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Adult Clinical Perfusion Practice Survey: 2020 results★

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Abstract – *Background*: Cardiovascular perfusion is a dynamic healthcare profession where new practices are frequently introduced. Despite the emergence of evidence-based clinical practice guidelines, little is known about their dissemination at the institutional level. Clinical practice surveys have been used to identify current trends in perfusion practice in the areas of equipment, techniques, and staffing. This survey aims to describe clinical perfusion practices across adult cardiac surgical programs located in a large, single, geographical region of the United States. *Methods*: Following Institutional Review Board (IRB) approval, an 81-question survey was distributed to 167 adult perfusion programs across the Zone IV region of the American Society of Extracorporeal Technology (AmSECT), a non-profit professional society representing the extracorporeal technology community. Surveys were distributed to chief perfusionists through the Research Electronic Data Capture (REDCap) web-based survey response system. *Results*: Responses were received from 58 of 167 centers across (34.7% response rate). Centrifugal pumps were used at 81% (n = 47) of centers and 96.6% (n = 56) use an open venous system or hard-shell venous reservoir. Del Nido was the most frequently used cardioplegia strategy with 62.1% (n = 36) of centers reporting its use. The use of electronic medical records was reported in 43% (n = 25) of centers, while 84.5% (n = 49) reported using Cardiopulmonary Bypass (CPB) protocols (>75% of all CPB activities). Extracorporeal Membrane Oxygenation (ECMO) support was reported in 93.1% (n = 54) of programs, with 59.2% of programs (n = 34) employing a perfusionist as ECMO Coordinator. The n + 1 staffing model was reported by 50% (n = 29), with 24% supporting the n + 1 staffing for after-hours and on-call procedures. *Conclusion*: Clinical practice surveys can be effective tools to inform clinicians about contemporary perfusion practice and identify deviations from professional standards and guidelines. Subsequent surveys may describe trends over time, assess standardization of practice, measure adherence to evidence-based guidelines, and foster improved patient care and outcomes.

Key words: Clinical practice survey, Adult perfusion, Standards, Clinical practice guidelines, Variability.

Introduction

Cardiac surgery is one of the most performed inpatient operations in the United States [1]. Despite large-scale improvements in outcomes over the nearly seven decades since the first cardiopulmonary bypass (CPB) procedure [2], appreciable interhospital variability persists in both the conduct of and outcomes associated with CPB [3]. Several efforts have emerged to advance the conduct and safety of CPB, including clinical registries, evidence-based guidelines [4–6] as well as professionally based standards and guidelines [7–9].

Despite the promulgation of these resources for practicing clinicians, little is known about contemporary CPB practices for adult cardiac surgery. While several large-scale clinical registries have emerged, publications to date often focus on a discrete area of practice (e.g., nadir hematocrit during CPB) rather than broadly covering the conduct and practice of CPB. With several topic-specific (e.g., blood management) guidelines have been published, evaluations of the implementation into practice have been infrequent [10–12]. Finally, while The American Society of ExtraCorporeal Technology (AmSECT) has developed professional standards and guidelines for adult CPB, few studies have evaluated real-world practice patterns. This survey aim to describe clinical perfusion practices across adult cardiac surgical programs located in a large, single, geographical region of the United States.

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Materials and methods

Following exempt status approval from the Institutional Review Boards (IRB) of the University of Michigan (HUM00194742) and the Medical University of South Carolina (Pro00107747), an 81-question, the closed-question survey was distributed through the Research Electronic Data Capture (REDCap; Nashville, TN). REDCap is a web-based and secure application for data capture and clinical research database development [15]. The survey topics included program staffing and demographics, equipment, techniques and monitoring, and clinical protocols *(*Appendix). The unit of analysis were center-level adult cardiovascular perfusion programs located in the eastern and mid-Atlantic regions of the United States. A database repository consisting of chief perfusionists (or designee) contact information from programs located in the Zone IV region of AmSECT was previously collected and maintained at the University of Michigan (*Cardiovascular Perfusion Data Repository: Submission ID: REP00000060*). AmSECT Zone IV comprises 15 states and the District of Columbia across the eastern region of the United States, ranging from Maine to South Carolina. A total of 234 cardiac surgical programs were identified in the Zone IV region (Appendix).

The survey questionnaire requested program and procedural data that described clinical practice for the 2020 calendar year. Several questions were also included to identify practice trends over the previous three-year period. Subjects were recruited directly via email invitation on June 8th, 2021. The survey invitation remained open for five weeks, with a closure date of July 16th, 2021. To maximize response rates, non-respondent subjects received up to three notices for participation prior to survey closure. The initial survey was sent to 234 cardiac institutions; however, removing pediatric programs, duplicate or erroneous entries, and missing data resulted in 167 confirmed centers.

Descriptive statistics were used to analyze survey responses. Responses collected from the University of Michigan REDCap repository were de-identified by a database analyst and provided to study investigators. De-identified data were imported into SPSS (IBM SPSS Statistics for Macintosh, Version 27.0, Armonk, NY: IBM Corp.) for analysis and reporting of completed surveys.

Results

Responses were received from 58 of 167 centers for an overall response rate of 34.7%. Survey responses were received from 13 states with the number of responses between states ranging from 1 to 16 (Table 1). Pennsylvania, New Jersey, New York, and Massachusetts represented 67.3% (n = 39) of the responses received.

Staffing and demographics

Thirty-two (55.2%) centers reported performing 600 CPB procedures or less in 2020, with 16 (28%) reporting less than 300 (Figure 1). Centers performing 150 CPB standby or less were reported in 35 (60.3%) of responses (Figure 2). The reported distribution of surgical case type is reported in Figure 3.

Table 1. Number of respondents and location (n = *58*).

State	n/N	State response rate (%)	Survey response rate (%)
Connecticut	4/11	36.4	6.9
Delaware	2/4	50.0	3.4
Maine	2/3	66.7	3.4
Maryland	3/13	23.1	5.2
Massachusetts	7/12	58.3	12.1
New Hampshire	3/4	75.0	5.2
New Jersey	8/17	47.1	13.8
New York	8/30	26.7	13.8
Pennsylvania	16/55	29.1	27.6
Rhode Island	1/1	100	1.7
South Carolina	2/16	12.5	3.4
Virginia	1/14	7.1	1.7
Vermont	1/1	100	1.7

n – number of center respondents, N – number of state centers, % – percent responses.

The most frequently reported surgical procedures were coronary artery bypass grafting (CABG) and valve repair/replacement procedures (n = 57, 98.3%). Most programs reported the use of both veno-arterial (VA) and veno-venous (VV) extracorporeal membrane oxygenation (ECMO) support (91.4% and 87.9%, respectively). The least frequent surgical procedures reported were ex-vivo lung perfusion (n = 1, 1.7%) and organ procurement during transplant (n = 3, 5.2%).

