JECT. 2014;46:287–292
The Journal of ExtraCorporeal Technology

Original Articles

A 2013 Survey on Pressure Monitoring in Adult Cardiopulmonary Bypass Circuits: Modes and Applications

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Abstract: Pressure data acquired from multiple sites of extracorporeal circuits can be an important parameter to monitor for the safe conduct of cardiopulmonary bypass (CPB). Although previous surveys demonstrate that CPB circuit pressure monitoring is widely used, there are very little data cataloging specific applications of this practice. Therefore, the purpose of this study is to survey the perfusion community to catalog 1) primary CPB circuit site pressure monitoring locations; 2) type of manometers used; 3) pressure monitoring interface and servoregulation with pump console; and 4) the rationale and documentation associated with pressure monitoring during CPB. In June 2013, a validated 27-question online survey was sent directly through an e-mail link to the chief perfusionists in the northeast United States. Completed surveys were received from 75 of 117 surveys deployed yielding a 64% response rate. Arterial line pressure monitoring during CPB is reported by 99% with six distinct circuit site locations identified. Cardioplegia system pressure was monitored by 95% of the centers. For vacuum-assisted venous drainage (VAVD) users, the venous pressure was measured by 72% of the responding centers. Arterial line pressure servoregulation of the arterial pump was indicated by 61% of respondents and 75% of centers record arterial line pressure in their perfusion record. Most centers (77%) report the use of a transducer that is integrated into the pump console providing a digital pressure display, whereas 20% combine an aneroid gauge manometer with the integrated digital transducer. This study demonstrates that the practice of arterial line pressure monitoring during CPB is nearly universal. However, the selection of the pressure monitoring site on the circuit, modes of monitoring pressure, and their applications are highly variable across the perfusion community. **Keywords:** cardiopulmonary bypass, safety, pressure monitoring, safety devices, cannula position, dissection. *JECT. 2014;46:287–292*

Pressure data acquired from multiple sites of extracorporeal circuits can be an important parameter to monitor for the safe conduct of cardiopulmonary bypass (CPB). These sites include arterial line pressure (ALP) monitoring, cardioplegia line pressure (CLP) monitoring, and venous line pressure monitoring (1). This circuit line pressure data may be important because it can alert the perfusionist of abnormal conditions such as high resistance to flow (kinked or clamped line, cannula malposition, clotted component) or a pressurized venous reservoir. In addition, the modes and techniques used to monitor circuit pressures during CPB may have important safety implications (2).

Received for publication July 31, 2014; accepted October 21, 2014.
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The senior author has stated that the authors have reported no material, financial, or other relationship with any healthcare-related business or other entity whose products or services are discussed in this paper.

Although previous perfusion surveys generally indicate that CPB circuit pressure monitoring is widely used internationally (3–7), there are very little data cataloging specific applications of this practice. Therefore, the goal of this study is to fill this knowledge gap and describe a more complete and detailed understanding of circuit ALP monitoring practice by conducting a U.S. regional survey of perfusion programs. In collecting this information, a comparison can then be made regarding: 1) the level of adherence to the new Standards and Guidelines provided by AmSECT; 2) specific ALP monitoring practices, techniques, and modes used in the perfusion community; and 3) applied use of ALP monitoring in evaluating arterial cannula placement and patency.

METHODS

Institutional Review

This study was submitted to the Institutional Review Board and was determined to be exempt according to federal regulations (exemption category #2).

Timeframe

This survey was deployed and received between April 2013 and July 2013.

Survey Instrument

The web-based survey (www.Surveymonkey.com) contained 27 questions spanning the topics of 1) perfusion team demographics; 2) equipment usage details; 3) circuit pressure monitoring; 4) team protocols; and 5) methods for determining cannula patency. The survey instrument was reviewed for face, content, and construct validity by three recognized experts in the field of perfusion (see "Acknowledgments"). Based on these critiques, a final validated iteration was approved for use. The survey data security and confidentiality of participants were ensured through physical protection, software devices, and hardware features.

