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The Fundamental Skills and Deconstructed Sub-Steps of Pediatric Cardiopulmonary Bypass

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Abstract Perfusion education programs use simulation to provide students with clinical skills prior to entering the operating room. To teach the psychomotor execution of skills in a simulation lab requires a list of validated skills and deconstructed sub-steps to fully optimize adult learning. A list of the fundamental skills of adult cardiopulmonary bypass (CPB) was recently published; however, no defined list exists regarding pediatric CPB skills. The purpose of this survey is to form a definitive list of skills fundamental to *pediatric* CPB. A survey of 23 proposed pediatric CPB clinical skills and 291 proposed skill sub-steps was developed. Proposed pediatric CPB skills were evaluated using an established frequency and harm index. If the skill is performed >50% of the time (frequency), *and* if >50% believe that if the skill is performed incorrectly patient harm is probable (risk), then the skill is accepted as fundamental. The survey content was validated by subject matter experts and then distributed to practicing perfusionists between September 2020 and December 2020. Of the 125 survey respondents, 57.9% had 10 or more years in the field. 35.2% of respondents are American Society of Extracorporeal Technology (AmSECT) Fellows of Pediatric Perfusion (FPP) and pediatric CPB represents >50% of the annual caseload for 69.7% of respondents. 22 of the 23 proposed skills were accepted as fundamental in the conduct of pediatric CPB and 258 of the 291 proposed sub-steps associated with CPB skills were accepted as integral to skill performance. By surveying practicing pediatric perfusionists, this study identifies 22 skills as fundamental to the safe execution of pediatric CPB. In addition, skill sub-elements were identified as necessary for skill execution. This knowledge will assist perfusion programs in developing a pediatric simulation curriculum that matches current clinical execution of pediatric skills. **Keywords:** pediatric, cardiopulmonary bypass, simulation, education, competency, psychomotor skills, assessment. *J Extra Corpor Technol. 2021;53:251–62*

Competent operation of a heart–lung machine (HLM) for cardiopulmonary bypass (CPB) requires the collective mastery of several technical and non-technical procedural skills. Traditionally, the perfusion field has applied the Halstead model of medical education that has long been the standard of medical training. In this model, CPB skills, for both adult and pediatric patients, are taught in the setting of actual clinical open-heart surgery procedures using a "see one, do one" approach (1). In this application, an expert perfusionist clinical instructor demonstrates CPB skills and then gradually supervises and evaluates the student's effort to execute these skills on patients requiring CPB. More recently, teaching pre-clinical skills using principles of adult learning and active engagement have been strongly advocated in medical curriculum (2–4).

In a 2010 collaborative project between the American Academy of Cardiovascular Perfusion (AACP) and the American Society of Extracorporeal Technology (AmSECT), over 80% of the 432 perfusionists surveyed believed that perfusion education programs should document specific pre-clinical skills *before* allowing a student to practice these skills on live patients (5). To help achieve the goal of pre-clinical skill competence, many schools have added perfusion simulation as a component of their programs (6–8). Using simulation to optimize adult learning in health professions education requires that validated clinical skills and their respective *deconstructed* sub-steps are well understood (9,10).

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Defining and validating skills in any clinical procedure is challenging (11). Despite this, a recent publication by Searles et al. identified 20 unique fundamental perfusion skills of adult CPB (12). Within this work, each fundamental skill was deconstructed into its sub-steps. This validated list of skills has provided important data required for immersive simulation-based training in the practice, assessment, and acquisition of the pre-clinical CPB skillset.

Pediatric CPB is recognized as a unique specialty in perfusion and while extensive resources exists on the pediatric knowledge-base, techniques, practice guidelines, and technical considerations (13–16), there is not a validated list of deconstructed sub-steps that can be used to inform the curricular design for pediatric CPB training in the simulation lab. The aim of this study is to fill this gap by identifying, via practicing pediatric perfusionist opinion, the fundamental skills of pediatric CPB.

METHODS

Institutional Review

The SUNY Upstate IRB has determined this project is EXEMPT FROM IRB REVIEW according to federal regulations; Approval date: July, 26, 2020 [1581762–1].

Survey Instrument

The survey (and the validation surveys used to build it) took place using the Research Electronic Data Capture application (REDCap) hosted by SUNY Upstate Medical University and developed by Vanderbilt University (17). REDCap supports secure survey creation through the following capabilities: response deidentification, data analysis on the platform itself, exportable data packages to commonly used statistical programs, and audit trails for data manipulation and export procedure tracking.

Survey Design and Validation

The adult skills survey previously used by our research group was triaged (12) for its application to pediatric CPB. Initial modifications were made that included expansion of the ultrafiltration (UF) section to four individual skills (Pre-Bypass Ultrafiltration [Pre-BUF], Conventional Ultrafiltration [CUF], Zero Balance and Dilutional Ultrafiltration [DUF/ZBUF], and Modified Ultrafiltration [MUF]). This iteration resulted in a survey of 23 proposed fundamental skills. In addition, each skill was broken down into proposed sub-step elements to determine what steps are used to perform the skill.

Next, the survey questions underwent a rigorous content and construct validation process based on recommendations made in the field of scientific survey validation (18,19). Validity testing of each question was performed in the following order:

Content validation—questions were considered valid with 80% agreement by five subject matter experts (see Acknowledgments).

Construct validation—question construction was validated using The University of Memphis' Question Understanding Aid (QUAID) Tool (20).

Pilot testing—10 volunteer pediatric perfusionists performed the survey to test the analysis methods.

Additional details on the steps taken to validate and finalize the survey are shown in Figure 1. The resultant finalized survey was then deployed.

