Cardiac Function Assessment

The Transonic Hemodialysis Monitor, An Instrument to Combat the Epidemic of Cardiovascular Disease

“If you measure vascular access flow, you can save an access. If you measure cardiac output, you can save a life.” Lynn Cook

INTRODUCTION
Cardiovascular disease is the leading cause of morbidity and mortality in End-Stage Renal Disease (ESRD) patients whose lives depend on hemodialysis. The American Journal of Kidney Disease (1998; 32(S): Suppl 3) dedicated a full issue to what they termed “an epidemic of cardiovascular disease” and reported that “cardiovascular mortality in ESRD patients, depending on age, is up to 500 times greater than that in the general population” (ibid, Foley et al, p S115). While this statistic is alarming, there is strong reason to believe that this trend can be reversed. Hemodialysis patients come under nursing care in a clinical setting three times a week. This offers a unique opportunity to proactively monitor the cardiac health of these patients. Through this monitoring, the nephrologist will receive early warning if a patient’s cardiovascular status deteriorates, and can start treatment when it is most effective.

CURRENT MARKET SITUATION
To combat the epidemic of cardiovascular disease, hemodialysis clinics must incorporate Cardiovascular Disease Screening in their routine patient physical exams.

TRANSONIC RESPONSE TO THIS PATIENT CARE DEMAND
We offer a comprehensive Cardiac Function Testing module in our HD03 that meets this emerging demand of the market. Clinics can now complement their vascular access assessment with cardiac function tracking.

TRANSONIC SALES PROGRAM
✓ Update existing HD03 accounts to the HD03 with Cardiac Function Test & Flow-QC tubing use.
✓ Promote Cardiac Function Tracking as the emerging standard of care, to be performed as part of the routine physical exam of hemodialysis patients.
✓ Sell all new accounts exclusively the HD03 with Cardiac Function Tracking.

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REFERENCE
Transonic: Innovator in Hemodialysis Patient Care

TRADITIONAL ROLES
The traditional role of the dialysis care team is to administer dialysis. Without adequate dialysis a patient is chronically ill and slowly dying.

- The Dialysis Adequacy Monitoring function of the Transonic HD03 helps the clinic to perform this function more efficiently.
- Transonic’s introduction of the first-ever accurate recirculation monitor set a new standard of patients care. 0% recirculation for all hemodialysis patients with vascular accesses. All new access devices and temporary catheters are now rated on how well they approach 0% recirculation.
- The dialysis adequacy tests (recirculation, and comparison of actual pump flow with the pump flow setting) diagnose conditions that would cause under-dialysis -- both the common errors (erroneously reversed needles, pump mis-calibration, incorrect needle size or placement, etc.) and the severe problems (manufacturer’s tubing defects, collapsed tubing) that would cause blood hemolysis and imminent death of the patient.

TRANSONIC: PIONEER OF INDICATOR DILUTION
Transonic invented and pioneered Indicator Dilution Access Flow Measurement. The research community jumped at the diagnostic opportunities generated by this test.

- A new role emerged for the dialysis care team as a consequence and Flow-based Access Patency Management has now become the standard of patient care.
- Most hemodialysis access shunts (grafts and fistulae) suffer from the disabling disease of stenosis: progressive narrowing of the shunt. If left untreated, this disease will lead to irreversible failure and thrombosis of the graft, and the patient must undergo surgery to create a new shunt elsewhere on the body. Transonic pioneered the test to track the progression of this disease: indicator dilution measurement of access flow. This test gives the nephrologist the tool to schedule access interventions in time and to extend the life of the access. According to the NKF-KDOQI guidelines, this test should be administered monthly to both grafts and fistulae.

CARDIAC FUNCTION ASSESSMENT
Cardiac Function Assessment with the HD03 expands the role of the hemodialysis care team to managing the cardiovascular health of the patient.

