Global perspectives on cardiothoracic, cardiovascular, and cardiac surgical training

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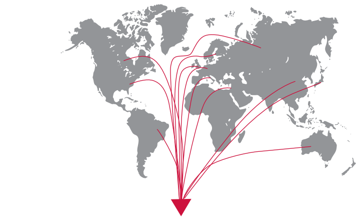
ABSTRACT

Objective: Various methods for cardiothoracic, cardiovascular, and cardiac surgical training exist across the globe, with the common goal of producing safe, independent surgeons. A comparative analysis of international training paradigms has not been undertaken, and our goal in doing so was to offer insights into how to best prepare future trainees and ensure the health of our specialty.

Methods: We performed a comparative analysis of available publications offering detailed descriptions of various cardiothoracic, cardiovascular, and cardiac surgical training paradigms. Corresponding authors from previous publications and other international collaborators were also reached directly for further data acquisition.

Results: We report various approaches to common challenges surrounding (1) selection of trainees and plans for the future surgical workforce; (2) trainee assessments and certification of competency before independent practice; and (3) challenges related to a changing practice landscape.

Conclusions: Cardiothoracic surgery remains a dynamic and rewarding specialty. Current and future trainees face several challenges that transcend national borders. To foster collaboration and adoption of best practices, we highlight international strengths and weaknesses of various nations in terms of workforce selection, trainee operative experience and assessment, board certification, and preparation for future changes anticipated in cardiothoracic surgery. (J Thorac Cardiovasc Surg 2021;161:168-74)



Countries providing input for comparative analysis of training paradigms.

CENTRAL MESSAGE

Varied cardiothoracic training paradigms exist across the globe; learning respective strengths and weaknesses from other nations may help train future surgeons while addressing anticipated challenges.

PERSPECTIVE

Incorporation of training methodologies and best practices from other countries may serve to improve the training experience in host nations, and we hope to shed light on areas in need of improvement around the globe.

See Commentaries on pages 175 and 176.

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To train the next generation of surgeons, varied training paradigms have arisen around the globe. Training methods for thoracic surgeons vary substantially between US and non-US surgeons.[1] Further examination of specific cardiothoracic, cardiovascular, and cardiac training paradigms have included Canada, the United Kingdom, Germany, Brazil, Israel, Australia, and New Zealand.[2-8] Although not encapsulated in a single publication, aspects of cardiothoracic training in the United States have been examined.[9-14] Comparisons of training methodologies for cardiac surgeons globally are further nuanced by the varied training paradigms (cardiothoracic vs cardiovascular vs cardiac) used and the fact that outcome measures are difficult to objectively measure.

Cardiothoracic surgery remains a dynamic specialty, despite being besieged by challenges that transcend borders, and creative solutions will be needed. To this end, we performed a comparative analysis of cardiothoracic surgical training in the United States, Canada, Brazil, the United Kingdom, Germany, Italy, the Nordic countries (Sweden, Denmark, Finland, Norway, and Iceland collectively), Israel, Russia, China, Japan, and New Zealand. We have chosen to focus our international comparisons on 3 areas: (1) issues related to the future surgical workforce; (2) trainee assessments and certification; and (3) challenges related to changing practice landscapes (Figure 1 and Video 1).

MATERIALS AND METHODS

We performed a literature review for available publications regarding international cardiothoracic, cardiovascular, or cardiac surgical training paradigms. Additional nations were sought for broadened perspectives. All potential co-authors from respective nations were sent a standardized template of questions regarding their nation's methodology for cardiothoracic, cardiovascular, or cardiac surgical training, with additional room for open commentary on their nation's relative strengths or weaknesses (Appendix E1). Any clarification of responses was addressed by direct communication between the first author and any respective co-author. Ultimately, this resulted in sufficiently detailed responses across 17 countries, including the United States, Canada, Brazil, the United Kingdom, Germany, Italy, the Nordic countries (Sweden, Denmark, Finland, Norway, and Iceland collectively), Israel, Russia, China, Japan, and New Zealand, as depicted in the Figure 1. Respective co-authors and the nations they represented are detailed in Appendix E2.

Workforce-Related Challenges

Reports have heralded a shortage of cardiothoracic surgeons in the United States and Canada because of the convergence of an aging population, anticipated retirements, and previously declining rates of applicants for cardiothoracic training positions.[15-17] As the worldwide population continues to age, there is little reason to believe a shortage would not also be present internationally.[18] For instance, the most recent examination of cardiovascular surgical training in Brazil demonstrated that only 62 of the available 228 training positions nationwide were filled.[3]