Target Population, Time Frame, and Deployment Method

The target population was self-identified practitioners of pediatric perfusion. Survey responses were collected through voluntary survey completion between September–December 2020. A three-pronged survey deployment strategy was used to recruit participants; 1) direct e-mail, 2) perfusion forums, and 3) social media. Specifically, a standardized e-mail was sent to the Fellows of Pediatric Perfusion (FPPs) containing the survey description and link, a listing was made on the Perfusion.com Pediatric Perfusion Forum on and on AmSECT's PerfList Discussion Forum, and finally, social media posts were added to various perfusion-related pages on both Facebook and LinkedIn. Ten days after the initial survey deployment, a second recruitment round was initiated using the same approach as described above.

Frequency and Harm Index

Using a previously described methodology (12), the proposed skills were evaluated by respondents based on the following two categories:

1. *Frequency of Use*—respondents selected how often (% of the time) the proposed skill was used during pediatric CPB.
2. *Risk of Harm*—respondents provided their opinion by agreeing/disagreeing that the patient is at risk of harm if the skill is not conducted properly.

To ensure that survey respondents had a sufficient understanding of our interpretation of these category definitions, the survey introduction included a section on important definitions.

Fundamental Skill Inclusion Criteria: The 50% Rule

To meet the criteria of a pediatric CPB fundamental skill, two metrics must be met. First, the skill must be conducted in most cases (Frequency of Use)—and, second, if not properly conducted can harm the patient

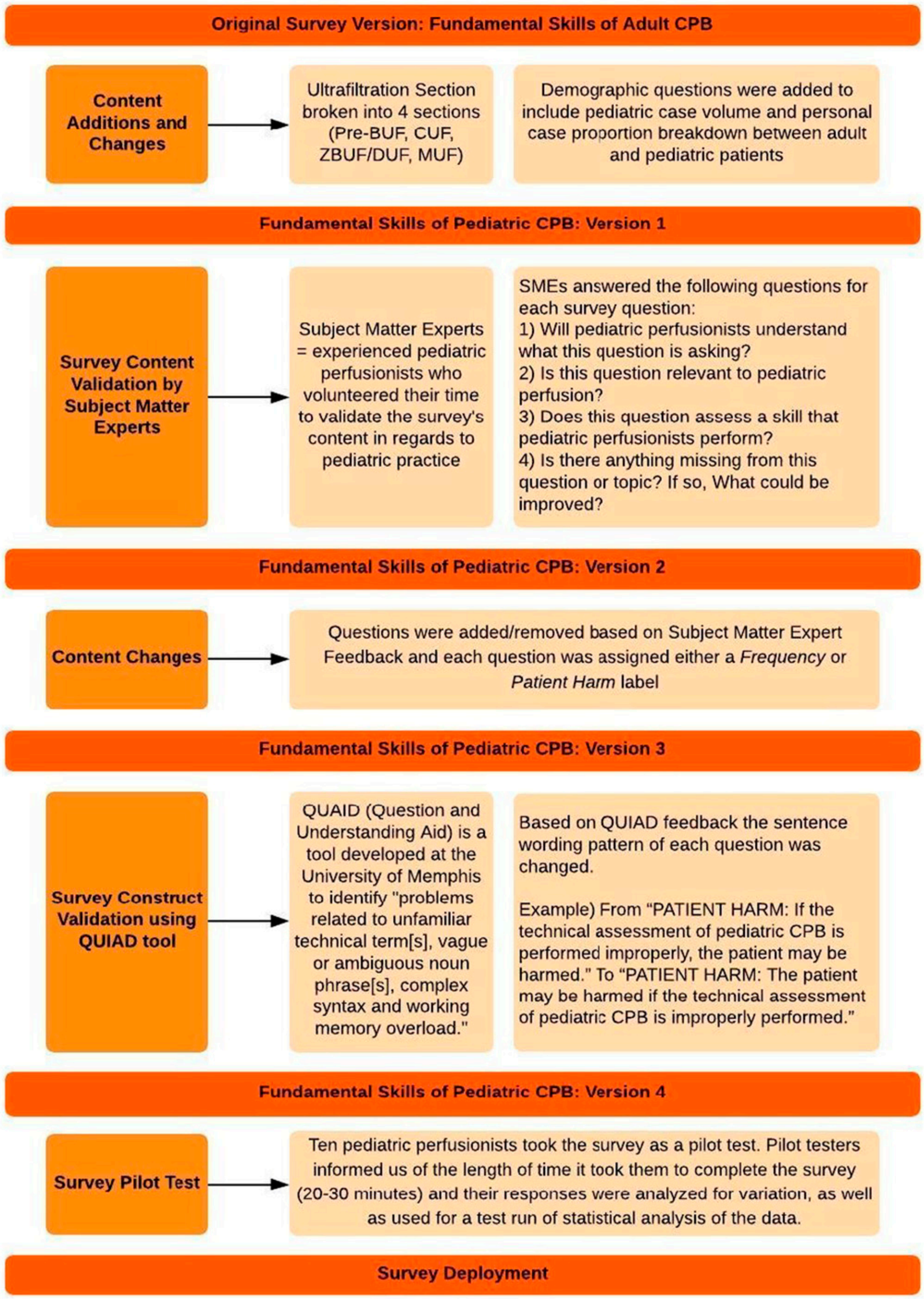

Figure 1. Survey development.

(Risk of Harm). When >50% of respondents acknowledged that:

1. they perform a skill more than 50% of the time

   AND

2. if improperly performed, there was a risk of harm to the patient or the provider

then a skill was determined to be a fundamental skill.

Sub-Step Inclusion Criteria

A list of proposed deconstructed sub-steps that could be associated with CPB skills were surveyed. If 50% of respondents included that sub-step, it was accepted as part of the fundamental skill.

Survey Exclusion Criteria

Surveys submitted by perfusion students were excluded. Only complete responses to each individual skill section were accepted.

Data Presentation

Survey data is expressed as percent (%) of total responses.

