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Special Article

Cardiopulmonary Bypass Priming Practices and Blood Product Availability in Neonatal Cardiac Surgery: A European Survey

Sascha Meier^{*,1}, Theofili Koussi[†], Birgitta Romlin[‡],
Dorela Haxhiademi[§], Marcus Lance^{||}, on behalf of EACTAIC
Paediatric & Congenital Subspecialty Committee and Haemostasis
and Transfusion Subspecialty Committee



Neonatal cardiac surgery requires cardiopulmonary bypass (CPB) strategies that minimize hemodilution while maintaining adequate oxygen delivery and hemostatic balance. Despite increasing emphasis on patient blood management (PBM), contemporary CPB priming and perioperative hemostasis practices across European neonatal cardiac surgery programs remain poorly characterized. This prospective, 26-item, web-based cross-sectional survey was designed to evaluate current practices in CPB priming, availability of blood products, and perioperative coagulation management strategies in neonatal cardiac surgery across Europe. The participants included anesthesiologists, congenital cardiac surgeons, and perfusionists from active neonatal cardiac surgery programs. A 26-item survey was distributed to 122 identified European neonatal cardiac surgery centers; 71 centers from 32 countries responded (58% response rate). Three main CPB machine platforms and four oxygenator types were reported. Priming volumes varied substantially across centers, ranging from 75 mL to 450 mL. Packed red blood cells were incorporated into the CPB prime in 58 centers (82%), while plasma products were used in 37 centers (52%). Coagulation factor concentrates were available in nearly half of the responding centers, and 64% reported that their use did not require hematology approval. Point-of-care coagulation testing was used to guide intraoperative hemostasis management in 86% of centers, although device availability and turnaround times varied widely. These results provide a contemporary snapshot and highlight substantial heterogeneity across European neonatal cardiac surgery programs in CPB priming strategies, blood product availability, and perioperative hemostasis management. While many centers have adopted point-of-care-guided PBM approaches and targeted factor replacement strategies, considerable variability persists in circuit configuration, priming volume, and transfusion resources. These findings highlight opportunities for collaborative research and for developing consensus-driven PBM frameworks to optimize neonatal CPB and perioperative hemostasis management.

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NEONATAL SURGERY FOR CONGENITAL HEART disease has the highest risk of mortality compared with other age subgroups and has the highest mean length of stay, while 30-day mortality has been decreasing in the past 25 years, according to the European Congenital Heart Surgeons Association database report.¹

Across Europe, neonatal cardiac surgery is organized differently across various healthcare system designs that reflect the federal structures of European Union (EU) member countries. Some EU countries have chosen to centralize neonatal cardiac surgery care, while others rely on more decentralized organizations, often related to population density or geographical

Collaborators: A full list of all collaborators with their affiliations is provided in Appendix A.

¹Address correspondence to: Sascha Meier, University Medical Center Groningen, Department of Anesthesiology, EB 32, PO Box 30001, Hanzplein 1, 9700 RB, Groningen, The Netherlands; Tel.: +31681455701.

E-mail address: s.meier@umcg.nl (S. Meier).

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circumstances. For example, Sweden centralized pediatric cardiac surgery from four centers to two centers in the 1990s.²

Despite increasing emphasis on patient blood management strategies and technological advances in neonatal perfusion, contemporary practice patterns across European congenital cardiac programs remain poorly characterized.³⁻⁵ Due to differences in healthcare systems, heterogeneity in clinical practice is observed across Europe.⁶

Considering these fundamental differences, it is intriguing to observe the similarities shared within the field. Therefore, the European Association for Cardiothoracic Anesthesia (EACTAIC) Paediatric & Congenital Subcommittee collaborated with the Hemostasis & Transfusion Subcommittee to conduct a survey on the availability of blood products, coagulation factors, and cardiopulmonary bypass (CPB) priming protocols in neonatal cardiac surgery.

Methods

A prospective, 26-item, web-based cross-sectional survey was created using Microsoft Forms (see Digital Supplement). Single-choice, multiple-choice, and open-ended questions were used.

All survey items were selected by the authors’ group based on a review of the available literature regarding blood and coagulation products, monitoring of coagulation, and treatment protocols. The survey did not cover different intra- or postoperative transfusion strategies. The survey did cover CPB priming and observations from clinical practice as pediatric cardiac anesthesiologists. The survey was done in neonatal cardiac surgery.

Ethical approval was waived in accordance with Dutch and European regulations. The survey was conducted from March 1, 2025, to June 30, 2025, using an online survey tool (Microsoft Forms). It was endorsed by the EACTAIC.

For this survey, “European” pediatric cardiac centers were defined as those located in the 27 EU member states, the United Kingdom (UK), nine EU candidate countries, and Switzerland and Norway.

In the absence of a European authority that provides an official registry on active pediatric cardiac surgery centers, the authors primarily relied on EACTAIC’s Paediatric & Congenital Subcommittee address list, which has been regularly updated and exchanges information about current active neonatal cardiac surgery programs with the European Board of Cardiovascular Perfusion and the European Congenital Heart Surgeons Association. A total of 122 centers were considered active at the time of survey preparation (Supplementary Table 1).

The lead pediatric cardiac anesthesiologist of these centers was invited to participate in the survey by the chairs of the EACTAIC Paediatric & Congenital Subcommittee via email with the survey link and QR code on February 28, 2025.

Email reminders were sent to centers that did not respond after 6 weeks, this time including surgeons and/or clinical perfusionists as recipients as well. Consent to participate was obtained from participants by entering the survey’s question section.

Statistics

Given the descriptive nature of the survey, no formal sample-size calculation or reliability and validity testing were performed. For descriptive analysis, both relative and absolute frequency, as well as median and average, were used. The statistical analysis was performed using IBM SPSS Statistics, version 27.