Fluctuations in the number of trainees may be more pronounced in less populous nations, resulting in various methods for workforce planning around the globe. The most formalized approach exists in New Zealand, applicants apply to a central governing body, and only 5 to 8 applicants are selected from a pool of at least 40 to 50 annually, and the cardiothoracic workforce is not flooded with young surgeons based on transient oversupply. Conversely, other nations, including Israel, Germany, the Nordic countries, Russia, and China, allow applicants to apply directly to each training center without a centralized application scheme or apparent regulation of the number of available training positions. However, a centralized application system is expected in Finland in the near future. In Japan, there is no formal limit to the number of trainees that can be used at a given center, which can dilute operative experience and possibly prolong training. Workforce fluctuations may be more pronounced and difficult to predict on the basis of the frequency of international trainees seeking jobs in another country. For instance, a recent examination of UK trainees found that many thought the influx of surgeons trained in other European Union countries made attractive jobs more difficult to find, especially considering that non-UK European surgeons are frequently trained in cardiovascular surgery and possess a unique skill set compared to the cardiothoracic UK training paradigm.[7] Conversely, most graduates of US training programs remain in the United States to begin practice, although international applicants frequently seek additional training in nonaccredited subspecialty fellowships at US centers (ie, aortic surgery, minimally invasive surgery).

TRAINEE ASSESSMENTS AND CERTIFICATION

Duration of Training

Myriad training paradigms exist around the globe, including cardiovascular surgery (Brazil, Russia, China, Japan), cardiac surgery (Canada, Germany, and Italy) with thoracic surgery representing a subspecialty of general surgery (Canada) or its own integrated training pathway (Italy), and cardiothoracic surgery (United States, United Kingdom, New Zealand, Israel, and the Nordic countries). The United States remains one of the few countries in which general surgery training serves as a possible prerequisite for cardiothoracic trainees. Alternative pathways for US training include a combined 4+3 pathway where trainees complete 4 years of general surgery (and are board eligible in general surgery) before early advancement into 3 years of cardiothoracic surgical training at the same institution. Another growing US pathway is the integrated 6-year (I-6) training pathway whereby trainees enter into cardiothoracic-focused training immediately after medical school. Examination of US residents has demonstrated that trainees primarily interested in cardiac surgery tend to make this decision earlier in their training, while those planning to pursue primarily thoracic surgery make their commitment later in their general surgical training, suggesting that availability of multiple training pathways may be beneficial to maximize qualified applicants.[11,12,14] Although Japan requires trainees to be board certified in general surgery before obtaining additional board certification in cardiovascular surgery, trainees may begin their cardiovascular training before obtaining general surgery

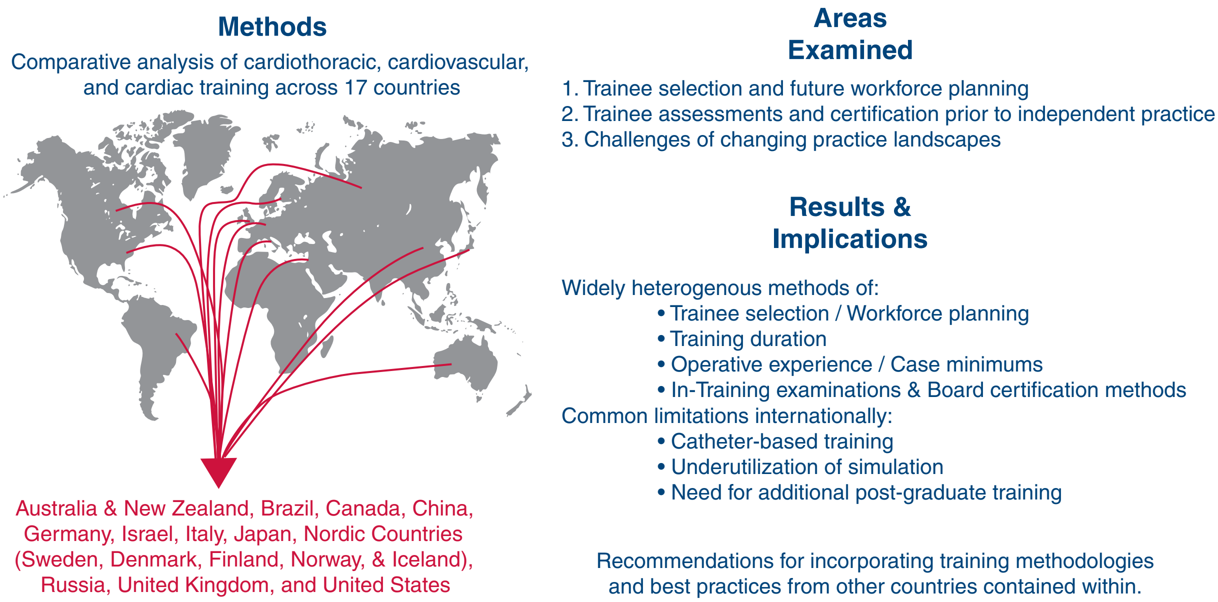

FIGURE 1. Research methodology, countries included in our comparative analysis, areas of research focus, and key findings.

certification and simultaneously accrue cases and other training requirements for both specialties. This leads to a highly variable duration of training in Japan, requiring a minimum of 7 years to obtain both general and cardiovascular board certifications, with no specified maximum training duration. The United Kingdom, New Zealand, the Nordic countries, and China require trainees to undergo a brief period (1-3 years) of general surgical training, without obtaining board certification in general surgery, before matriculation into formal cardiothoracic or cardiovascular surgical training. Other nations exclusively enroll applicants into cardiac (Canada, Germany, and Italy) or cardiovascular (Brazil, Russia) surgical training immediately after medical school graduation, with Germany having universally transitioned to this paradigm in 2018. Israel offers direct matriculation into cardiothoracic surgical training after medical school, which includes 4 years of core cardiothoracic training, followed by a choice among 5 two-year tracks for early subspecialization (adult cardiac, hybrid, congenital, thoracic, and intensive care) before graduation.