The mean number of full-time perfusionists was 6.43, with teams ranging from 1 to 33 perfusionists (Figure 4). Eleven programs (19%) had part-time perfusionists on staff, with 32 (55.2%) reporting the use of per diem or locum tenens coverage over the previous three years. Most respondents (n = 43, 72.4%) indicated that the annual number of clinical hours provided by the perfusion team had increased from 2017 to 2020.

The $n + 1$ staffing model, as defined by Guideline 15.1 in the AmSECT Standards and Guidelines for Perfusion Practice, establishes the minimum safe number of perfusion staff required to support operating rooms at any one given time per surgical center [7]. This guideline calls for the presence of one staff member above the number of procedures underway [7]. Respondents reported implementing $N + 1$ during the elective schedule in 50% (n = 29) of centers. A total of 4 (6.9%) respondents indicated using more than the $n + 1$, and nine programs (15.5%) reported staffing the minimum 1 perfusionist per procedure. The use of the $n + 1$ model for both elective scheduled and off-hour procedures was reported by 14 (24%) of respondents.

Equipment

Centrifugal pumps were reported at 47 (81%) centers and 56 (96.6%) utilized an open venous system and hard-shell venous reservoir (Table 2). Most centers reported utilizing arterial and cardioplegia line pressures (100%, n = 58), level detectors, and arterial and venous blood temperature monitoring (100% and 98.6%, respectively). Among the lowest reported safety features were one-way valves with centrifugal pumps

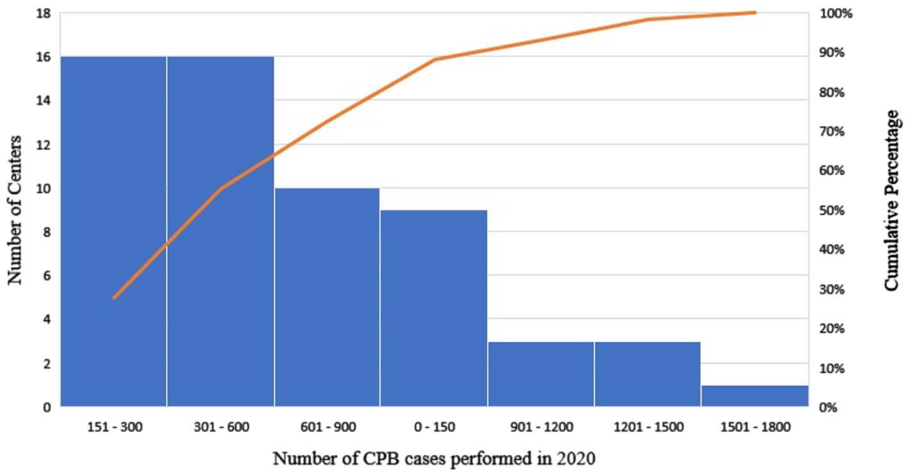

Figure 1. Number and percentage ranges of CPB procedures reported in 2020 (*n* = *58*).

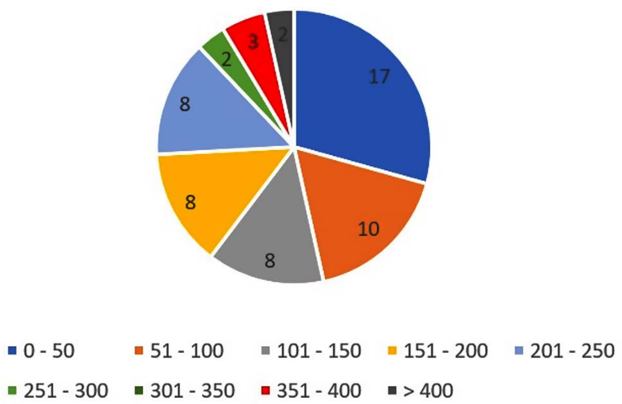

Figure 2. CPB-standby procedures (%) in 2020 (*n* = *58*).

(n = 24, 41.4%), electronic occlusion clamps (n = 27, 46.6%), low arterial pump speed alarms (n = 29, 50%), and venous reservoir pressure monitoring (n = 32, 55.2%). The use of biocompatible coating on all circuitry except cannulas was reported in 47 (81%) responses. Among those using biocompatible circuitry, only 2 (3.8%) were tip-to-tip biocompatible and 3 (5.2%) use bio-coating on limited circuit components.

The sites for temperature monitoring on patients are listed in Table 4. The most frequently reported core temperature used was a bladder catheter (n = 54, 93%). The least reported temperature sources were peripheral temperatures, both skin and tympanic, with an incidence of 1.7% (n = 1) and 6.9% (n = 4), respectively.

The use of short- and long-term mechanical circulatory support (MCS) devices are reported in Table 5. Respondents were asked to select the devices offered at their centers. Short-term device usage included peripheral access pumps such as the intra-aortic balloon pump (IABP) (100%, n = 58), ECMO (93.1%, n = 54), and Abiomed Impella (Abiomed, Danvers, MA, USA) (87.9%, n = 51). Long-term implantable devices included the Heartmate II and Heartmate III pumps (Abbott Cardiovascular, Plymouth, MN, USA), with a reported usage of 29.3% (n = 17) and 39.7% (n = 23), respectively.

ECMO utilization and support

Of the 58 centers, 54 (93.1%) offer ECMO at their institution and 59.2% (32/54) had a perfusionist as the ECMO Coordinator. Of those, 39.7% performed 10 ECMO procedures or less (Figure 6). Most centers (87.9%) indicated that the perfusion team was responsible for ECMO initiation and discontinuation, with 91.4% assigned to troubleshooting (Table 6).

Techniques

Arterial blood gas analysis was performed via point-of-care (POC) handheld device in 51.7% (n = 30) of centers. The use of inline blood gas monitoring was reported in 48.3% (n = 28). Oxygen delivery (DO2) monitoring during CPB was reported in 46.6% (n = 27), with 17 (29.3%) using automated, real-time DO2 monitoring technology and 10 centers (17.2%) performing manual calculations.

During mild to moderate hypothermia cases, 87.9% (n = 51) of centers employ alpha-stat for acid-base management, 10.3% (n = 6) use pH-stat, and 1.7% (n = 1) use a combination of both. In procedures requiring deep to profound hypothermia, 56.9% (n = 33) use alpha-stat, 22.4% (n = 13) use pH-stat, and 20.7% (n = 12) use a combination of both.

Plasmalyte-A was the most used priming solution (Table 8). The most common priming additives were heparin, mannitol, and sodium bicarbonate (Table 8). Other additives reported include dexamethasone, solumedrol, $MgSO_4$, or no additives at all (Table 8).

del Nido was the most frequently used cardioplegia substrate (62.1%, n = 36), followed by whole blood/microplegia (31%, n = 18), and Buckberg cardioplegia (25.9%, n = 15) (Figures 7 and 8). The type of cardioplegia used varied according to the surgical procedure. Fewer centers used del Nido on isolated CABG procedures (48.3%, n = 28). For these procedures, more centers used either 4:1 (46.6%, n = 27) or whole blood/microplegia (24.1%, n = 12) blood-based solutions. For non-CABG procedures 58.6% (n = 34) used del Nido, 41.4% (n = 24) used 4:1, and 24.1% (n = 14) used microplegia (Figures 7 and 8).