RESULTS

Demographics

There are 125 surveys included in the dataset. Of these, 67% of the respondents were from within the United States of which 94% are certified clinical perfusionists (CCP). Gender breakdown was 65% male, 34% female, and 1% other. The respondents' title classifications are shown in Table 1. Of note, 35.2% of respondents were AmSECT Fellows in Pediatric Perfusion (FPP). The response rate from the FPP population was 31%. The majority of respondents (57.9%) have over 10 years' experience (Table 2). Pediatric CPB represents >50% of the annual caseload for the majority (69.7%) of respondents.

Fundamental Clinical Skills, Risk, and Skill Sub-Steps Results

Respondent frequency and risk of the proposed pediatric CPB skills are shown in Table 3. Of the 23 proposed clinical skills, 22 met the 50% rule criteria to be classified as a fundamental skill. All 23 of the proposed clinical skills were determined to have risk to the patient if performed incorrectly. The only clinical skill performed less than 50% of the time during pediatric CPB was ZBUF/DUF (49%) and therefore did not meet the criteria of a fundamental skill. Accepted fundamental skills were unchanged when sorted by groups (International, USA, FPP) with the single exception of the frequency of ZBUF/DUF. Survey respondents use ZBUF/DUF 50% of the time or greater in their clinical practice with a frequency of: US: 49%; International: 50%; and FPP 55%. In all respondent subgroups, the majority agree that the patient may be harmed if ZBUF/DUF is performed incorrectly.

Of the 291 proposed sub-steps, 258 were found to be included as part of the skill. For a complete descriptive list of included and excluded sub-steps, please refer to Appendix A. Respondents also provided open-ended suggestions for additional proposed skills of pediatric CPB. These suggested skills include the following: assessment of adequacy of anesthesia, participation in time outs, emergency preparedness, ECMO competency, verification of venous cannula placement, cannulation technique awareness, and cell salvage techniques.

Table 1. Respondent demographics.

Respondent Titles	Respondents (%)
Staff perfusionist	62.1
Chief perfusionist	35.2
Clinical instructor	31.7
Full-time perfusion faculty	2.1
Fellow pediatric perfusion	35.2

Table 2. Respondent years in perfusion.

Years in Perfusion	Respondents (%)
0–10	42.1
11–20	28.9
>20	29

DISCUSSION

In perfusion training, as in other healthcare professions, it is becoming less and less acceptable for learners to practice new skills on actual patients (4,21,22). To be able to equip students with a documented level of psychomotor competence prior to clinical application requires a specialized learning environment, like simulation, and well described procedural skills to adequately measure and assess abilities. In various teaching approach models, having a validated list of *deconstructed* sub-steps has been shown to be effective in the process of learning skill execution, mental rehearsal, and practice (9,10,23,24).

Previously, CPB core communication skills were described and more recently, 20 deconstructed skills were determined in adult CPB procedures (12,25). This study now provides, through surveyed practitioner input, a similar list of skills and associated sub-steps performed by clinicians during pediatric CPB. This is relevant to advancing the concept of teaching pediatric skills and documenting some level of pre-clinical competence in pediatric perfusion. Interestingly, using the criteria of defining a fundamental skill, the adult and pediatric skills list and deconstructed sub-steps are very similar. While this survey suggests that pediatric and adult CPB largely share common fundamental skills, this is not to suggest that adult and pediatric perfusion procedures are the same. The survey did not address the known physiologic and anatomic differences between adult and pediatric CPB and how those factors may modify data synthesis and nuances of scale and precision in skill execution.

In previous surveys documenting techniques, it has been shown that *several* types of UF techniques have been increasing in use in pediatric perfusion (26). Likewise, it was determined during the current survey's content validation phase that UF should be considered in four categories; Pre-BUF, CUF, ZBUF/DUF, and MUF. Three of the four categories met the criteria of a fundamental skill with ZBUF/DUF being narrowly rejected by the frequency requirement (49%). It should be noted, however, that when the survey data was filtered to only

Table 3. Fundamental skills of pediatric CPB survey results.

Proposed Pediatric CPB Skill Category	Frequency (%)	Risk (%)	Skill Accepted	Sub-steps Accepted (see Appendix B)
Pre-CPB data and calculations	99 98	99	Yes	25/31
Pre-CPB component and circuit selection	99	99	Yes	11/11
Pre-CPB circuit assembly and priming	92 92	99	Yes	13/16
CPB checklist	98	97	Yes	33/33
Anti-coagulation	97	100	Yes	12/16
Verification of arterial cannula placement	99	99	Yes	8/8
Initiation of CPB	97	99	Yes	21/21
Evaluation of CPB	97	100	Yes	6/6
Myocardial protection	99	99	Yes	7/8
Evaluation of adequacy of perfusion	100	100	Yes	14/14
Hemodynamic management	100	100	Yes	8/11
CPB circuit volume management	100	99	Yes	8/8
Blood gas/Electrolyte management	100	100	Yes	15/16
Temperature management	100	99	Yes	7/7
Pre-BUF	67	90	Yes	7/8
CUF	93	96	Yes	6/6
DUF/ZBUF	49	96	No	7/12
MUF	68	100	Yes	12/17
Weaning and termination of CPB	99	100	Yes	13/14
Communication and team interactions	100	100	Yes	7/7
Sterile technique	100	98	Yes	7/8
Blood conservation	97	94	Yes	7/7
Standard precautions	95	97	Yes	4/6

CPB, cardiopulmonary bypass; CUF, conventional ultrafiltration; DUF/ZBUF, dilutional ultrafiltration/zero balance ultrafiltration; MUF, modified ultrafiltration; Pre-BUF, pre-bypass ultrafiltration.

include AmSECT FPP, it did meet the criteria (55%). In addition, 96% of survey respondents agree that there is patient risk involved in the performance of ZBUF/DUF. Therefore, we assert that it is worthwhile to include ZBUF/DUF in a skills list when considering fundamental pediatric CPB skills for a teaching model/curriculum. This is supported by the 2016 International Pediatric Perfusion Practice survey which found the following rates of UF use: Pre-BUF—57%, During CPB—97%, MUF—70% (14).

