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Contemporary transesophageal echocardiography practice patterns among paediatric cardiology centres in the United States and Canada

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Abstract

Objective: To characterise transesophageal echocardiography practice patterns among paediatric cardiac surgical centres in the United States and Canada. *Methods:* A 42-question survey was sent to 80 echocardiography laboratory directors at paediatric cardiology centres with surgical programmes in the United States and Canada. Question domains included transesophageal echocardiography centre characteristics, performance and reporting, equipment use, trainee participation, and quality assurance. *Results:* Fifty of the 80 centres (62.5%) responded to the survey. Most settings were academic (86.0%) with 42.0% of centres performing > 350 surgical cases/year. The median number of transesophageal echocardiograms performed/cardiologist/year was 50 (26, 73). Pre-operative transesophageal echocardiography was performed in most surgical cases by 91.7% of centres. Transesophageal echocardiography was always performed by most centres following Norwood, Glenn, and Fontan procedures and by < 10% of centres following coarctation repair. Many centres with a written guideline allowed transesophageal echocardiography transducer use at weights below manufacturer recommendations (50.0 and 61.1% for neonatal and paediatric transducers, respectively). Most centres (36/37, 97.3%) with categorical fellowships had rotations which included transesophageal echocardiography participation. Large surgical centres (>350 cases/year) had higher median number of transesophageal echocardiograms/cardiologist/year (75.5 [53, 86] versus 35 [20, 52], $p < 0.001$) and more frequently used anaesthesia for diagnostic transesophageal echocardiography ≥ 67% of time (100.0 versus 62.1%, $p = 0.001$). *Conclusions:* There is significant variability in transesophageal echocardiography practice patterns and training requirements among paediatric cardiology centres in the United States and Canada. Findings may help inform programmatic decisions regarding transesophageal echocardiography expectations, performance and reporting, equipment use, trainee involvement, and quality assurance.

Transesophageal echocardiography is an important diagnostic tool for evaluation of heart disease in children. In particular, transesophageal echocardiography is a critical imaging modality for post-operative evaluation following surgical repair of congenital heart disease and for peri-procedural guidance of structural heart interventions.[1,2] Given the rise of transesophageal echocardiography as an important clinical tool, guidelines for performance of a comprehensive transesophageal echocardiography in children and patients with CHD have been published.[3] Training guidelines have also been suggested for trainees in paediatric cardiology seeking to incorporate transesophageal echocardiography into their practice.[4] Finally, quality metrics have been developed for centres seeking to maintain transesophageal echocardiography programmes.[5] As paradigms of transesophageal echocardiography practice evolve, it is important to understand how practice recommendations and patterns are unfolding among the paediatric cardiology community. Several surveys have helped shape the perspective on use of transthoracic echocardiography in children with heart disease.[6–9] However, contemporary cross-sectional data describing transesophageal echocardiography practice patterns among paediatric cardiology centres are lacking. In this study, we sought to evaluate transesophageal echocardiography practice patterns among centres in the United States and Canada. We focused on evaluation of transesophageal echocardiography performance and reporting practices, equipment use, trainee participation in transesophageal echocardiography, and integration of quality improvement policies within the practice climate.

Materials and methods

A survey containing 42 questions was developed (Supplementary Material). Questions aimed to evaluate transesophageal echocardiography centre characteristics, performance and reporting patterns, equipment use, trainee participation in transesophageal echocardiography, and quality assurance practices among centres in the United States and Canada with affiliated cardiovascular surgery programmes. Questions about the use of post-operative epicardial echocardiography were included in the survey as this modality can supplement imaging obtained from post-operative transesophageal echocardiography. Among eligible centres, echocardiography laboratory directors were identified using publicly available information or through personal correspondence. The electronic survey was sent via email to 80 echocardiography laboratory directors using SurveyMonkey (San Mateo, California, USA). Only one response per centre was solicited. Up to two reminder emails were sent to each centre. The survey was closed for further input five weeks after the initial communication. Responses were anonymous, and reporting of centre by respondents was optional. Once aggregated, survey data were reviewed to ensure no duplicate responses were present.

Transesophageal echocardiography transducers were classified as neonatal, paediatric, or adult according to size. Generally, neonatal transducers are recommended for use in patients weighing $>$ 2.5 kg, paediatric transducers are recommended for use in patients weighing $>$ 3.5–5.0 kg, and adult transducers are recommended for use in patients weighing $>$ 30.0 kg, with some variability according to specific transducer and vendor.

