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COVID-19 Did Not Stop the Rising Tide: Trends in Case Volume Logged by Surgical Residents

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INTRODUCTION: The coronavirus pandemic has profoundly impacted all facets of surgical care, including surgical residency training. The objective of this study was to assess the operative experience and overall case volume of surgery residents before and during the pandemic.

METHODS: Using data from the Accreditation Council for Graduate Medical Education annual operative log reports, operative volume for 2015 to 2021 graduates of Accreditation Council for Graduate Medical Education-accredited general, orthopedic, neuro- and plastic surgery residency programs was analyzed using nonparametric Kendall-tau correlation analysis. The period before the pandemic was defined as AY14-15 to AY18-19, and the pandemic period was defined as AY19-20 to AY20-21.

RESULTS: Operative data for 8556 general, 5113 orthopedic, 736 plastic, and 1278 neurosurgery residency graduates were included. Between 2015 and 2021, total case volume increased significantly for general surgery graduates (Kendall’s tau-b: 0.905, p = 0.007), orthopedic surgery graduates (Kendall’s tau-b: 1.000, p = 0.005), neurosurgery graduates (Kendall’s tau-b: 0.905, p = 0.007), and plastic surgery graduates (Kendall’s tau-b: 0.810, p = 0.016). Across all specialties, the mean total number of cases performed by residents graduating during the pandemic was higher than among residents graduating before the pandemic, though no formal significance testing was performed. Among general surgery residents, the number of cases performed as surgeon chief among residents graduating in AY19-20 decreased for the first time in 5 years, though the overall volume remained higher than the prior year, and returned to prepandemic trends in AY20-21.

CONCLUSIONS: Over the past 7 years, the case volume of surgical residents steadily increased. Surgical trainees who graduated during the coronavirus pandemic have equal or greater total operative experience compared to trainees who graduated prior to the pandemic. (J Surg Ed 80:499–510. © 2022 Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery.)

KEY WORDS: surgical education, operative training, covid-19, residency training

COMPETENCIES: Patient Care, Medical Knowledge, Professionalism, Systems-Based Practice

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic has caused unprecedented global disruption, impacting nearly every aspect of education, health, economy, and society.1–5 The United States (US) healthcare system has been no exception. Beyond its devastating, direct impact on infected patients, the pandemic provoked a massive reduction in overall healthcare utilization,6–9 drastically affecting the delivery of ongoing requisite patient care,10–13 substantially altering undergraduate and graduate medical education,14–19 severely straining many hospitals and healthcare organizations financially,20,21 and threatening the resilience of medical workers and the supply of other necessary resources and medical equipment.22–28

The delivery of surgical care was particularly affected; for nearly 12 weeks, starting in late March 2020, most hospitals in the US cancelled or postponed nonessential surgeries, reserving hospital
capacity and associated resources for COVID-19 positive patients. Based on global survey data from more than 500 surgeons, including more than 60 surgeons in the US, the National Institute of Health Research COVIDSurg Collaborative estimated that 70% of total operations were cancelled during the peak 12-weeks of disruption. A second study using administrative claims data from a large US healthcare network found that surgical volume decreased by nearly 50% during the initial 2020 shutdown; however, after re-opening, the rate of surgeries quickly rebounded to 2019 levels, and this volume was maintained throughout the peak burden of disease during the subsequent fall and winter periods.

With regard to graduate medical training, the negative impact of the pandemic on the clinical experience of trainees in surgical and procedural specialties has been widely reported. Multiple survey-based and qualitative studies have highlighted how surgical trainees were redeployed to nonsurgical roles, experienced a substantial reduction in operative and ambulatory experience, or navigated a disrupted educational and didactic curriculum. Based on a national survey of surgical residents published in July 2020, 71.4% of all residents reported completing 4 or more cases per week prior to the pandemic, whereas 35.2% and 45.6% of respondents reported completing 0 cases per week and 1 to 3 cases per week during the initial wave of the pandemic, respectively. This data is consistent with estimates of reduced operative volume among vascular surgery residents at 3 academic medical centers in New York City. In response to reduced clinical training, residents and fellows across surgical sub-specialties have expressed concerns regarding their skill acquisition and technical competency, capacity to satisfy required Accreditation Council for Graduate Medical Education (ACGME) case volume requirements, and overall preparedness for fellowship and professional practice. Despite these documented concerns, the lasting impact of the pandemic on surgical training and operative volume is not yet well described.