VIDEO 1. Video available at: https://www.jtcvs.org/article/S0022-5223(20)30218-X/fulltext.

Duration of each training paradigm varies substantially among nations (Table 1). Trainees are required to complete a minimum of anywhere from 2 to 8 years of supervised training before board eligibility/certification. Some countries (Germany, Russia, China, and Japan) do not have rigid training timelines, instead focusing on attainment of operative experience or confirmation of training completion from each trainee's Department Chief before graduation and board eligibility/certification. In China for instance, after 3 to 5 years of basic cardiovascular surgical training, one may pass local examinations and earn the opportunity to perform simple cases independently, but still approximately 5 additional years are required to reach true independent practice.

When work hours are considered, the range of time spent training widens further. For instance, US trainees are prohibited from working more than 80 hours/week averaged over a 4-week period, and this is frequently viewed as a significant reduction from typical working hours of past generations.[13,19] New Zealand allows trainees to work up to 70 hours/week on average,[20] whereas Brazil limits trainees to no more than 60 hours/week.[3] As part of the European Working Time Directive, the United Kingdom and other European Union trainees are limited to no more than 48 hours/week, with serious concerns raised as to the limitations this places on operative experience, continuity of care, and resident satisfaction.[6,7,21] Canadian trainees are only limited in the number of overnight calls they are allowed to take during both their junior (4-6 calls/month) and senior (4-8 calls/month) years of cardiac surgical residency, without a total hour restriction,[2] whereas Israel, Russia, China, and Japan do not enforce work hour restrictions.

TABLE 1. Comparison of postgraduate cardiothoracic surgical training duration and milestones among various nations

Nation and training paradigm	Minimum training duration (y)	Minimum case benchmarks	Work hour limits (weekly)	Annual written in-training examination	Written and oral board examination
United States (CT)	6-8	Yes (Appendix E3)	80	Yes	Yes
New Zealand (CT)	6	Yes (Appendix E4)	70	No	Yes
United Kingdom (CT)	8	Yes (Appendix E5)	48	No	Yes
Germany (Cardiac)	6	Yes (Appendix E6)	48	No	No
Italy (Cardiac)	5	No	48	Yes	No
Brazil (CV)	5	Yes	60	Yes (Optional)	No
Japan (CV)	7	Yes (Appendix E7)	-	No	Yes
Canada (Cardiac)	6	No	-	No	Yes
Israel (CT)	6	Yes	-	No	Yes
Nordic countries (CT)	5-7	Variable	40	No	*
Russia (CV)	2	No	-	Yes	No
China (CV)	-	No	-	No	No

Training paradigms listed include cardiothoracic, isolated cardiac, and cardiovascular. Training duration represents total postgraduate surgical training after medical school graduation, not including advanced subspecialty training after completion of cardiothoracic surgical training (ie, transplant, congenital, aortic surgery, thoracic oncology). Continuous variables are denoted as values or ranges. Categoric variables are noted as "present" (yes) or "absent" (no). United States, Australia, New Zealand, and the United Kingdom. *CT*, Cardiothoracic; *CV*, cardiovascular. *Sweden, Denmark, Finland, and Norway each have their own method for board certification at training completion; however, obtaining board certification in 1 country entitles a surgeon to practice in the remaining Nordic and European countries.