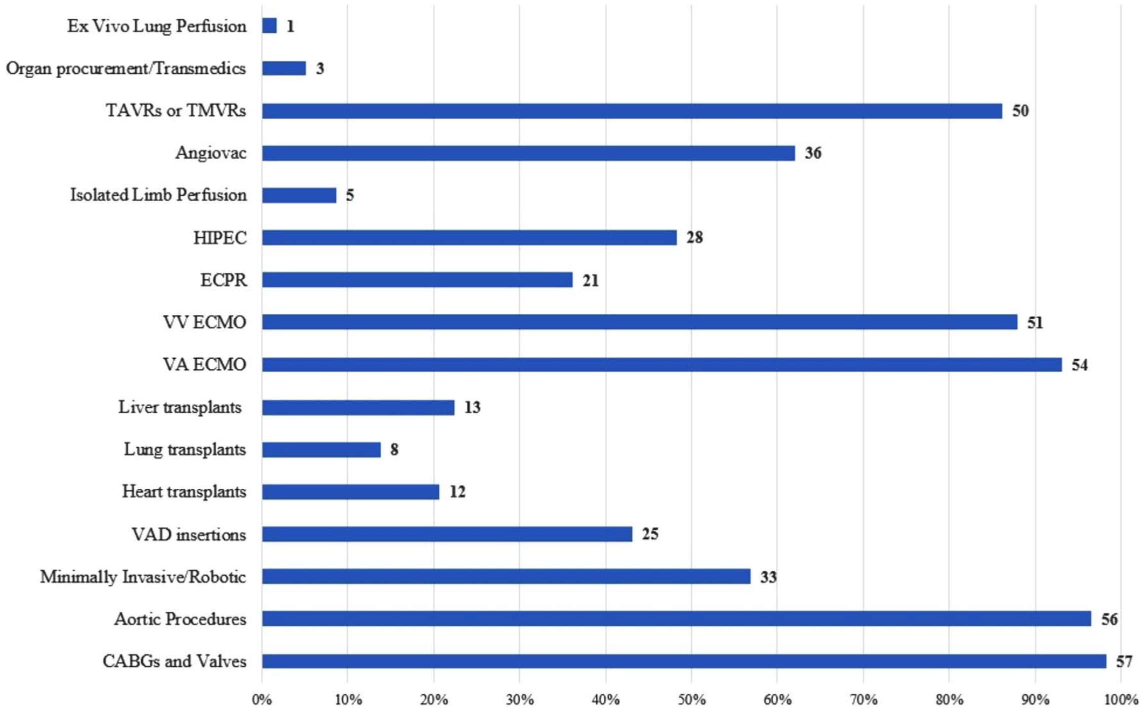

Figure 3. Axial cuts of a CT scan of pelvis, showing sacral osteolysis around caudal implants on the left side.

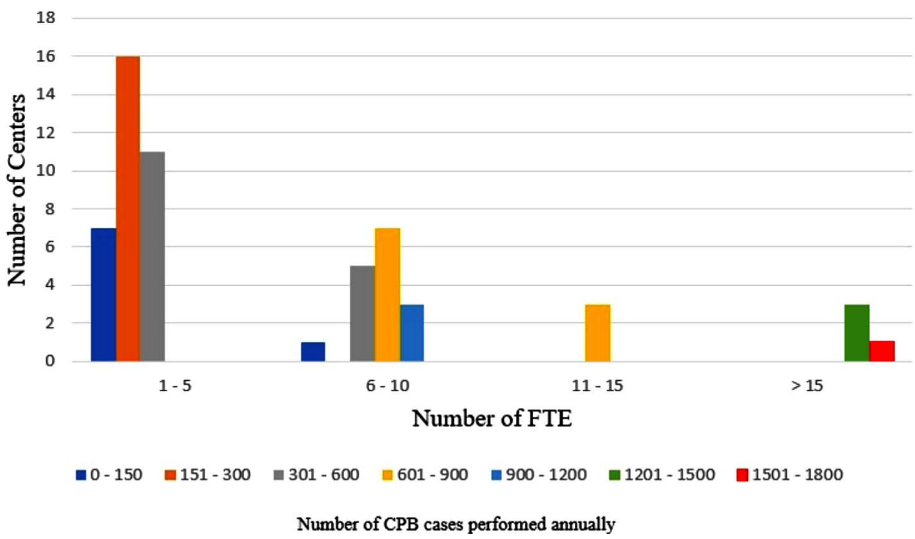

Figure 4. Number of reported Full-Time Equivalents (FTE) perfusionists (n = *57*).

Blood conservation and anticoagulation strategies

Of the centers that employ autologous circuit priming, 33 (56.9%) use it on most procedures, defined as 75–100% of the time (Table 9). Acute normovolemic hemodilution (ANH) was also reported by 7 (12.1%) centers on select procedures (Table 10). All 58 centers reported using at least one method for salvaging post-CPB circuit blood. Most (93.1%, n = 54) transferred post-CPB circuit blood to an autotransfusion device, 55.2% (n = 30) reinfused volume into the patient before cannula removal, 24.1% (n = 14) used modified ultrafiltration (MUF), 24.1% (n = 14) collect pump contents in a bag for reinfusion through a central line, and 1.7% (n = 1) use multi-pass ultrafiltration. Anticoagulation management is reported in Table 11. While all centers reported using activated clotting time (ACT) technology, 21.6% used heparin concentration monitoring. Most programs used 480 seconds as a target for CPB support. Protamine dose was calculated using a fixed dose (24.1%, n = 14), heparin-protamine titration (27.6%, n = 16), and a ratio of heparin given (46.6%, n = 27). Pump suction was terminated prior to protamine administration in 41.4% (n = 24) of centers, 31% (n = 18) terminate suction after

Table 2. CPB circuit components and safety device reporting (n = 58).

	Number, (%)
Arterial pump	
Roller	10 (17.2)
Centrifugal	47 (81)
Both	1 (1.7)
Circuit components	
Open reservoir	56 (96.6)
Closed reservoir	2 (3.4)
Arterial line filtration	
Integrated arterial filter/oxygenator	46 (79.3)
External arterial filter only	11 (19)
Both integral and external filters	1 (1.7)
Safety devices	
Arterial line pressure monitoring	57 (98.6)
Cardioplegia pressure monitoring	58 (100)
Venous reservoir pressure monitoring	32 (55.2)
Arterial line bubble detector	50 (86.2)
Level detector	56 (96.6)
Arterial blood temperature monitoring	58 (100)
Venous inlet blood temperature monitoring	56 (96.6)
One-way valve in vent lines	55 (94.8)
One-way valve in arterial line (centrifugal only)	24 (41.4)
Servoregulation of arterial pump	34 (58.6)
Electronically activated clamps/occluders	27 (46.6)
Low arterial pump speed alarms	29 (50)
Scavenge line on gas outlet	48 (82.8)
Manual hand cranks in room	56 (96.6)
Back-up gas supply in room	47 (81)
Backup battery supply in room	37 (63.8)
Perfusion EMR data capture during CPB	
Yes	26 (44.8)
No	32 (55.2)

Abbreviations: CDPG = cardioplegia; EMR = electronic medical record; CPB: cardiopulmonary bypass.

