Original Article

Association of Surgeon Age and Experience With Congenital Heart Surgery Outcomes

Brett R. Anderson, MD, MBA, MS; Amelia S. Wallace, MS; Kevin D. Hill, MD, MS; Brian C. Gulack, MD; Roland Matsouaka, PhD; Jeffrey P. Jacobs, MD; Emile A. Bacha, MD; Sherry A. Glied, PhD; Marshall L. Jacobs, MD

Background—Surgeon experience concerns both families of children with congenital heart disease and medical providers. Relationships between surgeon seniority and patient outcomes are often assumed, yet there are little data.

Methods and Results—This national study used linked data from the American Medical Association Physician Masterfile and the Society of Thoracic Surgeons-Congenital Heart Surgery Database to examine associations between surgeon years since medical school and major morbidity/mortality for children undergoing cardiac surgery. Sensitivity analyses explored the effects of patient characteristics, institutional/surgeon volumes, and various measures of institutional surgeon team experience. In secondary analyses, major morbidity and mortality were examined as separate end points. We identified 206 congenital heart surgeons from 91 centers performing 62 851 index operations (2010–2014). Median time from school was 25 years (range 9–55 years). A major morbidity/mortality occurred in 11.5% of cases. In multivariable analyses, the odds of major morbidity/mortality were similar for early-career (<15 years from medical school, ≈<40 years old), midcareer (15–24 years, ≈40–50 years old), and senior surgeons (25–35 years, ≈50–60 years old). The odds of major morbidity/mortality were ≈25% higher for operations performed by very senior surgeons (35–55 years from school, ≈60–80 years old; n=9044 cases). Results were driven by differences in morbidity. In extensive sensitivity analyses, these effects remained constant.

Conclusions—In this study of >200 congenital heart surgeons, we found patient outcomes for surgeons with the fewest years of experience to be comparable to those of their midcareer and senior colleagues, within the context of existing referral and support practices. Very senior surgeons had higher risk-adjusted odds of major morbidity/mortality. Contemporary approaches to training, referral, mentoring, surgical planning, and other support practices might contribute to the observed outcomes of junior congenital heart surgeons being comparable to those of more experienced colleagues. Understanding and disseminating these practices might benefit the medical community at large. **(*Circ Cardiovasc Qual Outcomes*. 2017;10:e003533. DOI: 10.1161/CIRCOUTCOMES.117.003533.)**

Key Words: health care quality, access, and evaluation ■ heart defects, congenital ■ mentoring ■ surgeons

Congenital heart defects affect ≈1 in 100 children.[1] Although pediatric cardiologists, cardiothoracic surgeons, nurses, and other healthcare providers work in concert to care for these patients, a transformative component of their care lies in the hands of surgeons. Previous research has demonstrated that there is substantial variation in outcomes between surgeons, even after adjusting for provider volumes,[2] yet there are little existing data connecting surgeon-specific factors to patient outcomes.

See Editorial by Waljee and Ohye

In adult subspecialties, provider experience (as measured either by age or years since completion of training) has been examined as a predictor of clinical outcomes with varying results.[3] Some studies have found better outcomes with an increasing number of years of experience, as might be predicted, with the worst outcomes among the most junior surgeons.[4–6] Other studies, in contrast, have described worse outcomes among the oldest providers.[7–11] The degree to which experience impacts clinical outcomes in a highly complex and diverse field such as pediatric cardiac surgery is not known.

We conducted a national study to examine the relationship between congenital heart surgeon years of experience and patient outcomes. We hypothesized that, even after adjusting

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From the Division of Pediatric Cardiology, NewYork-Presbyterian/Morgan Stanley Children's Hospital, Columbia University Medical Center (B.R.A.); Duke Clinical Research Institute, Durham, NC (A.S.W.); Department of Pediatrics, Duke Clinical Research Institute (K.D.H.) and Department of Surgery (B.C.G.), Duke University Medical Center, Durham, NC; Department of Biostatistics and Bioinformatics, Duke University, Durham, NC (R.M.); Division of Cardiovascular Surgery, Department of Surgery, Johns Hopkins All Children's Heart Institute, St. Petersburg, FL (J.P.J., M.L.J.); Division of Cardiac Surgery, Department of Surgery, Johns Hopkins School of Medicine, Baltimore, MD (J.P.J., M.L.J.); Division of Cardiothoracic Surgery, Columbia University College of Physicians and Surgeons, New York, NY (E.A.B.); and The Robert F. Wagner Graduate School of Public Service, New York University (S.A.G.).