- As before, Transonic Systems is at the forefront of this development, by providing the dialysis care team with tests for Cardiac Function Diagnosis.
- These tests track cardiovascular parameters of the ESRD patient, and thus provide the nephrologist with on-site diagnosis of cardiac disease and with early indications of deteriorating cardiac conditions that may lead to disease. Controlling the current epidemic of cardiovascular disease in ESRD patients is the challenge of the decade.
CARDIOVASCULAR TESTS DURING HEMODIALYSIS

Although nephrologists are thoroughly familiar with the many heart diseases that afflict a dialysis patient, traditional tests cardiac function (pressure, heart rate) are elementary. Periodically, a full examination is performed. If problems are suspected the patient is referred to a cardiologist.

Transonic’s cardiovascular tests can be administered during routine hemodialysis. Such tests place a minimal burden on the patient, reduce administration expense and invite frequent testing and proactive diagnosis. They complement the routine physical assessment with which every nephrologist is charged. Test results are trended by Transonic software to allow tracking of cardiovascular status and alarm the nephrologist when significant changes are observed.

As clinics take a leading role in combating the epidemic of cardiovascular disease, they will establish baseline readings of these parameters for each patient, track changes of these parameters over time to watch for deterioration, order additional tests and initiate treatments when a deterioration is observed.

HEMODIALYSIS: A TEST OF CARDIAC FUNCTION

In his presentation entitled “Cardiac Output, Peripheral Resistance, and Central Blood Volume, during Hemodialysis, Correlations with Clinical Status” (Transonic video: “Innovations in Technology for the Hemodialysis Patient”, 1988), Dr. T.A. Depner proposed that the hemodialysis process itself is a test of cardiac status. It evaluates the tolerance of the cardiovascular system to the stress of quick removal of large volumes of liquid. Just as one can monitor the heart’s response to exercise on a treadmill, so can one monitor changes in cardiovascular function as a result of the stresses of hemodialysis. This test requires that CO and its derived parameters be monitored at the beginning and end of dialysis. Dr. Depner observed that peripheral resistance increased in most of his patient population over the course of hemodialysis, but minimally in patients who died within one year of measurement. The latter group had significantly higher peripheral resistance, lower CO, and peripheral resistance increased only 3.5% on the average during dialysis vs. 20% in the patients who survived more than one year. He concluded “Measurement of peripheral resistance and its response to hemodialysis may be useful as an indicator of prognosis.”

CARDIOVASCULAR PROFILING

Dr. Thomas Tucker has performed cardiovascular profiling to analyze whether a patient’s dry weight has been estimated properly and whether medications administered during dialysis have the appropriate effect. A goal of dialysis is to restore the patient to good cardiovascular health. Failing cardiovascular status at the end of dialysis indicates, therefore, that the patient is not optimally treated and may even be put at risk by the current dry weight estimate and medication regime. Dr. Tucker has profiled a patient’s response to the hemodialysis treatment by taking at least four cardiovascular function measurements on a patient, spaced evenly over the course of the dialysis session. If the patient’s cardiac index falls to 2.5 or below, he evaluated and adjusted the patient’s dry weight target and the medication prescription administered during dialysis. Profiling and dialysis prescription adjustment is repeated until dialysis treatment has the intended effect of restoring cardiovascular health. The efficacy of the dialysis prescription is checked periodically thereafter.

In the next section the cardiac function assessment test are outlined. These tests are easily combined in a protocol of initial patient profiling studies and follow-up studies to assure that the patient’s treatments are and remain optimal, and to screen for early signs of cardiovascular failure:

<table>
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<tr>
<th>Test</th>
<th>Suggested Indication</th>
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<tr>
<td>Cardiac overload from high Qa (CO too high)</td>
<td>Abnormally high Qa (as compared to CO) puts a high stress on the heart and will lead to cardiomegaly and heart failure.</td>
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<tr>
<td>Inadequate Cardiac Function Test (The Depner test)</td>
<td>Low Cardiac Index and unusual response of the cardiovascular system to the stresses of hemodialysis identify patients at high 1-year mortality risk</td>
</tr>
<tr>
<td>Profiling of dialysis and medication prescription (The Tucker Study)</td>
<td>Cardiac function tracking during dialysis identifies whether a patient’s dry weight is properly estimated, and drug treatment is adequate, from changes in Cardiac Index and peripheral resistance.</td>
</tr>
<tr>
<td>Cardiovascular function tracking</td>
<td>Changes of cardiac function parameters over time (monthly, quarterly) provide early warning of deteriorating patient status.</td>
</tr>
<tr>
<td>Test for patient risk for hypovolemic circulatory collapse</td>
<td>Central Blood Volume depletion is a precursor to hypotensive episodes. Thus, monitoring CBV repeatedly during dialysis (profiling) may be used to establish a safe ultrafiltration rate without hypovolemic circulatory collapse.</td>
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Transonic tests use ultrasonic indicator dilution principles, and are administered during routine hemodialysis. Briefly, 30 ml of saline is injected into the venous blood line; after this saline is mixed and diluted in the heart chambers, a fraction returns into the access and is drawn into the arterial blood line. The saline concentration reflects the mixing ratio in the heart and thus CO. A Transonic flow dilution sensor, mounted on the arterial line, monitors the concentration of the saline indicator over time. From the area, shape and timing of the concentration curve the HD03 software derives cardiovascular parameters:

**CARDIAC OUTPUT (CO)**
Cardiac Output is the core parameter of human hemodynamic performance. If CO were just as easily measured as systolic/diastolic pressure, it would be assessed during each routine physical examination. Such is now the case for hemodialysis patients. Typical normal values for CO in hemodialysis patients are 4 to 8 L/min. What is “normal” depends on patient body size, sex and age.

The ratio between access flow (Qa) and CO is important. Kidneys receive about 20% of the total cardiac output. Therefore, in a patient with 5% residual renal blood flow, 15% of CO flowing through the access does not place an additional demand on the heart. When Qa is well over 20% of CO, the nephrologist will generally perform additional tests, request periodic monitoring and/or reduce access flow by banding the vascular access.

CO decreases substantially (18.3%, Depner study) during dialysis. Because access flow remains fairly constant during dialysis, an increasingly smaller amount of blood flow will remain available for the body to sustain vital functions. The healthy body will respond to this by increasing peripheral resistance to sustain the blood supply to the heart and brain.

**CARDIAC INDEX (CI)**
Cardiac Index CI = CO / Body Surface Area. HD03 software calculates body surface area from patient body height and weight. While CO tells how much blood the heart is pumping, CI relates this to the typical demands of the body based on the patient’s physique. Normal CI values in hemodialysis patients are: 2.5 to 4.5 L/min/m². CI is a more useful quantity to compare patient cardiac status than CO.

**STROKE VOLUME (SV) & STROKE VOLUME INDEX (SVI)**
This is the volume of the blood pumped by the heart in a single systolic contraction of the left ventricle. It can be calculated as CO divided by the heart rate. Typical values are: 60 to 130 milliliters (equivalent to ½ to 1 small teacup) The body increases its CO, not by changing SV but by increasing heart rate. An athlete will have a high stroke volume at a low heart rate thus providing a large cardiac reserve during exercise. Too small a value for SV (for the class of patient) indicates a failing heart. Stroke Volume Index (SVI) is found by dividing CI by the heart rate.

**CENTRAL BLOOD VOLUME (CBV)**
Central Blood Volume is defined as the volume of blood in the heart, lungs and the great vessels. This parameter is thought to be a factor in blood pressure maintenance. Most hemodialysis patients exhibit a drop in CBV during dialysis similar to CO, and probably precedes CO (Depner, *ibid.*). When CBV is depleted, hypotensive episodes may occur. Thus, monitoring CBV repeatedly during ultrafiltration of the blood may indicate how fast a patient can be dialysed without hypovolemic collapse.