Since the introduction of the ACGME case log system in 2001, operative volume has been a surrogate for operative proficiency and adequate surgical training. While novel methodologies of competency-based assessment are being developed, operative volume remains a principal standard for ensuring adequate surgical training. At both the hospital level and surgeon level, operative volume has been associated with improved patient outcomes. Among trainees, operative volume has been associated with increased confidence among graduating residents and performance on simulated tasks, including laparoscopic skills and completion of a hand-sewn bowel anastomosis. Given the reported impact of the COVID-19 pandemic on surgical training and the current role of operative volume in assessing proficiency and preparedness, it is critical to characterize how the pandemic impacted surgical trainees’ operative volume. In the current study, we utilize the most comprehensive dataset available, the ACGME case logs, to describe how the coronavirus pandemic impacted operative volume of surgical trainees in the US.

**METHODS**

**Data Source**

Operative log data for graduates of US ACGME-accredited general, orthopedic, neuro- and plastic surgery residency programs are maintained by the ACGME and are publicly available. Operative volume data are aggregated annually among all graduating residents without individual or program level information. The ACGME case logs from academic year (AY) 2014-2015 to AY2020-2021 were reviewed and analyzed. Academic year 2014 to 2015 was selected as the start of the pre-pandemic study period in order to adequately assess pre-COVID trends in case volume.

For general surgery residents, the ACGME case log system records total cases and cases by trainee role, classified as “Surgeon Chief,” “Surgeon Junior,” and “Teach Assist.” For each role, summary data include: mean number of cases per resident, standard deviation (SD) for all graduating residents, and maximum number of cases for any individual resident. In addition, the ACGME provides percentile benchmarks (10th, 30th, 50th, 70th, and 90th) to allow comparison of the average graduating resident operative experience across programs. For each specialty, the ACGME report also provides a distribution of volume by core operation. For general surgery residents, mean overall operative volume, percentile benchmarks for total case volume, mean volume by resident role was assessed. For neurosurgery residents, the ACGME case log system records the number of cases overall and by role, defined as “Senior Resident,” “Lead Resident,” and “Assistant Resident.” Mean combined operative volume for cases recorded as “Senior Resident” or “Lead Resident” was assessed. For orthopedic surgery residents, the ACGME case log system records cases for all patients, as well stratified by adult and pediatric. For plastic surgery residents, the ACGME case log system records total cases, with no delineation of trainee role. Accordingly, for both orthopedic and plastic surgery residents, changes in total logged operative volume were assessed.
**Statistical Analysis**

Given the limited sample size (N = 7 years of graduating resident cohorts), nonparametric analysis of trends in case volume was performed using Kendall rank correlation coefficients. Descriptive analysis was performed comparing mean volume before and during the pandemic. The prepandemic period was defined as AY14-15 to AY18-19 and the pandemic period was defined as AY19-20 to AY20-21. The distribution of case volume by operation was analyzed, and trends in mean volume by operation type were assessed using Kendall rank correlation. All analyses were performed using Stata, version 15.0 (StataCorp LLC). Significance was defined as p < 0.05.

**RESULTS**

**Baseline Characteristics**

Baseline characteristics are presented in Table 1. During the study, the number of ACGME-accredited general surgery residency graduates increased from 1142 in AY14-15 to 1357 in AY20-21 (287 programs) (Kendall tau-b: 0.905, p = 0.007). A similar trend was observed for orthopedic surgery, with 699 graduating residents in AY14-15 and 822 graduating residents in AY20-21 (Kendall tau-b: 0.714, p = 0.036). The number of ACGME-accredited neurosurgery residency graduates did not change significantly over the study period: 168 graduates in AY14-15 to 199 graduates in AY 20-21 (Kendall tau-b: 0.514, p = 0.158). Conversely, the number of ACGME-accredited plastic surgery residency graduates decreased during the study period: 133 graduates (65 programs) in AY14-15 and 77 graduates (44 programs) in AY 20-21 (Kendall tau-b: -0.951, p = 0.006).

**Operative Trend Analysis**

Over the entire study period, the total case volume increased significantly for general surgery graduates (Kendall’s tau-b: 0.905, p = 0.007), orthopedic surgery graduates (Kendall’s tau-b: 1.000, p = 0.005), neurosurgery graduates (Kendall’s tau-b: 0.905, p = 0.007), and plastic surgery graduates (Kendall’s tau-b: 0.810, p = 0.016) (Fig. 1). General surgery graduates in AY14-15 completed an average of 985 total cases whereas graduates in AY20-21 completed 1074 cases.

In addition, the lowest 10th percentile of reported case volume increased significantly over time for general surgery graduates (p = 0.007) and orthopedic surgery graduates (p = 0.003).