There are study limitations. While participants were well distributed across age, gender, professional practice, and geography, we were unable to determine a response rate as the pediatric perfusion target population is not well defined. Based upon our number of returned surveys, we infer that the response rate is low. Casting a wide net on what constitutes a practicing pediatric perfusionist, (our survey was open to all self-identified pediatric perfusion practitioners), could be construed as a limitation. However, we did not want to exclude people who perform pediatric CPB based upon arbitrary criteria such as years in profession or case volume. Given the scope of this study (determining what skills are used in pediatric CPB) it was deemed the most inclusive way to understand what is practiced clinically. Nonetheless, in this study nearly 60% of the respondents had over 10 years' experience and over a third of the respondents were FPP. Pediatric perfusion itself is also a difficult term to define as it can include patients from the neonate to the young adult. Therefore, interpretation of pediatric skills were left up to the respondents. Finally, this survey was conducted via RedCAP and deployed via the internet, so it is possible that the survey is victim to selection bias based on the avenues that were used to recruit participants.

Perfusion education simulation is now recommended by the accreditation agencies and contributes significantly to learners' pre-clinical exposure, acquisition, and assessment of CPB fundamental skills (27). In surgical simulation training, there is evidence that skills transfer to clinical practice (28), which strengthen similar feedback from our clinical sites on perfusion skill transferability. Given its challenges of scale, pediatric perfusion simulation is an area of keen interest. While this report shows a clear alignment of fundamental skills across pediatrics and adults, a focus of future research will examine the refinement of fundamental pediatric skills in simulation through deliberate practice. Additionally, future research that validates benchmark clinical technical parameters will be helpful to create high-fidelity pediatric perfusion simulation (29).

In conclusion, this research supplements other important resources (pediatric perfusion knowledge-base, pediatric CPB standards and guidelines, and perfusion practice surveys) by providing the validated deconstructed pediatric skills that are critical for the practice

Table 4. Representative survey questions and responses: MUF.

	0–25% of pediatric cases	26–50% of pediatric cases	51–75% of pediatric cases	76–100% of pediatric cases
FREQUENCY: In your clinical practice, how often do you monitor and manage MUF during pediatric CPB?	25.8%	6.1%	24.2%	43.9%

	Agree	Disagree
PATIENT HARM: The patient may be harmed if MUF is improperly performed.	100%	0%

SUB-STEPS: In your clinical practice, which of the following items are included in monitoring and managing MUF during pediatric CPB?	Sub-step Included (%)	Sub-step Not Included (%)	Skill Accepted
Incorporate patient size into decision to initiate MUF	74.2	25.8	✓
Use a Pre-MUF checklist	47	53	
UseAV MUF techniques	75.8	24.2	✓
Use VV MUF techniques	15.2	84.8	
Incorporate patient's hemodynamic status into decision to initiate/terminate MUF	78.8	21.2	✓
Incorporate hematocrit into decision to terminate MUF	56.1	43.9	✓
Incorporate completeness of circuit salvage into decision to initiate/terminate MUF	74.2	25.8	✓
Incorporate a calculated MUF pump flow	65.2	34.8	✓
Incorporate duration into decision to terminate MUF	65.2	34.8	✓
Evaluate and manage electrolyte changes during MUF	43.9	56.1	
Evaluate and manage anti-coagulation during MUF	37.9	62.1	
Evaluate arterial line pressure before and after initiating MUF	80.3	19.7	✓
Evaluate and communicate patient's volume status during MUF	78.8	21.2	✓
Temperature management/control during MUF	83.3	16.7	✓
AV MUF: Arterial flow does not exceed modified ultrafilter flow	52.3	47.7	✓
AV MUF: Use blood cardioplegia system/pump for MUF	56.9	43.1	✓
AV MUF: Servo-regulate arterial pump to a negative arterial line pressure	45.3	54.7	

AV, arteriovenous; CPB, cardiopulmonary bypass; MUF, modified ultrafiltration; VV, venovenous.

and rehearsal of the psychomotor elements of pediatric CPB skill execution.

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APPENDIX A. SURVEY QUESTIONS

Respondents were asked four types of questions for each Fundamental skill section. The first type was a "FREQUENCY" question and had the following answer options: 0–25% of pediatric cases, 26–50% of pediatric cases, 51–75% of pediatric cases, 76–100% of pediatric cases. Next, were "PATIENT HARM" questions that had the following answer options: Agree, Disagree. The FREQUENCY and PATIENT HARM questions asked are listed below. The third type of question was regarding fundamental skill substeps. Appendix B lists the sub-steps evaluated by skill. The final question for each skill was open-ended and allowed respondents to list any other parameters/sub-steps that they include in their execution of the skill.

DEMOGRAPHICS

1. Where do you live?
   - Northeast, Southeast, Midwest, West, Southwest, Alaska, or Hawaii, I live outside of the United States.
2. Please check all the boxes that describe yourself:
   - Perfusion Student, Staff Perfusionist, Chief Perfusionist/Manager, Clinical Instructor for a perfusion school, Full-Time Perfusion Education Faculty, Fellow of Pediatric Perfusion (FPP), Member of the AmSECT Pediatric Committee, Locum Tenens, Sales Representative/Clinical Specialist, Retired
3. Identify your professional credentials:
   - Certified by the ABCP, Licensed Perfusionist, I am ABCP "certification eligible", Never ABCP Certified, Formerly ABCP Certified
4. What is your gender?
   - Male, Female, Other
5. How long have you been a practicing perfusionist?
   - 0–5 years, 6–10 years, 11–15 years, 16–20 years, 21–25 years, >25 years
6. Your Adult (congenital or acquired)/Pediatric CPB case ratio:
   - Adult (>75%), Adult/Pediatric (75:25), Adult/Pediatric (50:50), Adult/Pediatric (25:75), Pediatric (>75%)
7. Your individual/personal average annual pediatric case volume?

