ADULT

Trends in the traditional cardiothoracic surgery resident operative experience for cardiac cases: An analysis of Accreditation Council for Graduate Medical Education case logs

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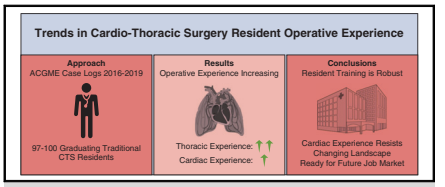
ABSTRACT

Objective: To determine whether the changing cardiac landscape has affected traditional cardiothoracic surgery (CTS) resident case volume, particularly cardiac case volume.

Methods: The Accreditation Council for Graduate Medical Education (ACGME) case logs for traditional CTS residents from 2016 to 2019 were reviewed. Using linear and nonlinear regression, trends in the annual volume and proportion of CTS operations were examined.

Results: Overall, the average number of total and category-specific CTS resident cases have increased from 2016 to 2019. However, in general, the proportion of thoracic surgery cases has been increasing, and the proportion of cardiac surgery cases has been decreasing. In particular, the proportion of coronary atherosclerosis (-0.2546 per 100 cases/year; $P < .001$) and valvular heart disease (-0.319 per 100 cases/year; $P < .001$) procedures demonstrated the greatest downward trends. The average operative experience for residents has increased (28.8 cases/resident/year; $P < .001$), but cardiac track residents (22.24 cases/resident/year; $P < .001$) have had a smaller increase than thoracic track residents (35.04 cases/resident/year; $P < .001$). Nevertheless, cardiac track residents experienced an increase in their average proportion of cardiac cases (0.176 per 100 cases/year; $P < .001$) compared with average (-0.263 per 100 cases/year; $P < .001$) and thoracic track (-0.978 per 100 cases/year; $P < .001$) CTS residents, indicating specialization of the tracks.

Conclusions: The overall CTS resident operative experience has increased over the last several years, with cardiac cases increasing more slowly than thoracic cases. The analysis reveals that cardiac operative volume has been asymmetrically allocated to cardiac track residents, indicating a greater specialization of the tracks. Annual evaluation of CTS resident case volume will provide essential insight into the field. (J Thorac Cardiovasc Surg 2021;161:1064-75)



CTS operative experience expanded, albeit cardiac cases rising slower than thoracic cases.

CENTRAL MESSAGE

The cardiac experience for traditional cardiothoracic surgery (CTS) residents is robust. Nonetheless, novel methods to increase the CTS resident operative experience should be pursued.

PERSPECTIVE

Our objective was to determine whether cardiac volume has been influenced by the evolving cardiac landscape. We found that despite cardiac cases growing at a slower rate than thoracic cases, the average graduating resident case volume for nearly all major CTS operative categories increased from 2016 to 2019. Regardless, we encourage the continued pursuit of strategies to improve the resident experience.

See Commentaries on pages 1076, 1077, and 1078.

Cardiothoracic surgery (CTS) residents rely on operative volume for surgical experience and proficiency.[1] Previous studies have demonstrated that increased surgical operative volume is associated with improved outcomes and with increased confidence of graduating residents.[2-4] In recent years, the evolving management of cardiac patients has led to reductions in the use of many common cardiac surgical procedures, including coronary artery bypass grafting (CABG) and surgical aortic valve replacement (SAVR).[5,6] Advancements in technology and patient

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Abbreviations and Acronyms

ACGME = Accreditation Council for Graduate Medical Education
CABG = coronary artery bypass grafting
CTS = cardiothoracic surgery
CV = cardiovascular
SAVR = surgical aortic valve replacement
TAVR = transcatheter aortic valve replacement
VATS = video-assisted thoracic surgery

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management have enabled physicians to reliably diagnose and treat cardiac patients with percutaneous endovascular procedures.[7,8] For example, from 2008 to 2012, CABGs decreased by 4.98% and accounted for only approximately 25% of cardiac revascularization procedures, and from 2009 to 2015, SAVRs decreased by 28.7% in the Medicare population.[5,9,10] In addition, because of the advances in medical management for atherosclerotic heart disease, the overall total number of revascularization procedures decreased by 42.2%.[5,11]

These trends represent only one of the many factors influencing CTS operative volume, however. Recent expansions in the elderly population may help CTS residents maintain or even increase their operative experience.[12] Nonetheless, because open cardiac procedures are still essential for many patients, residents and those involved in CTS resident education should be aware of the evolving landscape in the field and should ensure that graduating CTS residents are comfortable performing these operations. Early detection of inadequate operative volume will enable modification of CTS programs to maintain their residents' proficiency in open surgical techniques.

The primary goal of the present study was to assess how the shifting cardiac landscape has affected CTS residents' operative experience. We believe that frequent analysis of CTS trends will help the cardiac job market recognize changes in CTS graduate experience.

METHODS

This retrospective study used the annually published Accreditation Council for Graduate Medical Education (ACGME) operative case logs of traditional CTS residents completing their programs in 2016 to 2019. No other years of data for CTS were publicly available. These case logs combine 2- and 3-year traditional CTS residents and report the average number of cases performed by graduating residents for that specific year. These resident operative averages specify surgeries performed in the surgeon and assistant roles. For analysis, the surgeon and assistant volumes were totaled, because the reported assistant volume accounted for only 8% of the total case load during this time frame. The cases were categorized by the anatomy and/or the pathology involved in the surgery: chest wall, lung and pleura, tracheobronchial, mediastinum, diaphragm, esophagus, video-assisted thoracic surgery (VATS), congenital, valvular heart (ie, mitral aortic valvular repair, valve replacements, aortic root replacement, reoperation for valvular disease, and other), coronary atherosclerosis (ie, primary CABG, reoperation for recurrent disease, ventricular aneurysm surgery, surgery for acquired ventricular septal defects and coronary anomalies/fistulas, and other), pericardium, other major cardiac (ie, arrhythmia surgeries, insertion of epicardial electrical device, insertion and removal of cardiac assist devices, minimally invasive surgeries, surgeries for the removal of intracardial foreign bodies and the repair of injury from cardiac-related trauma, and other major cardiac procedures), thoracic vascular, transplantation, minor thoracic and cardiovascular (CV), and endovascular. In addition to examining variations in the average total and category-specific case volume across the 4-year span, the changes in case proportions in each of the categories (ie, category-specific cases/total number of cases) were examined. This helped adjust for natural increases in the total number of cases each year and revealed trends in category-specific cases within the field. Also, changes in the case threshold for the 10th and 90th percentiles of resident case volume were assessed for cardiac surgery cases from 2017 to 2019, because data for 2016 were unavailable. Changes in the percentiles would reflect changes in the range of the data.

The average-track CTS resident is defined as a resident of either the cardiac or thoracic track. These case volumes were stratified by the resident's specific track (ie, cardiac or thoracic) and grouped into the 4 major operative categories: total cardiac (ie, congenital and adult cardiac), congenital, adult cardiac, and general thoracic procedures. These track-specific procedure counts were reported by the ACGME only for the surgeon role procedures, except for total congenital procedures, which were reported as the total of surgeon and assistant role procedures. Again, variations in volume and category proportions (ie, category-specific cases/total cases for the specific residency track) were examined.

