Volume Flow Measurements during Microvascular Surgery

'To Measure Is To Know'

Microvascular surgery places high demands on the microvascular surgeon. Not only must the surgeon have finely honed technical skills, but he or she must make critical on-the-spot decisions as surgery progresses to ensure an optimal outcome for the myriad of microsurgical procedures performed, be they creation of free flaps, lymphovenous anastomoses (LVAs) or other repairs.

Non-constrictive, perivascular Microsurgical Flowprobes use gold standard transit-time ultrasound technology to measure volume flow directly in 0.5 mm - 4.0 mm vessels, grafts and ducts.

Time-Consuming Vessel Compromise

Although total flap loss rates are low (between 0.6 to 6%)[1], vascular compromise still leads to time-consuming flap re-exploration. Low venous pressure is susceptible to compression from improper positioning, pedicle tension, and/or hemodynamic compromise. An unrecognized venous thrombosis can progress to an arterial thrombosis and ultimately lead to flap failure. Arterial insufficiency, often from small thrombi that occlude perforators, is associated with the highest percentage (49.3%) of unsalvageable flaps.[1]

Quantitative Tool to Confirm Clinical Impressions

Now, with the introduction of transit-time ultrasound volume flow measurements in microvessels, the microvascular surgeon no longer has to rely solely on clinical impressions to assess the quality of the surgery during a procedure. This ground breaking, volume flow technology produces accurate, quantitative flow information that can be used to:

- Test Anastomotic Quality: Measuring anastomotic flow intraoperatively has already been found to be a useful tool in microsurgery training labs to test the progress of the participants;
- Measure Arterial (Perforator) Inflow: Knowing perforator flows beforehand helps the surgeon select an optimal perforator for flap inflow;
- Quantify Venous Outflow: Flap outflow can be quantified by measuring venous outflow;
- Measure Lymph Flow: Being able to actually measure lymph flow and to know its direction can guide the selection of the best lymph vessel for use during creation of LVAs.[2]
- Document Results: Measuring flow provides documentation of surgical results for the patient's record.

Microvascular Surgery

Microvascular Flowprobes & Flowmeters

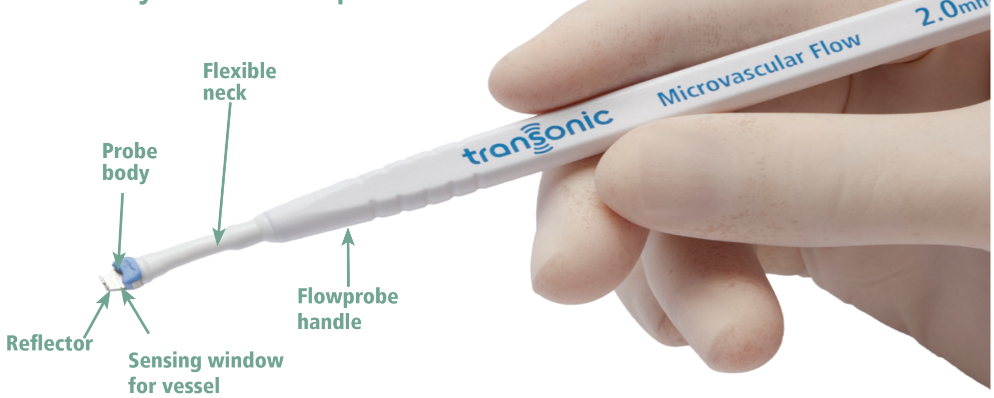
Transonic's non-constrictive Mirovascular Flowprobes (MU-Series), together with an Optima Flowmeter, measure volume flow in blood vessels or grafts from 0.5 to 4.0 mm diameter. Other Vascular Flowprobes (FMV) Series measure flows in vessels to 14 mm diameter.

The Flowprobe consists of a handle to hold the Flowprobe in place on the vessel, a flexible neck to conveniently position the probe around the vessel, a probe body that houses two piezoelectric crystals that send ultrasound pulses across the vessel in the sensing window to the stationary L-style reflector.

Flow measurements during microvascular procedures quantify unprecedented flows in the smallest vessels in order to objectively assess the quality of the reconstruction or replantation, guide better surgical decisions and give the surgeon an opportunity to correct otherwise undetectable flow restrictions before closing the patient. Larger Flowprobe sizes are also available.