**CENTRAL BLOOD VOLUME INDEX (CBVI)**
Central Blood Volume Index is found by dividing CBV by the patient’s weight. This value allows comparison of central blood volume patients of different weights.

**PERIPHERAL RESISTANCE (PR)**
Peripheral Resistance is the average total resistance to blood flow of the entire systemic circulation (CO minus vascular access flow). PR is calculated as mean arterial pressure divided by systemic flow (cardiac output minus access flow). If pressures are measured in mmHg, PR will be in units of mmHg min/L or dyne sec/cm by multiplying with 80.

“Peripheral Resistance is the holy grail of people studying hypertension…. We all measure pressure but what we really want to know is peripheral resistance. … This parameter… is not new to those working in intensive care units, but is new to those who work with outpatients” (Depner, *ibid*). The majority of hemodialysis patients has a PR in the range of 12 to 20 mmHg min/L; patients diagnosed with diabetes have a substantially higher PR. Because CO typically decreases during hemodialysis and pressure is maintained, PR will increase during dialysis for most patients but not for some. Dr. Depner speculated that those patients may have a problem with fluid overload. A failure of PR to increase in response to the challenge of dialysis, combined with higher initial PR and lower initial CO, correlated in the Depner study with increased 1-year mortality risk.

**TOTAL PERIPHERAL RESISTANCE INDEX (TPRI)**
Peripheral Resistance Index is the same arterio-venous pressure difference, divided by the systemic cardiac index rather than systemic flow. It allows for more accurate comparison of peripheral resistance between patients with different body size.
Interpretation of Cardiac Function Results

Patient function parameters depend on age, gender and clinical status such as diabetes or cardiac disease. The measured parameters may dramatically change during hemodialysis. Their baseline values, their changes during dialysis and their changes over time are diagnostic. It is suggested that clinics establish a cardiac function testing protocol that includes patient baseline screening with periodic follow-up tests to safeguard cardiovascular health and dialysis prescription adequacy of their patients.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical Range</th>
<th>Diagnostic Indication</th>
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<tbody>
<tr>
<td>CO</td>
<td>4 to 8 L/min</td>
<td>- CO is main indicator of patient cardiovascular status.</td>
</tr>
<tr>
<td></td>
<td>2.5 to 4.5 L/min/m²</td>
<td>- If Qa &gt; 20% of CO: monitor for risk of cardiovascular overload.</td>
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<tr>
<td></td>
<td></td>
<td>- Low value of CI: patient at risk.</td>
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<tr>
<td></td>
<td></td>
<td>- Sharp decrease of CO, CI during hemodialysis to CI less than 2.5: patient at risk.</td>
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<td></td>
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<td>- Compare CO at start and finish hemodialysis, to establish whether the patient responds normally to the &quot;stress test&quot; of dialysis.</td>
</tr>
<tr>
<td>CI</td>
<td>2.5 to 4.5 L/min/m²</td>
<td>- CO is main indicator of patient cardiovascular status.</td>
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<tr>
<td>SCI</td>
<td>1.5 to 4 L/min/m²</td>
<td>- SCI is main indicator of patient cardiovascular status.</td>
</tr>
<tr>
<td>SV</td>
<td>60 to 130 mL</td>
<td>- Too small SV for patient will lead to heart failure.</td>
</tr>
<tr>
<td>CVB</td>
<td>0.8 to 1.6L</td>
<td>- CVB is main indicator of patient cardiovascular status.</td>
</tr>
<tr>
<td>CVBI</td>
<td>10 to 17 mL/kg</td>
<td>- CVBI is main indicator of patient cardiovascular status.</td>
</tr>
<tr>
<td>PR</td>
<td>12 to 20 mmHg min/L 1000 to 1600 dyne sec/cm</td>
<td>- Low values indicate vasodilation while high values indicate vasoconstriction.</td>
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<tr>
<td></td>
<td></td>
<td>- Failure of PR to increase during dialysis suggests that the patient has increased 1-year mortality risk (the Depner test)</td>
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The relationship of vascular access flow values to CO is important. The percent distribution of access flow in native fistula and grafts in units that do not aggressively perform PTA interventions at low access flow:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low Flow (600 - 1800 mL/min)</th>
<th>Mid Flow (600 - 1800 mL/min)</th>
<th>High Flow (1800 - 4000 mL/min)4 to 8 L/min</th>
</tr>
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<tbody>
<tr>
<td>Fistula</td>
<td>30 - 35%</td>
<td>40 - 50%</td>
<td>15 - 25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65 - 75%</td>
<td>&lt; 5%</td>
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The location of the vascular access affects average flow values: upper arm accesses typically carry higher flows than lower arm accesses. Patients with grafts are more likely to be diagnosed with low access flow (20 -25%) and thus with more thrombosis and stenosis problems. Patients with fistulas have on the average higher access flows (25%) and greater potential for cardiovascular problems.
## Cardiac Function Tests: Features & Benefits