Operative Experience

Operative experience for cardiothoracic trainees is also highly variable, in terms of overall case requirements, component procedural requirements, and the level of detail provided (Table 1 and Appendices E3-E8). The United States and New Zealand both prescribe highly detailed minimum case requirements for trainees (Appendices E3 and E4),[22,23] including expectations for trainees to log various cases in both the primary surgeon and first assistant role. Both the United States and New Zealand track component procedures (eg, sternotomy, coronary anastomosis), which serve as benchmarks for more junior trainees before completing operations "skin-to-skin." The United Kingdom and Germany require trainees to complete a minimum number of various "major" cases (Appendices E5 and E6)[24] that cover an array of operations, requiring that trainee serve as primary operating surgeon. It is not uncommon for German trainees to require more than the prescribed 6 years to attain adequate case volumes. A recent examination of sixth year German trainees demonstrates that only 18% had reached 100 pump cases by their sixth year, and the mean number of pump cases logged in the sixth year of training was only 30, whereas approximately one-third of trainees logged zero pump cases in their sixth year.[8] Italian case requirements are less granular and include logging both the operating surgeon and first assistant role based on subjective case complexity, but without detailed procedural/anatomic subcategories. Brazil requires trainees to complete at least 150 pump cases to be board-eligible. Case requirements throughout the Nordic countries are variable, whereas Sweden and Norway require trainees to complete at least 20 aortic valve replacements, 55 coronary artery bypass operations, and 20 anatomic pulmonary resections as the operating surgeon. For instance, Denmark and Finland allow the operative requirements to be determined at individual training centers. Japan requires trainees to complete at least 50 major cardiovascular operations as both the primary surgeon and first assistant, including a wide array of possible case composition and subsequent heterogeneity from one trainee to the next, although no single case type can be counted more than 10 times (Appendix E7). Japanese trainees must also accrue a total of at least 500 points, which are calculated on the basis of operative case numbers, case complexity, and level of trainee involvement (example in Appendix E7). Although the Royal College of Physicians and Surgeons of Canada does not provide operative case requirements, a detailed list of expected competencies is provided,[25] with minimum number of rotations on key services (Appendix E8), and a recent examination of Canadian cardiac surgery trainees demonstrated a trainee-reported median of 238 major cardiac cases performed in the final year of training alone.[26] Still other nations such as Russia and China do not have formal operative requirements.

Other pertinent differences remain in the breadth of thoracic surgical exposure for countries who offer cardiothoracic training. Notably, in the United States, esophageal and other foregut operations are frequently performed by thoracic surgeons, and thus represent a substantial portion of a cardiothoracic trainee's surgical experience (Appendix E3). Conversely, in New Zealand, the United Kingdom, and other European countries, most esophageal/foregut operations are performed by dedicated upper gastrointestinal surgeons, whereas thoracic surgeons in these countries tend to focus more exclusively on tracheal, pulmonary, and nongastrointestinal mediastinal pathology (Appendices E4-E6).

Although case requirements may appear to be more stringent in the United States than some other nations, a key difference that facilitates earlier operative exposure for US trainees is the growth of midlevel providers (nurse practitioners or physician assistants) as part of care teams. Involvement of these midlevel providers, which are far less prevalent outside the United States, frequently frees junior residents from tending to nonurgent issues on the wards to instead obtain earlier operative experience.[6]

The use of simulation offers opportunities for trainees to rehearse procedures and management of complex situations before encountering them in the operating room.[27,28] Bootcamp training experiences for junior trainees in the United States and Canada offer simulation for conduct of cardiopulmonary bypass, various vascular anastomoses, and other critical skills.[29] The Brazilian Society of Cardiovascular Surgery hosts 4 wet lab courses for trainees every year, and at the Brazilian Society of Cardiovascular Surgery annual scientific meeting an additional hands-on wet lab for trainees has also been introduced.[3] The United Kingdom, through the Society for Cardiothoracic Surgery in Great Britain and Ireland, has a curriculum of courses for trainees covering both operative and nonoperative skills. The Japanese Board of Cardiovascular Surgery appears to be one of the first to require at least 30 hours of "off-the-job" training, including approved simulations and wet labs. Although these examples are encouraging, none of the nations examined have implemented formalized longitudinal simulation or wet lab curriculum, although we anticipate rapid change in the future.

In-Training Assessments

Goals of periodic in-training assessments include quantifying growth of trainee knowledge and skills, identifying areas for improvement, and ensuring readiness for board examination/certification. Although the United States, Italy, and Russia require annual written in-training examinations, Brazil offers a nonmandatory annual examination for their trainees. Alternatively, New Zealand requires 2 periodic in-training examinations during training in preparation for board certification. In New Zealand, trainees are expected to complete both an objective structured clinical examination by the end of their second year and a written in-training exam by the end of year 4. In Canada, trainees are required to pass 2 Royal College of Physicians and Surgeons examinations to achieve full certification. The first (Surgical Foundations Examination) is taken after at least 2 years of training. The second (Cardiac Surgery Examination) is taken after completion of 6 years of cardiac surgery residency. The United Kingdom and Canada appear to place greater emphasis on frequent direct observation and feedback from attending surgeons, including technical evaluations. Finally, there are no formal in-training examinations mandated in Germany, Japan, Israel, or the Nordic countries, and each training center must make its own determinations of trainee readiness for graduation and readiness for board examination/certification.

Competency-based evaluations represent a growing area of investigation, offering an avenue to ensure quality among trainees faced with inequities of exposure to rapidly expanding knowledge and new techniques. The most robust implementations of competency-based evaluations include the Milestones Project in the United States, which includes areas such as medical knowledge, patient care, and technical skills, as well as similar endeavors in Canada and New Zealand.[2,5,30] However, several important questions remain before widespread adoption of competency-based evaluations or their replacement of time-based training methods. Some of these include the following: How to objectively measure milestone attainment? How do countries determine the need to add/remove milestones in the future? How do programs/countries make arrangements for trainees who are ready for advancement earlier than anticipated or for those requiring remediation?