Across all specialties, the mean total number of cases performed by residents graduating during the pandemic was higher than among residents graduating before the pandemic: general surgery (1020.1 vs 1064.5 cases), plastic surgery (1931.2 vs 2427.4 cases), orthopedic surgery (1639.2 vs 1929.2 cases) and neurosurgery (1464.2 vs 1639.1 cases). However, given the sample size, no formal significance testing was performed to assess this difference. Among general surgery graduates, for the first time in 5 years, there was a decline in the mean number of total cases in AY19-20 (1054.8 cases) compared to AY18-19 (1070.5 cases). However, total mean case volume increased to 1074.1 total cases for general surgery residents graduating in AY20-21.

**Case Analysis by Trainee Role**

Among general surgery residents, graduating year was positively correlated with the total number of cases logged as “Surgeon Junior” (Kendall tau-b: 0.810, p = 0.016) and “Surgeon Chief” (Kendall’s tau-b: 0.714, p = 0.036) (Fig. 2). Cohort year was not associated with the number of cases logged as “Teach Assist” (Kendall’s tau-b: -0.159, p = 0.751).

The mean number of cases logged as “Surgeon Junior” (748.4 vs 781.5 cases) and “Surgeon Chief” (255.6 vs 267.5 cases) was lower for residents who graduated before the coronavirus pandemic compared to residents who graduated during the pandemic. The mean number of cases logged as “Teach Assist” (40.0 vs 39.5 cases) was similar for residents who graduated before and during the pandemic. While the mean number of cases completed as “Surgeon Chief” were similar between the 2 periods, residents graduating in AY19-20 only completed

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**TABLE 1. Resident and Program Demographics**

| Residency       | Number of Graduating Residents, N (%) |
|-----------------|----------------------------------------|
|                 | All         | AY14-15 | AY15-16 | AY16-17 | AY17-18 | AY18-19 | AY19-20 | AY20-21 |
| General surgery | 8556 [54.6%] | 1142 [53.3%] | 1172 [53.4%] | 1211 [54.2%] | 1198 [54.0%] | 1219 [55.7%] | 1257 [55.8%] | 1357 [55.3%] |
| Orthopedics     | 5113 [32.6%] | 699 [32.6%] | 705 [32.1%] | 709 [31.7%] | 729 [32.9%] | 725 [33.2%] | 724 [32.1%] | 822 [33.5%] |
| Plastic surgery | 736 [4.7%]   | 133 [6.1%] | 133 [6.1%] | 128 [5.7%] | 104 [4.7%] | 84 [3.8%] | 77 [3.4%] | 77 [3.1%] |
| Neurosurgery    | 1278 [8.1%]  | 168 [7.8%] | 186 [8.5%] | 186 [8.3%] | 186 [8.4%] | 159 [7.3%] | 194 [8.6%] | 199 [8.1%] |
| All programs    | 15683       | 2142 | 2196 | 2234 | 2217 | 2187 | 2252 | 2455 |
255 cases as “Surgeon Chief” whereas residents graduating in AY18-19 completed 283 cases as chief resident.

**General Surgery Case Analysis**

Reported case volume for general surgery residents grouped by individual core operation are presented in Table 2a. Graduating year was positively correlated with median case volume in the following subgroups: anorectal (Kendall tau-b: 1.000, p = 0.003), plastic (Kendall tau-b: 1.000, p = 0.003), esophageal (Kendall tau-b: 1.000, p = 0.003), amputation (Kendall tau-b: 0.976, p = 0.004), skin and soft tissue (Kendall tau-b: 0.905, p = 0.007), stomach (Kendall tau-b: 0.905, p = 0.007), trauma (K: 0.905, p = 0.007), large intestine (Kendall tau-b: 0.878, p = 0.01), endovascular (Kendall tau-b: 0.878, p = 0.01), upper extremity (Kendall tau-b: 0.845, p = 0.021), biliary (Kendall tau-b: 0.810, p = 0.016), transplant (Kendall tau-b: 0.810, p = 0.016) and surgical critical care (Kendall tau-b: 0.714, p = 0.056). Graduating year was inversely associated with pediatric (Kendall tau-b: -1.000, p = 0.005), cerebrovascular (Kendall tau-b: -0.951, p = 0.006), vascular access (Kendall tau-b: -0.905, p = 0.007), pancreas (Kendall tau-b: -0.878, p = 0.01), aneurysm repair (Kendall tau-b: -0.823, p = 0.019), vascular bypass (Kendall tau-b: -0.794, p = 0.026), spleen (Kendall tau-b: -0.751, p = 0.031) and thoracic (Kendall tau-b: -0.667, p = 0.048).

In addition to cumulative operative volume, we assessed the impact of the coronavirus pandemic on the number and distribution of cases performed as “Surgeon Chief” (Table 2b). As mentioned, the mean number of total cases completed as “Surgeon Chief” decreased in AY19-20 (N = 255) compared to AY17-18 (N = 272) and AY18-19 (N = 283). This decrease was observed across nearly every core operation group; a decrease in average volume was observed in 26 of 34 groups and a decrease of 1 or more cases (in mean volume) was observed in 7 groups, specifically large intestine, biliary, hernia, stomach, anorectal, vascular access and endocrine.