Statistical Analysis

Using SPSS version 23.0 (IBM, Armonk, NY), unadjusted linear regression analyses were performed to calculate regression coefficients and to determine the significance of trends for each CTS resident case category. Each annual average was weighted by the number of residents it surveyed. Although this method makes assumptions about the raw data used to calculate each average, it more accurately demonstrates the true robustness of the data, including the trends and effect size. However, weighting the averages did result in artificiality when calculating R^2 values from the regression analyses. Because of their misleading nature, we avoided reporting them. The focus of the study is on the effect size and trends of CTS resident operative experience. Nonlinear regression analyses were conducted to determine whether any of the track-specific dependent variables had significant quadratic associations with residency completion year. All statistical calculations were considered significant at $P < .05$.

These data do not have any patient identifiers and are available to the public and thus did not require review by Rutgers New Jersey Medical School's Institutional Review Board.

RESULTS

Trends in Category-Specific Case Volume

From 2016 to 2019, the number of operative procedures for the average CTS resident increased in each category despite a relatively constant number of graduating CTS

residents, CTS programs, and CTS operative minimum requirements (Table 1 and Table E1). The categories with the greatest increases were dominated by thoracic procedures: mediastinum (6.00 cases/resident/year; $P < .001$) and lung and pleura (5.93 cases/resident/year; $P < .001$). With the exception of "other major cardiac" procedures, the cardiac categories had moderate to minimal increases (Table 1). These relative differences between thoracic and cardiac procedures correlated well with the observed changes in resident case thresholds for the 10th and 90th percentile. Whereas the mediastinum and lung and pleural categories had increases in their 10th and 90th percentile case thresholds, for the most part, the coronary atherosclerotic and valvular heart categories had decreases in their 10th and 90th percentile case thresholds (Table E2). This shows that cardiac case volumes are becoming more moderate and that their distribution is becoming narrower. Overall, the growth of thoracic procedures exceeded that of cardiac procedures.

Further analysis of changes in category-specific proportions showed that by and large, thoracic operative proportions trended upward and cardiac operative proportions trended downwards (Figure E1). Similar to the case volume trends, the mediastinum (0.605 per 100 cases/year; $P < .001$) and lung and pleura (0.193 per 100 cases/year; $P < .001$) proportions increased significantly, and the coronary atherosclerotic (-0.255 per 100 cases/year; $P < .001$) and valvular heart (-0.320 per 100 cases/year; $P < .001$) proportions decreased significantly. Nonetheless, 2 cardiac procedural categories saw case proportion increases: other major cardiac (0.295 per 100 cases/year; $P < .001$) and endovascular (0.0447 per 100 cases/year; $P < .001$). Both of these categories include less invasive procedural techniques (Table 2).

For a more thorough understanding of the specific procedures responsible for the decline observed among the cardiac procedures, an analysis was performed on the largest cardiac categories: coronary atherosclerotic and valvular heart. In the coronary atherosclerotic category, nearly all of cases were listed in the subcategory of CABG, and thus CABGs were responsible for the observed trends. In the valvular heart disease category, case volume was spread among the subcategories of mitral aortic valvular repair, valve replacements, aortic root replacement, and reoperation for valvular disease. Analysis of these subcategories revealed an increase in mitral aortic valvular repair (0.670 cases/resident/year; $P < .001$) and replacement (1.670 cases/resident/year; $P < .001$) and a significant decrease in aortic root replacement (-0.200 cases/resident/year; $P < .001$) and reoperation for valvular disease (-0.510 cases/resident/year; $P < .001$) (Table E3).

Trends in Track-Specific Case Volume

From 2016 to 2019, despite a relatively constant number of cardiac and thoracic track residents, the average CTS resident operative experience increased the number of operative procedures for CTS residents: major operative (28.8 cases/resident/year; $P < .001$), total cardiac (15.78 cases/resident/year; $P < .001$), congenital cardiac (0.250 cases/resident/year; $P < .001$), adult cardiac (15.53 cases/resident/year; $P < .001$), and general thoracic (13.04 cases/resident/year; $P < .001$) (Table 3, Table E4). Of note, the operative

TABLE 1. Trends in case volume by operation type, 2016 to 2019

Operation type	2016	2017	2018	2019	Regression coefficient	*P* value*
Chest wall	17.4	18.8	22.4	21.7	1.65	<.001
Lung/pleura	121.0	130.9	133.5	139.9	5.93	<.001
Tracheobronchial	3.9	4.7	4.1	5.1	0.30	<.001
Mediastinum	27.5	34.2	33.9	47.6	6.00	<.001
Diaphragm	3.4	4.1	4.5	4.8	0.46	<.001
Esophagus	35.4	40.8	41.2	42.4	2.14	<.001
VATS	8.3	9.2	8.9	6.6	−0.54	<.001
Congenital	39.1	42.9	42.1	40.2	0.25	<.001
Valvular heart	127.0	124.4	130.1	131.4	1.89	<.001
Coronary atherosclerosis	112.7	118.3	116.2	119.9	1.95	<.001
Pericardium	6.2	5.7	5.4	6.5	0.06	.004
Other major cardiac	35.0	38.4	43.6	45.5	3.67	<.001
Thoracic vascular	23.4	21.6	21.9	22.1	−0.36	<.001
Transplantation	24.1	25.6	24.2	27.7	0.94	<.001
Minor thoracic/CV	152.3	165.8	150.5	163.3	1.77	<.001
Endovascular	2.7	2.5	2.1	4.4	0.47	<.001

Data are presented as average number of category-specific operations per cardiothoracic surgery resident. Linear regression analysis was performed on each operative category; the regression coefficient represents the change in cases per year. *VATS*, Video-assisted thoracic surgery; *CV*, cardiovascular. **P* value weighted by annual number of residents.

TABLE 2. Change in proportion of caseload by operation type, 2016 to 2019

Location	Regression coefficient	*P* value*
Chest wall	0.126	<.001
Lung/pleura	0.193	<.001
Tracheobronchial	0.019	<.001
Mediastinum	0.605	<.001
Diaphragm	0.041	<.001
Esophagus	0.105	<.001
VATS	−0.101	<.001
Congenital	−0.140	<.001
Valvular heart	−0.320	<.001
Coronary atherosclerosis	−0.255	<.001
Pericardium	−0.020	.004
Other major cardiac	0.295	<.001
Thoracic vascular	−0.145	<.001
Transplantation	0.008	<.001
Minor thoracic/CV	−0.457	<.001
Endovascular	0.045	<.001

Linear regression analysis was performed on each operative category; the regression coefficient represents the change in cases per total cases per 100 cases per year. *VATS*, Video-assisted thoracic surgery; *CV*, cardiovascular. **P* value weighted by the annual number of residents.

experience of cardiac track residents is increasing at a slower rate than the operative experience of thoracic track residents (22.24 cases/resident/year vs 35.04 cases/resident/year; $P < .001$) (Table 3). Significant quadratic equations were found for the major operative case volume of the average, cardiac, and thoracic tracks demonstrating a more curved increase for cardiac track CTS residents compared with thoracic track CTS residents (Figure 1, Table 3). However, as expected, the cardiac operative experience is increasing at a faster rate for cardiac track residents compared with thoracic track residents (16.15 cases/resident/year vs 9.94 cases/resident/year; $P < .001$). Significant quadratic equations were found for the adult cardiac case volume of the average, cardiac, and thoracic tracks demonstrating a more linear increase for thoracic track CTS residents compared with cardiac track CTS residents (Figure 2, Table 3).