Survey data were compiled and evaluated using descriptive statistics. Data are reported as mean ± standard deviations for normally distributed continuous data and medians (interquartile range) for non-normally distributed continuous variables or as number with percentages for categorical data. The denominator is provided for all data; denominators less than 50 indicate incomplete responses for the specific item. Data were grouped according to centre size and were compared. Categorical data were evaluated using Fisher's exact test or the chi-squared test as appropriate. Continuous data were compared using the Mann–Whitney U-test. A p-value of $<$ 0.05 was considered significant. Statistical analysis was completed using SPSS Statistics (version 28.0.0.0, International Business Machines, Inc., Armonk, New York, USA). This study was approved by the local Institutional Review Board.

Results

There were 50 responses (response rate = 62.5%) with at least one question answered. All responding centres confirmed that transesophageal echocardiography was performed at their centre. There were 34 centres which provided their centre name in the optional field.

Centre characteristics

Most centres were academic (43/50, 86.0%) with a smaller proportion of mixed academic/private or other centres (6/50, 12.0%) and a single private centre (1/50, 2.0%). Centres most frequently reported having 11-20 cardiologists (23/50, 46.0%) with 6–10 cardiologists considered as core echocardiography faculty (25/50, 50.0%). There were 21/50 (42.0%) of centres which reported $\geq$ 350 surgical cases with or without cardiopulmonary bypass in 2021 (Fig. 1).

Transesophageal echocardiography performance and reporting

Centres performed a median of 380 (172, 550) transesophageal echocardiographies each year. At each centre, a median of 7 (5, 10) cardiologists interpreted transesophageal echocardiographies, giving a median of 50 (26, 73) transesophageal echocardiographies interpreted per cardiologist per year by centre (Fig. 2). Physician coverage for transesophageal echocardiography was provided 24 hours per day on all days of the year by most centres (46/49, 93.9%). Transesophageal echocardiography was used to assist catheterisation-based interventions in the majority of centres (48/49, 98.0%). There were 8/50 (16.0%) of centres where the cardiologist inserted the TEE transducer, 9/50 (18.0%) of centres where the anaesthesiologist inserted the transesophageal echocardiography transducer, and 33/50 (66.0%) of centres where transesophageal echocardiography transducer insertion was undertaken by either the cardiologist or anaesthesiologist. All centres offered diagnostic transesophageal echocardiography in addition to transesophageal echocardiography for post-surgical evaluation and peri-procedural guidance.

Most centres used general anaesthesia for diagnostic transesophageal echocardiography. Sonographer participation in transesophageal echocardiography was variable, with sonographers never participating in transesophageal echocardiography at 18/49 (36.7%) centres and always participating in transesophageal echocardiography in 14/49 (28.6%) of centres. Pre-operative transesophageal echocardiography imaging was always performed by 26/48 (54.2%) of centres. For centres where pre-operative transesophageal echocardiography images were acquired and in whom post-operative transesophageal echocardiography images were also acquired, the majority of centres billed and reported these series of images separately (31/48, 64.6%) (Fig. 3). Most centres used 3-D transesophageal echocardiography for clinical purposes (45/49, 91.8%) and offered epicardial echocardiography (44/49, 89.8%). Among centres offering epicardial echocardiography, only the surgeon manipulated the transducer in 29/44 (65.9%) of centres and the surgeon or cardiologist manipulated the transducer in 13/44 (29.5%) of centres. The surgeon or surgical assistant manipulated the transducer in the minority of cases (2/44, 4.5%), and the cardiologist only or sonographer never independently manipulated the epicardial transducer.

The frequency of transesophageal echocardiography performance for specific surgical repair varied among centres. Most centres always performed transesophageal echocardiography following the Norwood procedure, bidirectional Glenn procedure, Fontan procedure, heart transplantation, and atrial septal defect repair. Less than half of centres always performed transesophageal echocardiography following systemic-to-pulmonary-artery shunt placement and a higher frequency of centres never performed transesophageal echocardiography following coarctation repair and epicardial pacemaker placement than for other surgeries (Fig. 4).