For each core operation, a comparison of (a) mean case volumes and (b) the proportion of each core operation to total volume before and during the pandemic are presented in Table 3.

**Plastic Surgery Case Analysis**

With regard to plastic surgery graduates, graduating year was positively correlated with the median number of breast reconstructive procedures (Kendall tau-b: 1.000, p = 0.003), aesthetic breast procedures (Kendall tau-b: 0.905, p = 0.007) and trunk procedures (Kendall tau-b: 0.810, p = 0.016). Conversely, graduating year was inversely associated with head and neck neoplasms (Kendall tau-b: -0.619, p = 0.072) and integument burns (Kendall tau-b: -0.714, p = 0.036) (Supplementary Table 1). For each operative domain, mean case volume before and during the pandemic are presented in Supplementary Table 2.

**Orthopedic Surgery Case Analysis**

For orthopedic surgery residents, graduating year was positively associated with all domains except microsurgeries: pelvis and hip (Kendall tau-b: 1.000, p = 0.003), leg and ankle (Kendall tau-b: 1.000, p = 0.003), shoulder (Kendall tau-b: 1.000, p = 0.003), forearm and wrist (Kendall tau-b: 1.000, p = 0.003), nervous system (Kendall tau-b: 1.000, p = 0.003), humerus and elbow (Kendall tau-b: 1.000, p = 0.003), hand and fingers (Kendall tau-b: 1.000, p = 0.003), foot and toes (Kendall tau-b: 1.000, p = 0.003), oncology cases (Kendall tau-b: 0.905, p = 0.007), femur and knee (Kendall tau-b: 0.905, p = 0.007), integumentary system (Kendall tau-b: 0.905, p = 0.007) and spine (Kendall tau-b: 0.810, p = 0.016) (Supplementary Table 3). For each orthopedic surgery operative domain, mean case volume before and during the pandemic are presented in Supplementary Table 4.
Neurosurgery Case Analysis

For neurosurgery residents, graduating year was positively correlated with the following operative domains: thoracic, lumbar or sacral spine (Kendall tau-b: 0.966, \( p = 0.013 \)), endovascular (Kendall tau-b: 0.966, \( p = 0.013 \)), posterior cervical decompression (Kendall tau-b: 0.966, \( p = 0.013 \)), anterior cervical decompression (Kendall tau-b: 0.966, \( p = 0.013 \)), trauma (Kendall tau-b: 0.966, \( p = 0.013 \)), pediatric trauma (Kendall tau-b: 0.966, \( p = 0.013 \)) and epilepsy (Kendall tau-b: 0.966, \( p = 0.013 \)). Graduating year was inversely associated with pediatric ventriculoperitoneal shunt (Kendall tau-b: -0.828, \( p = 0.035 \)). For each operative domain, mean case volume before and during the pandemic are presented in Supplementary Table 6.

DISCUSSION

To assess the impact of the COVID-19 pandemic on the operative training of surgical residents, we used ACGME summary case log data to describe trends in reported operative volume among surgical residents who graduated before and during the pandemic. Principally, we found that the number of logged cases was not significantly lower among surgical trainees who graduated during the pandemic, compared to prior graduates. Pre-pandemic trends in logged operative volume were largely unchanged during the pandemic period; however, there was a relative decline of uncertain clinical significance in the number cases performed as chief resident among residents graduating in AY19-20—compared to the prior two cohorts. Despite the profound