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Correspondence to Brett R. Anderson, MD, MBA, MS, NewYork-Presbyterian/Morgan Stanley Children's Hospital, 3959 Broadway, CH-2N, New York, NY 10032. E-mail bra2113@cumc.columbia.edu

WHAT IS KNOWN

- There is substantial variation in outcomes between congenital heart surgeons, even after adjusting for provider volumes, yet little data exist connecting other surgeon-specific factors to patient outcomes.
- In other surgical fields, both provider learning curves and attrition have been described, with worse outcomes among the most junior and the most senior practitioners.

WHAT THE STUDY ADDS

- Within the context of existing referral and support practices, outcomes for junior congenital heart surgeons are excellent.
- As congenital heart surgeons near the tail end of the experience spectrum, the performance of some seems to suffer, irrespective of provider volumes.

for patient characteristics and institutional volumes, nonlinear relationships exist between experience and outcomes.

Methods

Data Source

Data for this study were derived via a linkage of the Society of Thoracic Surgeons-Congenital Heart Surgery Database (STS-CHSD) and the American Medical Association (AMA) Physician Masterfile. The STS-CHSD is the largest congenital heart surgery registry in the world. It includes data on >360 000 surgeries conducted at 127 centers in North America. It captures data from ≈96% of all US centers performing congenital heart surgery, including ≈98% of all operations.[12] Member surgeons submit preoperative, operative, and outcomes data for all pediatric and congenital heart surgery cases they perform. The Duke Clinical Research Institute serves as the data warehouse and analytic center for all STS National Databases. Data quality is assessed through intrinsic verification of data, as well as formal data audits at ≈10% of participating institutions each year.[12–14] Recent investigation has reported 98% accuracy of data elements when compared with manual review of patient records.[15]

Surgeon age, years since completion of medical school, and years since terminal training were derived from the AMA Physician Masterfile, a public registry of current and historic data on virtually all physicians training or practicing in the United States. The AMA Masterfile is automatically populated during physician accreditation and tracks physicians from entrance into medical school and through postgraduate training, licensure, and practice (even if they are not members of the AMA) (http://www.ama-assn.org/ama/pub/about-ama/physician-data-resources/physician-masterfile.page). From the AMA Masterfile, we built a Pediatric Cardiothoracic Surgeon Masterfile, including training and licensing characteristics for all US pediatric cardiothoracic surgeons. For surgeons graduating from non-US medical schools or training abroad, data were supplemented with self-reported data from The Cardiothoracic Surgery Network Database (http://www.ctsnet.org/surgeons). This Pediatric Cardiothoracic Surgeon Masterfile was linked by National Provider Index Number to the STS-CHSD at the Duke Clinical Research Institute, and a limited data set, including only coded surgeon and patient identifiers, was abstracted.

This study was approved by the STS-CHSD Access and Publications Committee. It was considered by the Duke University Institutional Review Board and the Institutional Review Board at Columbia University Medical Center not to be human subjects research, in accordance with the Common Rule (45 CFR 46.102(f)), as it did not involve private information.

Patient Population

We initially included all index cardiovascular operations in patients ≤18 years of age undergoing cardiac surgery in the United States, with or without cardiopulmonary bypass, at institutions contributing data to the STS-CHSD (data version 3.0 or 3.22) between 2010 and 2014 (n=86 196 individual admissions at 111 centers). Index operations for which a Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery (STAT) mortality risk score[16] was not defined were excluded (2209 cases), as were cases limited to the surgical closure of patent ductus arteriosus in infants <2.5 kg (5002 cases). The STAT Mortality Risk Categories are an empirically derived classification system, which groups procedures based on the statistically estimated risk of mortality, with the objective of maximizing within category homogeneity (similarity) and between category discrimination of estimated risk. The categories serve as stratification variables that can be used to adjust for case mix when analyzing outcomes and comparing institutions or surgeons. Procedures are excluded from assignment to a STAT category if they are not considered to be cardiovascular procedures (with or without cardiopulmonary bypass support) or if they are sufficiently nonspecific that statistical estimation of mortality risk would not be meaningful (eg, cardiac, other or thoracotomy). To ensure the most accurate risk adjustment, 20 centers with >10% missing data on key patient characteristics or outcome data were excluded (15 633 cases). Individual index operations missing patient characteristics (n=77) or outcomes data (n=51) were also excluded, as were operations on neonates and infants with weight-for-age *Z* scores <−7 or >5 (n=278), to ensure data integrity. The final cohort included 62 851 individual operations occurring at 91 centers.

Surgeon Population

Surgeons were included who contributed ≥6 months worth of data to the STS-CHSD (231 surgeons). Surgeons were excluded if they performed <10 cardiovascular procedures per year during the time that they participated in the database (25 surgeons, 95 cases) as this cohort consisted almost entirely of adult, noncongenital, cardiac surgeons who happened to perform occasional procedures on patients with congenital heart disease.