The Optima Flowmeter takes transit-time ultrasound volume flow measurement capability to unsurpassed levels of accuracy and resolution with lower offsets.

Anatomy of a Flowprobe



2 mm non-constrictive Microvascular Flowprobe shows probe body that houses piezoelectric crystals, the reflector, the probe sensing window in which the vessel is positioned and the flexible probe neck for easy positioning

Steps for Successful Flow Measurements

Measure baseline vessel flow prior to surgical manipulation:

1. Select the appropriate size Flowprobe. The vessel should fill 70-100% of the probe-sensing window.
2. Clear approximately 1 cm of the vessel of extraneous tissue (i.e. fascia, fat) for an accurate measurement.
3. Fill the sensing window with ultrasonic gel or submerge the Flowprobe head in saline in the surgical field.
4. Apply the Flowprobe at right angles to the vessel without"twisting" or "lifting" the vessel.
5. Check the Flowprobe's ultrasonic signal strength on the monitor.
6. Document flow wih a snapshop (AureFlo) or printing (Optima Flowmeters).

Measure flow after creation of a vascular anastomosis.

1. Re-measure volume flow at a site distal to the anastomosis. Do not measure flow directly over the anastomosis. Sutures will interfere with acoustic coupling.
2. If flow is less than expected, consider:
   - Technical error in anastomosis creation
   - Poor run-off
   - Elevated SVR
   - Vasospasm, kinks or twists
   - Drop in MAP
   - Change in body temperature

The versatile AureFlo® system continuously measures, displays, records and documents absolute volume flow and other derived parameters. Shown here with the HT354 single-channel Optima Flowmeter, the AureFlo accommodates Transonic's wide range of specialized Flowprobes that include Transonic's new MU-Series Microsurgical Flowprobes.

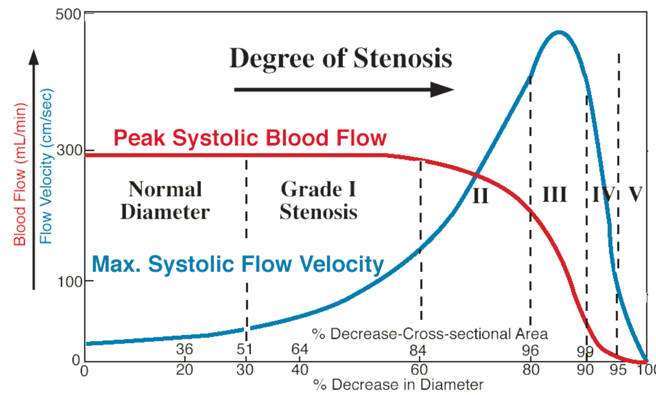
Volume Flow Measurements

Transit-time Ultrasound: Volume Flow, (mL/min) Not Doppler Velocity, (mm/sec)

For more than 30 years, transit-time ultrasound technology has been universally recognized as the gold standard for direct measurment of absolute volume flow. Developed at Cornell University by Transonic founder Cornelis Drost, the technology overcame the problems inherent with earlier electromagnetic flowmeters and quickly became the tool used by researchers and clinicians alike. Transit-time ultrasound technology has now been cited in more than 4,000 publications.

- **TTU Directly Measures Volume Flow, Not Velocity:** Wide beam ultrasonic illumination of transit-time ultrasound flowprobes measures velocity of fluid across the entire band width of graft/vessel to derive volume flow. Doppler derives flow from separate estimates of average velocity across a chord or inside vessel cross-sectional area.
- **TTU Measures Flow in All Fluids:** TTU flow measurement is not dependent on particulate matter in the fluid (i.e. RBCs), as with Doppler. Measurements can be made in arteries, veins, and even lymph vessels.
- **TTU Is Insensitive to Misalignment of Probe on Vessel.** The transit-time ultrasound flowprobe and reflector design compensates for misalignment of a vessel within the flow sensing window of the probe. Doppler misalignment with the vessel can produce serious inaccuracy in measurement.