Results

A total of 71 responses were received from the 122 centers initially contacted (58% response rate). Three centers submitted their responses multiple times (Policlinico San Donato Milan four times, Tübingen two times, and Ancona two times). Multiple entries were screened by the authors’ group, and agreement was reached on which entries were suitable for data clearance to produce one dataset per included center in the analysis. Key findings are summarized in Table 1.

Type and Manufacturer of CPB Machine, Tubing, and Oxygenator

Three models of CPB machines were identified as the most frequently used in neonatal care across Europe: LivaNova “S5,” LivaNova “Essenz,” and Spectrum Medical “Quantum” (Table 2).

Data on tubing systems were reported most inconsistently. Many institutions do not use “single-vendor” circuits, instead opting to combine different manufacturers or state “customized” (Supplementary Table 2).

“Capiiox FX5” (Terumo), “D100 Kids” (LivaNova), and “Quadrox i” (Getinge) were the most reported oxygenators, with “Affinitie Pixie” (Medtronic) only named by two centers (Table 2).

Volume of CPB Circuit System and Priming Constituents

A significant variation in CPB circuit volume was observed across all participating centers. Conveyed volumes range between 75 mL (reported by one center) and 450 mL, which four centers report (Fig 1).

Table 1
Key findings of the European Neonatal CPB Survey

Domain	Main Finding
CPB machines	3 dominant models across Europe
Oxygenators	4 main devices reported
Priming volume	75-450 mL
RBCs in prime	82% of centers
Plasma products	41%
Fibrinogen concentrate	89% availability
POC testing	86% of centers

Abbreviations: CPB, cardiopulmonary bypass; POC, point-of-care; RBC, red blood cell.

Table 2
CPB Machine and Oxygenator Used Across European Centers

CPB Machine	Number of Centers	%	Oxygenator	Number of Centers	%
S5	43	61	FX05	39	55
LivaNova	11	15	D100	17	24
Quantum	6	8	Quadrox-i	6	8
Essenz	4	6	D100, FX05	3	4
Stöckert	2	3	FX05, Quadrox-i, D101	2	3
S5 and Essenz	1	1	FX05, D100	1	1
S5, Essenz, HL20	1	1	Affinity Pixie	1	1
Maquet	1	1	D100, FX05, Affinity Pixie	1	1
Roller and Maquet	1	1	N/A	1	1
N/A	1	1	Total	71	
Total	71				

Types of CPB machines and oxygenators reported by centers, sorted by country and city. Due to different distributional names for the same CPB machine and oxygenator across European countries for the “Stöckert Model S5,” the acronym “S5” is used in the table for readability, “Essenz” for LivaNova Essenz, and “Quantum” for the Spectrum Medical Quantum CPB machine. Some centers provided only the manufacturer (eg, “Stöckert”) or the model (eg, “HL20”) of the CPB machine.

“D100” refers to “LivaNova KIDS D100® oxygenator.” “Quadrox-I” refers to “Maquet Quadrox-i Neonatal oxygenator.” “FX05” refers to “CAPIOX® FX05 Oxygenator” by Terumo. “Affinity Pixie” refers to “Medtronic Affinity Pixie® oxygenator.”

Abbreviations: CPB, cardiopulmonary bypass.

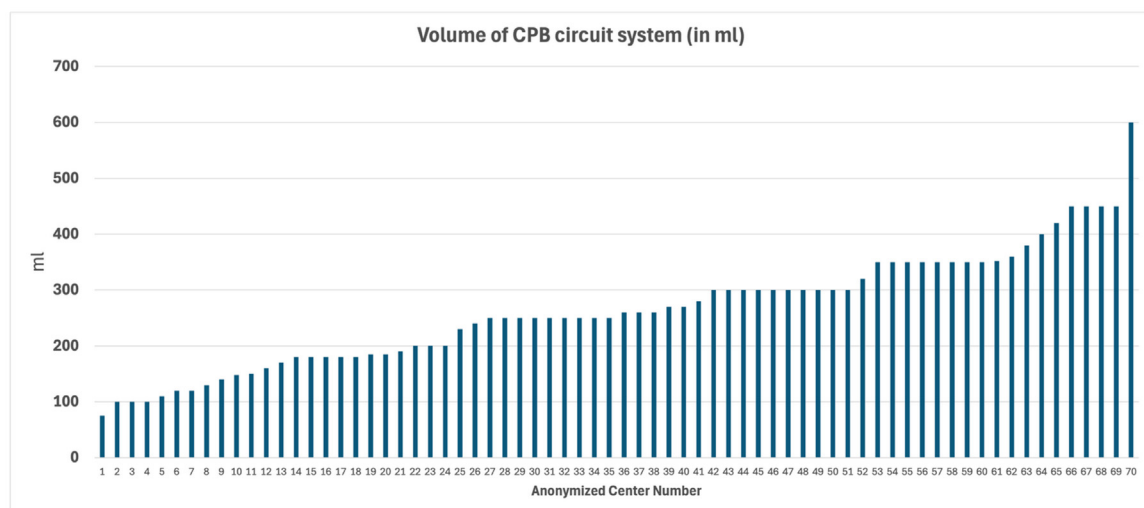


Fig 1. Each bar represents the CPB priming volume (in mL) reported by a center.

Priming volume is sorted from lowest to highest reported. One center did not provide a number for its priming volume.

Nine crystalloid solutions were identified for priming the CPB circuit, with Ringer's, Plasmalyte and Jonosteril being the most frequently used (Table 3). Three buffer solutions were added to the CPB system for priming, with sodium bicarbonate ($n = 41$) being the most utilized, whereas three centers add Tris-hydroxymethyl aminomethane and one center uses Na_2HPO_4 . Gelatine solution ($n = 4$) and a Hetastarch formulation ($n = 3$) were used for priming in UK centers. Few centers added antifibrinolytic agents ($n = 5$) or other drugs such as methylprednisolone ($n = 6$), antibiotics, furosemide, or fentanyl to the priming solution.