Equipment use

Among all transducer sizes, most centres used Philips (Andover, Massachusetts, USA) as the only vendor for transesophageal echocardiography transducers (32/48, 66.7%). A smaller percentage of centres used General Electric (Fairfield, Connecticut, USA) as the only vendor for transesophageal echocardiography transducers (5/48, 10.4%) and few centres reported use of other transesophageal echocardiography vendors or mixed vendors (Philips and General Electric 6/48 [12.5%], Philips and Siemens

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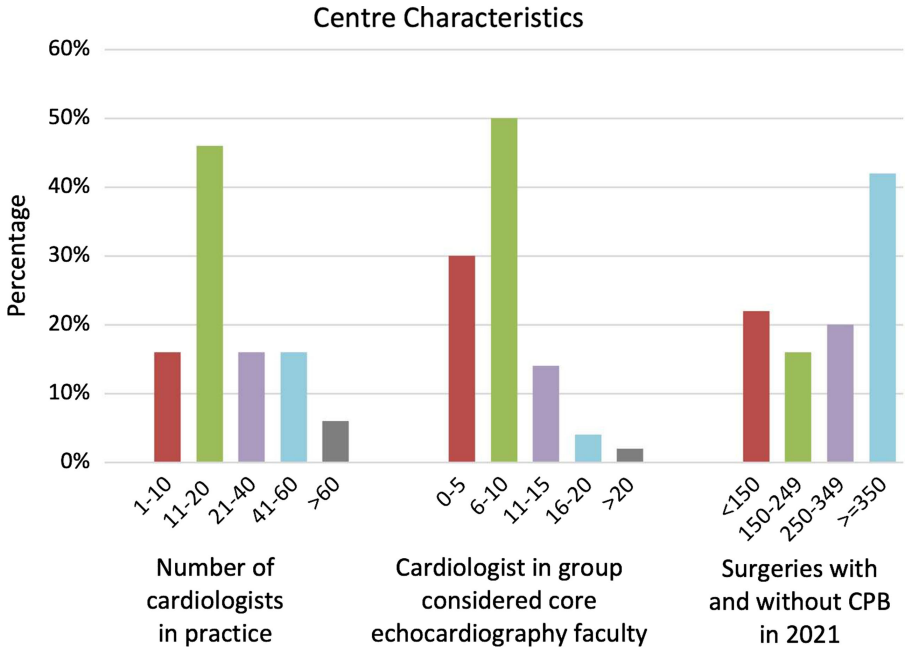

Figure 1. Cardiology practice characteristics and centre surgical volumes. CPB = cardiopulmonary bypass.

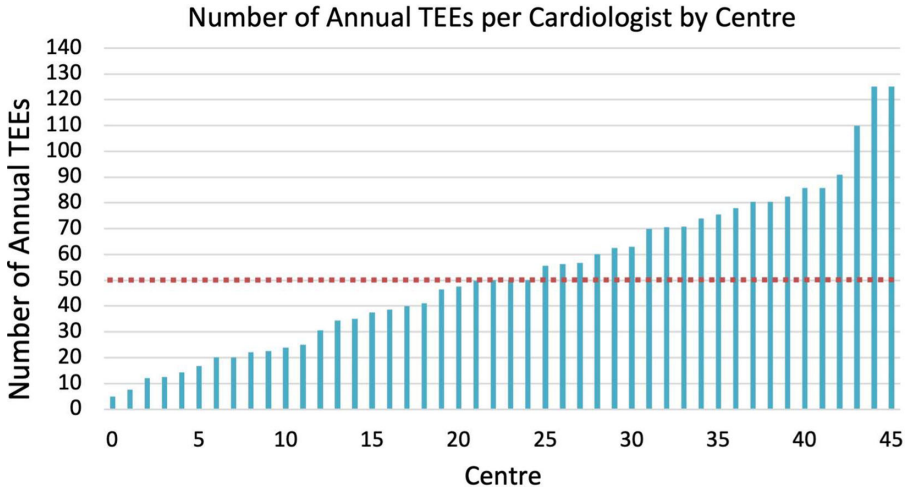

Figure 2. Number of transesophageal echocardiographies performed per cardiologist per year by centre. N = 46 centres with complete data. Dotted line = median; TEE = transesophageal echocardiogram.

(Munich, Germany) 2/48 [4.2%], General Electric and Siemens 1/48 [2.1%], Philips, General Electric and Siemens 2/48 [4.2%]).