Table 3. CPB filter usage.

Filter type	Always use it (%)	Sometimes use it (%)	Never use it (%)
Pre-Bypass filter	93.1	–	6.9
CPG crystalloid filter	19	–	81
CPG leukocyte filter	1.7	5.2	93.1
Blood transfusion filter	96.6	3.4	–
Systemic leukocyte filter	1.7	12.1	86.2

Abbreviations: CPG = cardioplegia.

Table 4. Patient temperature monitoring sites.

Location of temperature probe	Percent of centers
PA catheter	36.2
Tympanic membrane	6.9
Nasopharyngeal	39.7
Esophageal	29.3
Bladder	93.1
Rectal	12.1
Skin	1.7

Abbreviations: PA = pulmonary artery.

Table 5. Short and durable MCS device utilization. N based on the number of centers that reported performing VAD insertions and ECMO (MCS devices n = 58, VAD n = 25, ECMO n = 54).

	Number (%)
Short-term MCS	
Abbott CentriMag	31 (53.4)
Abiomed Impella	51 (87.9)
LivaNova TandemHeart	24 (96)
IABP	58 (100)
ECMO	54 (100)
Other	2 (3.4)
Durable MCS	
Abbott HeartMate II™	17 (68)
Abbott HeartMate 3™	23 (92)
HeartWare HVAD	10 (40)
Total Artificial Heart	3 (12)
Berlin Heart	1 (4)

Abbreviations: IABP = intra-aortic balloon pump; ECMO = Extracorporeal membrane oxygenation; MCS = Mechanical circulatory support.

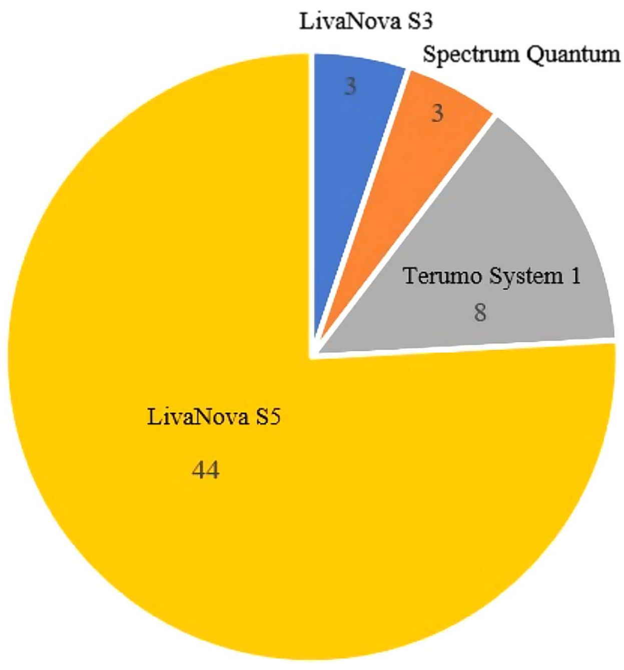

Figure 5. Heart-lung machine type.

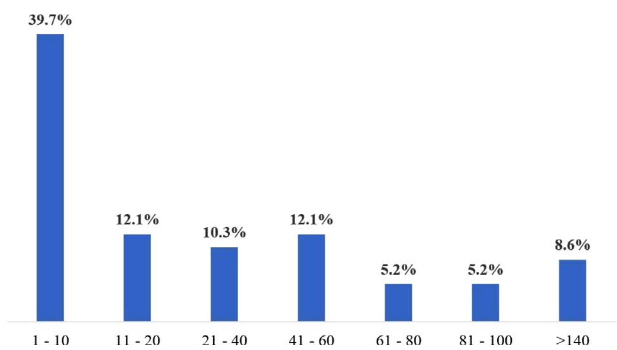

Figure 6. Percent of centers and ECMO procedure volume performed in 2020 (n = 54).

Table 6. Perfusion team's clinical responsibilities with ECMO.

ECMO Responsibility	Percent of Centers
Initiation and Discontinuation	87.9
Troubleshooting	91.4
Direct bedside staffing support	58.6
Rounding model (in house but not bedside)	36.2
Intra-hospital transport	75.9
External transport	69.0

Table 7. CPB techniques (n = 58).

	Number, (%)
Pulsatile perfusion	
None	54 (93.1)
During Aortic Cross Clamp Period	3 (5.2)
During Entire CPB	1 (1.7)
VAVD usage	
Always	24 (41.4)
Select procedures	29 (50)
Do not use	5 (8.6)
Carbon dioxide (CO_2) gas priming of the circuit	
Always	16 (27.6)
Sometimes	4 (6.9)
Never	38 (65.5)
Prescriptive oxygenation^{TM}	
Yes	18 (31)
No	40 (69)
Cerebral oximetry monitoring	
Always	31 (53.4)
Sometimes	22 (37.9)
Never	5 (8.6)
Blood gas analysis/management	
Point of care ABG device	30 (51.7)
CPB inline blood gas monitoring	28 (48.3)
Arterial and venous monitoring	18 (31)
Oxygen delivery monitoring	
None	31 (53.4)
Manual; calculate during CPB	10 (17.2)
Automated DO2 capture	17 (29.3)
Blood gas management strategy/mild hypothermia	
Alpha-stat management	51 (87.9)
pH stat management	6 (10.3)
Pulsatile perfusion	
None	54 (93.1)
During aortic cross clamp period	3 (5.2)
During Entire CPB	1 (1.7)
VAVD usage	
Always	24 (41.4)
Select procedures	29 (50)
Do not use	5 (8.6)
Carbon dioxide (CO_2) gas priming of the circuit	
Always	16 (27.6)
Sometimes	4 (6.9)
Never	38 (65.5)
Prescriptive oxygenation™	
Yes	18 (31)
Both	1 (1.7)
Blood gas management strategy/deep hypothermia	
Alpha-stat management	33 (56.9)
pH stat management	13 (22.4)
Both	12 (20.7)

Abbreviations: CPB = cardiopulmonary bypass.

Table 8. CPB circuit prime constituents.

	Number, (%)
Base Priming Solution	
Plasmalyte-A	43 (74)
Lactated Ringers	4 (7)
Normosol-R	9 (16)
Other	2 (3)
Prime additives	
Heparin	50 (86)
Sodium Bicarbonate	34 (59)
Albumin 5%	5 (9)
Albumin 25%	22 (38)
Mannitol	41 (71)
Amicar/TXA	18 (31)
Antibiotic	3 (5)
Other	8 (14)

Abbreviations: TXA = Tranexamic acid.