Evaluation of the proportions of major CTS operative categories revealed a greater specialization of the cardiac and thoracic track for CTS residents. Even though the average CTS resident operated on an increasing proportion of thoracic cases compared with a decreasing proportion of adult cardiac cases over the specific time span, track-specific trends were not necessarily reflective (Table 4, Figure 3). For the cardiac case proportions, cardiac track CTS residents encountered a shift toward a more focused adult cardiac experience, indicated by a significantly increasing slope (0.176 per 100 cases/year) and a significant upward opening quadratic ($y = 0.681 + -0.015x + 0.003x^2$) (Figure 3, Table 4). Thoracic track CTS residents encountered a shift toward a less focused adult cardiac experience, indicated by a significantly decreasing slope (-0.978 per 100 cases/year) and a significant downward opening quadratic ($y = 0.471 + -0.0002x + -0.002x^2$) (Figure 3, Table 4). These findings are supplemented by trends in the proportion of thoracic cases. Although both tracks showed an increase in their proportion of thoracic cases, thoracic track CTS residents had a larger increase in their proportion of thoracic cases compared with cardiac track CTS residents (Table 4).

TABLE 3. Change in major cardiothoracic operative cases by category, by track, 2016 to 2019

Cases	2016	2017	2018	2019	Regression coefficient	*P* value*
Average track						
Total cardiac	400.9	418.2	416.4	454.1	15.78	<.001
Congenital	39.0	42.9	42.1	40.1	0.25	<.001
Adult cardiac	361.9	375.3	374.3	414.0	15.53	<.001
Thoracic	200.7	219.4	225.9	242.0	13.04	<.001
Major operative	601.6	625.5	630.0	696.1	28.80	<.001
Cardiac track						
Total cardiac	474.8	476.3	483.3	526.1	16.09	<.001
Congenital	47.3	52.8	50.1	48.0	−0.06	<.001
Adult cardiac	427.5	423.5	433.2	478.1	16.15	<.001
Thoracic	164.2	171.7	183.7	180.5	6.09	<.001
Major operative	639.1	633.0	652.9	706.6	22.24	<.001
Thoracic track						
Total cardiac	282.5	315.5	286.6	326.6	10.34	<.001
Congenital	25.4	25.4	26.7	26.3	0.40	.667
Adult cardiac	257.1	290.1	259.9	300.3	9.94	<.001
Thoracic	270.1	303.9	307.8	351.1	24.69	<.001
Major operative	552.6	612.3	587.4	677.7	35.04	<.001

Data are presented as average number of category-specific operations per cardiothoracic surgery resident. Linear regression analysis was performed on each operative category; the regression coefficient represents the change in cases per year. Total cardiac = congenital + adult cardiac. **P* value weighted by annual number of residents.

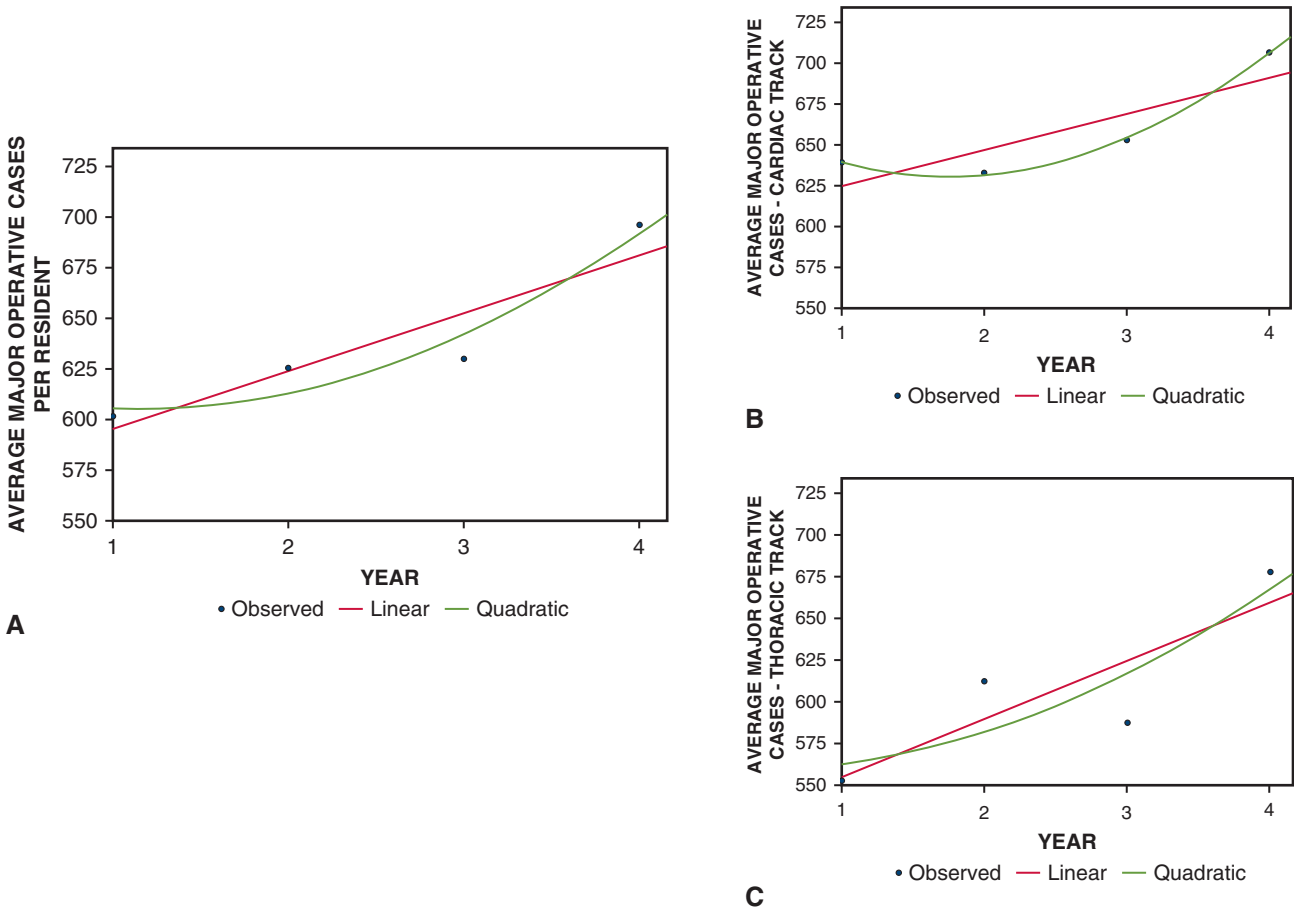


FIGURE 1. Trends in major operative case volume separated by cardiothoracic surgery (CTS) track from 2016 to 2019. Total cases for the average track (28.8 cases/resident; $P < .001$, linear regression test) (A), cardiac track (22.24 cases/resident; $P < .001$, linear regression test) (B), and thoracic track (35.04 cases/resident; $P < .001$, linear regression test) (C) CTS residents increased from 2016 to 2019. The thoracic track operative experience increased by more than the cardiac track operative experience. Significant quadratic equations were found for each track; cardiac track residents ($y = 677.1 + -52.5x + 15.0x^2$, nonlinear regression test) experienced a more narrow positive parabolic trend compared with the average ($y = 619.2 + -24.3x + 10.6x^2$, nonlinear regression test) and thoracic track CTS residents ($y = 558.6 + -4.0x + 7.8x^2$, nonlinear regression test). Tracks experienced a steep increase in operative experience from 2018 to 2019. The data represents the average cases per resident for the specific CTS tracks (cardiac and thoracic). Depending on the year, 97 to 100 residents were surveyed for each average. *X*-axis: 1, 2016; 2, 2017; 3, 2018; 4, 2019. Refer to Table 3 for raw values.