<table>
<thead>
<tr>
<th>Feature</th>
<th>Benefits</th>
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| *cardiac function analysis | puts nephrologist in charge of patient cardiovascular health  
-reduces patient morbidity and mortality |
| non-invasive | -no risk  
-convenient for patient  
-can be performed at the dialysis center  
nurse or technician can do it |
| *fast CO: 10 min per patient including patient | -low diagnostic cost  
-accurate and reliable CO method during dialysis |
| *fast CO protocol | -second CO measurement within 2 minutes |
| * self-prompting software | automatic, program guides the user  
-Easy, reliable and safe in use  
-only minimal training needed  
-easy to implement |
| * 15% accuracy | -reliable and trustworthy measurement  
software identifies erroneous measurements  
"Gold Standard" |
| * 4.1% reproducibility (difference between 2 measurements related to their average) | -reliable and trustworthy measurements  
accurate trending of cardiac parameters over time |
| *independent of RBC changes | -independent of hematocrit and blood volume  
no precautions needed, easy in use. |
| *Transonic Flow QC tubing | -high and consistent measurement accuracy  
disposable, annual revenue, cross merchandising.  
safe to inject saline into AV line  
only annual sensor calibration needed |
| *Cardiac Function Tests | -track cardiovascular condition of patient  
detect patient at risk of cardiovascular disease  
detect patient at risk of cardiac overload  
detect patient at risk of systemic collapse during dialysis  
complete vascular access measurement assessment  
-improved patient care  
-complete picture of cardiac status of patient |
Flow-QC® Tubing Sets

Transonic developed a special Flow-QC tubing set that should be placed between the needle tubing and blood line tubing. This Flow-QC set must be used because an accurate measurement of CO requires a fast injection of the 30 mL saline bolus; the Flow-QC set provides an injection port for that purpose. (The 10 mL calibration bolus must be injected into the venous bubble trap.) otherwise you will get incorrect measurements as was discussed in the product summary.

**Flow-QC Sets must be used for every CO measurement!**

The Flow-QC tubing set must be installed in the blood line circuit before Hemodialysis is started: it must primed and be made bubble free before connecting to the patient. The danger of blood loss makes it medically unacceptable to install these tubing sets during dialysis. Therefore, plan your patient demonstrations accordingly! Arrive before the start of the dialysis shift and get tubing sets installed on those patients that the clinic wants to see tested!