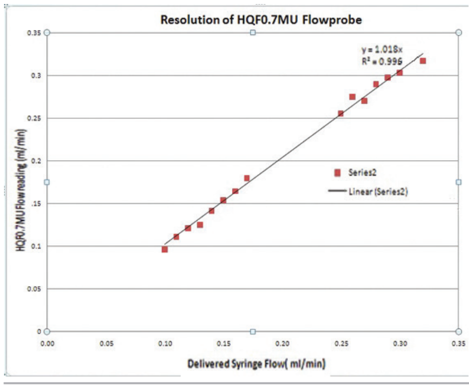
Front and side views of optimum vessel positioning within the ultrasonic window of a Transonic Microvascular Flowprobe. Two transducers send ultrasonic signals, alternately intersecting the vessel in upstream and downstream directions. The difference between the two transit times yields a measure of volume flow.

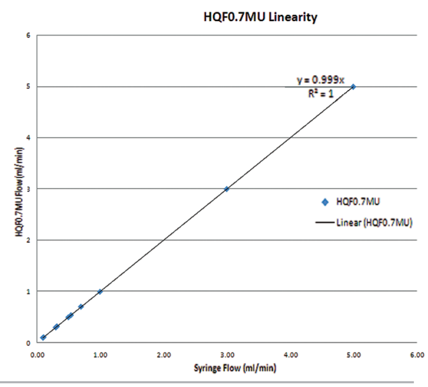


Graph shows difference between flow and velocity as the degree of stenosis increases within a vessel. Velocity spikes before dropping precipitously while flow remains stable until there is a 60% decrease in diameter and then flow falls off. (Adapted from Spencer P, Reid, JM, "Quantification of Carotid Stenosis with Continuous-Wave (C-W) Doppler Ultrasound," Stroke 1979; 10(3) 326-330.

Unprecedented Resolution and Accuracy of 0.7 mm Flowprobe

Graph displays resolution of 0.7 mm Flowprobe between 0.1 and 0.35 mL/min. Flow was pumped through 0.028" thin-walled tubing running through a water tank by a Medfusion 3500 syringe pump. A 0.7 mm Flowprobe was applied to the tubing in the water bath. Zero offset drifted from -0.042 to +0.0447 mL/min. Part of this drift was attributed to the change in ambient conditions over the five-hour measurement testing period. Zero offset ranged from -0.042 to - 0.0337 mL/min over the first three measurement points. Then there was an 80 minute break before the next measurement session. Thereafter, zero offset remained between 0.008 and 0.0447 mL/min.





Linearity of 0.7 mm MU-Flowprobe across range of 0.1 to 5.0 mL/min: Linearity was calculated by dividing the percentage error of zero compensated flow over true delivered flow across the measurement range.

Annotated References

1 Smith RM, Kang V, Al-Khudari S, "Vessel selection and free flap monitoring in head and neck microvascular reconstruction," World Journal of Otorhinolaryngology 2015 Feb; 5(1): 5-13. (Transonic Reference # 10250AHR) *"Surgical complications are not uncommon during microvascular free flap reconstructions. They prolong the procedure and can lead to the need for time-consuming surgical re-explorations."*

2 Chen WF, Zhao H, "Transit-time ultrasound technology-assisted lymphatic super-microsurgery," J Plast Reconstr Aesthet Surg. 2015 Nov; 68(11): 1627-8. *"The TTUT measurements consistently correlated with the surgeon's observations in all 28 lymphatic vessels — healthy-appearing lymphatic vessels demonstrated flow values higher than those from unhealthy-appearing lymphatic vessels. ...Based on the above findings, we concluded that TTUT holds promise in 1) guiding the lymphatic vessel selection, 2) confirming anastomotic patency, and that 3) the absence of "wash out" may not unequivocally indicate anastomotic occlusion."*

3 Selber JC, Garvey PB, Clemens MW, Chang EI, Zhang H, Hanasono MM, "A Prospective Study of Transit Time Flow Volume (TTFV) Measurement for Intraoperative Evaluation and Optimization of Free Flaps," Plast Reconstr Surg. 2013; 131(2): 270-81. (Transonic Reference # 9762AHM) *"... TTFV (Transit-time Flow Volume) provides novel physiologic flap data and identifies flow anastomoses and higher-flow venae comitantes. These data have clinical value in microsurgery and hold the potential to reduce microvascular complications and improve outcomes."*