Data Collection

Data collected from the STS-CHSD included patient demographics, baseline characteristics, preoperative risk factors, operative characteristics, and outcomes. Average annualized surgeon and center case volumes were also recorded. Surgeon and center case volumes were calculated using all index cardiopulmonary bypass or noncardiopulmonary bypass cardiovascular operations classifiable by the STAT Mortality Risk Categories.

Data collected from the Pediatric Cardiothoracic Surgeon Masterfile included surgeons' dates of birth, years of medical school graduation, and years of postgraduate trainings.

The primary predictor of interest was surgeon years of experience, derived from the Pediatric Cardiothoracic Surgeon Masterfile and defined as the number of full years since medical school graduation on the date of a patient's index operation. Surgeon age and years since last postgraduate training were also calculated and assessed.

Outcomes

The primary outcome of interest was major morbidity or mortality, assessed as a composite variable. We decided *a priori* to use this composite outcome as (1) the incidence was assumed to be higher than that of mortality alone, and (2) it has been suggested that mortality might be less reflective of the work of individual surgeons and more reflective of the efforts of the entire medical team, acknowledging the potential importance of the concept known as failure to rescue.[17] In secondary analyses, mortality and major morbidity were assessed as separate end points. In keeping with standard STS definitions, mortality was defined as (1) all deaths, regardless of cause, occurring during the hospitalization in which the operation was performed, even if after 30 days (including patients transferred to other acute care facilities); and 2) all deaths, regardless of cause, occurring after discharge from the hospital but before the end of the 30th postoperative day.[18] Major morbidity was defined as ≥1 of six previously defined major complications, including temporary or permanent renal failure requiring dialysis or temporary hemofiltration, neurological deficit persisting at discharge, atrioventricular block or arrhythmia requiring a permanent pacemaker, postoperative mechanical circulatory support, phrenic nerve injury, or any unplanned cardiac surgical or catheter-based reintervention before discharge.[19]

Analysis

Baseline patient, provider, and institutional characteristics were described using standard summary statistics. Surgeon experience (expressed as years since medical graduation) was evaluated as both continuous (linear) and categorical variables. When assessed as a categorical variable, it was analyzed first in 4 predetermined groups: <15 years (early career), 15 to 24 years (midcareer), 25 to 34 years (senior), and ≥35 years (very senior) since medical school graduation. These roughly corresponded to surgeons <40, 40 to 50, 50 to 60, and 60 to 80 years old or <6, 6 to 15, 15 to 25, and >25 years since fellowship. Differences in patient characteristics across surgeon experience categories were compared using χ^2 rank-based group means score statistics, Wilcoxon rank-sum or Kruskal–Wallis, and Cochran–Mantel–Haenszel tests. Surgeon average annualized volume was also plotted as a function of surgeon experience, using a scatter plot, and Spearman correlation was used to assess the marginal association.

To assess the relationships between surgeon experience and each of the measured outcomes, logistic mixed-effects models were constructed, selecting control variables from the previously established congenital heart surgery risk model and refitting the model after the introduction of the surgeon experience parameters.[20] This model adjusts for baseline patient characteristics, including age at surgery, prematurity, weight (among neonates and infants), sex, year of surgery, presence of noncardiac anatomic abnormalities or syndromes/chromosomal abnormalities, previous cardiothoracic operation, and preoperative mechanical ventilation, circulatory support, persistent shock, renal failure, or the presence of any other preoperative risk factor coded in the STS-CHSD, as well as STAT Mortality Category for the primary operative procedure. It is associated with a C statistic of 0.86 in predicting surgical mortality in the STS-CHSD.[20] Surgeon experience was entered into this model first as a continuous variable and then as a categorical one. Surgeon experience was defined as the number of full years since medical school graduation on the date of a patient's index operation, and thus, surgeons were allowed to change age categories over the study period. To these models, 2 different measures of surgeon team experience were then added; surgeon team experience was assessed first as the average number of years since medical school for all surgeons operating at each center in a given year and then as the number of years since medical school for the most senior surgeon at each center. Both of these measures were assessed as linear variables. Because surgeon and center volumes were highly collinear, and because surgeon volume differed with surgeon experience, these models were tested with and without the inclusion of center volumes. Adjusted results were then calculated and plotted using restricted cubic splines, accounting for the nonlinear relationship between surgeon experience and the composite outcome. To further investigate the effects of possible mediation or effect modification by volume, data were also stratified by surgeon volume tertiles, and models were rerun. A volume–experience interaction term was also tested in the models. In additional sensitivity analyses, to test the possibility that our findings were driven by the outcomes of a small number of very high-volume surgeons (n=7), we then excluded surgeons performing >250 cases per year and reran our analyses again. Next, to explore the effects within the very senior surgeon category, this cohort was further divided on the basis of years of experience (into those surgeons 35–40 years and those ≥40 years post-medical school), and analyses were rerun. Finally, our composite outcome was separated into its component parts, and mortality and major morbidity were tested separately. All models included center- and surgeon-level random intercepts.