The flow-QC sets must also be promoted for routine access flow measurements and for dialysis adequacy testing. It is our experience that clinics do not follow the semi-annual probe recalibration schedule required to maintain measurement accuracy. To make matters worse, clinics regularly change dialysis tubing brands and manufacturers change the specifications of their dialysis tubing sets -- all these changes affect Transonic measurement accuracy. The Flow-QC sets are a (partial) solution for this. The H4FX sensors are now placed, not on the blood lines but on the Flow-QC lines. Transonic controls the material properties of the Flow-QC tubings for consistently high measurement accuracy. As a consequence, clinics do not need to send their probes back to Transonic for recalibration every time they change blood line brands, and the H4DFX sensor will only need annual calibration. Even if annual calibration is skipped the chance for a sensor being out of calibration is less, since the “wrong tubing” error is eliminated.

→ **Flow-QC Sets must be used for every Access Flow measurement to assure high measurement accuracy and unquestionable diagnostic precision!**
Frequently Asked Questions

Q. Why must the saline injection be pre-warmed to 37-degree Celsius?
A. The transit-time of ultrasound changes with temperature. When CO is measured, the saline bolus travels through the cardiovascular circuit before returning to the arterial line sensor. Saline must be pre-warmed to body temperature so there will be no additional thermal changes added to the saline indicator bolus on its passage through the body.

Q. How can I pre-warm the saline to 37°C?
A. It takes you at least 45 to 60 minutes to pre-warm the bag of saline. The easiest method is, to use the saline bag warmer or an incubator: these are adjusted to maintain an inside temperature of 37°C. You may leave bags of sterile saline in these for prolonged periods. Alternately, one can adjust the temperature of low power laboratory heating plates so a saline bag placed atop reaches 37°C.

Q. How accurately must I pre-warm the saline?
A. The acceptable temperature range for the injected bolus is: between 35 and 38°C.

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A. The acceptable temperature range for the injected bolus is: between 35 and 38°C.

Q. How should I inject the 30 mL?
A. This must be injected into the injection side port of Transonic's Flow-QC tubing. It must be injected in one single pass at a fairly rapid rate (4 to 7 seconds for the full volume). The software automatically identifies injection errors (direct recirculation; transit-time errors of saline in the blood lines).

Q. How accurate is a Transonic CO measurement?
A. Documents submitted by Transonic for FDA approval of the CO function include comparisons with thermo-dilution (PA) catheters in patients, and with chronically implanted Transonic A-probes in animal studies. The method was demonstrated to have a 2s accuracy of 15% (meaning that, if all calibration and measurement precautions are followed, 19 out of 20 measurements fall within 15% of actual CO).

Q. Why is there a difference in readings between two successive CO measurements?
A. The technology has a repeatability of ± 4%: this means that noise between successive measurements may give variations in reading with a standard deviation of 4%. A further source of variability comes from the heart itself: CO varies during the course a respiratory cycle, over the course of the dialysis treatment, and when the patient becomes aroused or excited.

Q. How do I know whether the measurement I made was without technical errors?
A. Especially during baseline studies, CO must be measured twice in succession. If the second CO measurement is within 0.5 litres/min or 15% of the first measurement, the average of these two measurements is recorded as the patient’s CO. If the difference is larger than 15%, you should perform a third measurement and discard from the set of three the measurement that deviates the most: this measurement must have incurred a technical error.

Q. What are normal hemodialysis patient values for CO, CI, SV, CBV and resistance?
A. CO  4 to 8 L/min (dependent on patient weight and height)
     CI   2.2 to 4.5 L/min/m²
     Heart Rate 60 to 100 beats/min
     Stroke Volume 60 to 130 mL
     CBV   0.8 to 1.6 L
     Peripheral resistance 1000-1400 dyne-sec/cm

Q. What is the difference between CO and CI?
A. CO varies strongly with body size, sex and physique of the patient: a baby’s heart pumps less blood than the heart of an adult. CI is equal to CO, normalised by body surface area. Therefore, CI reflects the patient’s condition of the heart, independent of body size.

Q. Why do we recommend setting the pump to 200 mL/min during CO measurement?
A. From experience we know that at this pump setting you will make a reliable consistent measurement more often. Injecting 30 mL of saline over 6 seconds increases the outflow rate of the venous blood line temporarily by 300 mL/min. Lowering the pump setting reduces the chance of the pump stop during venous pressure elevation and also reduces the chance that the saline injection triggers recirculation.