Comparison of Trends for Adult Cardiac Cases: 2016 to 2018 Versus 2018 to 2019

Most of the increase in cardiac-related cases occurred between 2018 and 2019. A subanalysis comparing the case trends between 2016 to 2018 and 2018 to 2019 revealed that for the average CTS resident, total cases increased by 45.2 cases/resident and 44.5 cases/resident, respectively, and adult cardiac cases increased by 12.4 cases/resident and 39.7 cases/resident, respectively (Figure 2). Specifically, coronary atherosclerotic operations increased by 3.5 cases/resident and 3.7 cases/resident, respectively. These findings were supported by decreases in the 10th and 90th percentile case thresholds for coronary atherosclerotic operations (-1 and -24 cases/resident, respectively) from 2017 to 2018 and by increases in the 10th and 90th percentile case thresholds for coronary atherosclerotic operations (6 and 9 cases/resident, respectively) from 2018 to 2019 (Table E2). In addition, for cardiac and thoracic track CTS residents, adult cardiac cases increased by 5.2 cases/resident between 2016 and 2018 and by 44.9 cases/resident between 2018 and 2019 for the former and by 2.8 cases/resident between 2016 and 2018 and by 40.4 cases/resident between 2018 and 2019 for the latter (Figure 2). This expansion of cardiac volume in 2019 is reflected in cardiac track residents by a reversal of the downward trend in the proportion of adult cardiac procedures from 2016 to 2018 and in thoracic track residents by a flattening of the downward trend in the proportion of adult cardiac procedures (Figure 3).

DISCUSSION

This retrospective analysis of ACGME CTS resident case logs has identified trends in graduating CTS resident surgical volume over the 4-year span of 2016 to 2019. Our

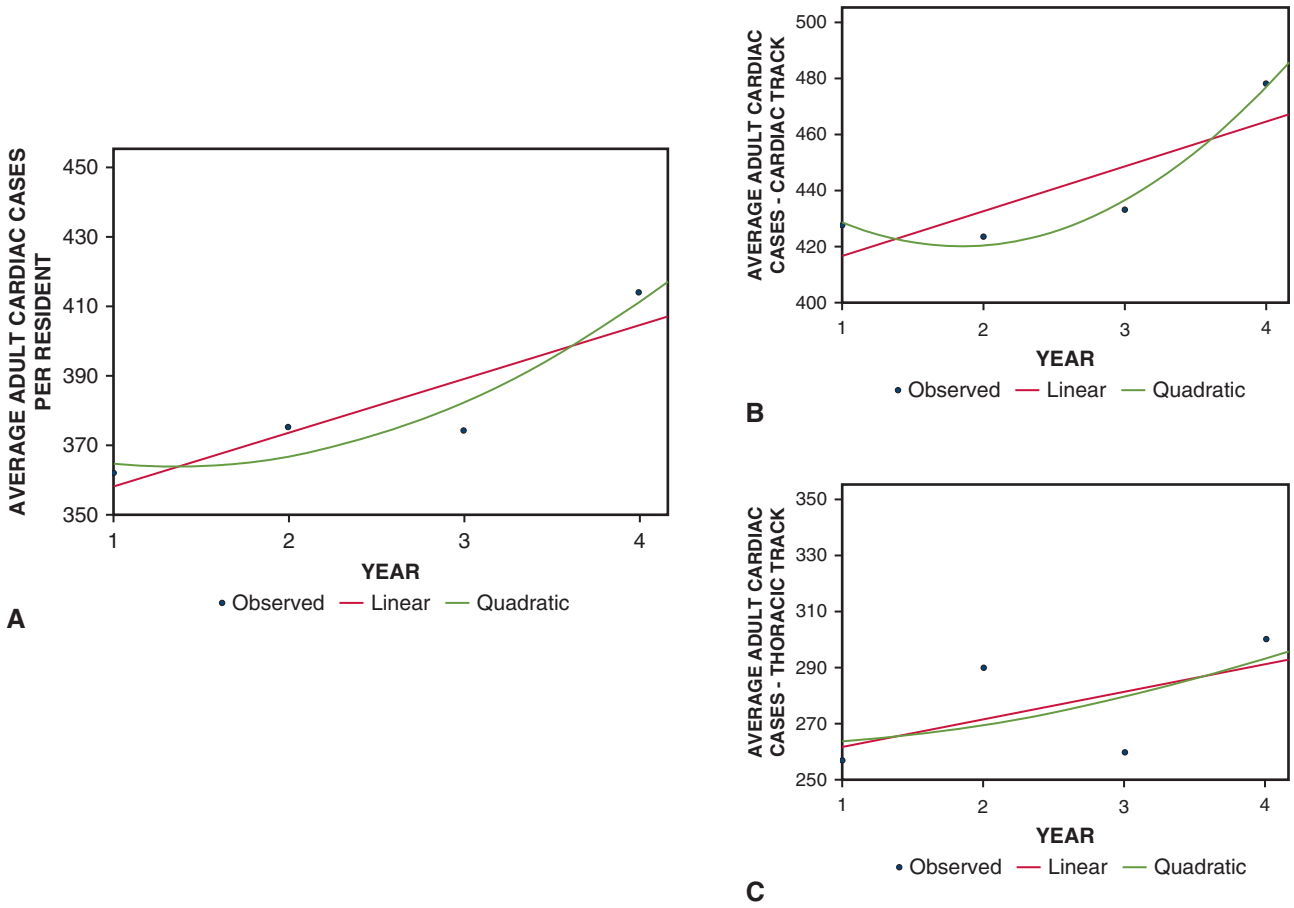


FIGURE 2. Trends in adult cardiac case volume by cardiothoracic surgery (CTS) track from 2016 to 2019. Adult cardiac cases for the average track (15.53 cases/resident; $P < .001$, linear regression test) (A), cardiac track (16.15 cases/resident; $P < .001$, linear regression test) (B), and thoracic track (9.94 cases/resident; $P < .001$, linear regression test) (C) CTS residents increased from 2016 to 2019. The adult track adult cardiac operative experience increased by more than the thoracic track adult cardiac operative experience. Significant quadratic equations were found for each track; cardiac track residents ($y = 461.4 + -45.1x + 12.2x^2$, nonlinear regression test) experienced a more narrow positive parabolic trend compared with the average ($y = 375.6 + -17.6x + 6.6x^2$, nonlinear regression test) and thoracic track CTS residents ($y = 261.6 + 0.2x + 2.0x^2$, nonlinear regression test). Tracks experienced a steep increase in operative experience from 2018 to 2019. The data represents the average cases per resident for the specific CTS tracks (cardiac and thoracic). Depending on the year, 97 to 100 residents were surveyed for each average. *X*-axis: 1, 2016; 2, 2017; 3, 2018; 4, 2019. Refer to Table 3 for raw values.

findings show that CTS residents have had an expansion of their overall operative experience, with cardiac track residents experiencing a slower operative increase than thoracic track residents and cardiac cases expanding at a slower rate than thoracic cases. Track-specific analysis revealed increasing specialization of the 2 tracks, as residents from both tracks maintained a greater increase in the volume and proportion of cases in their respective specialties. In particular, the largest expansion among CTS cases was from 2018 to 2019.

