

Technique Articles

Optimizing Venous Drainage Using an Ultrasonic Flow Probe on the Venous Line

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Abstract: The use of smaller cannulae for minimally invasive surgery techniques and/or aggressive miniaturization of the cardiopulmonary bypass (CPB) circuitry has necessitated the need to augment venous drainage to achieve adequate flow rates. Vacuum assisted venous drainage (VAVD) has become the dominant method to augment venous drainage. VAVD, however, has been associated with a number of known side effects including increased transmission of gaseous microemboli to the patient, venous line chatter, and increased arterial to venous shunts in the circuit. Historically, our practice has been to monitor the arterial output flow rate and to monitor VAVD by observing venous line chatter and changes in the venous reservoir level. In 2008 our pediatric

cardiothoracic service began monitoring venous line flow rates by using a second ultrasonic flow probe placed on the venous line. After 12 months, our staff perfusionists reviewed the impact of monitoring venous line flow rates on VAVD and its known side effects on daily clinical practice. When monitoring venous line flow rates, empiric observation revealed that less overall vacuum pressure was needed for our CPB cases. This novel approach to monitoring venous drainage has aided us in providing optimal vacuum levels and therefore, may reduce some of the known side effects experienced with excessive VAVD. **Keywords:** ultrasound flow probe, venous drainage, vacuum assisted venous drainage, venous/arterial flow mismatching. *JECT. 2011;43:157–161*

Minimally invasive procedures (1,2) and aggressive miniaturization of the cardiopulmonary bypass (CPB) circuit have continued to gain favor in the perfusion community. When performing minimally invasive procedures on larger patients, it is common to access the venous system via the femoral vein with a cannula that features a reduced diameter and increased length. When miniaturizing the extracorporeal circuit, clinicians reduce not only the venous cannula size, but also the venous line diameter and length. These changes in clinical practice have necessitated the need to augment the venous drainage to achieve adequate perfusion flow rates.

The main benefit of reducing circuit dimensions is the reduction of required prime volume. This is one method to reduce not only hemodilution associated with cardiopulmonary bypass, but to also reduce homologous blood product usage (3,4). An added benefit of miniaturized extracorporeal circuits is a reduction of artificial surface-blood interface. This exposure causes the release of inflammatory mediators and is believed to be part of the systemic inflammatory response to CPB (3,5).

Venous drainage is affected by many factors including cannula type, size, position, venous line diameter, and length. Patient factors may include blood viscosity, patient anatomy, and blood temperature (6). Venous drainage can be augmented by using kinetic assisted venous drainage (KAVD) or vacuum assisted venous drainage (VAVD). For KAVD, a centrifugal pump is placed in the venous line. When engaged, the pump will magnify the siphon that is already present. KAVD augments venous line flow without applying negative pressure to the reservoir. Rider et al. describe increased emboli generation with KAVD in

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the presence of venous air (7,8). This sequelae, in addition to the added cost of the centrifugal pump head, have rendered KVAD without wide acceptance.

For VAVD, the venous reservoir is sealed and vacuum is then applied via a regulator. This vacuum is transmitted up the venous line to aid the siphon affect already present. These techniques are particularly useful when femoral venous cannulation is used on larger patients where minimally invasive procedures may be advantageous or for reoperations after previous cardiac surgery.

An airlock can occur if a large air embolus enters the venous line and negates the pressure created through gravity siphon. If an airlock is present, the clinician must "walk" the air down the venous line to the reservoir to reinitiate gravity drainage. This can be a safety issue and particularly difficult for the perfusionist if the venous line does not have the length to facilitate such maneuvers. VAVD negates the need to walk the air down the venous line, although clinicians should still be cautious of venous air when using VAVD.