Board Certification and Independent Practice

Most frequently, nations use a combination of both written and oral examinations for board certification testing, including the United States, Canada, United Kingdom, Israel, New Zealand, and Japan. Conversely, Italy and Germany rely heavily on oral examination, and in Germany oversight of board certification is performed at the state level, rather than the national level, with inherent variability, although no formal statistics for annual pass rates are available.[8] Brazil uses written examinations and direct observation of the trainee performing a case of at least moderate complexity as the operating surgeon, whereas the Nordic countries more heavily emphasize written examination and submission of completed training requirements before a certifying board of senior surgeons. Finally, Russia and China do not have uniform nationwide board certification processes, instead relying heavily on individual institutions to confirm trainee readiness.

Several nations also mandate completion of research including varying numbers of publications or national presentations during training, including Brazil, the United Kingdom, Italy, Israel, Japan, and New Zealand. The Nordic countries similarly encourage trainees to take dedicated time for research during their training and obtaining additional degrees is common.

Emphasis should be added that obtaining board certification is not necessarily synonymous with readiness for independent practice globally. For example, in Germany where board certification is subject to a significant degree of senior mentor discretion and there is no strict timeline for training, the process can become prolonged and has resulted in a pyramidal training structure with frequent attrition in the junior trainee ranks. Even after board certification is obtained, independent practice is not an immediate expectation, and instead the junior surgeon (Facharzt) still trains and performs most operations under supervision until they obtain the rank of senior specialist (Oberarzt). In Italy, a similar level of supervision after board certification is ubiquitous prior to gaining the ability to practice independently. In China and Japan, after board certification many junior surgeons maintain an apprentice-type role operating under a single senior surgeon to whom cases are directed while this senior surgeon's expertise further accumulates. It is not uncommon for surgeons to remain in a trainee/apprentice type role for 10 to 15 years before reaching true independent practice in China, despite possessing board certification. Junior surgeons may also seek additional international fellowship training or other academic avenues to distinguish themselves and reach independent practice more quickly.

Even if trainees feel subjectively prepared for independent practice, they may not immediately find such opportunities after graduation from residency. In Canada for instance, despite 88% of graduating residents feeling prepared for independent practice, pursuit of additional fellowship training after cardiac surgery residency is essentially mandatory to obtain an academic faculty position.[26] Despite Canadian cardiac surgery residency training being 6 years, the mean length of training for surgeons is substantially longer at 9.4 years.[2]

CHANGING PRACTICE LANDSCAPE

Catheter-Based Proficiency

Cardiothoracic surgery is in the midst of an endovascular revolution, demanding that surgeons obtain expertise in these areas should they want to maintain a foothold in the management of aortic and structural heart pathologies.[31-33] These skills remain highly sought after, and formalized training is relatively uncommon, as a previous survey of US I-6 trainees demonstrated that 100% desired increased exposure to cardiac catheterization and other endovascular techniques.[34] One approach for increased exposure to emerging techniques in centers of excellence has been adopted in New Zealand, requiring that trainees rotate through at least 3 centers during their training, thus increasing the likelihood that trainees will have exposure to endovascular training. Without question, training paradigms for cardiac surgery still require substantial overhaul in the formalization and dissemination of endovascular skills globally.

Specialty Fragmentation and Advanced Fellowships

Although subspecialty fellowships in congenital cardiac surgery and transplantation have existed for some time, there is an increasing number of advanced fellowships in aortic surgery, endovascular and structural heart therapies, and minimally invasive surgery. It remains unclear the degree to which pursuit of advanced fellowships is driven by (1) trainee interest in niche subspecialization; (2) inability to obtain gainful employment without subspecialty fellowship training; and (3) trainee perception of inadequate residency training and the need for additional experience before independent practice. Although advanced fellowship training allows surgeons to obtain a high degree of focused expertise, it remains incumbent upon residency programs to not necessarily see this as a perfunctory step after graduation. Advanced fellowships may not be as beneficial for those seeking to practice a broader scope of cardiothoracic or cardiovascular surgery, or work in rural/underserved communities.

Public Reporting

Cardiothoracic surgery remains a highly scrutinized specialty. Drawbacks of external pressures for public reporting of surgeon-specific outcomes include the potential for development of risk-averse practices and pressure on faculty to perform greater portions of operations themselves when they may have previously delegated such learning opportunities to qualified trainees. The practice of surgeon-specific public reporting is most widely used in the United Kingdom, and the accuracy, objectivity, and ability to draw meaningful conclusions from such data remain questionable.[2,35] Any future adoption of public reporting should have significant surgeon involvement to ensure the reported data is accurate, meaningful, and actionable.