We have demonstrated that, even in this changing landscape, CTS residents still have a robust operative experience, as the average total and category-specific number of cases have increased annually from 2016 to 2019. Even when separated by track, all CTS residents experienced increases in all operative categories: total cardiac, general thoracic, and major operative. However, the data do show increasing specialization among CTS residents, with cardiac track residents having a larger increase in cardiac cases and thoracic track residents having a larger increase in thoracic cases. These findings were interesting amid the large decrease in cardiac surgeries observed over the last decade.[5,6] They reveal that academic centers, as high-volume institutions, have maintained their cardiac surgery operative volume even as the general population requires fewer cardiac surgeries.

However, CTS residents have not been immune to the evolving management of adult cardiac patients. Investigation of the CTS resident operative categories revealed a downward trend in the proportion of procedures in the cardiac-related categories, particularly coronary atherosclerotic and valvular heart disease. These findings were supplemented by decreases in the proportion of adult cardiac cases for the average and thoracic track CTS resident.

TABLE 4. Change in the proportion of case volume by category, by track, 2016 to 2019

Category	Regression coefficient	*P* value*
Average track		
Total cardiac	−0.498	<.001
Congenital	−0.234	<.001
Adult cardiac	−0.263	<.001
Thoracic	0.499	<.001
Cardiac track		
Total cardiac	−0.073	<.001
Congenital	−0.249	<.001
Adult cardiac	0.176	<.001
Thoracic	0.057	.317
Thoracic track		
Total cardiac	−1.152	<.001
Congenital	−0.175	<.001
Adult cardiac	−0.978	<.001
Thoracic	1.156	<.001

Linear regression analysis was performed on each operative category. The regression coefficient represents the change in cases per total cases per 100 cases per year. Total cardiac = congenital + adult cardiac. **P* value weighted by annual number of residents.

Although cardiac track residents have shown an increase in the proportion of cardiac case volume (a finding partially attributable to specialization), for the most part thoracic cases have expanded more rapidly than cardiac cases. This may be due in part to enhanced screening techniques for lung cancer and increasing rates of lung cancer surgeries.[13,14] Nonetheless, evolving management of adult cardiac patients may be primarily responsible. Recent landmark trials, such as the PARTNER3, the 10-year follow up of the SYNTAX, Evoltu Low Risk, and NOBLE trial, have shown endovascular procedures to be as effective and reliable as their surgical counterparts and have led to the publication of more conservative guidelines.[7,15-17] In particular, treatments for atherosclerosis and valvopathies have become more dependent on transcatheter procedures, which has led to significant declines in surgical aortic valve replacement and coronary artery bypass grafting.[18] Furthermore, medical management of cardiac conditions has improved, allowing diseases that had previously required surgical treatment to be managed earlier and more effectively with medical therapies.[11,19]

Looking forward, several factors may continue to benefit CTS resident case volume and may offset the shift toward less invasive and nonsurgical management, including the expansion of the elderly population and the advent of integrated CTS programs. Advancing age is a significant risk factor for the development of CV disease, and based on several epidemiologic studies, the proportion of the population age ≥65 years is expected to double by 2040 as a result of increasing life expectancy and the introduction of the "baby boomer" generation into the Medicare population.[12] CV disease is expected to increase with this increase in the elderly population; by 2035, approximately 50% of the US population is expected to have CV disease, and the prevalence of coronary heart disease is expected to increase by 7 million people.[12,20] In this study, evidence of the recent growth in the cardiac patient population is demonstrated by the large increase in cardiac procedures, particularly atherosclerotic procedures, with the most significant increase occurring from 2018 to 2019. In addition, for cardiac track CTS residents, the proportion of cardiac procedures followed an upward curved pattern, demonstrating an increase from 2018 to 2019, which was a reversal compared with the decreasing trend seen from 2016 to 2018. Therefore, even as nonsurgical management improves and the use of minimally invasive procedures increases, the increase in pathology may maintain the volume of cardiac procedures, particularly surgeries for coronary atherosclerotic disease.

The other major factor that may maintain overall CTS resident caseload is the advent of integrated CTS programs. These programs have expanded the number of CTS-specific training years from the traditional 2 to 3 years to 6 to 8 years.[21] Integrated CTS residents, now compose approximately 20% of the current CTS resident population, and the proportion continues to expand each year. In the midst of an increasing number of endovascular and less invasive procedures, this reconstruction of resident education is vital, as studies have demonstrated volume to be directly correlated to resident confidence and success in the operating room.[1,3] In addition, the expanded years of dedicated CTS training enables residents to become more proficient in novel, less invasive diagnostic and therapeutic techniques that they can use in their future practice.

This analysis reports on all of the available thoracic surgery ACGME case logs and is the first analysis of CTS resident case logs published to date. There are many barometers for characterizing the current field of cardiac surgery, such as analyzing the Medicare population; however, evaluating ACGME case logs is the best way to understand the trends in CTS resident volume and operative procedures. Therefore, the ACGME logs serve to elucidate how CTS resident operative volume has been affected by changes in cardiothoracic medical practices.

Limitations

Our study has certain unavoidable limitations. First and foremost, the study is limited by the categories and averages provided in the ACGME logs. The reported categories did not have specific subcategories to examine changes in specific procedures such as aortic valve replacements and mitral valve replacements. In addition, individual resident data are not available from these case logs, so the study relied on analysis of the average number of cases performed by graduating residents per year. Presentation of the data as averages limited us from seeing the variance within the