There were two neonatal transducers used among centres (Philips S8-3T and General Electric 10T-D), both of which have manufacturer-recommended minimum weight for use of 2.5 kg [personal correspondence with Philips and General Electric industry representatives].[10] There were 20 centres which reported having a written institutional policy governing minimum weights for use of transesophageal echocardiography transducers. Of the 16 centres listing a specific minimum weight for use of a neonatal transducer in their written policy, the median lower weight was 2.3 (interquartile range 2.0, 2.5, range 1.0–5.0) kg, with 50.0% of centres reporting a lower weight limit for use of the neonatal transducer than manufacturer recommendation. Centres performing ≥ 350 cases per year had lower permitted weight limits than other centres, although this difference was not significant (median lower weight 2.0 [2.0, 2.3], N = 7 versus 2.5 [2.0, 3.0], N = 9, p = 0.23). There were 5/7 (71.4%) versus 3/9 (33.3%) centres performing ≥ 350 surgeries per year with policies permitting use of a lower weight limit for neonatal transducers than manufacturer recommendation (p = 0.31).

There were three paediatric transducers reported as used among centres, with most reporting use of the Philips S7-3T and General Electric 9T transducers and one reporting use of the Siemens V7M transducer. The suggested lower weight limit for the Philips S7-3T transducer is 3.5 kg, and the suggested lower weight limit for the General Electric 9T transducer is 5.0 kg [personal correspondence with Philips and General Electric industry representatives]. Of 20 centres reporting a written weight policy for paediatric transesophageal echocardiography transducers, 18 responded with their centre's specific listed minimum weight for use of a paediatric transducer. One of these centres listed a lower weight limit of 1.5 kg; this weight was excluded from analysis as this weight was significantly below the manufacturer recommendation and could not be verified. Among the 10 centres which exclusively used the Philips S7-3T, the median lower weight was 3.0 (interquartile range 2.8, 3.4, range 2.5–3.5) kg, with 7/10 (70.0%) of centres reporting a lower weight

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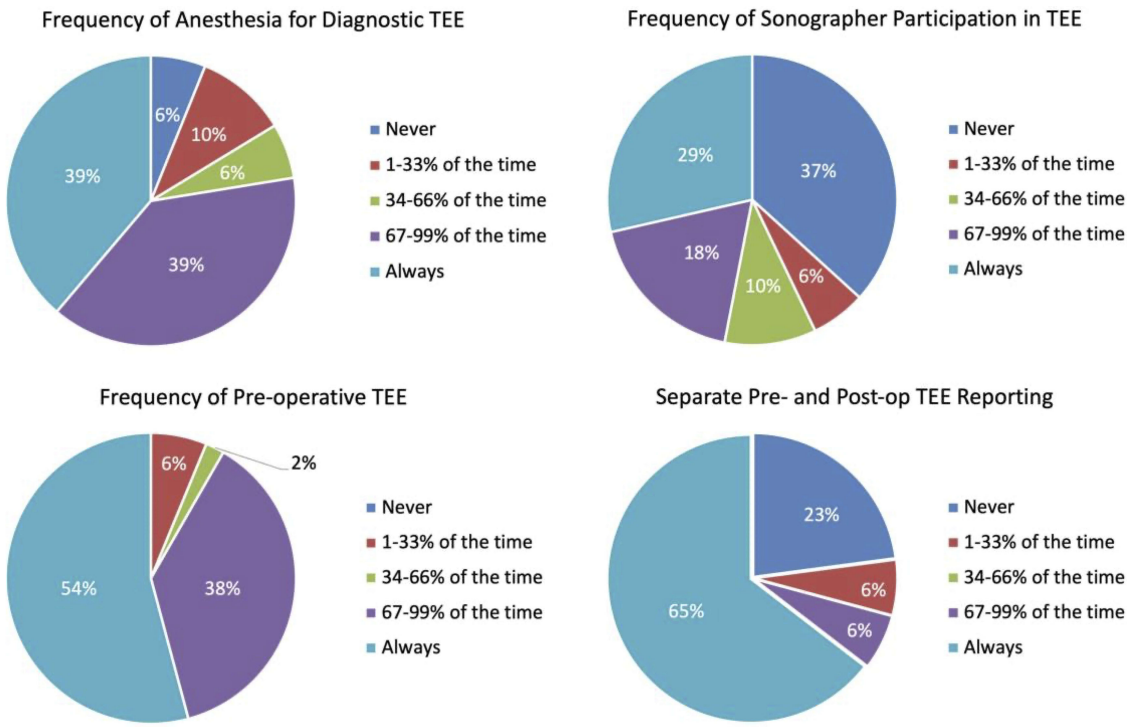