Analyses were performed using SAS version 9.4 (SAS Institute, Inc, Cary, NC) and R version 3.2.1 (R Foundation for Statistical Computing, Vienna, Austria). *P* values <0.05 were considered statistically significant.

Results

We identified 206 surgeons from 91 centers. They performed a total of 62 851 index operations (6198 by the most junior surgeons and 9044 by the very senior surgeons). As of the end of the study period (2014), the median surgeon was 51 years old (interquartile range, 46–59; range, 35–80 years old) and was 25 years post-medical school graduation (interquartile range, 19–32; range, 9–55 years). The median surgeon finished his/her last postgraduate training 9 years after medical school (interquartile range, 8–11). Years since medical school graduation was highly correlated with both age (ρ=0.97, *P*<0.0001) and years since fellowship (ρ=0.97, *P*<0.0001). Approximately 1 quarter of the surgeons in our cohort were the only surgeons operating at their centers and 90% operated at centers with 3 or fewer surgeons (Table 1), although only 1 surgeon with <15 years of experience operated as the sole surgeon at his/her institution. Very senior surgeons operated in similarly sized divisions/departments as their midcareer and senior colleagues. Average surgeon volumes were lowest among the youngest surgeons, peaked among midcareer and senior surgeons, and then tapered among the most senior. No surgeon <18 years or >40 years from medical school performed >250 operations per year (Figure 1; Table 2).

There were some differences in baseline patient characteristics between surgeon experience quartiles. The most junior surgeons tended to perform fewer STAT Mortality Risk Category 5 cases (the highest risk category; 3.4% versus 5.4%, *P*<0.0001), fewer STAT Morbidity Category 5 cases (3.1% versus 4.2%, *P*<0.0001), fewer cases on children with preoperative risk factors (when considered as a composite variable) (29.0% versus 32.4%, *P*<0.0001), and fewer reoperations (20.9% versus 28.8%, *P*<0.0001). Very senior surgeons tended to operate on slightly older children (median age 10 versus 7 months, *P*<0.0001), including fewer neonates and infants (52.6% versus 60.0%, *P*<0.0001). Their patients were also slightly less likely to be coded for prematurity (14.9% versus 16.0%, *P*<0.0001) and had, on average, a statistically higher (though clinically similar) weight-for-age *Z* score. These very senior surgeons were more likely than their younger counterparts to perform operations on children who had previously undergone congenital heart surgeries (31.9% versus 27.4%, *P*<0.0001). There were no clear differences in STAT Morbidity[19] or STAT Mortality Risk Categories[16] or other preoperative risk factors between the very senior surgeons and their senior or midcareer colleagues. Missing data were rare (Table 3).

Major morbidity or mortality occurred in 11.5% of children (n=7236); major morbidity alone occurred in 8.8% (n=5500) and 3.6% died (n=2236). In multivariable analyses,

Table 1. Number of Surgeons per Center and Median Surgeon Experience by Academic Year

	Academic Year (No. of Centers)					
	2009–2010 (n=70)	2010–2011 (n=78)	2011–2012 (n=82)	2012–2013 (n=85)	2013–2014 (n=84)	Overall (n=91)
No. of surgeons per center						
1 Surgeon	17 (24.3%)	20 (25.6%)	20 (24.4%)	24 (28.2%)	21 (25.0%)	17 (18.7%)
2 Surgeons	37 (52.9%)	31 (39.7%)	37 (45.1%)	33 (38.8%)	32 (38.1%)	28 (30.8%)
3 Surgeons	11 (15.7%)	20 (25.6%)	18 (22.0%)	19 (22.4%)	22 (26.2%)	24 (26.4%)
4 Surgeons	4 (5.7%)	4 (5.1%)	4 (4.9%)	6 (7.1%)	6 (7.1%)	12 (13.2%)
5 Surgeons	1 (1.4%)	2 (2.6%)	2 (2.4%)	1 (1.2%)	0 (0.0%)	4 (4.4%)
6 Surgeons	0 (0.0%)	1 (1.3%)	1 (1.2%)	2 (2.4%)	1 (1.2%)	3 (3.3%)
7 Surgeons	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (1.2%)	1 (1.1%)
8 Surgeons	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (1.2%)	2 (2.2%)
Cumulative surgeon experience per center*						
Median (IQR)	47.0 (33.0, 67.0)	45.5 (32.0, 58.0)	48.0 (33.0, 65.0)	46.5 (33.0, 67.0)	46.0 (34.0, 69.0)	55.0 (39.0, 81.5)
Average surgeon experience per center†						
Median (IQR)	23.0 (20.3, 26.5)	23.1 (20.0, 27.0)	23.6 (19.0, 27.0)	23.8 (20.0, 28.0)	24.3 (20.9, 28.3)	22.9 (20.0, 26.3)