Blood Products Utilized for CPB Priming

Red blood cells (RBCs) were added to the prime in 58 centers (82%), whereas 29 centers (41%) added fresh frozen

plasma (FFP) and 9 centers (13%) added solvent detergent plasma (SDP). SDP is a pharmaceutical product available in the EU with standardized content of clotting factors, devoid of antibodies implicated in transfusion-related acute lung injury pathogenesis, and with a very high level of decontamination from transfusion-transmissible infectious agents.⁷ Only one center used no blood products at all for priming.

Regarding the age of blood products, there was considerable variability in defining acceptance limits for RBCs, and 38% of centers had not defined a limit (Fig 2).

Minimum Hematocrit and/or Hemoglobin Level Accepted on Bypass and/or DO_2 Level

Hematocrit or hemoglobin levels during bypass, or DO_2 targets, were reported inconsistently by the participating centers.

Table 3
Priming Constituents

Electrolyte Solution	n	(%)	Colloids	n	(%)	Buffer	n	(%)
Ringer	10	14	Gelafundin	4	6	NaHCO ₃	41	58
Plasmalyte	9	13	Hetastarch	3	4	THAM	3	4
Jonosteril	5	7				Na ₂ HPO ₄	1	1
Sterofundin	4	6						
Duosol	3	4						
Ionolyte	3	4						
Isolyte S	1	1	Albumin	36	51	Heparin	47	66
Hemosol	1	1	Mannitol	29	41			
Isofundine	1	1						
Elektrolytes			Antifibrinolytics			Other		
Calcium	22	31	TXA	5	7	Ascorbic acid	1	1
Magnesium	3	4	Aprotinin	1	1	Fentanyl	1	1
Reidratante III	1	1				Furosemide	1	1
						Methyl-prednisolon	6	8
RBCs	58	82						
FFP	29	41						
SD-plasma	8	11						

Priming constituents reported in number (n) and percentage (%).

Nine crystalloid solutions can be identified for priming the CPB circuit, with Ringer's, Plasmalyte and Jonosteril being the most frequently used.

Abbreviations: FFP, fresh frozen plasma; RBC, red blood cell; SD, solvent detergent; THAM, Tris-hydroxymethyl aminomethane; TXA, tranexamic acid.

A total of 26 centers provide a DO₂ target level, while hematocrit (n = 28) or hemoglobin targets (n = 49) appeared the most predominantly measured (Fig 3). The minimum hematocrit level at weaning from bypass was reported by 46 centers: 29 provided a hemoglobin target and 13 a DO₂ target (Fig 4). In 56 centers, different transfusion triggers were reported for cyanotic and noncyanotic patients, whereas 15 centers did not report different triggers.

Blood Bank Location and Supply

Among the 71 participating centers, the majority (69/71, 97.2%) reported that the institutional blood bank was located in the same hospital building as the operating rooms (Table 4).

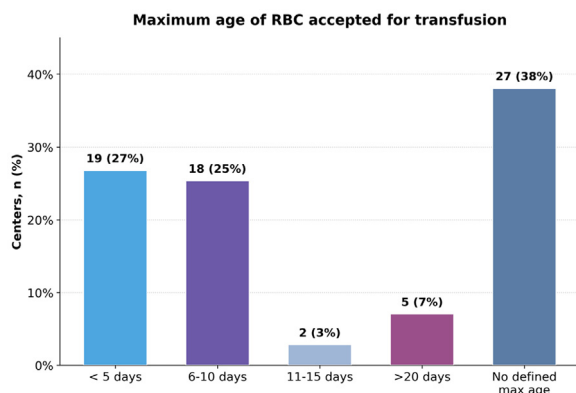


Fig 2. Age of red blood cells (RBCs) accepted for transfusion. A total of 38% of centers did not have a defined RBC age limit for transfusion in neonatal cardiac surgery.

Only two centers (2.8%) indicated that their blood bank was located elsewhere within the same city. Regarding supply structure, 40 centers (56.3%) reported that their blood bank served their hospital exclusively, while 31 centers (43.7%) indicated that their supplier provided blood products to additional regional healthcare facilities.

Availability of Blood Products for Intraoperative Use

All centers reported availability of RBCs for intraoperative transfusion. FFP was available in 60 centers (84.5%), while 10 centers (14.1%) reported no FFP use, and 1 center (1.4%) did not respond. Nearly all centers that lacked FFP (9 of 10) reported access to SDP, suggesting a deliberate institutional strategy to avoid FFP, particularly in neonatal cardiac surgery. Overall, SDP was available in 30 centers (42.3%), absent in 40 (56.3%), and not reported in 1 (1.4%).

Thrombocyte product availability showed marked variability. Single-donor (SD) platelet concentrates were available in 26 centers (36.6%), pooled five-donor (P5D) platelets were available in 22 centers (31.0%), and both SD and P5D platelets were available in 20 centers (28.2%). Two centers (2.8%) reported not using platelet products intraoperatively, while 1 center did not respond. Prothrombin complex concentrate was reported to be available at 60 centers (84.5%) and unavailable at 10 (14.1%), with 1 nonresponse.