| Operation               | Academic Year | Kendall’s tau-b | p-value |
|-------------------------|---------------|-----------------|---------|
|                         | 14-15         | 15-16           | 16-17   |
|                         | 17-18         | 18-19           | 19-20   |
|                         | 20-21         |                 |         |
| Positive Correlation    |               |                 |         |
| Anorectal               | 29.5          | 30.7            | 32.4    |
| Plastic                 | 22.1          | 23.0            | 23.4    |
| Esophageal              | 10.8          | 11.0            | 11.2    |
| Amputation              | 15.3          | 15.8            | 16.1    |
| Skin/Soft tissue        | 53.5          | 55.1            | 59.5    |
| Stomach                 | 35.8          | 36              | 36.8    |
| Trauma                  | 27.1          | 27.7            | 30.0    |
| Large intestine         | 136.2         | 136.9           | 139.6   |
| Endovascular            | 6.9           | 7.6             | 7.3     |
| Upper extremity         | 1.9           | 1.9             | 1.9     |
| Biliary                 | 121.3         | 121.2           | 125.6   |
| Transplant              | 10.5          | 10.8            | 10.6    |
| Negative correlation    |               |                 |         |
| Pediatric               | 28.5          | 26.9            | 26.3    |
| Cerebrovascular         | 11.1          | 11.1            | 10.6    |
| Vascular access         | 32.8          | 32.7            | 32.6    |
| Venous                  | 9.0           | 9.3             | 8.9     |
| Pancreas                | 10.8          | 10.5            | 10.5    |
| Aneurysm repair         | 6.4           | 6.1             | 6.0     |
| Vascular bypass         | 1.7           | 1.8             | 1.7     |
| Spleen                  | 2.7           | 2.8             | 2.6     |
| Thoracic                | 40.2          | 39.5            | 38.1    |
| Nonsignificant correlation |             |                 |         |
| Hernia                  | 125.9         | 125.6           | 129.1   |
| Abdomen general         | 38.5          | 40.3            | 42.5    |
| Small intestine         | 36.6          | 35.7            | 35.3    |
| Breast                  | 63.8          | 62.4            | 62.5    |
| Vascular trauma         | 2.4           | 1.8             | 2.5     |
| Genitourinary           | 4.0           | 4.0             | 4.1     |
| Endocrine               | 33.6          | 32              | 33.2    |
| Head and neck           | 22.7          | 22.8            | 22.2    |
| Liver                   | 9.8           | 9.9             | 10.0    |
| Gynecology              | 2.4           | 2.2             | 2.2     |
| Peripheral obstructive  | 20.0          | 20.0            | 19.9    |
| Hand                    | 2.7           | 2.6             | 2.6     |
| Orthopedics             | 1.4           | 1.5             | 1.3     |
disruption of surgical care and clinical responsibilities of providers during the COVID-19 pandemic, this data suggests that the overall operative training of trainees graduating in AY19-20 and AY20-21 was not substantially undermined by pandemic-related disruptions in surgical care.

In response to the coronavirus pandemic, there was a near-complete shutdown of nonessential surgeries between late-March and May 2020 in the US. Based on our analysis, the full effect of this immediate response to the pandemic may not be appreciated in the summative ACGME case logs of graduating residents. For the first time in 5 years, there was a modest year-over-year decline in the mean number of total cases among general surgery resident graduates in AY19-20. However, total volume quickly rebounded to prepandemic levels for AY20-21 graduates, and the mean total number of logged cases was similar among general surgery residents graduating prior to and during the COVID-19 pandemic. The cause and significance of this single-year decline cannot be definitively ascertained with the current data. Despite the pandemic, residents graduating in AY19-20 performed as many total cases as residents graduating in each of the prior 5 years, with the exception of AY18-19, and performed an equivalent number of cases in their final year of residency as residents graduating in AY16-17. As discussed in detail below, the decline in the number of cases performed as “Surgeon Chief” warrants