Continued on next page.
Frequently Asked Questions cont.

Q. Why must there be 0% recirculation during the CO measurement?
A. For an accurate CO measurement, the full saline bolus must reach the heart: the CO calculation equation includes a bolus volume of 30 mL. If there is recirculation, a part of the bolus will disappear back into the arterial blood line; the lost saline would introduce a measurement error. The monitoring software will recognize recirculation during the CO measurement injection, and warn the user to repeat the measurement at a lower pump flow setting.

Q. Why is a CO measurement not possible with CVCs?
A. Cardiac output measurement requires recording a dilution curve in any artery after intravenous indicator introduction. The lack of mixing conditions for the indicator injected through the CVC with the whole cardiac flow prevents CO measurements. Q. Why calibrate with a 10 ml injection?
A. The patients’ blood hematocrit is unknown; the saline calibration injection establishes the calibration constant K to receive the concentration curve [(ml saline)/(ml blood)] for the CO measurement at the time the measurement is made.

Q. If I repeat a CO measurement, must I repeat the 10 ml calibration injection as well?
A. The calibration injection must be repeated only when the patient’s hematocrit has changed. If you make a CO measurement at the beginning of dialysis and again in an hour or at the end, you need to precede each measurement with the calibration injection step. If you repeat a CO measurement within say 10 minutes, a single calibration injection step will suffice.

Q. At what interval should a clinic measure CO on its patients?
A. First, the patient profiling should be performed to assess the absolute values of the cardiac parameters, and the adequacy of the medication prescription and hemodialysis dose delivery. When the cardiovascular baseline is established for a patient, CO should be measured every time the patient’s access flow is measured (i.e., monthly). This baseline must be established when a patient originally is entered into the Transonic monitoring program, and when the patient returns from a clinical admission. The baseline may consist of four consecutive monthly measurements. After the baseline period the nephrologist should select a clinically acceptable measurement frequency for each patient, and whether the analysis of changes in cardiovascular parameters induced by hemodialysis should continue. The nephrologist will base this on an estimate of how rapidly the patient’s cardiovascular condition may deteriorate. As a rule, the measurement frequency should be at least 4x that deterioration period. For instance, if the cardiovascular status of the patient may critically deteriorate over a 4-month period, monthly CO measurements must be maintained to produce good trending of the cardiovascular parameters. If the patient is stable enough so such a change will take 8 months or more, bi-monthly measurement will suffice.

Q. Why do I need to enter the patient’s height and body weight?
A. These quantities are needed to calculate the patient's body surface area, and thus CI. The CO measurement can be executed without these values, but the software would not calculate CI.

Q. Do I have to enter pressures?
A. You do not need to enter pressures, but then the software will not calculate peripheral resistance.

Q. Can I save the measurements for later playback?
A. Yes. All the patient records are saved automatically. Playback is simple via the Administrative software.

Q. Why do I need to use the Flow QC tubing set?
A. You need a safe injection port for quick injection of the CO measurement bolus. If you were to inject the bolus on another site such as the bubble trap, the injection period would become too long and the program may not be able to separate the timing of the first cardiopulmonary recirculation from which CO is determined from subsequent recirculations of the saline bolus. (The time between start of injection and appearance of the CPR bolus is only 8 to 12 seconds!). Furthermore, Flow-QC tubing provides a controlled, consistent measurement environment. Transonic inspects the ultrasonic and mechanical properties of these tubing sets to guarantee optimum measurement accuracy. Therefore, use of these tubing sets is also recommended for access flow studies. They optimize measurement accuracy, eliminate measurement variability from blood line brand variations, and reduce the need for periodic H4D sensor calibration. Flow-QC tubing provides optimum measurement accuracy.