RECOMMENDATIONS

Recognizing each nation will have unique needs, there remain a number of outcome and performance measures likely to benefit from standardization in nations that do not already have certain metrics in place. It seems difficult to imagine that weekly work restrictions of approximately 40 hours does not meaningfully interrupt operative experiences and continuity of patient care, and this limitation should likely be liberalized. Nations should set forth operative experience/case minimums that are sufficiently detailed to be actionable and beneficial for trainees. Pyramidal and open-ended training programs also expose trainees to situations in which they may train for prolonged periods of time without substantial gains in operative skills or independence. Simulation remains woefully underutilized and standardized training opportunities as seen in some countries at society-level training events for residents is likely the best starting point for wider dissemination of high-fidelity simulation experiences. Adding objectivity to training progression and board certification remains necessary in approximately half of the countries studied and should likely include both written and oral examinations. Opportunities for subspecialization should include focused training in predetermined areas (ie, structural heart, aortic surgery) during the final year(s) of training or be offered as separate postresidency fellowships to not only offer these additional opportunities for gaining expertise but also allow trainees seeking niche subspecialization the opportunity to distinguish themselves.

CONCLUSIONS

Cardiothoracic surgery represents a vibrant specialty that is rapidly changing, while various training programs across the globe aim to prepare the next generation of surgeon leaders. Individual nations have adopted widely variable methods for training. Incorporating training methodologies and best practices from other countries may serve to improve the training experience in host nations, and we hope to shed light on areas in need of improvement globally.

Conflict of Interest Statement

Dr Schmitto: consultant for Abbott and Medtronic. Dr Nguyen: consultant for Abbott, Edwards LifeSciences, and LivaNova. All other authors have nothing to disclose with regard to commercial support.

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Key Words: surgical education, cardiac surgery, global surgery

APPENDIX E1

Name/Degree(s):

Affiliation(s):

If you could please briefly comment on the following topics in your country/region as applicable. There are no word/length limitations to your replies. Feel free to include/list specific references below as needed.

- Prerequisites and Recruitment:
  - Medical School and any Preliminary/Core Surgical Training
  - Residency Applicant Selection Process
- Cardiothoracic Surgery Training Pathways:
  - Training in Cardiothoracic vs Cardiovascular vs Cardiac Surgery
  - "Traditional" vs "Integrated" Pathways and any required General Surgery Training
  - Advanced Fellowships after residency
  - Use of Simulation during Training
  - Research during Training
- Trainee Assessments:
  - Required Operative Experience
  - In-Training Exams
  - Board Certification
- Future Challenges:
  - Endovascular/Catheter-Based Skills
  - Work Hour Restrictions
  - Attracting the "Best and Brightest"
  - Competency-Based Evaluations

If you could please briefly complete the below table as able (row for US training included for example). Feel free to include/list specific references below as needed.

Nation and (training paradigm)	Minimum training duration (y)	Minimum case benchmarks	Work hour limits (weekly)	Annual written in-training examination	Written and oral board examination
United States (CT)	6-8	Yes	80	Yes	Yes
New Zealand (CT)					
United Kingdom (CT)					
Germany (Cardiac)					
Italy (Cardiac)					
Brazil (CV)					
Japan (CV)					
Canada (Cardiac)					
Israel (CT)					
Nordic countries (CT)					
Russia (CV)					
China (CV)					

Comparison of postgraduate cardiothoracic surgical training duration, and milestones among various nations. Training duration represents total postgraduate surgical training after medical school graduation, not including subspecialty training after completion of cardiothoracic surgical training (ie, transplant, congenital, aortic surgery, thoracic oncology). Continuous variables are denoted as values or ranges. Categoric variables are noted as "present" (X) or "absent" (blank).

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APPENDIX E3

US cardiothoracic surgical trainee minimum case requirements: applies to 5/2, 5/3, 4+3 trainees and I-6 residents who are postgraduate year (PGY) 4-6. Adapted from the US Accreditation Council for Graduate Medical Education.[22] Interim operative experience required during PGY 1 to 3 years of I-6 programs not included are shown.

Cardiac focused			Thoracic focused	
Total	Subtotal	Requirements	Subtotal	Total
		Congenital		
	5	Primary surgeon		
	15	First assistant	10	
20		Subtotal congenital heart disease		10
		Adult cardiac		
60		Acquired valvular heart disease		30
	25	Aortic valve repair/replacement	15	
	15	Mitral valve repair/replacement	5	
	5	Tricuspid repair/replacement	5	
	5	TAVR as primary	0	
	10	TAVR as first assist	5	
80		**Myocardial revascularization**		35
	15	**Re-do sternotomy** *Can be double-counted with other Cardiac procedures	5	
15		**Interventional wire-based procedures**		5
	5	Left heart catheterization, PCI, TEVAR, mitral clip		
	10	Intra-aortic balloon pump	5	
5		**Conduit dissection and preparation**		5
10		**Aortic procedures** *Can be double-counted with other CABG/valve cases		5
10		**Arrhythmia surgery**		
	5	Left atrial or biatrial maze, pulmonary vein isolation, right-sided maze, isthmus ablation. *Can be double-counted with CABG/valve cases		
	5	Pacemaker insertion/removal		
5		**Cardiopulmonary bypass setup and pump run with perfusionist**		5
10		**Circulatory assist** Any combination of extracorporeal membrane oxygenation and VAD *Can be double-counted with other cases		5
215		**Subtotal adult cardiac** (not including congenital cases)		100
		General thoracic		
60		**Lung**		105
	30	Major anatomic resection	50	
	5	VATS/RATS lobectomy specifically	25	
	25	Open or VATS lung biopsy/wedge	30	
10		**Pleura**		25
		Major (decortication, pleurectomy, other pleural tumor resection)	5	
		Minor (biopsy, VATS sympathectomy, VATS pleurodesis, hemothorax evacuation)	15	
		Interventional (in-dwelling catheter insertion)	5	
5		**Chest wall and diaphragm**		10
5		**Mediastinum**		10
0		**Tracheobronchial**		5
10		**Esophagus**		35
	5	Esophagectomy	20	
	5	Benign esophagus	10	
		Laparoscopic hiatal or paraesophageal hernia repair	5	
90		**Subtotal general thoracic**		190
305		**Total major operative experience**		**290**
		Minor procedures *All may be double-counted		
30		**Bronchoscopy**		40