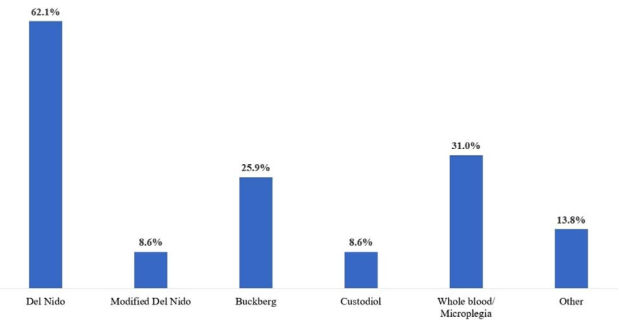

Figure 7. Center-level cardioplegia usage (n = 58).

1–25% of protamine has been delivered, and 27.6% (n = 15) terminate suction when 26–50% of protamine is administered.

Protocol adoption and adherence

All centers reported using a checklist for some part of their practice (Table 12). Most centers used a checklist for assembly/ priming, and initiation of CPB. 65.5% (n = 38) of centers keep a dry assembled circuit for routine on-call coverage, and 34.5% (n = 20) keep a primed assembled circuit. Once a pump is primed, 4 programs (6.9%) keep it for up to 48 hours, and 10 (17.2%) will use it for up to 72 h. Six centers (10.3%) will keep a primed circuit for up to 1 week. Most centers reported 76–100% of their CPB clinical practice is guided by written departmental protocols (Table 13).

Discussion

This survey provides an analysis of adult perfusion practice in the Northeast and Mid-Atlantic regions of the United States. We identified substantial variation in multiple areas of perfusion clinical techniques, equipment, staffing, and adoption of clinical practice guidelines. Due to the paucity of comprehensive surveys conducted across US adult clinical perfusion programs, few opportunities have existed to identify and report trends in operative equipment and techniques. The most recent surveys

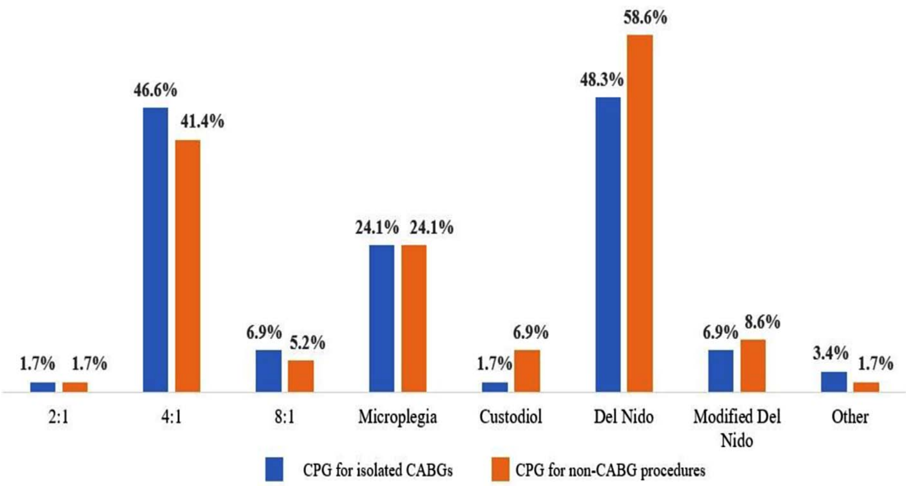

Figure 8. Cardioplegia formulas used for CABG and non-CABG procedures.

Table 9. Autologous prime usage.

Autologous prime is used	Percent of centers
Never	12.1
1–25% of the time	13.8
26–50% of the time	5.2
51–75% of the time	12.1
76–100% of the time	56.9

Table 10. ANH usage.

Percent of procedures that use ANH	Percent of centers
Never	43.1
1–25	29.3
26–50	5.2
51–75	10.3
76–100	12.1

conducted outside of the country may not reflect contemporary US perfusion practice [13, 14]. North American-centric comprehensive surveys date back nearly 27 years [15]. Regional, multi-institutional clinical registries have previously described similar variations in CPB equipment and clinical management strategies; however, the generalizability of these findings is restricted by the number of participating programs [16, 17]. Validated survey tools may broaden the scope of program recruitment and improve our understanding of current perfusion practice. Further, a longitudinal survey design can not only assess clinical trends and guideline adoption, but also identify where the gaps exist for continued consensus development.

The results highlight areas of contrast between published evidence-based guidelines and real-world clinical practice. In 2007, a collaboration between the Society of Thoracic Surgeons (STS) and the Society of Cardiovascular Anesthesiologists (SCA) resulted in a seminal publication of 57 perioperative clinical practice guidelines in cardiac surgical blood conservation and management [18]. Since then, updates to the guidelines were published in 2011 and 2021 [6, 19]. Although several perfusion and intraoperative interventions were assigned high-level recommendations (ACC/AHA Class I and IIa), our

Table 11. Anticoagulation and hemostasis management.

	Number (%)
Minimum ACT For CPB (s)	
350	4 (6.9)
400	37 (63.8)
450	4 (6.9)
480	10 (17.2)
Other	2 (3.4)
Target ACT for CPB (s)	
350	1 (1.7)
400	11 (19)
450	6 (10.3)
480	36 (62.1)
500	1 (1.7)
Other	2 (3.4)
Anticoagulation Monitoring	
ACT only	46 (79.3)
ACT/HMS	11 (19)
HMS only	1 (1.7)
Perioperative Viscoelastic testing	
Yes	20 (34.5)
No	38 (65.5)
Protamine Dosing	
Fixed Dosing	14 (24.1)
HPT Titration	16 (27.6)
Ratio of heparin given	27 (46.6)
Other	1 (1.7)
CPB Cardiotomy suction termination	
Start of Protamine	24 (41.4)
1–25% of protamine	18 (31)
26–50%	16 (27.6)

Abbreviations: ACT = activated clotting time; CPB = cardiopulmonary bypass; HMS = Hemostasis Management System; HPT = heparin protamine titration.

findings suggest the application of these techniques have not yet achieved widespread adoption. Examples include the use of autologous circuit priming and perioperative viscoelastic testing. Only 34.5% of respondents reported using perioperative viscoelastic testing, and 69% of centers indicated autologous

Table 12. CPB intraoperative checklist utilization.

Checklist type	Centers that use them (%)
Assembly/priming	96.6
Initiation of CPB	77.6
Weaning/termination of CPB	53.4
Post-CPB	46.6
Transition of care (Hand-off)	36.2
Autotransfusion	43.1
Case Completion	34.5
VAD/MCS	32.8

Abbreviations: CPB = cardiopulmonary bypass; VAD = ventricular assist device; MCS = Mechanical circulatory support.