**TABLE 2B.** General Surgery Residency Core Cases Performed as Chief Resident Grouped by Change Over Time

| Operation                      | Academic Year | Kendall’s tau-b | p-value |
|-------------------------------|---------------|-----------------|---------|
|                               | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 | 20-21 | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 | 20-21 | 14-15 | 15-16 |
| Positive correlation          |           |           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Head/Neck                     | 3.4      | 3.5      | 3.5   | 3.9   | 4.1   | 3.8   | 4.4   | 0.781 | 0.023 |
| Esophagus                     | 4.9      | 4.9      | 5.2   | 6.1   | 6.8   | 6.1   | 6.5   | 0.751 | 0.031 |
| Large intestine               | 40.6     | 41.3     | 42.5  | 47.2  | 48.8  | 45.0  | 47.9  | 0.714 | 0.036 |
| Bilary                        | 30.2     | 31.3     | 33.1  | 37.8  | 39.3  | 36.1  | 40.6  | 0.810 | 0.016 |
| Hernia                        | 31.1     | 31.9     | 33.7  | 37.9  | 38.7  | 34.8  | 40.5  | 0.810 | 0.016 |
| Amputation                    | 1.9      | 2.1      | 2.1   | 2.3   | 2.3   | 2.4   | 2.4   | 0.926 | 0.008 |
| Trauma                        | 6.0      | 7.1      | 7.7   | 7.9   | 8.0   | 7.9   | 8.5   | 0.878 | 0.010 |
| Breast                        | 7.8      | 7.7      | 7.4   | 10.4  | 10.1  | 9.5   | 9.5   | 0.195 | 0.649 |
| Skin/Soft tissue              | 10.1     | 9.9      | 10.9  | 12.3  | 12.2  | 11.5  | 12.0  | 0.429 | 0.230 |
| Stomach                       | 13.4     | 13.2     | 14.3  | 16.8  | 17.5  | 15.3  | 17.3  | 0.619 | 0.072 |
| Small intestine               | 13.1     | 12.7     | 12.6  | 15.7  | 15.8  | 14.7  | 15.5  | 0.333 | 0.368 |
| Anorectal                     | 6.6      | 7.1      | 7.7   | 9.5   | 9.9   | 8.9   | 9.4   | 0.619 | 0.072 |
| Abdomen general               | 13.0     | 13.6     | 14.2  | 16.0  | 15.4  | 14.5  | 14.5  | 0.619 | 0.072 |
| Negative correlation          |           |           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Pancreas                      | 6.8      | 6.6      | 6.6   | 6.1   | 6.2   | 5.6   | 5.8   | -0.781| 0.023 |
| Spleen                        | 1.3      | 1.2      | 1.2   | 1.1   | 1.1   | 1.0   | 1.0   | -0.900| 0.011 |
| Aneurysm repair               | 2.0      | 1.8      | 1.8   | 1.6   | 1.6   | 1.4   | 1.6   | -0.794| 0.026 |
| Cerebrovascular               | 3.3      | 3.2      | 3.0   | 2.9   | 2.7   | 2.5   | 2.4   | -1.000| 0.003 |
| Venous                        | 1.2      | 1.3      | 1.2   | 1.1   | 1.0   | 0.8   | 0.9   | -0.781| 0.023 |
| Nonsignificant correlation    |           |           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Liver                         | 4.8      | 4.9      | 5.0   | 4.9   | 4.8   | 4.3   | 4.5   | -0.429| 0.219 |
| Peripheral obstructive        | 5.2      | 5.3      | 5.2   | 5.3   | 5.0   | 4.6   | 5.0   | -0.514| 0.162 |
| Upper extremity               | 0.4      | 0.4      | 0.4   | 0.5   | 0.5   | 0.5   | 0.5   | 0.756 | 0.052 |
| Vascular bypass               | 0.5      | 0.5      | 0.5   | 0.5   | 0.4   | 0.4   | 0.4   | -0.756| 0.052 |
| Vascular trauma               | 0.6      | 0.6      | 0.6   | 0.8   | 0.7   | 0.6   | 0.7   | 0.350 | 0.396 |
| Endovascular                  | 1.4      | 1.5      | 1.4   | 1.4   | 1.5   | 1.6   | 1.8   | 0.688 | 0.057 |
| Vascular access               | 4.5      | 4.9      | 4.7   | 5.2   | 5.4   | 4.2   | 5.0   | 0.238 | 0.548 |
| Endocrine                     | 11.3     | 11.3     | 11.3  | 11.4  | 11.2  | 9.7   | 10.4  | -0.514| 0.158 |
| Hand                          | 0.2      | 0.3      | 0.2   | 0.2   | 0.3   | 0.3   | 0.2   | 0.126 | 0.860 |
| Thoracic                      | 6.4      | 7.3      | 6.7   | 7.3   | 7.7   | 7.0   | 6.5   | 0.098 | 0.879 |
| Pediatric                     | 1.8      | 2.1      | 1.9   | 1.7   | 1.8   | 1.9   | 1.9   | 0.053 | 1.000 |
| Genitourinary                 | 0.7      | 0.8      | 0.8   | 0.9   | 0.8   | 0.8   | 0.9   | 0.583 | 0.126 |
| Gynecology                    | 0.5      | 0.4      | 0.4   | 0.5   | 0.4   | 0.7   | 0.4   | 0.000 | 1.000 |
| Plastic                       | 2.1      | 2.4      | 2.7   | 3.3   | 3.2   | 2.9   | 2.9   | 0.488 | 0.172 |
| Orthopedics                   | 0.1      | 0.1      | 0.1   | 0.2   | 0.1   | 0.1   | 0.1   | 0.178 | 0.803 |
| Organ transplant              | 1.2      | 1.4      | 1.2   | 1.4   | 1.6   | 1.3   | 1.4   | 0.371 | 0.341 |
| All cases                     | 233      | 238      | 252   | 272   | 283   | 255   | 280   | 0.714 | 0.036 |
consideration, but its significance and impact on resident competency and preparedness is uncertain.

There are several possible explanations for the overall observed findings. First, despite the undeniably drastic impact of the pandemic on surgical practice, there is evidence that total case volume returned to prepandemic levels relatively quickly following the initial shutdown, and was maintained at this level throughout the subsequent surges.30 Thus, it is possible that the impact on operative training was temporally contained. Second, there is some evidence that surgical residents, specifically within general surgery and urology, do not fully capture their operative experience in ACGME case logs, with estimates that 25% to 28% of completed cases are not logged in ACGME.50,51 Given this incomplete capture of cases, it is possible that residents more diligently and accurately logged cases during the pandemic, given the uncertainty of the period and concerns regarding their operative volume and ability to satisfy ACGME minimum case requirements. Lastly, an examination of the logged operative volume over the past decade prior to the pandemic demonstrates a gradual, yet marked, increase in mean total operative volume, across all 4 studied disciplines. This baseline trend likely buffered any declines in volume during the initial surge of the pandemic. Based on the nature of ACGME reports, our analysis is limited to residents who graduated in AY19-20 and AY20-21, and does not assess the operative experience of junior residents during the pandemic.