Fibrinogen concentrate was the most consistently available hemostatic product, reported in 63 centers (88.7%). Factor XIII (FXIII) concentrate was available in 27 centers (38.0%), while recombinant activated factor VII (FVIIa) was reported in 10 centers (14.1%), 1 of which required hematology

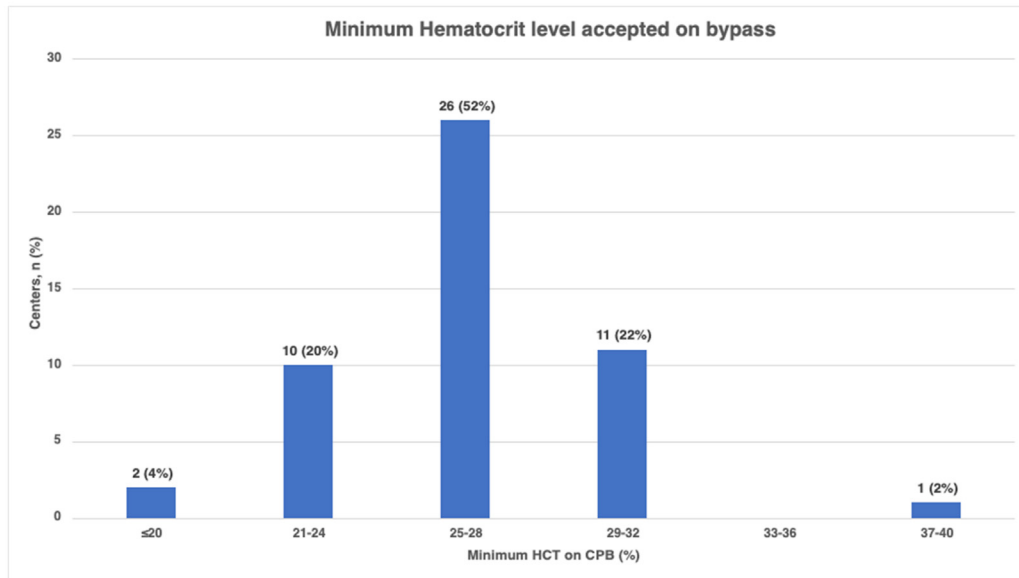


Fig 3. Histogram of minimum hematocrit (HCT) on cardiopulmonary bypass (CPB).

A total of 50 of the 71 participating centers reported target values for HCT on CPB.

approval prior to use. Antithrombin was available in 57 centers (80.3%). Cryoprecipitate was available in 21 centers (29.6%) and absent in 50 centers (70.4%). Three centers reported access to FXIII alone, and two centers reported combined FVIII and FXIII concentrates. FVIII concentrate was available in only 5 centers (7.0%).

Delivery times for blood products varied across institutions: Median delivery times for RBCs were reported as 5-10 minutes (interquartile range [IQR] <5 minutes to 15-20 minutes), for plasma 20-25 minutes (IQR 10-15 minutes to >30 minutes), and 10-15 minutes for thrombocyte products (IQR 5-10 minutes to 15-20 minutes). Fibrinogen and prothrombin complex concentrate were available more quickly (median

<5 minutes, IQR <5 minutes, 5-10 minutes, respectively) than eptacogalpa (Median 5-10 minutes, IQR 5-10 minutes to 25-30 minutes) and cryoprecipitate (Median 25-30 minutes, IQR 5-10 minutes to >30 minutes).

Institutional Protocols and Oversight

Institutional transfusion protocols were reported by 51 centers (71.8%), while 20 centers (28.2%) lacked such policies (Table 4). Similarly, 44 centers (62.0%) reported a formal institutional protocol for coagulation management, and 27 centers (38.0%) did not (Table 4). Hematology approval for the use of certain blood products or factor concentrates was

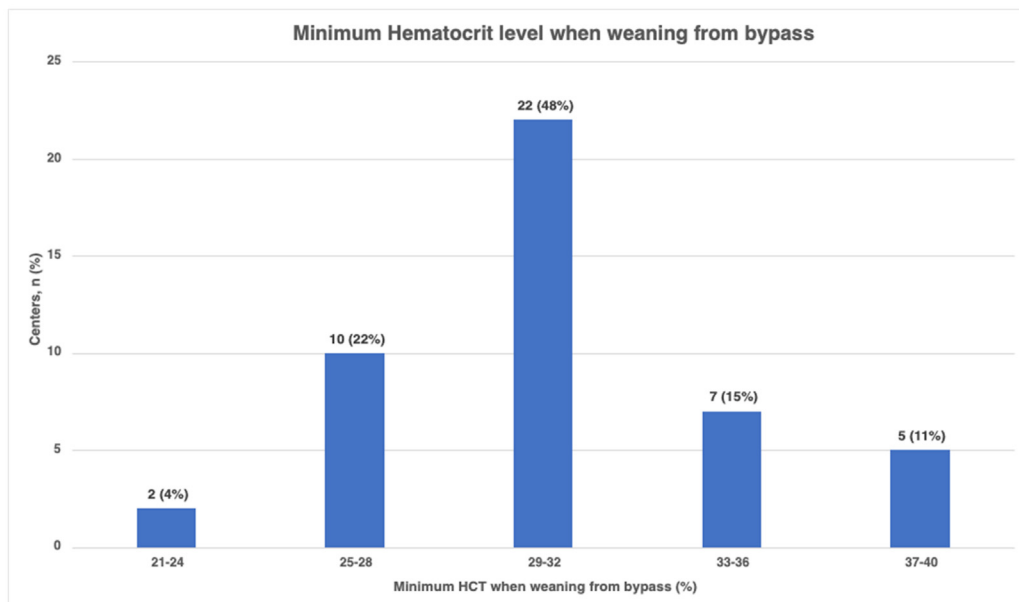


Fig 4. Histogram of minimum hematocrit (HCT) when weaning from cardiopulmonary bypass (CPB). A total of 46 centers of the 71 participating in the survey report target values for HCT when weaning from CPB.