Table 13. Percent of CPB practice supported by institutional protocols.

Percent of practice (%)	Respondents (%)
0–25	1.7
26–50	5.2
51–75	8.6
76–99	44.8
100	39.7

Abbreviations: CPB = cardiopulmonary bypass.

priming in at least half of all CPB procedures. Both interventions are class I recommendations [16]. Mitigating unwanted variation in clinical practice has been associated with a higher quality of care and lower hospital costs [20, 21]. Specifically, several perfusion-related initiatives have highlighted the importance of evidence-based guidelines adherence, outcome reporting, and the reduction in practice variability [22–24].

Most respondents indicated that the large majority of CPB care plans are supported by institutional protocols. One of the primary responsibilities of a professional society is to develop standards and guidelines of practice to guide the community in safe and effective patient care. The AmSECT Standards and Guidelines, first formed in 1993, aim to define the minimum requirements for safe cardiopulmonary bypass [25]. These guidelines serve as a framework for developing institution-specific CPB protocols [7]. Clinical practice surveys can assist in reporting guideline dissemination and inform key stakeholders of opportunities to support their adoption. For example, Standard 12.1 recommends the discontinuation of CPB cardiotomy suction at the onset of protamine administration to avoid circuit thrombus formation [7]. However, most respondents reported continued suction use after protamine initiation, despite the inability to predict ACT responsiveness. Jansa et al. reported a 40% decrease in the ACT value following a partial test dose of protamine, resulting in a value lower than the institutional standard for safe CPB support [26]. While the decision to continue suction use may not ultimately be at the perfusionist's discretion, reducing these discrepancies in care may require further collaboration and endorsement between surgical and perfusion societies.

The survey results also identify several other areas of non-compliance with professional standards and guidelines. Among them are backup CPB battery availability (64%), backup gas supply (81%), medical gas scavenging of the oxygenator output port (83%), and arterial line bubble detection (86%). Each of these elements is recommended by both AmSECT and the EACTS/EACTA/EBCP guidelines as minimum standards for the safe conduct of CPB. These findings may highlight the importance of understanding the barriers that prevent their adoption. Such barriers may include a lack of awareness of the standards, economic constraints, or perceived benefit of their usage. Professional societies may offer opportunities in facilitating the implementation of these practices at the local level.

Practice surveys may also inform the community about techniques that lack guideline support or clear consensus. Substantial variation is observed across various aspects of cardioplegia use. A recent international survey of cardioplegia practices by Ali and colleagues reported significant variation in myocardial protection strategies [27]. Although blood substrates were the most frequently reported formulas, the dilution ratios and cardioprotective additives were highly variable. Similarly, our survey found both center-level and procedural differences in formulas. In particular, del Nido cardioplegia was the most frequently reported formula in both CABG and non-CABG procedures. The transition to del Nido solution in adults is a recent phenomenon, with the first reported case in 2014 [28]. This was preceded by nearly 25 years of experience in pediatric congenital surgery [29]. The pediatric perfusion survey, first conducted by Groom and colleagues in 1990, has described both domestic and international pediatric perfusion for over 30 years [30–35]. The 2016 survey reported a 74% use of del Nido in North America, a 2.3-fold increase from the 2011 survey results [34, 35]. Similar opportunities for adult surveys performed serially over time would provide valuable insight into the diffusion of new and emerging techniques. Other reported practices lacking clear consensus in the survey included pulsatile perfusion (7%), heparin concentration monitoring during CPB (20.7%), and albumin as a circuit prime additive (47%).

Practice surveys can help describe current and future requirements regarding workforce and staffing. The expansion of adult ECMO services, MCS device implants, and transplant procurement services may necessitate additional perfusion clinical support resources. Respondents reported an increase in clinical workload over the last three years, and most centers indicated the use of part-time and per diem perfusion coverage for relief. Trends in workforce demographics are essential for perfusion supervisors, hospital administrators, and perfusion education programs. Approximately 38% of the certified clinical perfusionists that responded to the 2015–2016 American Board of Cardiovascular Perfusion (ABCP) Perfusion Profile Survey anticipated working 10 more years before retiring [36]. A 2019 survey of perfusion vacancy and turnover estimated rates of 12.3% and 14.7%, respectively [37]. Both rates exceeded those reported in nursing. Considering the timing of these findings and the unknown long-term consequences of the COVID-19 pandemic, workforce survey data is paramount in supporting practitioners and optimizing the quality of care.

There are several limitations to our survey. There are recognized sources of bias in conducting survey research such as sampling bias, compound questioning, recall bias, and respondent misinterpretation of questions. Survey participation was limited to programs located in the Zone IV region of AmSECT, with a response rate of 34.7%. A majority of center responses were received from Northeastern programs. Data collected from these centers may not be generalizable to centers outside of this region. Survey recruitment across additional zones would appreciably increase our understanding of adult perfusion practice. Additionally, the timing of the survey may have been influenced by the Covid-19 pandemic, as centers may have experienced changes in both cardiac surgical and ECMO procedural volume. Recruitment was also restricted to a database containing names and emails of chief perfusionists and managers. The lapse in time between database data collection and survey recruitment may have contributed to lower survey response rates. Many of the non-respondents were attributed to invalid contact information, as several perfusion managers may have left their place of employment prior to the recruitment period. Lastly, this survey did not collect data on all aspects of clinical perfusion service. Examples include ultrafiltration, departmental quality improvement initiatives, or perfusion position vacancy rates.

Conclusion

Clinical practice surveys can be effective tools in identifying current perfusion staffing, techniques, and equipment utilization. Professional organizations may offer opportunities to promote the recruitment of member center participation. Additional research is warranted to help explain the gaps that may exist between clinical practice guidelines and current perfusion practice. This survey identified several elements of perfusion practice that did not reach thresholds consistent with high-level clinical practice guidelines and professional standards. Longitudinal surveys may describe clinical trends over time and measure adherence to evidence-based and professional standards and guidelines. Benchmarking and trending analysis is necessary to identify areas of improvement, help predict changes in clinical resource management, and foster improved patient outcomes.

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Conflict of interest

Dr. Likosky reported (1) partial salary support to his institution from Blue Cross Blue Shield of Michigan in advancing quality in Michigan and (2) serving as a consultant to AmSECT.

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Data availability

The Informed Consent and Survey Tool used in this study is available in the Appendix of this article.

Ethics

No animals or animal blood was used in this study. This study did not involve obtaining biospecimens or medical information from the participants, so institutional review board approval was not sought.

Authors contributions

The authors confirm contribution to the paper as follows: study conception and design: B.L., B.M., K.O., R.C., D.F.; data collection: J.W., B.L.; analysis and interpretation of results: B.L., B.M., K.O., R.C., D.L., D.F., L.D.; draft manuscript preparation: B.L., B.M., K.O., D.F., D.L., L.D. All authors reviewed the results and approved the final version of the manuscript.