IQR indicates interquartile range.
*Cumulative surgeon experience refers to the total number of years since medical school graduation of all surgeons operating at each center.
†Average surgeon experience refers to the average number of years since medical school graduation of all surgeons operating at each center.

when assessed as a continuous, linear, variable, surgeon experience was not associated with any of the measured outcomes. Assessed as a categorical variable, we found that the odds of major morbidity or mortality were similar for early-career, midcareer, and senior surgeons, even after adjusting for patient characteristics, center volumes, and surgeon team experience. The odds of major morbidity or mortality were ≈25% higher for patients operated on by the very senior surgeons (Figure 2). The magnitude of this effect remained similar before and after adjusting for known confounders, including patient characteristics, center volumes, and surgeon team experience. Stratifying analyses by surgeon volume, the effect of surgeon seniority was seen only in the highest volume stratum (among surgeons performing >152 cases per year). This remained true in sensitivity analyses, after excluding surgeons performing >250 cases annually (Table 4). The interaction term for volume and experience was not significant. Additional sensitivity analyses tested the hypothesis that the observed associations were importantly influenced by a relatively small number of surgeons with the most years since training (≥40 years since medical school or roughly ≥65 old); splitting the very senior surgeon cohort to isolate those

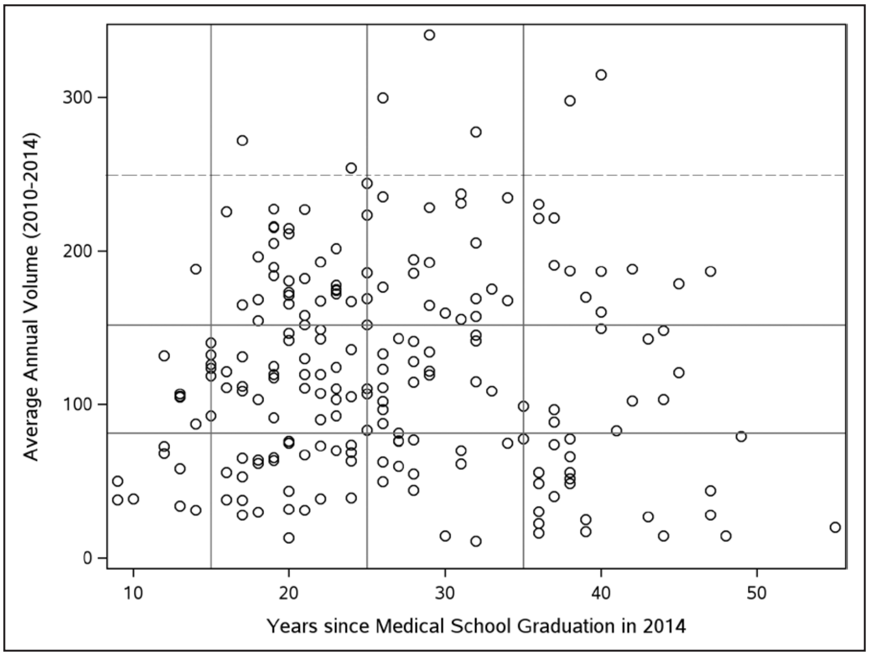

Figure 1. Surgeon average annualized volume as a function of surgeon experience at study completion (2014). Vertical lines represent divisions between surgeon experience quartiles. Horizontal lines represent divisions between surgeon volume tertiles.

Table 2. Surgeon Experience and Volume Characteristics, 2014

Surgeon Experience, 2014	Surgeon Volume				
	<81.4	81.4–152	152–250	250+	Total
<15 y	8 (3.9%)	5 (2.4%)	1 (0.5%)	0 (0.0%)	14 (6.8%)
15–24 y	25 (12.1%)	33 (16.0%)	28 (13.6%)	2 (1.0%)	88 (42.7%)
25–34 y	14 (6.8%)	21 (10.2%)	21 (10.2%)	3 (1.5%)	59 (28.6%)
35+ y	22 (10.7%)	10 (4.9%)	11 (5.3%)	2 (1.0%)	45 (21.8%)
Total	69 (33.5%)	69 (33.5%)	61 (29.6%)	7 (3.4%)	206 (100.0%)

This table displays surgeon volumes by surgeon experience category in the last year of the study, 2014.

Surgeon experience was defined as the number of full years since medical school graduation on the date of a patient's index operation; thus, surgeons were allowed to change age categories over the study period.

surgeons ≥40 years post-medical school did not meaningfully change our results, and our results remained statistically significant for the group 35 to 39 years out from medical school (odds ratio, 1.24; confidence interval, 1.02–1.50; *P*=0.0282), suggesting that our results were not skewed by a select few surgeons with the most years in practice.