Furthermore, it is important to consider that among general surgery residents graduating in AY19-20 and AY20-21, any decline in volume involved cases that

### Table 3. General Surgery Residency Case Volume Before and During the COVID-19 Pandemic

| Operation       | Proportion of Total Experience | Mean Case Volume Per Resident |
|-----------------|--------------------------------|-------------------------------|
|                 | Before COVID-19 | During COVID-19 | Before COVID-19 | During COVID-19 |
| Large intestine | 13.8%           | 14.0%            | 139.3           | 148.6           |
| Hernia          | 12.8%           | 12.5%            | 128.7           | 133.5           |
| Biliary         | 12.3%           | 12.4%            | 124.4           | 132.3           |
| Breast          | 6.3%            | 6.3%             | 63.5            | 66.7            |
| Skin/Soft Tis   | 5.8%            | 6.1%             | 58.1            | 65.1            |
| Abdomen general | 4.2%            | 4.4%             | 42.3            | 47.0            |
| Stomach         | 3.8%            | 4.3%             | 37.9            | 45.5            |
| Thoracic        | 3.9%            | 3.6%             | 39.3            | 38.1            |
| Small intestine | 3.6%            | 3.8%             | 36.7            | 40.8            |
| Anorectal       | 3.2%            | 3.6%             | 32.1            | 38.4            |
| Endocrine       | 3.3%            | 3.1%             | 33.1            | 32.8            |
| Vascular access | 3.2%            | 2.8%             | 32.6            | 30.1            |
| Trauma          | 2.8%            | 2.9%             | 28.7            | 30.9            |
| Pediatric       | 2.7%            | 2.2%             | 26.9            | 23.9            |
| Plastic         | 2.3%            | 2.5%             | 23.4            | 26.4            |
| Head/neck       | 2.3%            | 2.1%             | 22.7            | 22.1            |
| Peripheral vascular | 2.0%       | 1.9%              | 20.0            | 20.3            |
| Amputation      | 1.6%            | 1.6%             | 15.9            | 16.7            |
| Esophageal      | 1.1%            | 1.4%             | 11.5            | 14.8            |
| Transplant      | 1.1%            | 1.1%             | 10.7            | 12.2            |
| Pancreas        | 1.0%            | 0.9%             | 10.4            | 9.6             |
| Cerebrovascular | 1.1%            | 0.9%             | 10.6            | 9.3             |
| Liver           | 1.0%            | 0.9%             | 9.9             | 9.7             |
| Venous          | 0.9%            | 0.7%             | 9.0             | 7.7             |
| Endovascular    | 0.7%            | 0.9%             | 7.6             | 9.2             |
| Aneurysm repair | 0.6%            | 0.5%             | 6.0             | 5.6             |
| Genito-urinary  | 0.4%            | 0.4%             | 4.1             | 4.2             |
| Vascular trauma | 0.2%            | 0.3%             | 2.4             | 2.9             |
| Hand            | 0.3%            | 0.3%             | 2.6             | 2.7             |
| Spleen          | 0.3%            | 0.2%             | 2.7             | 2.4             |
| Gynecology      | 0.2%            | 0.2%             | 2.2             | 2.5             |
| Upper extremity | 0.2%            | 0.2%             | 1.9             | 2.1             |
| Vascular bypass | 0.2%            | 0.1%             | 1.7             | 1.5             |
| Orthopedics     | 0.1%            | 0.1%             | 1.4             | 1.3             |