Target Population and Data Collection

Target participants for this survey were all chief perfusionists in the northeastern United States (Maine, Massachusetts, Vermont, New Hampshire, Rhode Island, New York, New Jersey, Pennsylvania, Maryland, Delaware, Connecticut, the District of Columbia). Hospitals providing adult cardiac surgery services were first identified using the AHA Guide 2013: The Directory of U.S. Hospitals and Guide to the Health Care Field (8). From this list, by direct e-mail, the survey link was then distributed to chief perfusionists at institutions performing open heart surgery. Approximately 4 weeks later a reminder e-mail was sent to the entire population because the survey was anonymous and specific responses could not be linked to individuals. Each chief was asked to respond on behalf of his or her team and their responses were extrapolated to reflect the practice of their entire team.

Statistical Analysis

Confidence interval of the survey was calculated using a confidence level of 95% and the population of chief perfusionists in the northeastern United States whose contact information could be obtained (n = 117). All other data are expressed as percentages within the total number of respondents.

RESULTS

Demographics

There was a 64% response rate: 75 of the total 117 chief perfusionists responded. This provided a confidence interval of 6.81 with a 95% confidence level. These chiefs represented 522 total perfusionists and over 44,000 cases annually. Centrifugal arterial pumps were used by 72% of the centers. Integrated arterial line filters are being used by 31%. Arterial line pressure was included as an entry in the perfusion record for 75% of the centers. Other perfusion team details are shown in Table 1.

Table 1. 2012 perfusion team profile.

Perfusion Team Characteristics	
Hospital-based/teaching	47.3% (35)*
Hospital-based/community	29.7% (22)
Contract (>100 employees)	8.1% (21)
Contract (<100 employees)	14.9% (11)
Perfusionists	
Total represented	522
Average no. of perfusionists/center	7.15 ± 7.44
CPB cases	
2012 total	44,107
Range	2–3850
Average 2012 cases/center	588 ± 614
Primary pump console	
Sorin S3	34% (25)
Sorin S5	24.5% (18)
Terumo System 1	24.5% (18)
Maquet HL-20	7% (5)
Sarns 8000	5% (4)
Other	5% (4)
Arterial pump	
Roller pump	28% (21)
Centrifugal pump	72% (54)
Oxygenator (primarily used)	
Integrated ALF	31% (23)
Nonintegrated ALF	69% (51)
Arterial line pressure included in perfusion record	
Yes	75% (56)
No	25% (19)

*Values in parentheses represent number of centers.
CPB, cardiopulmonary bypass; ALF, arterial line filter.

Pressure Monitoring

ALP and CLP were monitored by 99% and 95% of centers, respectively. For the 67 centers that use vacuum-assisted venous drainage (VAVD), 72% monitor circuit venous pressure when applying vacuum to the venous reservoir (Table 2). For the centers using VAVD and monitoring venous circuit pressures, 79% of these measure indirectly through a Luer connection on the top of the venous reservoir, whereas the remaining 21% measure directly on the venous line.

Regarding ALP, there were six primary locations identified within the CPB circuit where centers are measuring ALP (Figure 1). The most common location was through the arterial line filter purge (37%). A postoxygenator site

Table 2. Circuit pressure monitoring.

Circuit Pressure Monitoring	Percent of Centers Monitoring
Arterial line pressure	99
Cardioplegia line pressure	95
Venous pressure (vacuum-assisted venous drainage users)	72

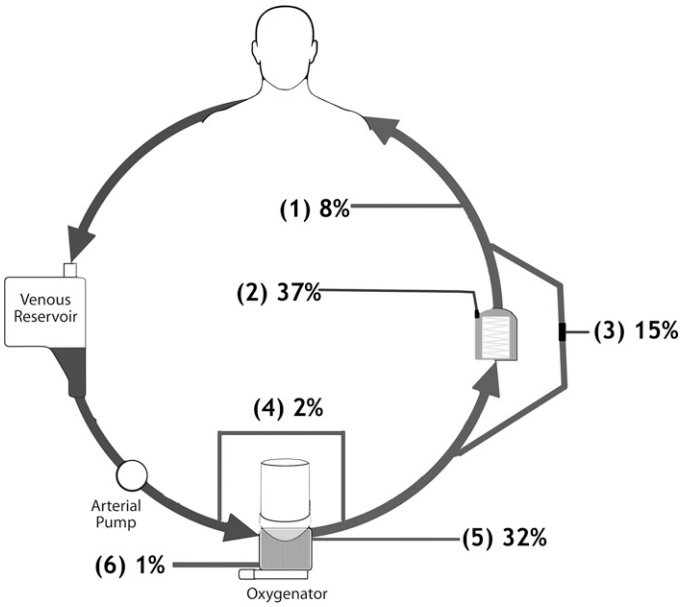

Figure 1. Specific site locations for (1) monitoring arterial line pressure distal to the arterial line filter, (2) arterial line filter purge, (3), arterial line filter bridge, (4) pre- to postoxygenator bridge, (5) postoxygenator site (6), preoxygenator site.