VALIDATION OF FUNDAMENTAL SKILLS AND THEIR CONSENSUS ITEMS

1. PRE-CPB—PATIENT DATA AND CALCULATIONS
   a. FREQUENCY: In your clinical practice, how often do you evaluate patient-specific data (e.g., patient size, laboratory values, pathology, and comorbidities) to prepare for a pediatric CPB case?
   b. FREQUENCY: In your clinical practice, how often do you CALCULATE patient-specific parameters (e.g., pump flow, oxygen carrying capacity etc.) to prepare for a pediatric CPB case?
   c. PATIENT HARM: The patient may be harmed if patient data review or calculations are improperly performed.
2. PRE-CPB—COMPONENT/CIRCUIT SELECTION
   a. FREQUENCY: In your clinical practice, how involved are the perfusionists at critically evaluating and appropriately selecting pediatric CPB components and circuitry?
   b. PATIENT HARM: The patient may be harmed if circuit components are improperly selected.
3. PRE-CPB—CIRCUIT ASSEMBLY AND PRIMING
   a. FREQUENCY: In your clinical practice, how often do you assemble the extracorporeal circuit for a pediatric CPB case?
   b. FREQUENCY: In your clinical practice, how often do you prime the extracorporeal circuit for a pediatric CPB case?
   c. PATIENT HARM: The patient may be harmed if CPB circuits are improperly assembled or primed.
4. CPB CHECKLIST
   a. FREQUENCY: In your clinical practice, how often do you perform a written or electronic pediatric CPB checklist?
   b. PATIENT HARM: The patient may be harmed if a pediatric CPB checklist is improperly performed.
5. ANTI-COAGULATION
   a. FREQUENCY: In your clinical practice, how often do you perform anti-coagulation assessment for pediatric CPB cases?
   b. PATIENT HARM: The patient may be harmed if anti-coagulation is improperly performed.

6. VERIFICATION OF ARTERIAL CANNULA PLACEMENT
   a. FREQUENCY: In your clinical practice, how often do you assess and verify arterial cannulation placement during pediatric CPB cases?
   b. PATIENT HARM: The patient may be harmed if an arterial cannula assessment is improperly performed.
7. INITIATION OF CPB
   a. FREQUENCY: In your clinical practice, how often do you initiate CPB on pediatric CPB cases?
   b. PATIENT HARM: The patient may be harmed if initiation of CPB is improperly performed.
8. EVALUATION OF CPB: CIRCUIT FLOW AND FUNCTION
   a. FREQUENCY: In your clinical practice, how often do you evaluate and troubleshoot the technical aspects of pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if the technical assessment of pediatric CPB is improperly performed.
9. MYOCARDIAL PROTECTION
   a. FREQUENCY: In your clinical practice, how often do you monitor, deliver, and manage myocardial protection during pediatric CPB cases?
   b. PATIENT HARM: The patient may be harmed if myocardial protection is improperly performed during pediatric CPB.
10. EVALUATION OF ADEQUACY OF PERFUSION
   a. FREQUENCY: In your clinical practice, how often do you monitor, manage, and troubleshoot the physiologic aspects of pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if the physiologic aspects of pediatric CPB are improperly performed.
11. HEMODYNAMIC MANAGEMENT
   a. FREQUENCY: In your clinical practice, how often do you monitor and manage hemodynamic pressures during pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if the hemodynamic pressures during pediatric CPB are improperly managed.
12. CPB CIRCUIT VOLUME MANAGEMENT
   a. FREQUENCY: In your clinical practice, how often do you monitor, manage, and troubleshoot circuit/reservoir volume during pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if the circuit/reservoir volume is improperly managed.
13. BLOOD GAS/ELECTROLYTE MANAGEMENT
   a. FREQUENCY: In your clinical practice, how often do you monitor and manage blood gas and electrolyte concentrations during pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if the blood gas or electrolyte concentrations are improperly managed during pediatric CPB.
14. TEMPERATURE MANAGEMENT
   a. FREQUENCY: In your clinical practice, how often do you monitor and manage temperatures during pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if the patient's temperature is improperly managed during pediatric CPB.
15. PRE-BYPASS ULTRAFILTRATION (PRE-BUF)
   a. FREQUENCY: In your clinical practice, how often do you monitor and manage PRE-BUF during pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if PRE-BUF is improperly managed during pediatric CPB.
16. CONVENTIONAL ULTRAFILTRATION (CUF)
   a. FREQUENCY: In your clinical practice, how often do you monitor and manage CUF during pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if CUF is improperly managed during pediatric CPB.
17. ZERO BALANCE ULTRAFILTRATION/DILUTIONAL ULTRAFILTRATION (ZBUF/DUF)
   a. FREQUENCY: In your clinical practice, how often do you monitor and manage ZBUF/DUF during pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if ZBUF/DUF is improperly managed during pediatric CPB.
18. MODIFIED ULTRAFILTRATION (MUF)
   a. FREQUENCY: In your clinical practice, how often do you monitor and manage MUF during pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if MUF is improperly performed.
19. WEANING AND TERMINATION OF CPB
   a. FREQUENCY: In your clinical practice, how often do you monitor and manage the patient hemodynamics while weaning and terminating pediatric CPB?
   b. PATIENT HARM: The patient may be harmed if the weaning and termination of pediatric CPB is improperly managed.
20. COMMUNICATION AND TEAM INTERACTIONS
   a. FREQUENCY: In your clinical practice, how often do you communicate and interact with the patient's surgical team during a pediatric CPB case?
   b. PATIENT HARM: The patient may be harmed if communicating and interacting with the surgical team during pediatric CPB is improperly managed.
21. STERILE TECHNIQUE
   a. FREQUENCY: In your clinical practice, how often do you monitor and maintain the sterility of the

CPB circuit during your preparation and conduct of a pediatric CPB case?
 b. PATIENT HARM: The patient may be harmed if the sterility of the pediatric CPB circuit is not maintained.