VAVD is not without its complications. There have been a number of publications outlining the theoretical sequelae associated with gaseous micro emboli when VAVD is used with air introduction into the venous line (9–11). There are also concerns of hemolysis and damage to the veins, atrium, and other intracardiac structures when excessive levels of vacuum are used (12). These events can be related to the occurrence of venous line chatter. Chatter can be described as shaking or popping of the venous line. This is caused by rapid changes of pressure in the venous line by the occlusion, opening, and re-occlusion of part of the venous cannula over a short period of time. There has been a report of retrograde air embolus up the venous line when the circuit was incorrectly setup and the venous reservoir had become pressurized (13). The sucker and vent roller-head pumps had been engaged when the reservoir did not have a positive pressure valve in place and was not vented to atmosphere, which caused rapid pressurization of the reservoir. This resulted in de-priming of the venous line in a retrograde fashion, resulting in a gross air embolism to the patient after the venous line clamp was removed. If the venous reservoir is exposed to an unregulated source of vacuum, reservoir implosion could occur. The probability of this occurring can be attenuated by using a positive/negative pressure valve which would limit the amount of pressure applied to the reservoir. Protection is further augmented with the use of a pressure monitor that alarms at both positive and negative thresholds set by the user.

There is a delicate balance of venous inflow and arterial outflow that must be maintained. If this Venous to Arterial (V:A) flow ratio is not maintained the patient's blood volume will either be exsanguinated to the CPB reservoir or all of the volume from the CPB circuit will be transfused into the patient. Arterial flow is ultimately limited by the

amount of venous drainage present. V:A flow mismatching is manifested by a dramatic change of the volume in the venous reservoir over time. It can occur quite rapidly depending on the flow rate of the arterial pump and changes in venous drainage.

Under ideal conditions, the V:A flow ratio will be equal. The use of intra-cardiac suction, shed blood salvage, and aortic root venting results in some discrepancy between what is delivered through the arterial line and what is received from the venous line. If the venous flow and added flow from suckers and vents are equal to arterial line flow, there should be no change in the reservoir level.

When venous drainage is suboptimal, the engorgement of the heart and greater veins may be seen and is relayed to the perfusionist by way of the surgeon. The liver can become engorged should the inferior vena cava (IVC) conduit be snared and sub-optimal IVC flow occur; this may be unnoticed because of surgical drapes and instruments. Over time, the perfusionist can identify a V:A flow ratio mismatch by observing the reduced volume found in the venous reservoir. If the ratio remains relatively constant but volume is lost over time, then it can be inferred that volume is being held up or lost at the surgical field, removed via ultrafiltration/autologous cell salvage device, or there is a reduction in patient systemic vascular resistance. Therein lies the difficulty associated with maintaining an adequate V:A flow ratio, determining which event is occurring and which response is most appropriate.

Transonic Systems Inc. (Ithaca, NY) patented ultrasonic transit-time technology in 1983 and it has since been used for quantifying blood flow through a vessel with the use of a perivascular transducer (14,15). This technology has also been applied to extracorporeal circuits by placing a clamp-on sensor over the tubing and is found on many pumps manufactured for CPB. Ultrasound requires a dense medium to allow the sound wave to pass through; consequently, when air passes through a flow probe it will disrupt the measurement. This is beneficial because it could then be integrated into an alarm giving clinicians a way to identify venous air and facilitate immediate correction. Using ultrasound technology, clinicians can now unequivocally quantify their arterial and their venous flow rates instantaneously and simultaneously when applied to both the arterial and the venous line.

DESCRIPTION

At the University of Texas Health Science Center at San Antonio (UTHSCSA), many of the previously mentioned techniques to reduce circuit prime volume and the artificial surface area to which patients are exposed to have been used in our pediatric service. Previously, only one flow probe transducer on the arterial line, after the arterial line filter, was used to quantify arterial flow to the pediatric

patient. The operative team discussed the potential benefit of using flow probe technology on the venous line in our pediatric practice and decided to test its use in trial. After using the technology for 12 months, it was decided that we would start using the technology routinely on all of our pediatric cases.

