft. A poor graft can still have a PI of less than 5. For instance, competitive flow will reduce mean flow and increase pulsatility. A proximal stenosis or a partial distal stenosis may greatly reduce pulsatility and mean flow. Sole reliance on PI could encourage confidence in a poorly performing graft and possibly obscure a correctable technical error.

The following case demonstrates this point. A 65-year-old male patient underwent CABG to bypass a lesion in the LAD with a LIMA graft. The initial PI was 3.8. That would usually indicate a patent graft. However, LIMA-LAD mean flow only measured 8.8 mL/ min. The graft was revised and mean flow improved to 60 mL/min. The 0.8 PI was accompanied by a classic, diastolic dominant waveform profile. The lesson is not to rely solely on PI to determine graft patency.

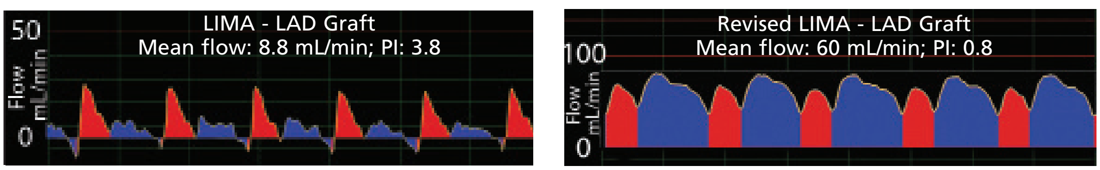


Figure 8
Left waveform: LIMA-LAD graft before revision. Right waveform: graft flow following revision.

DF% or D/S Ratio

Other secondary indicators of graft patency are the interchangeable diastolic fraction percentage (DF%) or diastolic to systolic ratio (D/S Ratio). These are useful when a problematic waveform is being examined to quantify the relationship between systole and diastole but have minimal clinical value.

Summary

Perform measurements properly by using a correctly sized non-constrictive Flowprobe with an adequate ultrasound couplant. If flow is lower than anticipated, quickly compare flow with and without occluding the native coronary artery to evaluate competitive flow.

Assess Mean Flow to Confirm Graft Patency

Normal (≥20 ml) mean flow = patent graft. Flow under 5 mL/min = graft in trouble. Look for kinks, twists in the graft, low MAP, vasospasm. Redo the anastomosis if indications point to technical error.

If flows are between 5 mL/min and 20 mL/min, look at the waveform to see if the flow exhibits the expected patterns. For left-sided grafts, look for a diastolically dominant waveform. For right-sided grafts, look for a systolic/diastolic balanced waveform.

Also, consider other factors such as small target vessel, small patient, small graft capacity, or poor runoff to account for lower flow. Finally, assess secondary indicators of graft patency including pulsatility index and DF % or D/S ratio to corroborate earlier conclusions.

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Americas
Transonic Systems Inc.
34 Dutch Mill Rd
Ithaca, NY 14850
U.S.A.
Tel: +1 607-257-5300
Fax: +1 607-257-7256
support@transonic.com

Europe
Transonic Europe B.V.
Business Park Stein 205
6181 MB Elsloo
The Netherlands
Tel: +31 43-407-7200
Fax: +31 43-407-7201
europe@transonic.com

Asia/Pacific
Transonic Asia Inc.
6F-3 No 5 Hangsiang Rd
Dayuan, Taoyuan County
33747 Taiwan, R.O.C.
Tel: +886 3399-5806
Fax: +886 3399-5805
support@transonicasia.com

Japan
Transonic Japan Inc.
KS Bldg 201, 735-4 Kita-Akitsu
Tokorozawa Saitama
359-0038 Japan
Tel: +81 4-2946-8541
Fax: +81 4-2946-8542
japan@transonic.com