22. BLOOD CONSERVATION
 a. FREQUENCY: In your clinical practice, how often do you take actions to minimize patient's exposure to donor blood products?
 b. PATIENT HARM: The patient may be harmed if blood conservation techniques are improperly performed.
23. STANDARD PRECAUTIONS
 a. FREQUENCY: When preparing for and conducting pediatric CPB, how often do you comply with standard precautions (gloves/eye protection)?
 b. PATIENT HARM: The perfusionist may be harmed if standard precautions are not following.

COMMENTS

Are there any other FUNDAMENTAL SKILLS in CPB that should be included? Please list any that you wish to add (we have defined a FUNDAMENTAL SKILL as a skill that is conducted nearly every case and if not properly conducted can harm the patient).

APPENDIX B. SKILL SUB-STEP RESULTS

1. PRE-CPB DATA AND PT CALCULATIONS: 25/31
 Sub-steps/Calculations Included: Height (99.2%), Weight (100%), Age (100%), Sex (86.3%), Comorbidities (97.6%), Medical History (93.5%), Cath Lab Report/Cardiac Function Parameters (93.5%), Hematology related lab results (98.4%), Coagulation-related lab results (76%), Renal-related lab results (81.5%), BSA Calculation (99.2%), Cardiac Index Calculation (96.8%), Flow Rates per Kg (82.3%), Resultant Hematocrit Calculations (96.8%), Allergy Screening (89.5%), Identifying Scheduled Procedure (96%), Blood Type (95.2%), Determine Cannula Sizes (96%), Calculate Circuit and Oxygenator Size Requirements (100%), Patient Surgical History (97.6%), Assess patient pre-op mechanical support (74.2%), Determine cardioplegia dosage (97.6%), Determine cardioplegia strategy (92%), Assess intracardiac and extracardiac shunts (92%), Assess intracardiac obstructions (86.4).
 Not Included: Cold Agglutinins Result (39%), Pulmonary System Function Parameters (33.6%), BMI Calculation (41.5%), Personally Meet Patients and Confirm ID (35.5%), Assess patient ventilator settings (29%), Assess current lines and drips in place (45.2%).
2. PRE-CPB COMPONENT AND CIRCUIT SELECTION: 11/11
 Sub-steps Included: Tubing (100%), Oxygenators (100%), Reservoirs (98.2%), Filters (90.2%), Hemoconcentrators (100%), Cannulas (97.3%), Blood pumps (98.2%), HLM console and systems (97.3%), Heater/coolers (94.6%), Cardioplegia delivery system (97.3%), In-line blood gas analyzers (89.3%).
3. PRE-CPB CIRCUIT ASSEMBLY AND PRIMING: 13/16
 Sub-steps Included: Circuit assembled in a logical sequence (98/1%), Circuit primed in a logical sequence (98.1%), Proper direction of circuit pathway (99.1%), Neat and orderly tubing and component arrangement (98.1%), Connection integrity assured (98.1%), Heat exchanger tested for leaks prior to priming (92.6%), Circuit sterility assured (98.1%), Components completely de-aired (99.1%), Safety devices properly engaged (99.1%), Assembly in less than 40 minutes (58.3%), Assembly in less than 20 minutes (54.6%), Priming in less than 20 minutes (56.5%), Priming in less than 10 minutes (59.3%).
 Not Included: Circuit CO2 flushed (35.2%), Assembly in less than 10 minutes (29.6%), Priming in less than 5 minutes (33.3%).
4. PRE-CPB CHECKLIST: 33/33
 Sub-steps Included: Patient history reviewed (96.2%), Confirmation of patient-specific data (94.3%), Confirmation of circuit sterility (98.1%), Confirmation of de-aired circuit (100%), Confirmation of roller pump calibrated to boot size (100%), Confirmation of roller pump occlusion (100%), Confirmation of each pump's function (99%), Raceway direction correct (99%), Pressure transducers zero'd (97.1%), Flow probes zero'd (77.1%), Flow probes in correct orientation (77.1%), Confirmation of circuitry component function (97.1%), Confirmation of electrical connections (97.1%), Confirmation of temperature management system function (100%), Confirmation of cardioplegia system function (100%), Cardioplegia solution confirmed (96.2%), Confirmation of safety device function (99%), Alarms set (100%), Confirmation of assisted venous return system function (82.9%), Confirmation of gas/vaporizer/blender system function (98.1%), Confirmation of monitoring devices function (98.1%), Confirmation of back-up supplies (91.4%), Confirmation of back-up equipment (90.5%), Confirmation of back-up battery function (94.3%), Confirmation of blood product availability (99%), Confirmation of POC coagulation monitoring equipment function (81%), Confirmation of POC blood gas and blood chemistry equipment function (80%), Cannulation checklist completed (71.4%), Initiation Checklist completed (87.6%), UF checklist completed (54.3%),

Confirmation of tasks to be completed prior to termination of CPB (61.9%), Confirmation of tasks to be completed post-CPB (58.1%), Confirmation of tasks to be completed prior to emergent reinitiation of CPB (63.8%).