Figure 3. Frequency of use of anaesthesia for diagnostic transesophageal echocardiography, frequency of sonographer participation in transesophageal echocardiography, frequency of performance of pre-operative transesophageal echocardiography in patients for whom post-operative transesophageal echocardiography is planned, and frequency of separate reporting and billing of pre-operative and post-operative transesophageal echocardiographies for patients in whom post-operative transesophageal echocardiography is requested. Post-op = post-operative; TEE = transesophageal echocardiogram.

limit for use of this specific paediatric transducer than manufacturer recommendation. Of the three centres which exclusively used the General Electric 9T transducer, all centres listed 5.0 kg as the lower weight limit. Centres using Philips transducers performing ≥ 350 cases per year had lower permitted weight limits than other centres, although this difference was not significant (median lower weight 3.0 [2.8, 3.0], N = 6 versus 3.5 [3.0, 3.5], N = 9, p = 0.16). There were 5/6 (83.3%) versus 5/11 (45.5%) centres performing ≥ 350 surgeries per year with policies permitting use of a lower weight limit for paediatric transducers than manufacturer recommendation (p = 0.30).

There was increased heterogeneity of adult transesophageal echocardiography transducer use among centres, with 18/20 centres with a written policy reporting their centre's specific minimum weight for use of an adult transducer. Among the 11 centres exclusively using Philips transducers (the X8-2T, X7-2T, and/or S7-2 transducers), the median lower weight was 20.0 (interquartile range 15.5, 25.0, range 13.0–30.0) kg. Of the two centres exclusively using General Electric transducers, both used the 6VT-D transducer; one recommended a lower weight limit of 18.0 kg and the other a lower weight limit of 30.0 kg.

Trainee participation in transesophageal echocardiography

A categorical paediatric cardiology fellowship was present at the majority of centres (37/50, 74.0%). Of these centres, most implemented a structured rotation for categorical fellows which included participation in transesophageal echocardiography (36/37, 97.3%). There were no centres where categorical fellows always or never participated in transesophageal echocardiography. Fellows participated in transesophageal echocardiography during 1–33% of cases at most centres (23/36, 63.9%), 34–66% of cases at 9/36 (25.0%) of centres, and 67–99% of cases at 4/36 (11.1%) of centres. A minority of centres required a minimum number of transesophageal echocardiographies before fellows could graduate (14/36, 38.9%). Of these centres, the median number of TEEs required for graduation was 33 (25, 50). Of the 22/50 (44.0%) centres with fourth-year advanced imaging fellowships, 8/22 (36.4%) specified a minimum number of transesophageal echocardiographies required for graduation. The median number of transesophageal echocardiographies required for advanced imaging fellowship among the seven centres reporting specific minimum requirements was 50 (50.0, 62.5).

Quality assurance

Complications associated with transesophageal echocardiography were formally captured and reviewed at the majority of centres (45/47, 95.7%, and 44/47, 93.6%, respectively). Most centres recorded pre-operative transesophageal echocardiography discrepancies compared to operative findings (46/47, 97.9%) and formally reviewed these findings (45/47, 95.7%). Similarly, most centres captured pre-operative transesophageal echocardiography discrepancies compared to pre-operative transthoracic echocardiogram findings (43/47, 91.5%) and formally reviewed these findings (42/47, 89.4%), with one centre reporting that pre-operative transesophageal echocardiographies were not performed at their centres. Transesophageal echocardiography discrepancies were shared with physicians by individual feedback (29/48, 60.4%), periodic feedback in a group setting (41/48, 85.4%); no standard process for feedback was reported at 4/48 (8.3%) of centres and 5/48 (10.4%) of centres reported using a process other than the preceding listed options.