Surgeon experience was not significantly associated with mortality when assessed as an independent outcome. It was

Table 3. Baseline Patient Characteristics, Preoperative Factors, and Hospital Volumes, Stratified by Surgeon Experience for the Surgeon of Record

	Overall (n=62 851)*	Surgeon Experience in Years Since Medical School†				*P* Value‡
		Early Career <15 y (n=6198)	Midcareer 15–24 y (n=29 391)	Senior 25–34 y (n=18 218)	Very Senior 35+ y (n=9044)	
Age at Surgery, y	0.6 (0.1, 3.9)	0.5 (0.1, 3.8)	0.5 (0.1, 3.4)	0.6 (0.1, 4.2)	0.8 (0.2, 5.1)	<0.0001
Age at Surgery, d						<0.0001
<30	13 700 (21.8%)	1352 (21.8%)	6693 (22.8%)	3915 (21.5%)	1740 (19.2%)	…
≥30 and <365	23 390 (37.2%)	2375 (38.3%)	11 369 (38.7%)	6626 (36.4%)	3020 (33.4%)	…
≥365	25 761 (41.0%)	2471 (39.9%)	11 329 (38.5%)	7677 (42.1%)	4284 (47.4%)	…
Sex (Female)	28 457 (45.3%)	2872 (46.3%)	13 358 (45.4%)	8125 (44.6%)	4102 (45.4%)	0.0687
Premature birth	9989 (15.9%)	1032 (16.7%)	4784 (16.3%)	2821 (15.5%)	1352 (14.9%)	0.0001
Weight-for-age *Z* score	−1.0 (−2.0, −0.1)	−1.1 (−2.1, −0.1)	−1.1 (−2.1, −0.1)	−1.0 (−2.0, −0.1)	−1.0 (−2.0, −0.0)	<0.0001
Any preoperative risk factors	20 183 (32.1%)	1797 (29.0%)	9319 (31.7%)	6153 (33.8%)	2914 (32.2%)	<0.0001
Any noncardiac anatomic abnormalities	2340 (4.2%)	242 (4.2%)	1114 (4.3%)	658 (4.0%)	326 (4.2%)	0.4879
Any syndrome/chromosomal abnormalities	15 255 (24.3%)	1506 (24.3%)	7273 (24.7%)	4296 (23.6%)	2180 (24.1%)	0.0468
STAT mortality complexity level						<0.0001
1	18 018 (28.7%)	2067 (33.3%)	8623 (29.3%)	4786 (26.3%)	2542 (28.1%)	…
2	18 309 (29.1%)	1747 (28.2%)	8452 (28.8%)	5409 (29.7%)	2701 (29.9%)	…
3	8227 (13.1%)	716 (11.6%)	3746 (12.7%)	2483 (13.6%)	1282 (14.2%)	…
4	15 039 (23.9%)	1456 (23.5%)	7013 (23.9%)	4515 (24.8%)	2055 (22.7%)	…
5	3258 (5.2%)	212 (3.4%)	1557 (5.3%)	1025 (5.6%)	464 (5.1%)	…
STAT morbidity complexity level						<0.0001
1	21 419 (34.1%)	2391 (38.6%)	10 122 (34.4%)	5775 (31.7%)	3131 (34.6%)	…
2	16 478 (26.2%)	1598 (25.8%)	7591 (25.8%)	4859 (26.7%)	2430 (26.9%)	…
3	8491 (13.5%)	727 (11.7%)	3920 (13.3%)	2628 (14.4%)	1216 (13.4%)	…
4	10 820 (17.2%)	1036 (16.7%)	5134 (17.5%)	3215 (17.6%)	1435 (15.9%)	…
5	2567 (4.1%)	193 (3.1%)	1215 (4.1%)	757 (4.2%)	402 (4.4%)	…
Previous cardiothoracic operation(s)	17 623 (28.0%)	1295 (20.9%)	7766 (26.4%)	5680 (31.2%)	2882 (31.9%)	<0.0001

*n=The number of index operations performed within each surgeon experience category.
†Data presented as medians and interquartile ranges or number of cases with percentages.
‡*P* values compare patient and hospital characteristics between surgeon experience categories.
STAT indicates Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery Risk Category.