*Mean proportion of total experience during each period. Before COVID-19 includes graduating cohorts for AY14-15, AY15-16, AY16-17, AY17-18, and AY18-19. After COVID-19 includes graduating cohorts for AY19-20 and AY20-21.
would have been performed as either a PGY-4 or PGY-5 clinical resident. Comparing AY18-19 and AY19-20 alone, we observed a decline in cases logged as surgeon chief (283 cases for AY18-19 and 255 cases for AY19-20). While the period means (AY14-15 to AY18-19 and AY19-20 to AY20-21) did not appear to vary significantly, this represents a 10% numerical decline in the total number of cases as surgeon chief between graduates in AY18-19 and AY19-20. For trainees, performing surgeries as surgeon chief, and leading a clinical service as a chief resident, plays an important role in their operative, clinical and professional development.52–57 It is unknown whether eliminating 10% of cases performed as a chief resident would substantially impact a surgeon’s proficiency and preparedness for clinical practice. A survey administered in April 2020 of exclusively general surgery chief residents found that despite the pandemic, most respondents were confident in the extent of their operative training and ability to satisfy ACGME minimum requirements.58 However, there are multiple studies indicating that surgical graduates feel variably prepared for independent professional practice.59–63 Concerns regarding proficiency have linked to increased interest in post-residency clinical fellowships.63,64 Additional operative exposure in a quality teaching environment is inherently beneficial for trainees, and the perceived disruption and impact of the coronavirus pandemic on clinical training and surgeon development, as highlighted in the aforementioned survey-based and qualitative studies of surgical residents, underscores the extent to which trainees desire operative experience and hands-on training. Nonetheless, while we observed a slight decline in chief cases from AY18-19 to AY19-20, the operative experience of chief residents in AY19-20 does not represent a substantial departure from earlier recent graduates, with equivalent volume as residents graduating in AY16-17.

Inevitably, the pandemic differentially impacted chief residents’ operative experience; an assessment of average volumes, overall and by major operation type, will not capture the reality that the pandemic impacted training during a concentrated period—disrupting 1 or 2 specialty rotations. Based on the structure of programs and the resident’s professional goals, the pandemic may have severely impacted their training experience and preparedness. For instance, a chief resident pursuing colorectal surgery who had disruptions to their colorectal rotation may have been severely impacted, whereas a resident pursuing trauma surgery who experienced disruptions to their minimally invasive surgery rotation may have been marginally affected. Alternatively, with regard to long-term training and exposure, one could argue that the trainee pursuing colorectal fellowship would have a year of additional training to compensate for the missed operative experience, whereas the resident pursuing trauma surgery may have missed out on critical laparoscopic training that is not readily replaced in fellowship or as an attending. Operative volume alone does not capture the impact of the coronavirus pandemic on operative training and specialty-specific surgical preparedness.

In addition, it is critical to emphasize that the current study does not assess the impact of the pandemic on the experience of interns and junior residents during the initial pandemic, who will graduate in AY21-22, AY22-23, and AY23-24, in the absence of professional development years. Based on the results of several qualitative studies, it has been hypothesized that the operative experience of junior residents was most impacted by the pandemic. A multicenter study evaluating operative logs of residents from 18 participating sites observed a significant decrease in operative volume in AY19-20, which disproportionately impacted junior residents.65 Moreover, junior residents during the initial wave of the pandemic experienced multiple disruptions to their operative training, which would not have been captured in the current study.

Using the operative logs of current residents, research should be conducted by either the ACGME itself or individual programs to assess the impact of the pandemic on the operative training of individual residents and ensure that needed adjustments can be facilitated. The full impact of the coronavirus pandemic on surgical training will not be known without assessing its impact on interns and junior residents at the onset of the pandemic, who have trained during multiple waves of the pandemic and may have experienced a greater burden of cancelled and/or postponed cases. The current data only measures longitudinal volume among graduating residents, rather than annual volume by training year, which is a limitation of the present study and available data.

The current study has several limitations. First, resident operative volume is self-reported and the accuracy and completeness of ACGME resident log has been previously contested.60,66–68 Nonetheless, this national dataset represents the largest, most complete, and nationally standardized reference to assess trends and changes in logged case volume. Secondly, summary data for each of the graduating cohorts does not reliably reflect the operative experience of each resident; inevitably, some residents and programs were more substantially impacted by the pandemic. Third, although measuring case volume is useful in assessing the breadth and depth of training, it is an imperfect metric for assessing competence, as it does not provide insight into intra-operative performance, clinical reasoning and overall proficiency. The disruption posed by COVID-19 underscores the
importance of incorporating competency-based assessment of clinical proficiency, and tailoring training to individual trainees' strengths and areas for development.

In conclusion, over the past 7 years, we observed a significant uptrend trend in logged operative volume among surgical trainees across multiple surgical specialties, including general, orthopedic, neuro- and plastic surgery. Despite the marked impact of the coronavirus pandemic on surgical care and graduate medical education, the number of logged operative cases was not significantly lower among trainees across several surgical subspecialties who graduated during the pandemic, compared to prepandemic graduates. Additional research evaluating operative volume among residents who were interns and junior residents at the onset of the pandemic is needed to quantify the full impact of the pandemic on surgical training. Surgical residents graduating during the pandemic undoubtedly encountered distinct circumstances as senior residents; however, there is no definitive evidence from currently available ACGME case log data that the pandemic undermined their overall training and preparedness for practice.

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**SUPPLEMENTARY INFORMATION**

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jsurg.2022.11.005.