Table 4
Survey Questions on Blood Product Availability and Patient Blood Management—Abridged Questions With Summary of Responses

Variable	Response	n	(%)
Location of blood bank	Within hospital (with OR)	69	97
	Same city as hospital	2	3
Supplying blood bank	Sole supplier	40	56
	Supplies other facilities	31	44
Blood products intraoperatively	RBC available	71	100
FFP available	Yes	60	85
	No	10	14
	No answer	1	1
SDP available	Yes	30	42
	No	40	56
	No answer	1	1
Thrombocyte products	SD	26	37
	P5D	22	31
	Both	20	28
	Do not use	2	3
	No answer	1	1
PCC available	Yes	60	85
	No	10	14
	No answer	1	1
Fibrinogen available	Yes	63	89
	No	7	10
	No answer	1	1
FXIII available	Yes	27	38
	No	43	61
	No answer	1	1
FVIIa available	Yes	10	14
	No	60	85
	No answer	1	1
AT available	Yes	57	80
	No	13	18
	No answer	1	1
Cryoprecipitate available	Yes	21	30
	No	20	28
	FXIII used instead	3	4
FVIII available	Yes	5	7
	No	65	92
	No answer	1	1
Institutional transfusion protocol	Yes	51	72
	No	20	28
Coagulation management protocol	Yes	44	62
	No	27	38
Coagulation management strategy	POC/intraoperative lab	61	86
	Lab outside OR	9	13
	No response	1	1
POC device availability	In OR/next door	50	70
	Outside OR	20	28
	No answer	1	1
POC turnaround time	Instant/live	6	8
	<5 min	3	4
	<10 min	19	27
	<15 min	18	25
	<20 min	10	14
	<25 min	11	15
	<30 min	8	11
	<40 min	1	1
	<60 min	1	1
	No answer	4	6
Hematology approval for factors	Yes	8	11
	No	8	11

(continued)

Table 4 (continued)

Variable	Response	n	(%)
POC results accessible to other specialties	Depends on product	15	21
	Yes	50	70
	No	18	25
	No answer	3	4

All centers reported availability of RBCs for intraoperative transfusion. Institutional transfusion protocols were reported by 51 centers (72%). Coagulation management was primarily guided by POC testing or intraoperative laboratory parameters in 61 centers (86%). Abbreviations: AT, antithrombin; FFP, fresh frozen plasma; OR, operating room; PCC, prothrombin complex concentrate; POC, point-of-care; RBC, red blood cells; SDP, solvent detergent plasma.

required in 8 centers (11.3%), not required in 8 centers (11.3%), and conditional, depending on the product, in 15 centers (21.1%).

Coagulation Management Practices and Point-of-Care Testing

Coagulation management was primarily guided by point-of-care (POC) testing or intraoperative laboratory parameters in 61 centers (85.9%), whereas 9 centers (12.7%) relied solely on conventional laboratory parameters processed outside the operating room. One center (1.4%) did not respond (Table 4). POC testing devices were readily accessible in most institutions. Fifty centers (70.4%) reported having POC analyzers in or adjacent to the operating room, while twenty centers (28.2%) indicated that samples needed to be sent to another location for testing. One center (1.4%) did not respond.

Turnaround Time for POC Testing and Data Accessibility

Turnaround time for POC results varied substantially among institutions. Six centers (8.5%) reported live or instantaneous result display, and three centers (4.2%) received results within 5 minutes. Nineteen centers (26.8%) obtained results within 10 minutes, 18 centers (25.4%) within 15 minutes, and 10 centers (14.1%) within 20 minutes. One center each reported results within 25 minutes (1.4%), 40 minutes (1.4%), and 60 minutes (1.4%), while eight centers (11.3%) indicated a 30-minute delay. Four centers (5.6%) did not provide a response.

Access to POC results also differed across institutions. Fifty centers (70.4%) reported that POC results were integrated into the central laboratory reporting system, thereby making them accessible to all clinical specialties via the electronic patient record. In contrast, 18 centers (25.4%) reported standalone, printed result formats that were not electronically integrated, and three centers (4.2%) selected “other” or did not specify.

Discussion

The present survey provides a contemporary overview of CPB priming practices and perioperative hemostasis

management in neonatal cardiac surgery across Europe. With responses from 71 centers in 32 countries, representing approximately 58% of identified active European neonatal cardiac surgery programs, this study offers one of the most comprehensive snapshots of current practice patterns in this highly specialized field. The most striking finding of the survey is the marked heterogeneity in CPB circuit configuration, priming composition, and blood management strategies.

Priming volumes ranged from 75 mL to 450 mL, reflecting substantial differences in circuit design, institutional practices, and local technological resources. Ultra-low-volume CPB circuits with priming volumes below 100 mL have been previously described and applied in neonatal cardiac surgery.^{3,8-11} Boettcher and colleagues reported the successful routine implementation of bloodless priming strategies using circuits with priming volumes of approximately 75 mL, demonstrating the feasibility of minimizing hemodilution during neonatal CPB.⁸ While the miniaturization of CPB circuits has long been recognized as a critical strategy to reduce hemodilution and transfusion requirements in neonates, the variability observed in the present survey suggests that implementation of ultra-low-volume circuits remains uneven across institutions.

The observed heterogeneity likely reflects several interacting factors, as has recently been described in pediatric cardiac transplantation.¹² Practice variability is also closely tied to the perfusion technology accessible to a given center. The range of commercially available pediatric-specific CPB platforms and oxygenators is narrow,^{3,10} and the choice of circuit components has direct consequences for priming volume, hemodilution, and transfusion exposure.