Two ultrasound transit time flow probe HT-110 systems (Transonic Systems Inc., Ithaca, NY) with either 1/4 inch or 3/8 inch XL-series flow probes (Figures 1 and 2) are applied to the arterial and venous lines. Each circuit is set to allow instantaneous application of VAVD, but is not necessarily used on each case. The VAVD setup is simply a

water trap connected to the circuit via tubing conduit and a “Y” connector that allows atmospheric venting. A positive pressure valve is integrated or applied to the venous reservoir depending on which product is in use (Dideco [The Sorin Group, Mirandola, Italy] D100, D101, and Terumo [Terumo Cardiovascular, Ann Arbor, MI] RX-15). A DLP 66,000 pressure monitor (DLP, Grand Rapids, MI) connected to the venous line is used to monitor and alarm for both positive and negative pressure (Figure 3).

DISCUSSION AND CONCLUSION

Several benefits were observed after implementing this technology into practice. First, it was noticed that one could very rapidly identify V:A flow mismatches; more specifically, the perfusionist can observe immediate venous flow changes as the surgeon relates events in the surgical field that might affect venous return. This would include, but not be limited to, snaring of caval conduit, clamping of a venous line, or manipulation of the heart. The clinician can easily quantify the flow to the CPB circuit, which makes for more precise communication to the surgeon as to the severity of venous blood flow impedance. This also provides the clinician with a very rapid and precise method of balancing the arterial blood flow with the venous return. When used in conjunction with the surgeon’s input, it should be a more effective method to match the V:A ratio. It is important to note that with certain congenital anomalies, there can be a significant number of aortopulmonary shunts. Placing a vent will cause a significant differential in V:A flow but can be easily accounted for through monitoring the output in the vent tubing. To combat liver engorgement, it is standard practice for perfusionists to remind the surgeon to “check the liver” every 10–20 minutes during IVC snaring periods.

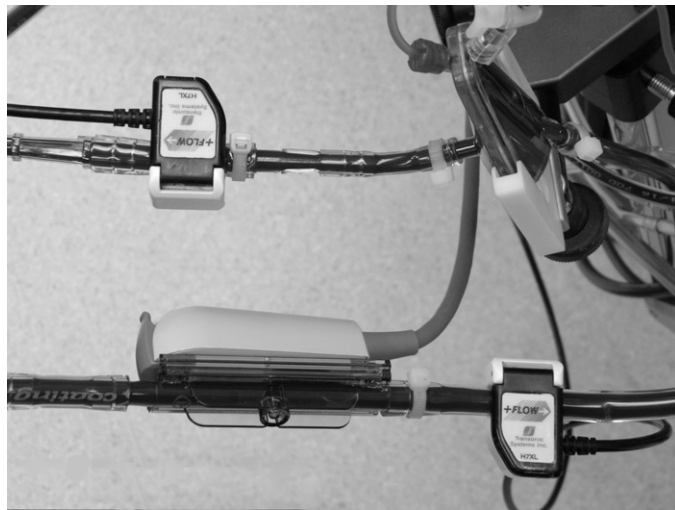


Figure 1. Arterial and venous transonic flow probe measurement devices (Transonic Systems Inc., Ithaca, NY).



Figure 2. Arterial (top) and venous (bottom) H7XL ultrasound transit time flow probe transducers (Transonic Systems, Inc., Ithaca, NY). “Ultrasound %” displayed shows the amount of ultrasound signal being transmitted based on the manufactured specifications. Small changes in signal quality can be improved by adding ultrasound gel to enhance the transmission of the sound wave. A greater than 10% loss in transmission quality may require the device to be recalibrated.

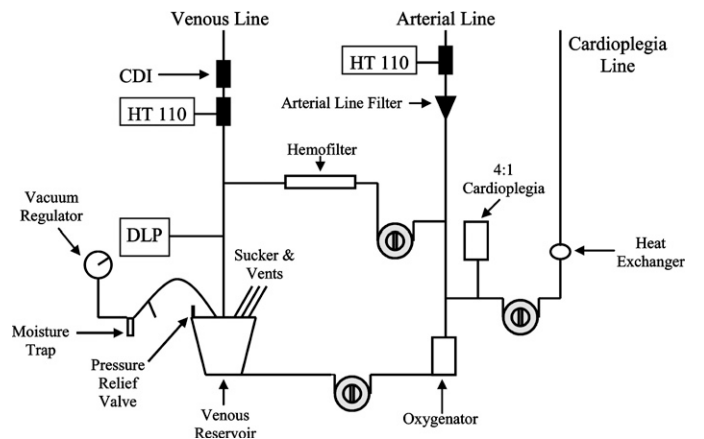


Figure 3. Schematic of the UTHSCSA pediatric CPB circuit. Notice that the HT 110 Transonic flow probes are prior to the MUF circuit on the venous line and distal to all shunts present in the arterial line to account for exact flow measurements to and from the patient.