proximal to the arterial line filter (ALF) was used by 32% of centers and 15% used a Luer site on the ALF bridge. Two centers (2.7%) affirmed that they simultaneously measure pre- and postmembrane pressures during CPB. The majority of centers (59%) reported the ALP monitoring location rationale was selected based on a historical precedence that has long been used at their center.

Center-specific protocols for monitoring ALP are shown in Table 3. Briefly, most centers (77%) monitor ALP through a pump console display provided by digital transducers. Another 20% combine an aneroid gauge manometer to the pump consoles integrated digital system. ALP was servoregulated (e.g., pump slow down, pump stop, coast, autoclamp) to the arterial pump as reported as a center protocol by 60.6% of respondents.

Table 3. CPB arterial line pressure monitoring.

Pressure Monitoring	Centers
Digital transducer only (integral to the pump console)	77% (54)*
Digital transducer (standalone)	1.5% (1)
Aneroid gauge only	1.5% (1)
Combined aneroid and digital transducer (integral to the pump console)	20% (13)
Pressure Monitoring Protocol Mode	Centers
No protocol (left up to perfusionist performing case)	2.8% (2)
Visual only (no audible alarm/no pump interaction)	9.9% (7)
Visual and audible alarm (no pump interaction)	26.8% (19)
Visual and audible alarm with arterial pump servoregulation	60.6% (43)

*Values in parentheses represent number of centers.
CPB, cardiopulmonary bypass.

Centers using the pump consoles integrated digital pressure monitoring are either 1) reusing the disposable pressure transducers by keeping the transducer dry using a pressure separator (54%); or 2) fluid priming the transducer for single use (45%). Of the centers reusing the transducer, 71% report having no standard schedule for replacing them.

Pressure Monitoring Techniques to Assess Arterial Cannula Patency

The use of the CPB circuit ALP to aid in the assessment of arterial cannulae placement was reported by 97% of the centers. Of these, 76% indicate cannula patency verification is included on the pre-CPB checklist.

The technique of verification of arterial cannula patency was performed as a specific, distinct step with communication between surgeon and perfusionist (76.5%), whereas the remaining 23.5% stated that the perfusionist is expected to independently evaluate patency and communicate only when there is an abnormality.

The elements of cannula patency assessment and verification were standardized within centers by 87% (36% written protocol, 51% unwritten consensus) with 13% having no standard method within the team. Those elements evaluated to assess arterial cannula patency are shown in Table 4. The majority of centers use a combination of elements for assessment with the majority using three primary elements: 1) pre-CPB, comparing ALP with patient mean arterial pressure; 2) pre-CPB, performing a test infusion; and 3) observation of ALP for abnormal elevations during initiation. For the 61% who perform a test infusion, the center-specific descriptions of the details of their "test infusion" to access cannula patency are shown in Table 5.

The incidence of a dissection at the arterial cannula site in the past 5 years has not occurred for 79%, whereas 8% experienced dissection once and 14% have had a dissection occur two to four times at the cannula site. It should be noted that several instances of these dissections were observed at the time of insertion before attaching the

Table 4. Elements used in pre-CPB arterial cannula patency assessment.

Elements Used to Verify Acceptable Arterial Cannula Patency	Centers Using
Before initiation, identify pulsatility (gauge swing) in circuit ALP manometer	39%
Before initiation, compare ALP to patients MAP	74%
Before initiation, perform a test infusion through arterial cannula	61%
During initiation, as pump flow is increased, ALP is observed for abnormal elevations	52%
Other	13%

CPB, cardiopulmonary bypass; ALP, arterial line pressure; MAP, mean arterial pressure.

Table 5. Description of test infusion.