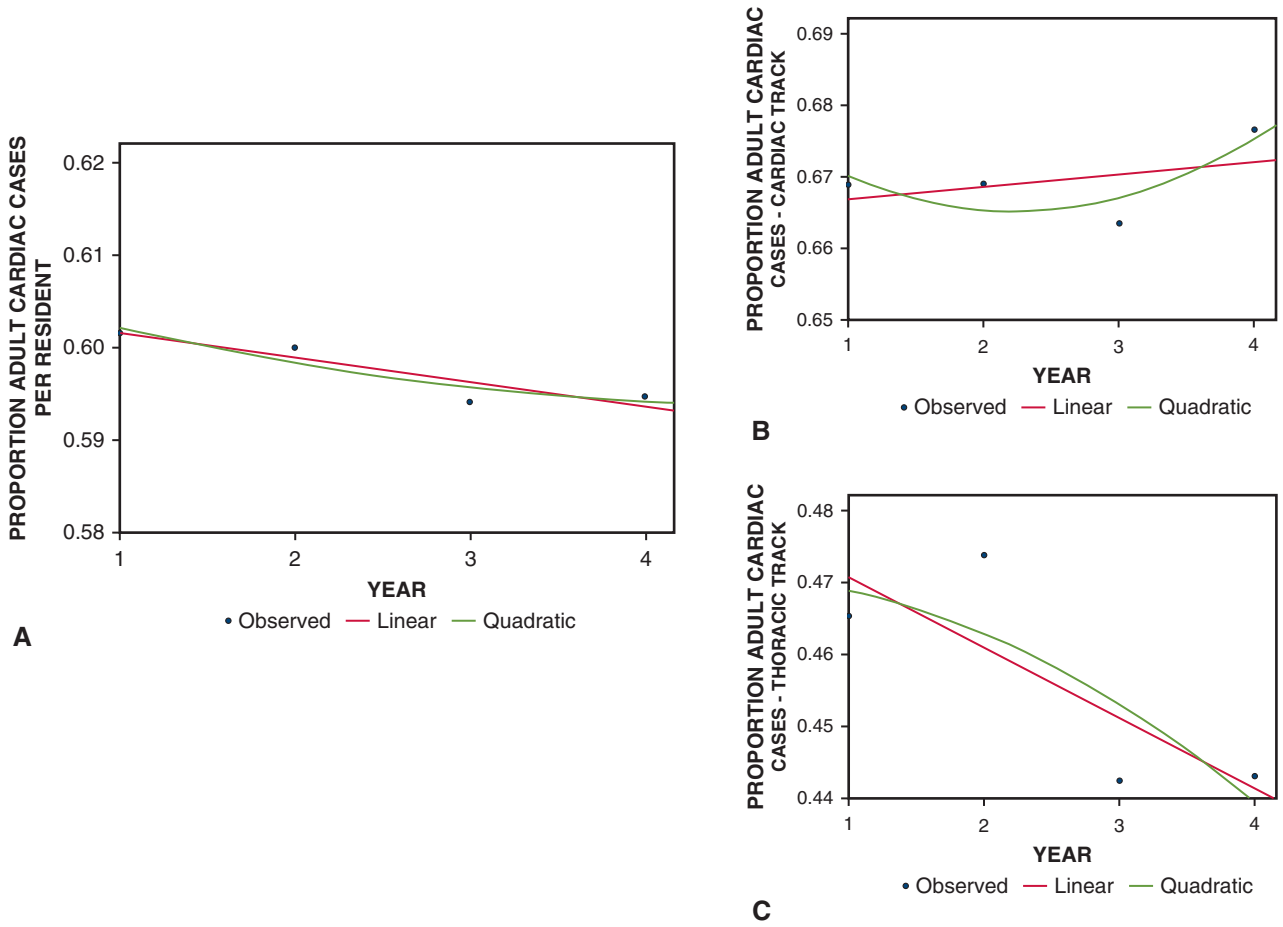


FIGURE 3. Trends in the proportion of adult cardiac cases for cardiac track residents: comparison between 2016 and 2019. The proportion of adult cardiac cases for the average track (-0.263 per 100 cases/year; $P < .001$, linear regression test) (A), cardiac track (0.176 per 100 cases/year; $P < .001$, linear regression test) (B), and thoracic track (-0.978 per 100 cases/year; $P < .001$, linear regression test) (C) cardiothoracic surgery (CTS) residents increased from 2016 to 2019. The increasing upward trend for cardiac track CTS residents compared with thoracic track CTS residents indicates an increase in specialization of the tracks. Significant quadratic equations were found for each track; cardiac track CTS residents ($y = 0.681 + -0.015x + 0.003x^2$, nonlinear regression test) experienced a more narrow positive parabolic trend that encompasses the downward trend from 2016 to 2018 and the steep upward trend from 2018 to 2019 compared with the average track ($y = 0.607 + -0.005x + 0.001x^2$, nonlinear regression test) and thoracic track CTS residents ($y = 0.471 + -0.0002x + -0.002x^2$, nonlinear regression test). The operative proportions are calculated by dividing the category-specific case volume by the total CTS case volume. *X*-axis: 1, 2016; 2, 2017; 3, 2018; 4, 2019. Refer to Table 4 for raw values.

years and required us to weight the averages by the appropriate number of residents to more accurately represent the effect size significance. Weighting the data is not an exact representation of the data, but it does reproduce the desired sample size, which tends to guide significance. In addition, these averages did not include integrated CTS residents and grouped both 2- and 3-year traditional CTS residents together, precluding stratification and further analysis.

A second limitation is that the ACGME case logs are self-reported, and the reflection of cardiac case volume is only as good as the reporting. Robich and colleagues[22] demonstrated variations in accurate case logging between traditional and integrated CTS residents. This study focuses only on traditional CTS residents, however; thus, if logging biases are present, they most likely will be present for each year and for each type of case. As we are interested primarily in trends, widespread logging biases would not have a large impact on the conclusions. In addition, ACGME case logs are quite important for evaluation of programs, and thus we believe that program directors will enforce regular and accurate case logs. Nevertheless, reporting of assistant cases in particular might not be applied consistently across programs. For these analyses, surgeon and assistant role volumes were totaled to represent complete ACGME-reported data on resident case volumes. Sensitivity analyses indicated that removing the assistant volumes, which accounted for only 8% of the total case load, did not change any of the trends found in the present study.

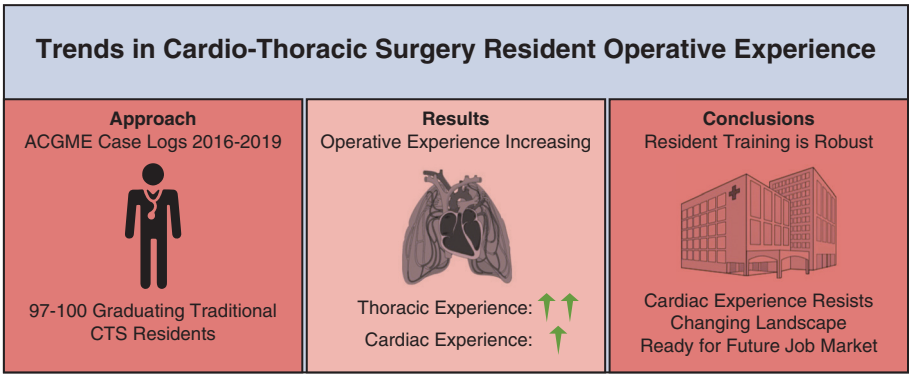


FIGURE 4. Traditional cardiothoracic surgery (*CTS*) resident training is robust. CTS ACGME case logs were assessed to evaluate cardiac and thoracic case volume. Depending on the year, each case log summarized data from 97 to 100 residents. Overall, the CTS resident experience expanded, with both cardiac and thoracic case volume increasing; however, thoracic case volume increased faster than cardiac case volume. Although residency programs should continue to follow CTS resident case volume, CTS training is robust and has resisted the changing cardiac landscape. CTS residents are well trained for the job market. *ACGME*, Accreditation Council for Graduate Medical Education.