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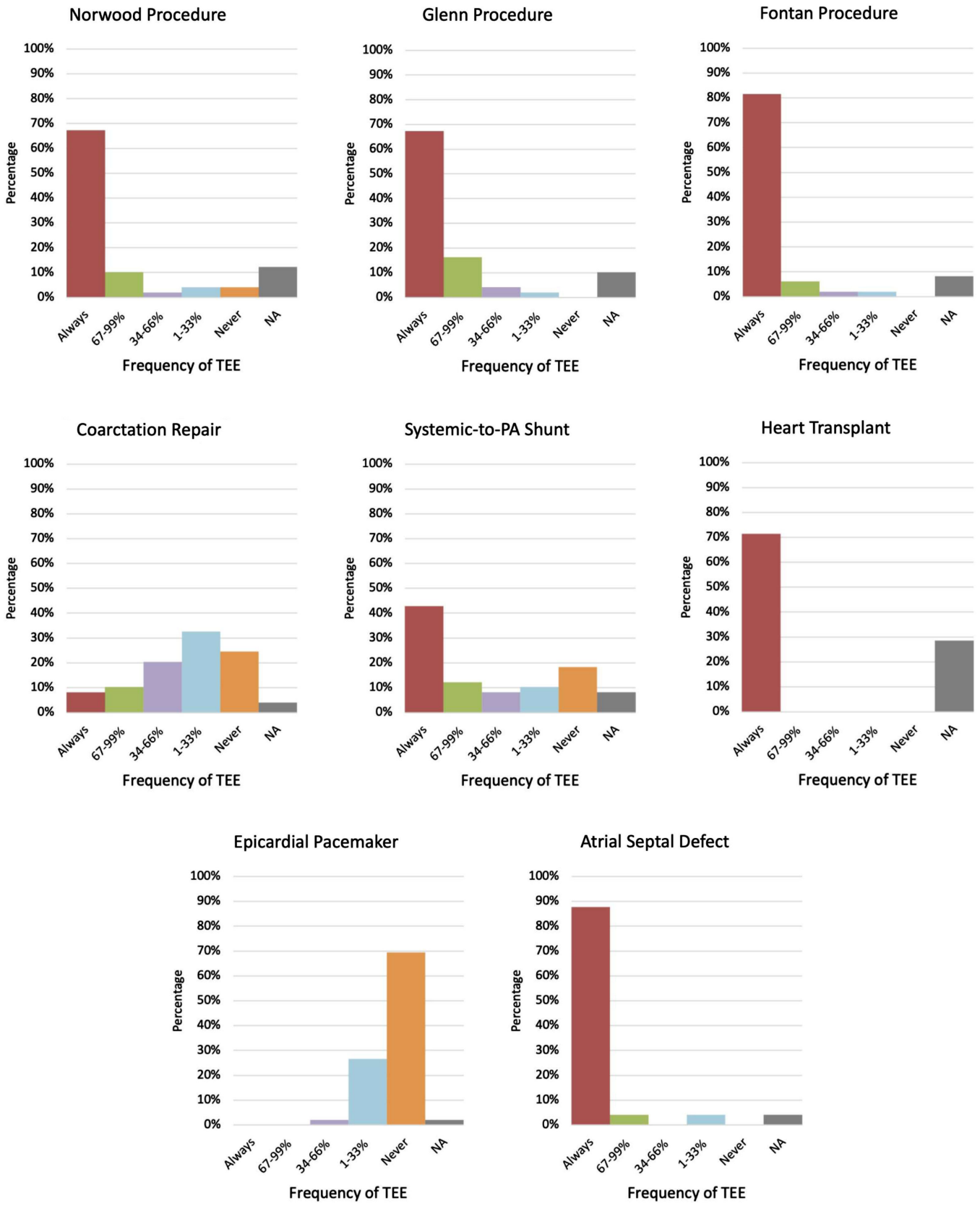

Figure 4. Frequency of transesophageal echocardiography performance among centres for specific surgeries. PA = pulmonary artery; NA = not available (procedure not performed at centre).

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Table 1. Comparison of transesophageal echcoardiography performing and reporting characteristics and equipment use according to centre by size.