A second benefit was discovered while performing modified ultrafiltration (MUF). At UTHSCSA, MUF is performed on all pediatric patients and few very small adult patients. While performing MUF, the amount of volume removed per minute can be quantified by observing the difference between the arterial and venous flow probe measurements. This observation can result in very exact volume administration from the reservoir to the MUF circuit, preventing any major volume shifts of the patient, positive or negative.

The third observed, and perhaps most significant benefit, was the ability to optimize the amount of vacuum being applied to the reservoir. Previously, clinicians depended on the vacuum being applied and monitoring the venous line for chatter, changes in the venous reservoir volume over time, or input from the surgical field. Jones et al. concluded that keeping the vacuum negative pressure less than -40 mmHg does not reduce the circuit's ability to remove gaseous microemboli (9). It therefore becomes important to understand what minimal amount of vacuum is needed to achieve optimal venous drainage.

A conceptual graph shows the relationship between VAVD and venous line blood flow (Figure 4). As the VAVD increases, there is a peak that represents optimal blood flow returning to the CPB circuit. As the VAVD increases beyond this point, the venous blood flow decreases as tissues surrounding the cannula drainage ports restrict blood flow. It is not until further down the slope that we can actually observe venous line chatter and more dramatic changes in reservoir blood levels.

VAVD is a valuable tool available to clinicians when performing surgeries that require reduced instrumentation, circuit prime volumes, and blood product utilization. The application of a flow probe to the venous line provides a method of quick quantification of changes in venous

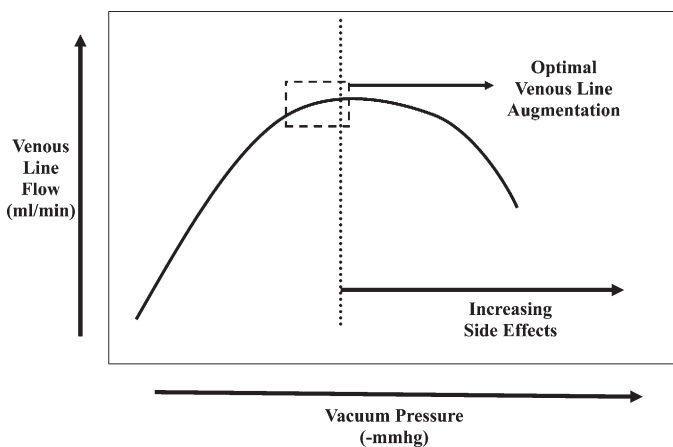


Figure 4. This is a conceptual graph depicting the relationship between vacuum pressure and venous line flow. Notice the box highlighting the small area of optimal flow versus vacuum pressure.

drainage which can aid the perfusionist when communicating to the surgeons a change in the extracorporeal blood flow. Clinicians can optimize VAVD by keeping the level of VAVD at the top of the curve and perhaps reduce the negative side effects associated with VAVD.

While these are empiric observations, it was found that considerably less negative pressure was applied using VAVD by using venous line flow monitoring via ultrasound transit time technology, rather than making changes based on venous line chatter and reservoir level. The information provided a method to quantify flow variations throughout the surgical process which aided in communications with the surgeon. Based on these experiences, this institution is currently in the process of applying the practice to all patient populations and believes that this technology should be implemented for all CPB cases.

A limitation of this report is that while indicators of venous flow were monitored, none were recorded. Therefore, a retrospective chart review was not possible. This technique should be researched further. This institution is planning comparison studies evaluating gaseous micro emboli transmission as it relates to the technique used to augment venous flow in the future.

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