4 Visscher K, Boyd K, Ross DC, Amann J, Temple C, "Refining perforator selection for DIEP breast reconstruction using transit time flow volume measurements," J Reconstr Microsurg. 2010; 26(5): 285-90. (Transonic Reference # CV-9953AHM) *This study evaluated the correlation among computed tomographic angiography (CTA), intraoperative TTFV measurements, and hand-held Doppler signals in identifying perforators in ten consecutive free DIEP breast reconstructions. "Of the 54 perforators identified, TTFV showed arterial flow waveforms in 15 of 16 perforators identified by CTA and in 2 of the remaining 38 vessels. The sensitivity and specificity of TTFV in identifying arterial perforators were 94 and 95%, respectively. In contradistinction, hand-held Doppler was misleading in 70% of vessels. TTFV distinguishes arterial from venous waveforms in vessels that appear arterial by hand-held Doppler signals. CTA and TTFV are highly correlated, and the use of TTFV may prevent poor perfusion seen in some DIEP flaps."*

5 Herberhold S, Röttker J, Bartmann D, Solbach A, Keiner S, Welz A, Bootz F, Laffers W. "Evaluation and Optimization of Microvascular Arterial Anastomoses by Transit Time Flow Measurement," Laryngorhinootologie 2015 Dec 15. (Transonic Reference # 10035AHM) *This prospective study combined ultrasound imaging and transit time flow measurements to assess anastomotic quality of 15 radial forearm flaps. ..."Results: Mean blood flow immediately after opening the anastomosis and 15 min later were 3.9 and 3.4 ml/min resepectively showing no statistically significant difference (p=0.96). ...Conclusion: Transit time flow measurement contributes to the improvement of anastomotic quality and therefore to the overall outcome of radial forearm flaps. The examined measurement method provides objective results and is useful for documentation purposes."*

7 Takanari K, Kamei Y, Toriyama K, Yagi S, Torii S, "Differences in blood flow volume and vascular resistance between free flaps: assessment in 58 cases," J Reconstr Microsurg. 2009 Jan;25(1):39-45. (Transonic Reference # 10313AH) *"We investigated blood flow in the flap by transit-time ultrasound flowmeter in 58 free-flap transfers. Flow volume was compared between flap tissues as vascular resistance in the flap was calculated. Fasciocutaneous and osteocutaneous flaps had relatively low blood flow volume, myocutaneous flaps had more, and intraperitoneal flaps had still higher blood flow volume. These differences were statistically significant. Vascular resistance significantly decreased in the same order of comparison. Our findings will help in selecting the most suitable flaps for reconstructive surgery."*

7 Lorenzetti F, Giordano S, Tukiainen E, "Intraoperative hemodynamic evaluation of the latissimus dorsi muscle flap: a prospective study," J Reconstr Microsurg. 2012; 28(4): 273-8. (Transonic Reference # 10035AHM) *Measurements of blood flow were performed intraoperatively in 27 patients using a 2- to 5-mm probe ultrasonic transit-time flowmeter around the dissected vessels. "Registrations were made in the thoracodorsal artery before and after harvesting the flap, after compressing and cutting the motor nerve, and after anastomosis. Mean blood flow of in situ harvested thoracodorsal artery as measured intraoperatively by transit-time flowmeter was 16.6 ± 11 mL/min and was significantly increased after raising the flap to 24.0 ± 22 mL/min (p <0.05); it was 25.6 ± 23 mL/min after compressing the motor nerve and was significantly increased after cutting the motor nerve to 32.5 ± 26 mL/min (p <0.05). A significant increase of blood flow to 28.1 ± 19 mL/min was also detected in the thoracodorsal artery after flap transplantation with end-to-side anastomosis (p <0.05)."*

AMERICAS
Transonic Systems Inc.
34 Dutch Mill Rd
Ithaca, NY 14850
U.S.A.
Tel: +1 607-257-5300
Tel: +1 800-353-3569 (US, CAN)
Fax: +1 607-257-7256
support@transonic.com

EUROPE
Transonic Europe B.V.
Business Park Stein 205
1185 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 04-2946-8541
Fax: +81 04-2946-8542
info@transonic.jp