	≥350 cases/yr	<350 cases/yr	p
TEE Performance and Reporting			
TEEs/Cardiologist/year	75.5 (53, 86)	35 (20, 52)	<0.001
GA with TEE ≥67% of time	20/20 (100.0)	18/29 (62.1)	0.001
Sonographer participation ≥67% of time	6/20 (30.0)	17/29 (58.6)	0.048
Frequency that pre-op TEEs always performed	9/20 (45.0)	17/28 (60.7)	0.28
Separate pre-op TEE reports ≥67% of time	14/20 (70.0)	20/28 (71.4)	1.0
Clinical use of 3-D TEE	20/20 (100.0)	25/29 (86.2)	0.14
Epicardial echocardiography	19/20 (95.0)	25/29 (86.2)	0.64
Equipment Use			
Philips only	13/19 (68.4)	19/29 (65.5)	0.84
General Electric only	2/19 (10.5)	3/29 (10.3)	1.0
Written TEE policy	8/19 (42.1)	12/29 (41.4)	0.96

GA = general anaesthesia; TEE = transesophageal echocardiography.
Data are presented as median (interquartile range) for continuous data and N (%) for categorical data.

Comparison of centres by volume

A higher number of transesophageal echocardiographies per cardiologist per year were performed among centres with ≥ 350 cases per year (median 75.5 [53, 86] versus 35 [20, 52]). Centres with ≥ 350 cases per year more frequently used general anaesthesia for diagnostic transesophageal echocardiography and sonographers participated in transesophageal echocardiography less frequently at these centres. No significant differences by centre size were detected with regard to separate reporting of pre-operative and post-operative transesophageal echocardiographies, clinical use of 3-D transesophageal echocardiography, use of epicardial echocardiography, or equipment use (Table 1).

Discussion

This survey helps characterise transesophageal echocardiography practice patterns among paediatric centres in the United States and Canada performing cardiovascular surgery. While some practices such as those related to recording and discussion of transesophageal echocardiography quality metrics were performed by a majority of centres, other domains showed significant variability. Findings provide a lens for individual centres through which internal transesophageal echocardiography practices may be evaluated.

Transesophageal echocardiography performance and interpretation

Most centres maintained a core group of cardiologists dedicated to transesophageal echocardiography interpretation, with a median number 50 transesophageal echocardiographies interpreted per year for each dedicated transesophageal echocardiography cardiologist by centre, and offered transesophageal echocardiography for surgical, structural, and diagnostic cases. Published guidelines from ASE and other organisations suggest performance and/or interpretation of 25–50 transesophageal echocardiographies per year for maintenance of skills.[11,12] However, within the paediatric cardiology landscape, transesophageal echocardiography volume by centre may be limited by the number of operative cases. Consistent with this notion, a higher number of annual transesophageal echocardiographies were completed per cardiologist at the high-volume centres. Centres must balance the need to staff transesophageal echocardiography coverage to maintain case volume for physicians while also ensuring a reasonable distribution of call. Notably, almost all centres maintained 24-hour available transesophageal echocardiography coverage.

Variability was noted in frequency of procurement of pre-operative imaging in operative cases with request for post-operative transesophageal echocardiography, although more than half of centres acquired pre-operative transesophageal echocardiography images in all cases. While data support use of post-operative transesophageal echocardiography as standard of care for most intracardiac surgeries, the role for pre-operative imaging is less well-defined.[13–16] Frequent performance of pre-operative imaging and separate reporting of pre- and post-operative studies by the majority of centres suggests perception of value added by pre-operative imaging with transesophageal echocardiography. We suggest that at a minimum, pre-operative imaging can serve as a baseline against which post-operative findings may be evaluated. Having a pre-procedural transesophageal echocardiography baseline could be valuable given the different baseline hemodynamic conditions conferred by anaesthesia in comparison to pre-operative transthoracic imaging. More importantly, pre-operative transesophageal echocardiography can potentially influence surgical strategy and provide insight beyond what has been elucidated from previous imaging.

Questions about transesophageal echocardiography for specific surgical procedures were aimed at those procedures where variability of transesophageal echocardiography performance might be expected; even so, transesophageal echocardiography was always performed for most of the specific procedures. Transesophageal echocardiography was even performed in some cases of coarctation repair, despite absence of intracardiac surgical manipulation and known limitations of transesophageal echocardiography in evaluation of the aortic arch. Interestingly, most centres offered epicardial echocardiography as a complement to transesophageal echocardiography. This modality might provide additional information on structures not well-seen on transesophageal echocardiography such

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as the left pulmonary artery and anterior structures such as right-ventricle-to-pulmonary-artery conduits. Furthermore, epicardial echocardiography might be considered for post-operative evaluation in patients who are too small for safe use of transesophageal echocardiography transducers or at locations where neonatal transducers are unavailable. We suggest that epicardial echocardiography should be considered as an adjunct modality for a complete post-operative evaluation in select cases.[17,18]