Center	Description of the Details of the Test Infusion
1	"Monitor line pressure during a 3- to 5-second infusion at approximately .3–.5 LPM"
2	"Low RPM with transfusion of 100 mL"
3	" Infuse a couple hundred cc and watch for an abnormal increase in pressure"
4	"Visual inspection of blood Normosol interface movement and pressure monitoring"
5	"Set RPMs to 1700 and determine flow and pressure response. . ."
6	"Several turns with arterial head/roller observation of pressure"
7	"No real formula, look for a fast pressure spike with slow infusion"
8	"Deliver about 100 mL of prime check for sharp rise in pressure"
9	"Transfuse 100 mL, looking for a rapid change in arterial line resistance"
10	"Delivery of 100c volume at a rate of 1 L/min not to exceed a pressure of 80 mmHg"
11	"500 mL/min with a pressure rise less than 20 mmHg"
12	"One pump head revolution slowly while observation of line pressure correlation of patient's mean"
13	"Slow infusion of .5 LPM with visual confirmation of moderate increase in line pressure"
14	"Line pressure tested to well to about 150 at about 4 L"
15	"Flow, give volume, watch pressure"
16	"Infuse 100 mL at 1.0 L/M with pressure rise of 10 mmHg"
17	"Give a 100 mL observe excursion of pressure"
18	"Run at.5 LPM, 15–20 mmHg rise, 100-mL infusion"
19	"Give 100"
20	"Test dose 100 cc at 2000 RPMs"
21	"Infuse prime for 100–200 mL into patientobserving line pressure, flow velocity, and deflection of needle in aneroid manometer"
22	"Infuse 100 mL of volume to check resistance is present and adequate"
23	"Pump flow ramping up to 1 LPM transfusing approximately 100 cc volume monitoring pressure noting/observing any arterial line pressure spikes"
24	"RPM at 1500–1600 with 1.0 LPM with a pressure of 25–50 mmHg"
25	"Give 100 mL and look a rise in pressure"
26	"A brisk 50-mL infusion confirming a rapid return to baseline"
27	". . .set pump to 2000 RPM while infusing check that pressure and flow are appropriate and that there is no pressure spike"
28	"100 cc in with <20 mmHg increase"
29	"Transfuse 100–200 mL while observing pressure reading, no set flow rate due to centrifugal pump and varying mean art pressures"
30	"Flow to 2–3 L/m, line pressure <180–220 mmHg (depending on cannula used)"
31	"1–1.5 LPM, 30-mmHg increase"
32	Attempt 1.0–2.0 LPM and check for line pressure, should be less than 200 mmHg"
33	"Infuse 100 mL after cannula placement; observe line pressure"
34	"1500 RPM; release clamp, see forward flow, view line pressure"

circuit arterial line and could not be attributed to pressure at initiation.

DISCUSSION

In 1980, the AmSECT continuing education committee conducted a job survey finding that 72% of perfusionists routinely measured ALP on the CPB circuit (AmSECT Continuing Education Committee report). Since then, monitoring of the CPB circuit ALP has seen progressive and widespread adoption by the perfusion community. In a 2000 publication, Mejak et al. (3) found that 94% of centers were measuring circuit ALP and now, this present study indicates a 99% adoption of this bypass parameter in perfusion practice.

The recently updated AmSECT's Essentials and Guidelines for Perfusion Practice have specific recommendations for monitoring arterial line pressure (9). This study's data are presented alongside these practice recommendations for evaluation of adherence (Table 6).

Adherence to Standard 7.2 is 99% in the present survey. Standard 3.2 recommends that ALP be recorded in the perfusion record and in this survey, 75% of the centers did include this entry. The multipart Standard 6.1 demonstrates strong adherence in the arterial and cardioplegia pressure monitoring and audible and visual alarms: 99%, 95%, and 90%, respectively. For VAVD users, there was a dropoff in adherence for the practice recommendation of monitoring venous reservoir pressure (72%). The use of pressure servoregulation of the arterial pump (61%) was also an area of lower adherence. This, however, is a substantial increase from the Mejak et al. survey that showed only 35% using pressure servoregulation of the arterial pump (4).

Additionally, this survey demonstrates that the specific location that centers use to monitor ALP is highly variable and for most, the site selected is rooted in historical precedence. Over half the respondents measure ALP from the ALF or the ALF bridge. As the adoption of oxygenators that have integrated ALF become more widespread, it will be interesting to see how pressure monitoring practices relating to the site location may change.