A third limitation is the assessment of CTS resident training based on case volume. This has been the traditional barometer for resident training; however, several studies have proposed using other indicators as quality of training might not necessarily correlate with the number of performed cases.[23] Furthermore, based on the revelation from Robich and colleagues of inaccurate resident case logging, the number of CTS resident–reported cases might not equal the number of CTS resident–performed cases. This is certainly a limitation for determining the surgical competency of graduating residents, and additional data, like board exam pass rates and postgraduation job surveys, may be needed.[22] Nonetheless, our goal was to primarily assess whether the changing landscape has affected CTS resident training, rather than to assess the merit of CTS resident training as a whole. Finally, we had access to publicly available data only for 4 subsequent ACGME years. Trends are typically more robust with increasing years. Nonetheless, our analysis summarizes all the CTS resident data available on the ACGME website and is unique by demonstrating trends in the annual number and annual proportion of major CTS resident procedures.

CONCLUSIONS

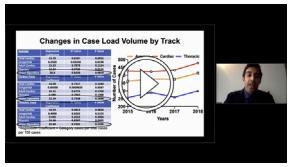
Our data elucidate the effects of the changing landscape of cardiac surgery on CTS residents. Our analysis of the CTS resident ACGME operative case logs over the last 4 years has shown an overall increase in CTS resident operative experience and an increase in track specialization. The job market should not be worried, as CTS residents are receiving adequate surgical volume. In addition, the future patient population may continue to increase CTS resident case volume (Figure 4). This being said, programs must continue to survey the shifting landscape and must implement new strategies to maintain CTS confidence and operative training. We believe that surgical simulations and the current comprehensive, integrated CTS programs are significant measures to strengthen CTS resident training.

Future Considerations

Looking forward, studies such as these should be continuously performed to understand the landscape of the field and adapt accordingly. Resident education must be driven by data. We believe that ACGME operative experience data can synergize with data on cardiothoracic board exam scores and on interviews that evaluate graduate CTS resident confidence. This information would better evaluate and help correlate graduate experience with postgraduate performance.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/20AM/Presentations/Trends%20in%20Traditional%20Cardiothoracic.mp4.



Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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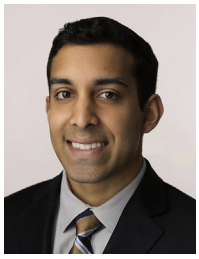
Key Words: education, cardiothoracic surgery residents, volume, case logs, ACGME

ADULT

Discussion



Mr Aakash M. Shah (*Newark, NJ*)

Dr Joseph A. Dearani (*Rochester, Minn*). Thank you, Dr Keshavjee, and the AATS Committee for the invitation to participate in what has been a great Leadership and Scholarship session so far, and to discuss this important paper. I don't have any disclosures. Congratulations to you, Aakash. I hope you are strongly considering a career in cardiac surgery. Thank you for this crisp and clear presentation on a timely topic of cardiothoracic surgery education. CT surgery education has evolved dramatically in recent years to incorporate a different landscape of operative procedures that residents are involved with, as well as different educational tools that have been implemented, such as simulation.

This has also occurred in parallel with the introduction of more advanced fellowship training programs. So the discussion of resident case volumes relative to the changing backdrop of the specialty is very timely and appropriate. I appreciate receiving the slides in advance but have not yet had the opportunity to read the manuscript. So my comments will reflect the slide presentation.

Strengths of your review include an analysis of a contemporary cycle of the most recent 4 years of the traditional cardiothoracic surgery training programs. Robust numbers are present. However, they reflect really just the general categories of procedures, as opposed to specific procedures, for example, TAVR versus open aortic valve replacement.

One of the most important findings in this review is the declining number of coronary bypass grafting procedures. This is particularly important, since the STS database still documents coronary bypass grafting as the most frequent cardiovascular procedure still being performed in the United States, in the face of declining numbers nationally. And despite the reduction in the coronary bypass grafting volume, adult cardiac surgery case numbers continue to

be strong, with an overall increase in volume.

One of the most significant limitations that you refer to is the lack of the I6 numbers, which is growing in popularity for the training pathway. I appreciate the sophisticated statistics, but I will confess it is challenging to follow regression coefficients and R^2 values in the absence of absolute numbers of specific procedures to use as a reference point. Importantly, specific procedures such as aortic valve replacement, mitral valve repair, mitral valve replacement, etc, as opposed to just looking at general numbers in a "valve category"—residents submit absolute numbers of specific cases, and this is what is monitored to help us determine competency and to direct changes or modifications in a program. So I hope and would suggest that this type of case granularity could be available for the paper so that strategies for improvement could be applied.

I have 3 questions. Traditional programs that you have examined are either 2 or 3 years. Could you clarify if these overall numbers in these general categories are stratified by a given year of training or the total length of the program? And if it's a total length of the program, is it 2- or 3-year programs, or both? Obviously through your programs, we'll have larger numbers. This requires some clarification.

Mr Shah. First, I'd like to say thank you Dr Keshavjee and Dr Dearani for the kind remarks. And Dr Dearani, I appreciate your thorough analysis of the work, and I do agree that the manuscript, which we will be submitting soon, certainly needs to expanded on a little bit more. But for the sake of the presentation and the overall picture, the idea was just to look at the changing volume and the landscape.

To answer your question, this does include second- and third-year programs. That does mean that there would be a group of residents that would bring the mean a little bit higher. However, this is just looking at overall graduating cardiothoracic residents.

Dr Dearani. The second question would revolve around the types of cases that counted for the overall increase in cardiac numbers. This is important to understand; there should be some specifics as opposed to just the general categories—for example, "endovascular" alone is not specific enough. That, I think, would be really helpful to know where we're gaining numbers in cases; this will help the profile of a given resident in terms of whether rotations and particular procedures they need exposure to need to be modified along the way of their training pathway.

Mr Shah. I agree. Particularly for the endovascular procedures, the ACGME case log only reported "endovascular." However, for the other categories, they are much more detailed and itemized. This is certainly data that we will contact the organization for and see if there's a way of getting more numbers. However, from the available data that they have reported, particularly for the endovascular category, it isn't itemized, and unfortunately there is no more detail than we provided.

I'd also like to make a statement about the linear regression. The reason we chose to analyze the data with linear regressions instead of just taking the start and end and subtracting the two, was because it adds a little bit more information about the continuity and the consistency of the change. So, as you saw for the coronary atherosclerotic procedures, that line was relatively straight—versus the valvular heart procedures had more variable averages, as there was a year where it declined and then the next year it increased. The linear regression takes into consideration the nuances and variations within the data points of those 4 years.

Dr Dearani. Fair enough. It's just that the coefficients will mean more to somebody like you in a few years when you're in your residency and we're trying to figure out whether it's 30 coronary bypass procedures or 50. That's where it becomes practical.

For my final question: With the data that you now have, even having the privilege of having maybe some more specific data that you couldn't share in the presentation, what recommendations would you make now to the ABTS based on the findings in terms of case numbers? Is there something specific that we should be looking at, or should we be making modifications to programs in the in the foreseeable future? All of this is changing very quickly.

Mr Shah. Thank you for that question. If we believe that the extent of the volume increase hasn't been enough to be optimistic, I have 2 points regarding this. The first point is that we believe that volume is a proxy for resident education. But the real thing that we're looking at is quality. So even as these case numbers increase or decrease, as long as residency programs maintain the quality of the operative experience, residents will continue to have excellent training. Several techniques that residency programs have used have been simulation training sessions and expanding on the education/research component of resident training. These techniques will enhance resident exposure to cardiac techniques without patient interaction, and although they don't replace operative experience, they may supplement and strengthen the operative experience. Maybe the ABTS should continue to expand on residency and fellowships by necessitating competency in techniques in simulation labs.