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Appendix: Informed Consent and Survey Tool

2021 Adult Perfusion Practice Survey

You are being asked to participate in this study because you are recognized as the Chief Perfusionist at your institution. This survey is open to all centers that perform adult cardiac surgery on the East Coast of the United States. The expected time to complete the survey is 10-15 minutes.

Students at the Medical University of South Carolina designed this survey to identify key elements of adult clinical perfusion practice using a cross-sectional survey of adult cardiac surgical programs. The questions were developed to identify current perfusion staffing, program demographics, equipment, and techniques. Completion of this survey is voluntary. Any information that you provide will be kept strictly private, confidential, and anonymous. While the survey tool collects the identity of your program, this information is blinded to the study researchers. We the investigators at MUSC will not be receiving nor analyzing any raw data from this survey. All data will be de-identified and coded by the University of Michigan before being released to us. The results of the survey will be presented at a national perfusion conference and submitted for peer review. If you have any questions pertaining to this research study, please contact Breana Lohbusch lohbusch@musc.edu.

Note the questions are directed at the practices of your institution, not your personal perfusion practice. If you are the Chief at multiple centers please submit a survey for each institution.*

Staffing and Demographics

Name of Institution

____

Which state is your institution in?

- ○ Connecticut
- ○ Delaware
- ○ District of Columbia
- ○ Maine
- ○ Maryland
- ○ Massachusetts
- ○ New Hampshire
- ○ New Jersey
- ○ New York
- ○ North Carolina
- ○ Pennsylvania
- ○ Rhode Island
- ○ South Carolina
- ○ Vermont
- ○ Virginia
- ○ West Virginia

Does your institution participate in a local, regional or national registry?

- ○ Yes
- ○ No

Select the types of procedures performed at your facility in 2020 (select all that apply)	☐ CABG ☐ Valve ☐ Aortic procedures ☐ Minimally invasive/robotic procedures ☐ Implantable VAD insertion ☐ Transplant - Heart ☐ Transplant - Lung ☐ Transplant - Liver ☐ VA ECMO ☐ VV ECMO ☐ ECPR ☐ HIPEC ☐ Isolated limb perfusion ☐ Angiovac (thrombus removal) ☐ TAVR/TMVR ☐ Organ procurement/Transmedics OCS ☐ Other
If other please elaborate	________________________________
Approximately what percentage of the perfusion clinical care techniques associated with CPB support are guided by a written operating procedure (protocol)?	○ 0- 25% ○ 26 - 50% ○ 51 - 75% ○ 76 - 99% ○ 100%
How many adult ON-CPB procedures were performed by the perfusion team in 2020 at your facility?	○ 0 - 150 ○ 151-300 ○ 301-600 ○ 601-900 ○ 901-1200 ○ 1201-1500 ○ 1501-1800 ○ 1801-2000 ○ >2000
How many CPB-STANDBY procedures were supported by the perfusion team in 2020 at your facility (TAVR, OPCAB, lead extractions, return for bleeding, cath lab coverage)?	○ 0-50 ○ 51-100 ○ 101-150 ○ 151-200 ○ 201-250 ○ 251-300 ○ 301-350 ○ 351-400 ○ >400
How many NON-CPB autotransfusion (cell saver) procedures were performed by the perfusion team in 2020 at your facility?	○ 0 ○ 1-50 ○ 51-100 ○ 101-150 ○ 151-200 ○ 201-250 ○ 251-300 ○ 301-350 ○ 351-400 ○ >400

How many adult ECMO procedures were performed in 2020 at your institution?	○ None ○ 1-10 ○ 11-20 ○ 21-40 ○ 41-60 ○ 61-80 ○ 81-100 ○ 101-120 ○ 121-140 ○ >140
At my institution, a perfusionist serves as the ECMO Coordinator.	○ Yes ○ No ○ N/A
Please select all of the clinical responsibilities of the perfusion team's involvement with ECMO at your facility in 2020? (select all that apply)	☐ None ☐ Initiation /discontinuation ☐ Trouble-shooting ☐ Direct bedside staffing support ☐ Rounding model (in-house, not at bedside) ☐ Intra-hospital transport ☐ External transport
How many full-time perfusionists were employed at your facility in 2020?	______________________
How many part-time perfusionists were employed at your facility in 2020?	______________________
How many Per-diem perfusionists were employed at your facility in 2020?	______________________
Over the last 3 years, our program has utilized Per-diem / Locum tenens support to provide perfusion staff coverage	○ Yes ○ No
Over the last three years, the number of clinical hours provided by the perfusion team has ____________	○ increased ○ decreased ○ stayed the same
Please indicate the staffing model which best describes the perfusion support coverage in 2020	○ One perfusionist for each CPB procedure ○ n + 1 model (elective schedule) ○ n + 1 model (elective and after hours) ○ > n + 1 model ○ Other
If other please elaborate	______________________

Equipment and Techniques

Implantable VAD devices available (Select all that apply)	☐ Heartmate II ☐ Heartmate III ☐ Heartware HVAD ☐ Total Artificial Heart (TAH) ☐ Other
If other, what other devices?	______________________
Short-term Mechanical Circulatory Support devices available (Select all that apply)	☐ Centrimag ☐ Impella ☐ TandemHeart ☐ IABP ☐ ECMO ☐ Other
If other, what other devices?	______________________
Arterial pump head type	○ Roller ○ Centrifugal ○ Both
Venous reservoir system	○ Open system (hard-shell) ○ Closed system (venous bag)
Heart-Lung Machine	○ Gettinge HL-20 ○ LivaNova S3 ○ LivaNova S5 ○ Medtronic Performer ○ Sarns (8000/9000) ○ Terumo System I ○ Spectrum Quantum ○ Cobe Century ○ Other
If other, what machine?	______________________
Heater/Cooler Manufacturer	○ Cardioquip MCH ○ Cincinnati Sub-Zero ○ LivaNova 3T ○ Sarns TCM ○ Other
If other, what machine?	______________________

HLM Safety Devices (select all that applied in 2020)	☐ Arterial pressure line monitoring ☐ Cardioplegia pressure monitoring ☐ Venous reservoir pressure monitoring ☐ Arterial bubble detector ☐ Level sensor ☐ Arterial outflow temperature monitoring ☐ Venous inlet temperature monitoring ☐ One-way valve (vent line) ☐ One-way valve arterial line (Centrifugal heads only) ☐ Hard-stop arterial controls (servoregulation) ☐ Electronically activated clamps ☐ Low speed alarms ☐ Anesthetic gas scavenge line ☐ Manual handcrank (in room) ☐ Backup gas supply (in room) ☐ Back-up battery supply (in room)

Filtration usage

	Always	Sometimes	Never
Pre-CPB filter	○	○	○
CPG crystalloid filter	○	○	○
CPG leukofiltration	○	○	○
Blood transfusion filters	○	○	○
Systemic leukofiltration	○	○	○