Arterial dissection resulting from a malpositioned cannula is a rare complication of CPB that carries high morbidity and mortality for the patient. The hallmark of a malpositioned arterial cannula and risk of dissection is abnormally high resistance to flow (10,11). Accordingly, CPB textbooks

Table 6. Appling survey data to current AmSECT Standards and Guidelines for Perfusion Practices.

	AmSECT Essentials and Guidelines for Perfusion Practice		Adherence
Standard 7.2	Arterial line pressure shall be monitored continually during CPB		99%
Standard 3.2	Perfusion record: the record shall include: Appendix C. Arterial Line Pressure		75%
Standard 6.1	Pressure monitoring of the arterial line, cardioplegia delivery systems and	Arterial line	99%
	venous reservoir (when augmented venous drainage is used), shall be used	Cardioplegia	95%
	during cardiopulmonary bypass (CPB) procedures.	Venous reservoir (VAVD use)	72%
	• The pressure monitor shall be either servoregulated to control the arterial/cardioplegia pump or to allow interruption to the arterial/cardioplegia flow		61%
	• The pressure monitor shall include an audible and visual alarm		90%

VAVD, vacuum-assisted venous drainage.

advocate using CPB circuit ALP to aid in pre-CPB assessment of proper cannula placement in the lumen by observing a "swing" in the manometer that reflects the pulsatility of the patient's cardiac cycle (2,12). This study identifies that 39% apply this technique of monitoring ALP to observe pulsatility pre-CPB. The present study suggests that the use of aneroid (gauge) manometers to measure ALP is low. Most respondents (80%) report the use digital transducers that are integrated to the pump console. As a result, the pressure gauge "swing" technique becomes unavailable (although some respondents report that pulsatility can be visualized at the pressure separator). The advantages and disadvantages of aneroid versus integrated digital manometers have been elegantly discussed previously (13). The integrated electronic pressure monitoring has clear advantages over the aneroid gauge monometer, especially with regard to audible alarms, pressure limits, and pump servoregulation. At the same time, the aneroid manometer displays a more dynamic, real-time representation of line pressure compared with electronic because the pressure signal in most integrated systems is processed and averaged in such a way that there is a slight delay in the display of pressure values. How this delay in pressure display may influence the assessment of cannula placement is unclear, but given that nearly two-thirds of centers perform a brief test infusion and observe pressure as an element of position verification, this is an area of further study. Twenty percent combine the aneroid manometer with the digital system. This may capitalize on the advantages that each monitoring mode offers: real-time, instant visual feedback from the aneroid manometer and limits, alarms, and pump servoregulation from the integrated electronic system. It is believed that engineering a real-time, visual electronic "aneroid" manometer (along with the current electronic mode) into modern pump consoles would eliminate the data loss currently seen in electronic pressure monitoring.

The use of a test infusion to assess proper arterial cannula position before initiation is commonly used (Table 4). The individual center-specific descriptions of the test infusion were variable (slow infusion versus fast infusion) and often lacked specificity regarding pressure parameters (Table 5). Although most suggest giving volume and looking at the ALP, the volume of infusion and what constitutes an abnormal infusion pressure was often unquantified. Although this vagueness undoubtedly reflects the unconscious competence of experts (i.e., being able to recognize normal versus abnormal conditions without being able to fully describe why), some centers did provide specific criteria such as "[flow] 500 mL/min with a pressure rise less than 20 mmHg." The overall lack of consensus of what constitutes a "test infusion" is curious and deserves further inquiry.

There are limitations in this study. Although the survey had an excellent response rate, its target population was the Northeast region and may not necessarily reflect the national practices.

In summary, ALP and cardioplegia system pressure are almost universally used by perfusion teams. Although still the majority, far fewer centers measure venous system pressures when applying VAVD. Circuit sites selected for measuring ALP across centers were highly variable and usually steeped in historic tradition. ALP audible and visual alarms were used by most, but fewer than two-thirds use arterial pump servoregulation coupled with the ALP monitor. This study also suggests that pressure monitoring in the CPB circuit is a key important parameter in assessment of arterial cannula placement before initiation of CPB, although a specific description of what constituted good placement versus bad placement was ill defined.

ACKNOWLEDGMENTS

We thank Mark Kurusz, Alfred Stammers, and Robert Groom for their expert assistance in the validation process of the survey instrument.

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