Centers with access to ultra-low-volume circuits and small-volume oxygenators have been able to implement bloodless or near-bloodless priming strategies in neonates,⁹ whereas centers relying on circuits with larger residual volumes remain dependent on RBC incorporation into the prime to maintain oxygen-carrying capacity. Superimposed on these technical factors, national regulatory^{13,14} and procurement environments shape which blood components, factor concentrates, and platelet products are actually available in any given operating room: differences in national blood-establishment regulation, hospital formulary policy, and governance rules around hematology approval for off-label or pharmacy-controlled hemostatic agents all plausibly contribute to the heterogeneity observed.^{15,16}

Despite the variability in priming volumes and constituents, certain patterns emerged across centers. Crystalloid priming solutions, such as Ringer's solution and Plasma-lyte, were the most frequently reported base solutions, while packed RBCs were incorporated into the prime at most centers. This finding reflects the persistent challenge of maintaining adequate oxygen-carrying capacity during neonatal CPB, given the limited circulating blood volume and the unavoidable hemodilution introduced by extracorporeal circulation.^{4,17-19}

Another notable finding of the survey was the widespread availability of coagulation factor concentrates, particularly fibrinogen concentrate and prothrombin complex concentrate,

as well as SDP. SDP is a pooled plasma product that undergoes viral inactivation through solvent-detergent treatment. Compared with FFP, SDP provides more standardized coagulation factor concentrations and has been associated with a reduced risk of transfusion-related acute lung injury and pathogen transmission.⁷ This observation reflects a broader shift toward targeted factor-based hemostatic therapy in pediatric cardiac surgery. Compared with traditional plasma-based transfusion strategies, factor concentrates allow rapid correction of specific coagulation deficiencies with substantially lower volume exposure, which is particularly advantageous in neonatal patients.

In parallel with this evolution in hemostatic therapy, the survey demonstrated widespread adoption of POC coagulation testing, with the majority of centers reporting the availability of intraoperative viscoelastic or rapid coagulation testing platforms. Such technologies have become central components of contemporary patient blood management strategies, enabling individualized and timely correction of coagulopathy during complex cardiac procedures.

The current findings align with previous reports describing substantial variability in perfusion and transfusion practices in congenital cardiac surgery. Reagor and colleagues previously reported significant heterogeneity in perfusion strategies across North American congenital heart programs, particularly regarding circuit configuration, priming composition, and transfusion strategies.²⁰ The present study extends these observations to the European context, suggesting that variability in practice in neonatal CPB management persists across different healthcare systems.

An additional issue highlighted by this survey is the limited number of manufacturers supplying neonatal CPB equipment. While most centers rely on a small number of commercially available CPB platforms and oxygenators, many programs employ customized circuit configurations to achieve acceptable priming volumes. The limited number of manufacturers supplying neonatal CPB equipment reflects a broader structural challenge in pediatric medical device development. Potential strategies to address this issue may include collaborative European procurement programs, regulatory incentives to stimulate pediatric device innovation, and stronger partnerships between academic clinical networks and industry to support the development of ultra-low-volume perfusion technologies.

Limitations

Several limitations of this survey should be acknowledged. First, the survey focused primarily on the composition of CPB priming and the availability of blood products rather than on detailed intraoperative perfusion management strategies. Important aspects of neonatal CPB management, including temperature targets, acid-base management strategies (pH-stat v alpha-stat), ultrafiltration practices, and timing of transfusion during bypass, were not captured. Second, the survey evaluated the availability of blood products rather than actual transfusion utilization and therefore cannot provide conclusions

regarding overall transfusion exposure in neonatal cardiac surgery. Preoperative, intraoperative, and postoperative transfusion practices were not assessed. Finally, as with any voluntary survey, response bias is possible, although the relatively high response rate strengthens the representativeness of the findings.

Despite these limitations, the survey provides valuable insight into contemporary practice patterns across European neonatal cardiac surgery programs. The findings underscore the considerable diversity of current approaches to CPB priming and perioperative hemostasis management, highlighting potential opportunities for collaborative research and the development of consensus-driven guidelines. As neonatal cardiac surgery continues to evolve toward increasingly individualized and physiologically guided perfusion strategies, further multicenter studies will be essential to determine which approaches provide the best clinical outcomes.

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Declaration of Generative AI Use

During the preparation of this work, the authors used ChatGPT, OpenAI, to generate artwork for the graphical abstract. After using this tool and/or service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Sascha Meier: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Theofili Kousi:** Writing – review & editing, Writing – original draft, Supervision, Investigation. **Birgitta Romlin:** Writing – review & editing, Writing – original draft, Validation, Formal analysis. **Dorela Haxhiademi:** Writing – review & editing, Formal analysis. **Marcus Lance:** Writing – review & editing.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at [doi:10.1053/j.jvca.2026.06.045](https://doi.org/10.1053/j.jvca.2026.06.045).

Appendix A. Supplementary Material

Collaborators List in Alphabetical Order

EACTAIC Paediatric & Congenital Subcommittee Survey Group:

Tommaso Aloisio, Department of Cardiovascular Anesthesia and Intensive Care, I.R.C.C.S. Policlinico San Donato, Milan, Italy.

Eneli Anvelt, Department of Anaesthesiology and Intensive Care, University of Tartu, Tartu, Estonia.

Eva Base, Division of Cardiothoracic and Vascular Anesthesia and Intensive Care Medicine, Medical University Vienna, Vienna, Austria.

Mariana Correia, Departamento de Anestesiologia, Centro Hospitalar de Lisboa Ocidental EPE, Lisboa, Portugal.

Vera von Dossow, Institute of Anesthesiology and Pain Therapy, Heart and Diabetes Center Bad Oeynhausen, Ruhr University Bochum, Bad Oeynhausen, Germany.

Gabor Erdoes, Department of Anesthesiology and Pain Medicine, Inselspital, University Hospital Bern, University of Bern, Bern, Switzerland.