And the second thing is that I think that we should really be driven by the data. I think that certain trials have shown that in certain patient populations, there is a need for more endovascular procedures. It's still a surgical procedure. CT residents and CT attendings should still be involved in those procedures; they're not easy procedures and it may require opening and other nuanced techniques that a trained CT resident or attending would be able to help with and do. Therefore, the ABTS should continue to require training in endovascular procedures, and CT surgeons must learn to be proficient in performing these procedures early.

Also, CT surgeons must get early exposure in minimally invasive techniques to become more skilled in these

procedures. These procedures will likely be more commonplace in the future, and although fellows may need addition training, early exposure will make them more confident and skilled at performing their procedures earlier in their careers. In the future, as stronger data for minimally invasive techniques are generated, the ABTS can make minimally techniques a requirement for CTS training.

However, I really think that the volume is increasing, and that's a great sign. Overall, cardiac disease is a disease of the aging population. As there an increase in the aging population, we will always have cardiac cases, and it seems that will increase over the next few years. So in terms of volume, there really isn't too much to worry about. However, we also do have to continue to focus on supplementary training sessions and on endovascular and minimally invasive techniques, as they may be very beneficial for future CT residents as they enter the field.

Dr Dearani. Thank you. I would encourage some of the other panelists to comment, particularly those that are involved in training programs, because this obviously is a very important topic. I'm not sure that we should rest on our laurels and think that we're okay because the cardiac numbers are increasing; we really need to see exactly what they are, and it needs to be stratified by procedure, because if many of them are endovascular or transcatheter procedures, it's going to be at the at the expense of open procedures, so I don't think that we should feel overly comfortable or confident that we're looking good right now. I think looking at the absolute numbers will help guide us moving forward.

Dr Todd K. Rosengart (*Houston, Tex*). I think the challenge of going from open cases to interventional or noninvasive, minimally invasive, is one that's true across all the surgical specialties, and it's a real challenge—if you think of Malcolm Gladwell's rule of 10,000 hours or the like. So one suggestion might be to look at the ACGME surveys (at a minimum) that will tell us some information about graduating residents' confidence level. We believe that they've been adequately trained, but it would provide some insight in terms of whether the residents feel they've been adequately exposed to a number of cases. We frequently discuss simulation training, but I think many of us would feel that is, unfortunately, an inadequate substitute for the actual operative experience, at least at current standards of technology.

Mr Shah. I thank you for that comment. And I think that's certainly an important avenue to focus on. As mentioned before, the volume was associated with increasing confidence and competency in general. So if we see that fellows are still confident and prepared for their jobs after fellowships, that would certainly be good news for CTS programs. It would also help determine the overall performance of CTS fellowship programs.

Dr Shaf Keshavjee (*Toronto, Canada*). Getting back to a comment Dr Dearani made, Aakash, would you have the data to divide the number of years spent in cardiothoracic training, the number of cases—sort of looking at the difference between the 2-year and 3-year programs? And it might even be an interesting metric and the I6 programs to see cardiothoracic cases performed as the resident progresses through the training.

Mr Shah. Certainly. Thank you, Dr Keshavjee. I unfortunately don't have the breakdown between the second-year and third-year residents. However, now that you guys have mentioned it, it's certainly an important thing we will look at in the manuscript and expand on a little bit more. I do have some additional slides about the integrated programs. They're not looking at the specific numbers, but they look at the number of residents and how they've increased over the last 5 years. If you guys would like to look at those numbers, I can certainly present that, but as mentioned, the integrated data was not released by the ACGME and we needed other approval to acquire that data.

Dr Keshavjee. I would leave that for your discussion with the journal in terms of what should be included. I think it would enhance the paper to have some of those other factors in; as Dr Dearani said, we really have to pay close attention to it and just looking at the numbers may falsely reassure us as to what actually is going on, because there are some programs where residents just hang around longer until they can get cases done. And I don't know if that's lost in the data.

Mr Shah. Certainly. We will look at that for sure.

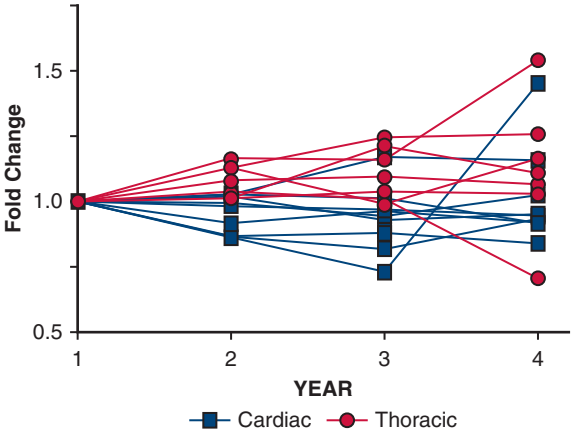


FIGURE E1. Trends in the proportion of category-specific case volume. Over the 4-year time span, the majority of thoracic type (*red line*) operative categories increased their proportion of total cardiothoracic surgery (CTS) resident cases. In contrast, the majority of cardiac type (*blue line*) operative categories decreased their proportion of total CTS resident cases. The data represent fold change, and each category's operative proportions are relative to their operative proportion in 2016. The operative proportions are calculated by dividing the category-specific case volume by the total CTS case volume. *X*-axis: 1, 2016; 2, 2017; 3, 2018; 4, 2019. Refer to Table 2 for raw values.

TABLE E1. Number of cardiothoracic surgery residents and programs, 2016 to 2019

Year	Graduating residents	Total programs	2-year programs	3-year programs
2016	100	57	47	21
2017	97	57	49	20
2018	100	60	52	20
2019	97	62	51	21

Includes all traditional cardiothoracic surgery residents and programs in the United States.

TABLE E2. 10th and 90th percentile case thresholds for cardiac cases, 2017 to 2019

Cases	2017		2018		2019	
	10th	90th	10th	90th	10th	90th
Congenital	3	35	3	35	2	33
Valvular heart	51	184	43	190	44	183
Coronary atherosclerosis	52	190	51	166	57	175
Pericardium	1	10	1	10	1	13
Other major cardiac	11	59	11	72	15	79
Heart transplantation	0	20	0	16	0	20
Endovascular	0	7	0	7	0	10

Data are the required number of logged cases by a cardiothoracic surgery resident to be in the specified percentile.

TABLE E3. Subcategory analysis of changes in case volume for valvular heart disease surgeries, 2016 to 2019

Surgery	Regression coefficient	*P* value*
Mitral aortic valve repair	0.670	<.001
Valve replacement	1.670	<.001
Aortic root replacement	−0.200	<.001
Reoperation for valvular disease	−0.510	<.001

Linear regression analysis was performed for each operative category; the regression coefficient represents the change in cases per year. **P* value weighted by annual number of residents.

TABLE E4. Number of traditional cardiothoracic surgery residents by track, 2016 to 2019

Year	Cardiac track	Thoracic track
2016	63	36
2017	62	35
2018	66	34
2019	62	35

Includes all traditional cardiothoracic surgery residents in the United States.