(Continued)

Continued

Cardiac focused Total	Cardiac focused Subtotal	Requirements	Thoracic focused Subtotal	Thoracic focused Total
10		**Upper gastrointestinal endoscopy**		30
15		**Mediastinal assessment**		55
55		**Subtotal minor procedures**		125
360		**Total operative experience**		**415**

TAVR, Thoracic endovascular aortic repair; *PCI*, percutaneous coronary intervention; *TEVAR*, thoracic endovascular aortic repair; *CABG*, coronary artery bypass grafting; *VAD*, ventricular assist device; *VATS*, video-assisted thoracoscopic surgery; *RATS*, robotic-assisted thoracoscopic surgery.

APPENDIX E4

Australia and New Zealand cardiothoracic surgical trainee minimum case requirements: adapted from the Royal Australasian College of Surgeons.[23] Interim operative experience required by the end of surgical education and training

Component procedures *As assisted or unassisted primary operator	Required case numbers
Aorto-coronary anastomosis	75
Cannulation for bypass	50
Distal coronary anastomosis	75
Insertion of coronary sinus cannula	50
Internal thoracic artery harvest	125
Median sternotomy	200
Radial artery harvest	50
Redo sternotomy	10
Saphenous vein harvest	125
Sternal closure	200
Operative experience	
Cardiac	
Coronary artery bypass	
Unassisted	10
Trainee assisted	75
First assistant	300
Aortic valve surgery	
Trainee assisted	10
First assistant	50
Aortic surgery	
First assistant	20
Mitral valve surgery	
Trainee assistant	5
First assistant	30
Other valve surgery	
First assistant	10
Pacemakers	
Trainee assisted	20
Total major cardiac procedures	
Trainee unassisted	10
Trainee assisted	100
First assistant	600
Thoracic	
Thoracotomy ± lung biopsy	
Trainee unassisted	5
Trainee assisted	10
First assistant	10
Pulmonary resection	
Trainee unassisted	5
Trainee assisted	20
First assistant	20
Total major thoracic procedures	
Trainee unassisted	10
Trainee assisted	30
First assistant	50
VATS procedures	
Trainee unassisted	20
Trainee assisted	50
Bronchoscopy	
Trainee assisted/unassisted	80

(Continued)

VATS, Video-assisted thoracic surgery.

APPENDIX E5

UK cardiothoracic surgical trainee summary of major cardiac and thoracic cases: 250 total major cases required for graduating trainees. Adapted from Zakkar and colleagues[7]

Cardiac major cases
CABG, alone or in combination with another operation
Valve repair or replacement alone or in combination with CABG or other cardiac operation
Other major cardiac operations involving cardiopulmonary bypass, such as postinfarct VSD repair, excision of atrial myxoma, or pericardiectomy
Heart or lung transplantation
Heart or lung retrieval
Any congenital cardiac operation (atrial septal defect, VSD closure, patent ductus arteriosus ligation)
Thoracic major cases
Anatomic lung resection (open, VATS, robotic)
Correction of pectus deformity
Decortication
Thoracotomy for trauma
Chest wall resection and reconstruction
Tracheal resection
Surgery for secondary pneumothorax (VATS, open)

CABG, Coronary artery bypass grafting; *VSD*, ventricular septal defect; *VATS*, video-assisted thoracic surgery.