Table 4. The Effects of Surgeon Experience on Major Morbidity or Mortality

	OR for Surgeon Experience (95% CI); *P* Value			
	Early Career <15 y	Midcareer 15–24 y	Senior 25–34 y	Very Senior 35+ y
Unadjusted	Reference	1.19 (1.04, 1.36); 0.0125	1.15 (0.98, 1.35); 0.0861	1.22 (1.01, 1.47); 0.0377*
Adjusted for patient characteristics	Reference	1.11 (0.97, 1.27); 0.1325	1.04 (0.89, 1.22); 0.5964	1.24 (1.03, 1.49); 0.0217*
Adjusted for patient characteristics and center volumes	Reference	1.11 (0.97, 1.27); 0.1314	1.04 (0.89, 1.22); 0.6412	1.24 (1.04, 1.49); 0.0197*
Adjusted for patient characteristics, center volumes, and average center surgical experience	Reference	1.11 (0.97, 1.27); 0.1286	1.04 (0.89, 1.23); 0.6173	1.25 (1.03, 1.51); 0.0219*
Adjusted for patient characteristics, center volumes, and maximum center surgical experience	Reference	1.12 (0.98, 1.28); 0.1121	1.05 (0.90, 1.24); 0.5265	1.27 (1.06, 1.54); 0.0115*
Stratified by surgeon volume				
Low volume (<81.4 cases per year)	Reference	1.16 (0.81, 1.66); 0.4116	1.24 (0.85, 1.82); 0.2639	1.28 (0.83, 1.98); 0.2622
Medium volume (81.4–152 cases per year)	Reference	1.14 (0.92, 1.42); 0.2391	1.10 (0.85, 1.42); 0.4897	1.11 (0.81, 1.52); 0.5178
High volume (>152 cases per year)	Reference	1.10 (0.90, 1.34); 0.3534	1.02 (0.80, 1.30); 0.8651	1.35 (1.04, 1.77); 0.0260*
Stratified by surgeon volume (excluding surgeons with >250 cases per year)				
Low volume (<81.4 cases per year)	Reference	1.16 (0.81, 1.66); 0.4217	1.24 (0.84, 1.81); 0.2759	1.28 (0.83, 1.98); 0.2673
Medium volume (81.4–152 cases per year)	Reference	1.14 (0.92, 1.43); 0.2306	1.10 (0.85, 1.42); 0.4738	1.11 (0.81, 1.53); 0.5081
High volume (152–250 cases per year)	Reference	1.09 (0.88, 1.35); 0.4308	1.03 (0.80, 1.34); 0.8126	1.37 (1.02, 1.84); 0.0338*

CI indicates confidence interval; and OR, odds ratio.
**P* value <0.05.

significantly associated with increased odds of major morbidity for patients operated on by surgeons with the most years of experience (Table 5).

Discussion

In this study of >200 congenital heart surgeons from 91 centers, we found patient outcomes for surgeons with the fewest years of experience to be comparable to those of their midcareer and senior colleagues, suggesting that the potential effects of the learning curve for junior surgeons in the field might be mitigated by some combination of existing referral patterns and other processes of care in place within institutions or professional societies. Patients operated on by very senior surgeons (35–55 years from medical school), however, had significantly higher risk-adjusted odds of the composite outcome, major morbidity or mortality (driven by differences in morbidity; Figure 2). The magnitude of these effects remained stable, even after considering patient characteristics, center volumes, and different measures of surgeon team experience. Surgeons with the least experience did tend to operate on lower-risk patients than did their midcareer and senior colleagues. There was no evidence to suggest that very senior surgeons operated on systematically higher-risk patients.

The existing literature on provider experience has been limited to adult subspecialties, and results have been mixed.[3] In general, studies involving surgical procedures on adult patients have tended to describe provider learning curves, with worse outcomes among the most junior practitioners, which gradually improve with time.[4–6] Some researchers have also pointed to declines in outcomes among very senior adult providers performing technically complex procedures.[7–11] Studies have shown that older physicians are less likely to incorporate new treatments into their practices relative to younger physicians,[21,22] have worse performance on recertification

Table 5. The Effects of Surgeon Experience on Mortality and on Major Morbidity as Separate Outcomes

	Unadjusted		Adjusted	
Model	OR (95% CI)	*P* Value	OR (95% CI)	*P* Value
Mortality				
Surgeon experience*				
<15 y	Reference	NA	Reference	NA
15–24 y	0.98 (0.80, 1.19)	0.8008	0.88 (0.73, 1.08)	0.2234
25–34 y	1.00 (0.80, 1.25)	0.9964	0.93 (0.74, 1.16)	0.5041
>35 y	0.89 (0.69, 1.16)	0.3992	0.98 (0.76, 1.27)	0.8935
Major morbidity				
Surgeon experience				
<15 y	Reference	NA	Reference	NA
15–24 y	1.19 (1.02, 1.38)	0.0249†	1.10 (0.95, 1.28)	0.2079
25–34 y	1.12 (0.94, 1.34)	0.2147	1.00 (0.84, 1.19)	0.9997
>35 y	1.28 (1.04, 1.58)	0.0191†	1.27 (1.03, 1.55)	0.0218†

CI indicates confidence interval; and OR, odds ratio.
*Surgeon experience is described as years since medical school graduation.
†*P* value <0.05.