5. ANTI-COAGULATION: 12/16
   Sub-steps Included: Baseline ACT Assessment (95.9), Initial Heparin dose calculation (90.7%), Pre-CPB Heparin Dose Response measurement to determine patient-specific heparin dose requirement (54.6%), POC machine QC procedures (81.4%), Evaluation of pre-operative coagulation labs (82.5%), Verification of appropriate ACT prior to pump sucker use (95.9%), Verification of appropriate ACT prior to initiation (97.9%), ACT measurements during CPB (97.9%), Heparin level measurements during CPB (53.6%), Heparin administration based on ACT results (90.7%), Protamine dose calculations (based on formula or protocol) (59.8%), field suction to reservoir discontinued upon protamine administration (91.8%).
   Not Included: Heparin administration based on patient-specific heparin level measurements (48.5%), TEG/ROTEM test performance (35.1%), TEG/ROTEM result interpretation (35.1%), Protamine dose calculations (based on heparin level results) (44.3%).
6. VERIFICATION OF ARTERIAL CANNULA PLACEMENT: 8/8
   Sub-steps Included: Identify pulsatility in the arterial line pressure prior to CPB (77.8%), Compare ALP to ABP prior to CPB (90%), Perform a test infusion prior to CPB (90%), ALP monitoring during initiation (96.7%), ALP monitoring during cross-clamp placement (97.8%), Scans ALP throughout CPB (96.7%), Setting and confirming electronic audible alarms to signal arterial line pressures outside of normal parameters (98.9%), Setting and confirming electronic interventions to prevent arterial line pressures outside of normal parameters (97.8%).
7. INITIATION OF CPB: 21/21
   Sub-steps Included: Communicate that you are initiating CPB (100%), Start CPB timer (100%), Turn on sweep gas flow (100%), Confirm appropriate FiO2 (100%), Turn on volatile anesthetic gas (95.4%), Remove arterial and venous line clamps (97.7%), Monitor arterial line pressure (98.9%), Confirm adequate venous drainage (100%), Apply and adjust VAVD as needed (94.3%), Achieve adequate arterial flow (100%), Open purge (85.1%), Manage/minimize hypotension (100%), Communicate that you have reached full flow (100%), Confirm that safety devices are active (88.5%), Documenting CPB initiation time (100%), Initiate medication administration (97.7%), Begin cooling if needed (98.9%), Ensure appropriate heart rate (82.8%), Ensure appropriate CVP (90.8%), Ensure appropriate NIRs values (97.7%), Ensure appropriate temperature (100%).
8. EVALUATION OF CPB: 6/6
   Sub-steps Included: Evaluate adequacy of venous drainage (100%), Evaluate adequacy of arterial flow (100%), Evaluate oxygenator gas exchange (98.8%), Evaluate circuit pressures/resistance (100%), Evaluate circuit integrity (98.8%), Evaluate heater cooler function (100%).
9. MYOCARDIAL PROTECTION: 7/8
   Sub-steps Included: Deliver cardioplegia within given pressure and flow parameters (100%), Evaluate pressure and flow data and communicate with surgical team to facilitate proper cardioplegia delivery (100%), Manage cardiac vent pump as appropriate to cardioplegia circuitry (95.1%), Monitor and communicate time between cardioplegia doses according to given protocol (100%), Monitor and communicate ECG electrical activity (97.5%), Manage cardioplegia solution composition and temperature according to given protocol (98.8%), Administer adjunctive pharmacology to augment myocardial protection according to given protocol (66.7%).
   Not Included: Measure myocardial temperature (22.2%).
10. EVALUATION OF ADEQUACY OF PERFUSION: 14/14
    Sub-steps Included: Evaluating and troubleshooting venous line oxygen saturation (100%), Evaluating and troubleshooting acid–base balance (100%), Evaluating and troubleshooting arterial line oxygenation (100%), Evaluating and troubleshooting patient arterial blood pressure (100%), Evaluating and troubleshooting blood flow rates (100%), Evaluating and troubleshooting SVR (75.9%), Evaluating and troubleshooting electrolytes (100%), Evaluating and troubleshooting lactate levels (87.3%), Evaluating and troubleshooting glucose levels (96.2%), Evaluating and troubleshooting cerebral NIRs values (94.9%), Evaluating and troubleshooting somatic NIRs values (69.6%), Evaluating and calculating arterial or venous oxygen content (67.1%), Evaluating and calculating oxygen delivery (DO2) (64.6%), Evaluating and calculating oxygen consumption (VO2) (54.4%).
11. HEMODYNAMIC MANAGEMENT: 8/11
    Sub-steps Included: Manage ABP within parameter range (100%), Identification and troubleshooting of inaccurate pressure monitoring systems (100%), CVP awareness/troubleshooting (94.8%), Management of injectable vasoactive agents (96.1%), Management of volatile anesthetic as vasoactive agent (94.8%), Calculation of cardiac index values (94.8%), Management of blood flow as an element of blood pressure (97.4%),

Recognizing the appropriate MAP range for patient based on age and anatomical shunts present (100%).
Not Included: PAP awareness/troubleshooting (42.9%), Calculating SVR (46.8%), Calculating PVR (23.4%).