APPENDIX E6

German cardiothoracic surgical trainee minimum case requirements: adapted from Wick and colleagues[8,24]

Required procedure, with cardiopulmonary bypass	Required case numbers
Total	100
Coronary revascularization	40
Conventional or catheter-based valve surgery	25
Assist in complex cardiac-related procedures (eg, combined operations or reoperations)	150
Required procedure, without cardiopulmonary bypass	**Required case numbers**
Total	170
Temporary pacemaker implantation	25
Implantation of cardiac implantable electronic device	25
Thoracotomy and exploration	35
Lung and mediastinal operations in the context of cardiac procedures	10
Operation on peripheral vessels in the context of cardiac procedures (eg, reconstruction after use of extracorporeal support, harvest of bypass grafts, thrombectomy)	50

APPENDIX E7

Japanese cardiovascular surgery trainee case requirements

1. ≥50 cases as a surgeon (the same procedure type can be counted up to 10 cases)
2. ≥50 cases as a first assist.
3. The total case point needs to be >500

Point Multiplier Chart Based on Case Complexity and Surgeon Role:

	Case classification		
Surgeon role	A	B	C
Primary surgeon	3	4	5
First assistant	1.5	2	2.5
Second assistant	0.3	0.4	0.5

CASE COMPLEXITY CLASSIFICATIONS

Class A

Patent ductus arteriosus closure, atrial septal defect closure, ventricular septal defect (VSD) closure (infundibular type), pulmonary artery banding, tricuspid valve repair, pericardial window, pulmonary vein isolation, arterial/venous thrombectomy, lower extremity bypass (femoral/popliteal), peripheral artery aneurysm repair, percutaneous arterial angioplasty (peripheral/visceral), varicose vein surgery, percutaneous venous angioplasty, inferior vena cava filter placement, dialysis access, thoracic sympathectomy, amputation, arterial/venous graft harvest, intra-aortic balloon pump or extracorporeal membrane oxygenation cannulation/decannulation.

Class B

Pulmonary artery shunt, coarctation repair, VSD closure (perimembranous/muscular type), partially anomalous pulmonary venous return repair, partial AVSD repair, sinus of Valsalva aneurysm repair, right ventricular outflow tract plasty, coronary fistula repair, bidirectional Glenn procedure, aortic valve replacement (AVR), mitral valve replacement, transcatheter aortic valve replacement (TAVR), single-vessel CABGx1, cardiac tumor resection, constrictive pericarditis repair, Maze procedure, ascending aortic repair, descending aortic repair, abdominal/iliac artery repair, endovascular aortic repair (EVAR) or thoracic endovascular aortic repair (TEVAR), open lower extremity bypass (tibial), upper extremity revascularization, carotid artery stenting, pulmonary artery thrombectomy, peripheral venous reconstruction, thoracic outlet syndrome without revascularization, vascular trauma, dialysis access (graft/superficialization).

Class C

Tetralogy of Fallot repair, transposition of the great arteries repair, double outlet right ventricle repair, total anomalous pulmonary venous return repair, complete AVSD repair, Fontan procedure, truncus arteriosus repair, repair of Ebstein's anomaly, Norwood procedure, supra/infra aortic stenosis repair, coronary anomaly repair, Ross procedure, multiple VSD repair, mitral valve repair, aortic valvuloplasty, multivalve procedures, aortic annular enlargement, aortic root repair, multivessel CABG, acute myocardial infarction complication repair, left ventricular aneurysm resection/repair, left or right ventricular assist device placement, aortic arch repair, thoracoabdominal aortic repair, open abdominal aortic aneurysm with suprarenal clamping, aortic dissection repair, inflammatory/infectious aortic aneurysm repair, ruptured aortic/peripheral/visceral aneurysm repair, EVAR/TEVAR with branch reconstruction, internal iliac aneurysm repair (including abdominal aortic aneurysm repair), lower extremity bypass (pedal), carotid endarterectomy, vertebral artery revascularization, prosthetic graft infection repair, infected aortic aneurysm repair, profundoplasty, thoracic outlet syndrome with revascularization, cavoplasty, pulmonary thromboendarterectomy, lymphatic anastomosis.

Example Point Calculation

1 venous graft harvest as primary surgeon, 1 AVR primary surgeon, and 2 multivessel CABG cases as first assistant = (1*3) + (1*2) + (2*2.5) = 3 + 2 + 5 = 10 total points toward minimum total of 500.

APPENDIX E8

Canadian Cardiac Surgery trainee rotation and specialty requirements. Adapted from Noly and colleagues[2]

Type of rotation/specialty	No. of blocks/ rotations required (1 block = 1 mo)
Foundational training in surgery (PGY1 and PGY2)	
Cardiac surgery	3
Critical care medicine	3
Anesthesia	1
General surgery	2
Trauma surgery	1
Cardiology (coronary care unit, ward, electrophysiology, interventional cardiology, echocardiography, cardiac imaging)	6
Emergency medicine	1
Vascular or thoracic surgery	4
Free choice: pathology, infectious disease, geriatrics, nephrology, neurology, cardiology, plastic surgery, cardiac surgery, general surgery, echocardiography	5
Royal College Examination: surgical foundations	
Academic/clinical enrichment	6 to 13
Specialty in cardiac surgery (PGY4 to PGY6)	
Cardiac surgery (at least 13 blocks as a senior resident and 6 blocks as a chief resident)	20
Thoracic surgery and vascular surgery (at least 3 as a senior resident in thoracic surgery and 6 as a senior resident in vascular surgery)	13
Congenital cardiac surgery	6
Royal College Examination: cardiac surgery	