Arterial line filtration	○ External filter ○ Integrated filter with oxygenator ○ Combination ○ None
Arterial pore filter size	○ 20 ○ 25 ○ 27 ○ 30 ○ 32 ○ 33 ○ 37 ○ 38 ○ 40 ○ 43 ○ Other
Crystalloid priming solution	○ Plasma-lyte A ○ Normosol R ○ Lactated Ringer ○ NaCl 0.9% ○ Other
If other, what kind?	____________________

Use of crystalloid priming additives (check all that apply)	☐ Heparin ☐ Sodium Bicarbonate ☐ Albumin 5% ☐ Albumin 25% ☐ Starch solution ☐ Mannitol ☐ Amicar / TXA ☐ Antibiotic ☐ Other
If other, what additives?	______________________________
Type of CPG used (select all that apply)	☐ Del Nido ☐ Modified Del Nido ☐ Buckberg ☐ Custodiol ☐ Whole blood / Microplegia ☐ Other
If other, please elaborate	______________________________
What type of cardioplegia formula was used in 2020 for isolated CABG procedures? (select all that apply)	☐ None ☐ 1:1 ☐ 2:1 ☐ 4:1 ☐ 8:1 ☐ Microplegia ☐ Crystalloid ☐ Custodial ☐ Del Nido ☐ Modified Del Nido ☐ Other
If other, please elaborate	______________________________
What type of cardioplegia formula was used in 2020 for non-CABG procedures (valve, aortic procedures)? Select all that apply.	☐ None ☐ 1:1 ☐ 2:1 ☐ 4:1 ☐ 8:1 ☐ Microplegia ☐ Crystalloid ☐ Custodial ☐ Del Nido ☐ Modified Del Nido ☐ Other
If other, please elaborate	______________________________

Biocoating area	○ None ○ Limited components ○ All but cannula ○ Tip to tip
If partial use, which components are biocompatible?	☐ Oxygenator ☐ Reservoir ☐ Arterial Filter ☐ CPG system ☐ Tubing/connectors
Perfusion EMR	○ No EMR ○ Cor EMR ○ Epic ○ GE-Centricity ○ Gettinge / Metavision ○ LivaNova (Connect or DMS) ○ Perfusion PRO ○ Perfusion.com on-cloud ○ Spectrum Medical (Quantum or Viper) ○ Terumo T-Link ○ Talis-ACG Perfusion ○ Other
If other, what EMR?	______________________
Pump readiness for routine on-call coverage	☐ Dry assembled circuit ☐ Primed circuit- all components ☐ Primed circuit- all but oxygenator ☐ None
If a CPB circuit is primed at your facility, how long is the wet-setup kept for?	☐ Under 24 hours ☐ 24-48 hours ☐ 48-72 hours ☐ 72 hours to 1 week ☐ > 1 week
Techniques	
Does the Perfusion team routinely adjust the CPB circuit according to patient size (prescriptive oxygenation)?	○ Yes ○ No
Does the perfusion team CO2 flush the circuit?	○ Always ○ Sometimes ○ Never
Pulsatile perfusion usage	○ None ○ During cross clamp period only ○ During CPB support
Augmented venous drainage usage	○ None ○ Select procedures ○ All CPB procedures

Type of augmented venous drainage used	☐ None ☐ VAVD ☐ Kinetic (KAVD)
Approximately what percentage of procedures utilize Autologous circuit priming?	○ None ○ 1-25% ○ 26-50% ○ 51-75% ○ 76-100%
Approximately what percentage of procedures utilize Acute Normovolemic Hemodilution (ANH)?	○ None ○ 1-25% ○ 26-50% ○ 51-75% ○ 76-100%
Methods used for salvaging post-CPB residual circuit blood (check all that apply)	☐ Vasodilation / reinfusion into patient before cannula removal ☐ Collect in a bag for patient reinfusion through central line ☐ Transfer to an autotransfusion device for processing ☐ Modified ultrafiltration (MUF) ☐ Multi-pass ultrafiltration recovery (Hemobag) ☐ Other ☐ None
If other, please elaborate	________________________
Monitoring	
What type of arterial blood gas monitoring is used?	○ Inline blood gases ○ Point of care device ○ Both
Inline Blood Gas trending device	○ LivaNova B-care ○ Medtronic- Biotrend ○ Spectrum (Arterial only) ○ Spectrum (Venous only) ○ Spectrum (Arterial and venous) ○ Terumo CDI (venous only) ○ Terumo CDI (Arterial only) ○ Terumo CDI (Arterial and venous) ○ Other
If other, what devcice?	________________________
Is cerebral oximetry used?	○ Never ○ Select procedures ○ All procedures
Cerebral oximetry manufacturer	○ Covidien- INVOS ○ CASMED ○ Nonin

Where is the patient's temperature measured? Select all that apply	☐ PA catheter ☐ Tympanic membrane ☐ Nasopharyngeal ☐ Esophageal ☐ Bladder ☐ Rectal ☐ Skin ☐ Not Measured
Acid-base management (mild to moderate hypothermia)	○ Alpha stat ○ pH stat ○ Combination
Acid-base management (deep to profound hypothermia)	○ Alpha stat ○ pH stat ○ Combination
Anticoagulation Monitoring	
Which method(s) are used for monitoring anticoagulation?	☐ ACT ☐ Heparin concentration ☐ Other
If other, please elaborate	______________________________
If ACT is used, what is the minimum ACT for CPB support?	○ 300 or less ○ 350 ○ 400 ○ 450 ○ 480 ○ 500 ○ Other
If other, what is the minimum ACT?	________________________
If ACT is used, what is the target ACT for CPB support?	○ 300 or less ○ 350 ○ 400 ○ 450 ○ 480 ○ 500 ○ Other
If other, what is the target ACT?	________________________
Method for determining initial heparin dose	○ Fixed-weight dose ○ Heparin-dose response
Method for calculating protamine dose	○ Fixed dose ○ Heparin-protamine titration ○ Ratio of heparin given ○ Other

If other, please elaborate	______________________________
Routine Viscoelastic (TEG/ROTEM) testing: check all that apply	☐ No ☐ Prior to CPB ☐ During CPB ☐ Post CPB
Timing of pump suction termination	○ Prior to protamine administration ○ 1-25% of protamine delivered ○ 26-50% of protamine delivered ○ > 50% of protamine administered
Protocols	
Checklist usage (check all that apply)	☐ None ☐ Assembly / Priming ☐ Initiation of CPB ☐ Weaning / Termination of CPB ☐ Post-CPB ☐ Transition of care (Hand-off) ☐ Autotransfusion ☐ Case completion ☐ VAD / MCS
Oxygen delivery monitoring	○ None ○ Calculated manually ○ Automated
Which oxygen delivery values do you monitor?	☐ DO2 only ☐ DO2 and VCO2
Would you like to continue receiving communications from the University of Michigan and participate in future research?	○ Yes ○ No

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