12. CPB CIRCUIT VOLUME MANAGEMENT: 8/8
Sub-steps Included: Manage arterial pump flow to appropriately accommodate venous drainage (97.2%), Communicate/troubleshoot low reservoir volume with surgical team (98.6%), Locate missing reservoir volume (98.6%), Demonstrate safe and appropriate volume administration (100%), Manage and respond to reservoir level-sensor devices (100%), Management and use of VAVD (94.4%), Evaluate field irrigation being returned to the reservoir (98.6%), Evaluate vent/sucker return contribution to reservoir volume (100%).
13. BLOOD GAS/ELECTROLYTE MANAGEMENT: 15/16
Sub-steps Included: Manage SvO2 (100%), Manage PaO2 (100%), Manage PaCO2 (100%), Manage AV CO2 difference (53.6%), Manage electrolytes (98.6%), Manage blood pH levels (100%), Manage blood bicarbonate levels (100%), Manage blood potassium levels (100%), Manage blood sodium levels (100%), Manage blood chloride levels (56.5%), Manage blood calcium levels (98.6%), Manage Hct/Hb (100%), Manage blood glucose levels (91.3%), Manage blood lactate levels (87%), Blood sampling according to a pre-determined frequency (87%).
Not Included: Manage anion gap (49.3%).
14. TEMPERATURE MANAGEMENT: 7/7
Sub-steps Included: Achieve and maintain target patient temperature (100%), Manage patient temperature within pre-determined limits (100%), Anticipate and communicate with surgical team regarding initiation of cooling and warming protocols (100%), Recognize patient-specific protocols that require special temperature management strategies (95.7%), Identifying and troubleshooting inaccurate temperature monitoring systems (100%), Manage arterial temperature below a pre-determined maximum value (98.6%), Alarms and alerts when approaching temperature limits (98.6%).
15. PRE-BUF: 7/8
Sub-steps Included: Addition of priming drugs in crystalloid replacement solution (65.7%), Addition of priming drugs after PRE-BUF (76.1%), Use of a calculated volume of crystalloid replacement solution (67.2%), Incorporate reservoir volume into decision to terminate PRE-BUF (70.1%), Evaluation of blood prime/blood gas/electrolytes following PRE-BUF (71.6%), Measure pump prime hematocrit following PRE-BUF (67.2%), Fine tune pre-CPB hematocrit in pump prime following PRE-BUF (62.7%).
Not Included: Evaluation of circuit anti-coagulation following PRE-BUF (40.3%).
16. CUF: 6/6
Sub-steps Included: Initiate/manage/terminate CUF based on hematocrit (92.5%), Initiate/manage/terminate CUF based on reservoir level (97%), Evaluate arterial line pressure before and after initiating/terminating CUF (85.1%), Evaluate and adjust arterial pump flow to accommodate shunt through conventional ultrafilter (92.5%), Evaluate and manage electrolyte changes during CUF (95.5%), Evaluate and manage anti-coagulation during CUF (95.5%).
17. ZBUF/DUF: 7/12
Sub-steps Included: Selection or preparation of a balanced electrolyte solution to use as replacement volume (79.1%), Evaluate and adjust arterial pump flow to accommodate shunt through zero balance or dilutional ultrafilter (82.1%), Evaluate arterial line pressure before and after initiating/terminating ZBUF/DUF (74.6%), Evaluate and manage electrolyte changes during ZBUF/DUF (83.6%), increased frequency of anti-coagulation monitoring during ZBUF/DUF (53.7%), Incorporate hematocrit into decision to initiate/terminate ZBUF/DUF (64.2%), Incorporate reservoir volume into decision to initiate/terminate ZBUF/DUF (65.7%).
Not Included: Add heparin to crystalloid replacement volume (34.3%), Incorporate rewarming into decision to initiate ZBUF/DUF (43.3%), Incorporate cross-clamp removal into decision to initiate ZBUF/DUF (49.3%), Manage a calculated method to determine total volume removal/replacement into decision to terminate ZBUF/DUF (28.4%), Manage a fixed method to determine total volume removal/replacement into decision to terminate ZBUF/DUF (38.8%).
18. MUF: 12/17
Sub-steps Included: Incorporate patient size into decision to initiate MUF (74.2%), Use AV MUF techniques (75.8%), Incorporate patient's hemodynamic status into decision to initiate/terminate MUF (78.8%), Incorporate hematocrit into decision to terminate MUF (56.1%), Incorporate completeness of circuit salvage into decision to initiate/terminate MUF (74.2%), Incorporate a calculated MUF pump flow (65.2%), Incorporate duration into decision to terminate MUF (65.2%), Evaluate arterial line pressure before and after initiating MUF (80.3%), Evaluate and communicate patient's volume status during MUF (78.8%), Temperature management/control during MUF (83.3%), AV MUF: Arterial flow does not exceed modified ultrafilter flow (52.3%), AV MUF: Use blood cardioplegia system/pump for MUF (56.9%).

Not Included: Use a pre-MUF checklist (47%), Use VV MUF techniques (15.2%), Evaluate and manage electrolyte changes during MUF (43.9%), Evaluate and manage anti-coagulation during MUF (37.9%), AV MUF: Servo-regulate arterial pump to a negative arterial line pressure during MUF (45.3%).

19. WEANING AND TERMINATION OF CPB: 13/14
    Sub-steps Included: Achieving and managing partial CPB (98.5%), Monitoring and maintaining proper patient filling pressures while weaning from CPB (100%), Communication regarding heart filling status (100%), Evaluate reservoir level as it relates to patient filling pressure (100%), Manage reservoir level through pump flow and venous drainage restriction (100%), Evaluate EKG before weaning (100%), Evaluate electrolytes before weaning (100%), Evaluate temperature before weaning (100%), Evaluate cardiac vent status before weaning (97%), Evaluate patient hematocrit before weaning (100%), Communication regarding ventilator use (84.8%), Communication regarding blood pressure management (95.5%), Communication regarding SVR management (62.1%).
    Not Included: Calculate SVR before weaning (26.2%).
20. COMMUNICATION AND TEAM INTERACTIONS: 7/7
    Sub-steps Included: Closed-loop communication with surgical field (96.9%), Clear communication (100%), Concise communication (100%), Confident communication (98.5%), Accurate communication (98.5%), Professional communication (100%), Casual communication (72.3%).
21. STERILE TECHNIQUE: 7/8
    Sub-steps Included: Check integrity of packaging of sterile items (100%), Verify expiration date of sterile items (98.4%), Record date and time of circuit assembly and/or priming (84.4%), Protect circuit connections and ports from exposure and contamination (100%), Maintain water bath solutions to minimize risk of contamination (92.2%), Discard circuits and components that have expired (98.4%), Wear a mask when assembling CPB circuits (84.4%).
    Not Included: Wear sterile gloves when assembling CPB circuits (25%).
22. BLOOD CONSERVATION: 7/7
    Sub-steps Included: Prime volume minimization (100%), Use of colloidal solutions (93.8%), Autologous circuit priming (RAP/VAP) (60.9%), Judicious anti-coagulation management (89.1%), Residual circuit blood salvage techniques (98.4%), Intraoperative cell saver techniques (85.9%), Intraoperative autologous donation techniques (53.1%).
23. STANDARD PRECAUTIONS: 4/6
    Sub-steps Included: Gloves during CPB (92.2%), Eye protection during CPB (78.1%), Blunt needles (71.9%), Avoid recapping needles (59.4%).
    Not Included: Protective barriers (fluid impermeable cover gowns/jackets during CPB) (29.7%), Needleless syringe devices (48.8%).