Equipment use

The preponderant use of Philips and to a lesser extent General Electric as vendors among centres likely reflects their provision of a neonatal transducer. While only a minority of centres reported weight guidelines for transducer use according to transducer size, the median listed minimum weight for neonatal and paediatric transducers among these centres was below the minimum weight listed by manufacturers. Safety data and transesophageal echocardiography complications were not collected as part of this study given limitations of survey architecture; certainly, diagnostic benefit of transesophageal echocardiography must be weighed against risk for harm with transducer manipulation.[19] However, within the confines of this limitation, use of transesophageal echocardiography transducers below manufacturer-specified weight guidelines at many centres argues indirectly for a tolerable risk/benefit profile with routine clinical use. Findings may serve as a platform for more formal investigation into complication rates of transesophageal echocardiography as related to transducer and patient size. Notably, most centres did not report a written policy governing transesophageal echocardiography transducer use at different weights and are excluded from analysis. In excluding centres without written guidance, we hoped to provide data on centre-wide policies and limit incorporation of individual anecdote into reported findings.

Among the paediatric cardiology community, there has been substantial need for paediatric transducer with 3-dimensional capabilities. 3-D imaging can help facilitate structural interventions and provide a more detailed evaluation of pre-operative anatomy. Notably, the vast majority of centres in this survey are already using 3-D imaging with transesophageal echocardiography for clinical use in patients who are large enough to allow use of an adult transducer. With recent introduction of a 3-D paediatric transducer by General Electric, vendor preferences among centres may shift.[20]

Trainee participation in transesophageal echocardiography and quality assurance

Although current guidelines do not require ability to perform and interpret transesophageal echocardiographies among graduating categorical paediatric cardiology fellows, incorporation of transesophageal echocardiography topics into curricula is recommended.[4] In this study, over 90% of centres with categorical fellowship reported a structured rotation which includes participation in transesophageal echocardiography, with variability noted in frequency of categorical fellow participation in transesophageal echocardiography and requirement to log transesophageal echocardiographies for graduation. These data raise consideration as to whether future paediatric cardiology training guidelines should be modified to more strongly advocate for categorical fellow participation in transesophageal echocardiography. Transesophageal echocardiography participation will increase trainee familiarity with transesophageal echocardiography indications, imaging planes and interpretation, and strengths and weakness of the modality. Observation of intraoperative communication between the cardiology and surgical teams at time of post-operative transesophageal echocardiography can also provide valuable perspective. Increasingly, advanced imaging fellowships beyond categorical training are for building skills necessary for practice in transesophageal echocardiography and other modalities. Among the minority of programmes with advanced imaging fellowships reporting trainee transesophageal echocardiography requirements, the median minimum number of transesophageal echocardiographies required for graduation of 50 matched that recommended by current training recommendations.[4]

Transesophageal echocardiography complications were captured and reviewed among most centres. Although widely considered as a safe procedure, complications may occur, and ongoing centre-specific surveillance should ensure that transesophageal echocardiography is used effectively in patient populations where diagnostic benefit outweighs risk.[19,21] Monitoring for transesophageal echocardiography discrepancies compared with other imaging data and surgical findings was also frequently undertaken among centres and should also be an important component of institutional practice.

Limitations

Findings reported herein are subject to limitations of a self-reported survey. Main limitations include those related to survey data, including incomplete response rate and lack of capture of all centres satisfying inclusion criteria. Given limitations of survey architecture, data on transesophageal echocardiography complications were not captured which is important for clinicians to consider when interpreting findings on use of transesophageal echocardiography transducers in patients at weights lower than listed manufacturer guidelines.

Conclusions

We report cross-sectional data on contemporary paediatric transesophageal echocardiography use among centres in the United States and Canada. Findings may help inform programmatic decisions regarding transesophageal echocardiography expectations, performance and reporting, equipment use, trainee involvement, and quality assurance. Future avenues of exploration include the evaluation of relationships between paediatric transesophageal echocardiography practice patterns and cost, value, safety, and clinical outcomes.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1047951123003633.

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Competing interests. None.

Ethical standard. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national guidelines on

human experimentation and with the Helsinki Declaration of 1975, as revised in 2008, and have been approved by the Children's Healthcare of Atlanta Institutional Review Board.

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