Jan-Oliver Friess, Department of Anesthesiology and Pain Medicine, Bern University Hospital, University of Bern, Bern, Switzerland.

Josefin Grabert, Department of Anesthesiology and Intensive Care Medicine, University Hospital Bonn, Bonn, Germany.

Katharina Gräfe, Department of Anesthesiology, Medical Faculty RWTH Aachen University, Aachen, Germany.

Till Humbert, University Hospital Mainz, Clinic of Anaesthesiology, Mainz, Germany.

Giuseppe Isgro, Department of Pediatric Intensive Care Unit, I.R.C.C.S. Policlinico San Donato, Milan, Italy.

Aniruddha Janai, Department of Anesthesiology and Intensive Care Medicine, Heart Center Leipzig, Leipzig, Germany.

Nadeen Habib Khalil, Department of Anesthesiology and Intensive Care Medicine, Heart Center Leipzig, Leipzig, Germany.

Maren Kleine-Brüggeney, Department of Cardiac Anesthesiology and Intensive Care Medicine, Deutsches Herzzentrum der Charité, Berlin, Germany; Charité-Universitätsmedizin Berlin, corporate member of Freie Universität Berlin and Humboldt-Universität zu Berlin, Berlin, Germany; German Center for Cardiovascular Research, partner site Berlin, Berlin, Germany.

Joost van der Maaten, Department of Anesthesiology, University of Groningen, University Medical Centre Groningen, Groningen, The Netherlands.

Mona Momeni, Department of Anesthesiology, Cliniques Universitaires Saint-Luc, Brussels, Belgium; Institute of

Experimental and Clinical Research, UCLouvain, Brussels, Belgium; Institute of Neuroscience, UCLouvain, Brussels, Belgium.

Pieter Okkerse, Department of Anesthesiology, Leiden University Medical Center, Leiden, The Netherlands.

Steffen Rex, Department of Anaesthesiology, University Hospitals Leuven, Leuven, Belgium.

Omer Savluk, Anesthesiology and Reanimation Clinic, Kartal Kosuyolu High Education and Training Hospital, Istanbul, Turkey.

Ehrenfried Schindler, Department of Anesthesiology and Intensive Care Medicine, University Hospital Bonn, Bonn, Germany.

Spela Pirtovsek Stupnik, Department of Anesthesiology, University Clinical Centre Ljubljana, Slovenia.

Mohamed Suliman, Sidra Medicine, Qatar.

Peter Szedlak, Leeds General Infirmary, The Leeds Teaching Hospitals NHS Trust, Leeds, United Kingdom.

Andrea Szekely, Department of Anesthesiology and Intensive Therapy, Semmelweis University, Budapest, Hungary.

Edgar Szekely, Gottsegen National Cardiovascular Center, Pediatric Heart Center, Anesthesia and Intensive Care Unit, Budapest, Hungary.

Michael Vandenheuvel, Department of Cardiac Anesthesia, Ghent University Hospital, Ghent, Belgium.

Markus Velten, Department of Anesthesiology and Pain Management, Division of Cardiovascular and Thoracic Anesthesiology, University of Texas Southwestern Medical Center, Dallas, TX.

Georgina Westcott, Department of Anaesthesia, Evelina London Children's Hospital, Guy's and St. Thomas' NHS Foundation Trust, London, United Kingdom.

Collaborators (other) in alphabetical order:

Marta Agulli, Sostieni la ricerca dell'IRCCS Azienda Ospedaliero-Universitaria di Bologna, Italy.

Philip Arnold, Jackson Rees Department of Pediatric Anesthesia, Alder Hey Children Hospital, Liverpool, United Kingdom.

Tuan-Chen Aw, Department of Anesthesia and Critical Care, Royal Brompton Hospital, London, United Kingdom.

Elisa Barberi, Fondazione Toscana Gabriele Monasterio, Heart Hospital, Via Aurelia Sud, Massa, Italy.

Christiane Beck, Clinic of Anesthesiology and Intensive Care Medicine, Hannover Medical School, Hannover, Germany.

Ioana Maria Belciu, Institute of Anesthesiology and Pain Therapy, Heart and Diabetes Center Bad Oeynhausen, Ruhr University Bochum, Bad Oeynhausen, Germany.

Gunnar Bentsen, Division of Emergencies and Critical Care, Department of Anesthesia and Intensive Care Medicine, Oslo University Hospital-Rikshospitalet, Oslo, Norway.

Indie Bilkhoo, Clinical Perfusion, Birmingham Children's Hospital, Birmingham, United Kingdom.

Pierre Bourgoïn, Anesthésie et Réanimation pédiatrique, Hôpital de la femme, de l'enfant et de l'adolescent, Nantes, France.

Clair le Calvez, Hôpital Necker-Enfants Malades, Assistance Publique - Hôpitaux de Paris, Paris, France.

Elena Caporossi, Department of Cardiothoracic and Vascular Intensive Care, University Hospital Integrated Trust of Verona, Verona, Italy.

Zeljko Colak, Department of Anesthesiology, Reanimatology and Intensive Care Medicine, University Hospital Center Zagreb, Zagreb, Croatia.

Richard Beringer, Department of Paediatric Cardiac Anaesthesia, Bristol Royal Hospital for Children, Bristol, United Kingdom.

Cesar Brunetti, Department of Pediatric and Congenital Cardiovascular Surgery, Timone Hospital, Aix Marseille University Hospital, Marseille, France.

Karli Degezelle, Department of Cardiac Surgery, University Hospitals Leuven, Leuven, Belgium.

Peter Dütschke, Department of Anesthesiology, University Hospital Schleswig-Holstein, Campus Kiel, Kiel, Germany.

Kristina Ehleben, Department of Anesthesiology, Evangelisches Klinikum Niederrhein, Duisburg, Germany.

Sergio Filippelli, University Hospital of Marche, Ancona, Italy.

Jakob Gjedsted, Department of Cardiothoracic Anesthesia, Copenhagen University Hospital Rigshospitalet, Copenhagen, Denmark.

Philippe Grieshaber, Division of Congenital Cardiac Surgery, Department of Cardiac Surgery, Heidelberg University Hospital, Heidelberg, Germany.

Bob Heger, Department of Anesthesia and Intensive Care, Strasbourg University Hospital, Strasbourg Cedex, France.

Lucy Hepburn, Department of Anaesthesia, Great Ormond Street Hospital for Children NHS Foundation Trust, Great Ormond Street, London, United Kingdom.

Tomas Hrtanek, Pediatric Cardiac Centre, National Cardiovascular Institute, Bratislava, Slovakia.

Enrico Iannace, Cardiovascular Department, Mediterranean Pediatric Cardiology Center, Bambino Gesù Children's Hospital, Taormina, Italy.

Till Kessler, Department of Anesthesiology, Center of Anesthesiology and Intensive Care Medicine, University Medical Center Hamburg-Eppendorf, Hamburg, Germany.

Ljubica Krajcinovic, Department of Anesthesiology, Friedrich-Alexander-University of Erlangen-Nuremberg, Erlangen, Germany.

Izabela Pagowska-Klimek, Department of Pediatric Anesthesiology and Intensive Care, Medical University of Warsaw University Clinical Centre, Warsaw, Poland.

Dritan Kolgjini, Azienda Ospedaliero-Universitaria Delle Marche, Ancona, Italy.

Saimir Kuci, Department of Intensive Care, University of Medicine, Tirana, Albania.

Inge I de Liefde, Department of Anesthesiology, Erasmus MC University Medical Center, Rotterdam, The Netherlands.

Wendy Lim, Department of Anesthesiology, Leeds Teaching Hospitals NHS Trust, Leeds, United Kingdom.

Estibaliz Azpeitia Lopez, Servicio de Anestesiología, Hospital Sant Joan de Déu, Esplugues de Llobregat, Barcelona, España; Grupo de Anestesiología Cardíaca Pediátrica,

Hospital Sant Joan de Déu, Esplugues de Llobregat, Barcelona, España.

Harry Magunia, Department of Anesthesiology and Intensive Care Medicine, University Hospital Tübingen, Eberhard Karls University, Tübingen, Germany.

Maria Dolores Méndez Marin, Anestesiología, Reanimación y Terapéutica del dolor, Hospital Universitario 12 de Octubre, Madrid, Spain.

Gabriele Micci, ASST Papa Giovanni XXIII di Bergamo, Bergamo, Italy.

Victoria Molyneux, Department of Perfusion, Great Ormond Street Hospital for Children NHS Foundation Trust, London, United Kingdom.

Matthias Friedrich Müller, Pediatric Cardiac Anesthesiology Service, Pediatric Heart Centre, Department of Anesthesiology Intensive Care Medicine, Pain Therapy, University Hospital Gießen and Marburg GmbH, Campus Giessen, Giessen, Germany.

Sandra Nonini, "De Gasperi" Cardio Center, ASST Grande Ospedale Metropolitano Niguarda, Milan, Italy.

Valeria Perez de Sa, Department of Pediatric Anesthesia and Intensive Care, Children's Heart Center, Skåne University Hospital, Lund, Sweden.

Selin Saglam, Department of Anesthesiology, Basaksehir Cam and Sakura City Hospital, Istanbul, Türkiye.

Patrick Scheiermann, Department of Anesthesiology, LMU University Hospital, LMU Munich, 81377 Munich, Germany.

Jacques Thes, Department of Anesthesiology, Marie Lannelongue Hospital, Paris Saint Joseph Hospital, Le Plessis Robinson, France; Cardiothoracic Intensive Care Unit, Marie Lannelongue Hospital, Paris Saint Joseph Hospital, Le Plessis Robinson, France; Cardiovascular Perfusionist Team, Department of Anesthesiology, Marie Lannelongue Hospital, Paris Saint Joseph Hospital, Le Plessis Robinson, France.

Paula Tynkkynen, Division of Anesthesiology, Hospital for Children and Adolescents, University of Helsinki and Helsinki University Hospital, Helsinki, Finland.

Christoph Ulrichs, Department of Anaesthesiology and Intensive Care Medicine, University Hospital Cologne, Cologne, Germany.

Giacomo Veronese, Pediatric Cardiac Anesthesia and Pediatric Intensive Care, Azienda Ospedaliera Papa Giovanni XXIII, Bergamo, Italy.

Federico Visconti, Anaesthesia and Intensive Care, Padova University Hospital, Padua, Italy.

Vincenzo Vitale, Pediatric Cardiac Intensive Care Unit, Bambino Gesù Hospital, Rome, Italy.

Reiner Wäschle, Department of Anesthesiology, University of Goettingen, Goettingen, Germany.

Linda van Wagenberg, Department of Anesthesiology, University Medical Center Utrecht, Wilhelmina Children's Hospital, Utrecht, The Netherlands.

James Warburton, Paediatric Heart Unit, Institute of Transplantation, Freeman Hospital, Newcastle upon Tyne, United Kingdom.

Kirstin Wilkinson, Department of Paediatric and Adult Cardiothoracic Anaesthesia, Southampton University NHS Hospital, Southampton, United Kingdom.

Mattia Zanin, Pediatric Cardiac Anesthesiology and Intensive Care Unit, Regina Margherita Children's Hospital, Torino, Italy.

Ameur Malik Zebouchi, University Hospital of Tours, Tours, France.

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