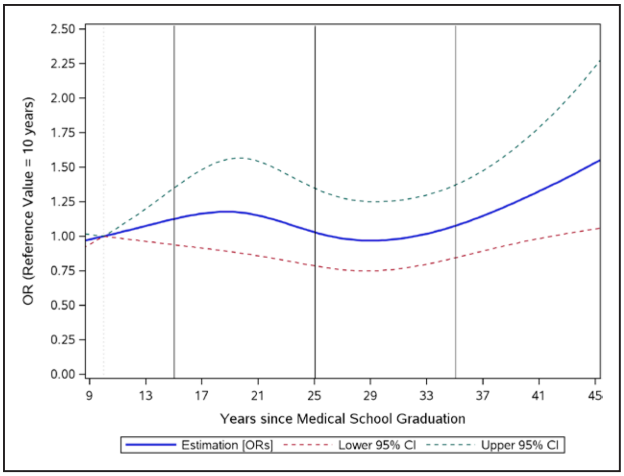

Figure 2. Risk-adjusted odds of major morbidity or mortality as a function of surgeon experience. Restricted cubic splines were used to visually display the risk-adjusted odds ratio (OR) of the composite outcome as a function of surgeon years since medical school graduation, including upper and lower 95% confidence intervals (CIs). Vertical lines demarcate surgeon experience categories and a reference value of 10 y since medical school graduation.

examinations,[23,24] and might, in fact, have diminished manual dexterity, visuospatial abilities, and sustained attention.[25–28]

Interestingly, in our study, we found no differences in outcomes for congenital heart surgeons early in their career when compared with their midcareer or senior colleagues. While we think that there is a learning curve for congenital heart surgeons, our data suggest either that it occurs very early (such that grouping all surgeons <6 years from terminal training into the same category obscures any perceivable differences in patient outcomes), or that the congenital heart community does an appropriate job of allocating cases and of supporting junior surgeons (or both). Certainly, it is true that many junior surgeons have senior or very senior colleagues who discuss operative plans with them or scrub in and assist with their more complicated cases, which is not recorded in our database. Many, in fact, operate for several years with very close supervision in what might be characterized as an extended apprenticeship model. Perhaps, it is also true that other surgeons, or even cardiologists, take time to work with the junior surgeons, to help them select their cases, and to plan pre- or postoperatively in ways that avert adverse events. This might take place through preoperative multidisciplinary planning conferences recommended by the Society of Thoracic Surgeons and the Congenital Heart Surgeons' Society, or through less formal mechanisms.[29] Although our data do not allow us to investigate these specific mentorship-related factors in detail, they suggest that the current mechanisms of support in place during the early portion of congenital heart surgeons' careers in the United States, in combination with patterns of surgical referral, are generally adequate to mitigate potential effects of a surgeon learning curve on patient outcomes.

It is notable that we do not see changes in the magnitude of the effects of surgeon experience on outcomes when adjusting for different measures of surgeon team experience, suggesting that junior surgeons in this community are well supported, regardless of the years of experience of the surgeons with whom they work. In considering these findings, it could be that the number of years that one's surgical colleagues have been in practice is not an accurate proxy for mentorship in the operating theater. Alternately, it could be that the experience of the entire cardiac care team (not just the surgeons) is critical. These possibilities warrant further investigation.

The decline in patient outcomes among very senior surgeons in our study is similar to the findings of several previous studies in adult subspecialties.[7–11] Waljee et al[7] noted this decline to be particularly prominent among surgeons performing the most technically or physically demanding operations—which certainly would include congenital heart surgeons. Contrasting with our study, Waljee et al[7] found surgical volume to be protective, with a decline in patient outcomes isolated to lower volume very senior surgeons. Their study prompted a call for surgeons to take an all-or-none approach to operating and to terminate rather than to gradually reduce their volumes and to "slowly fade away."[7] The volume–experience interaction we describe—with the poorest outcomes isolated to the highest volume very senior surgeons—suggests that, at least for congenital heart surgeons, volume might not be the solution.

Data for this study are derived from a clinical registry. As such, one has to consider the possibility that the observed differences in patient outcomes might be related to incomplete risk adjustment rather than the true effects of experience. Although the mortality risk model we used discriminates at a high level (C statistic 0.86),[20] it does not account for all potential confounders. In addition, this model has only been validated with respect to the mortality end point, not our composite outcome. Analyzing our data, we noted that the number of patients undergoing reoperations increased with surgeon seniority and we hypothesized that, perhaps, there were other, unmeasured risk factors that were also increasing. Perhaps, there were subtle differences in cardiac anatomy, ventricular function, number or complexity of preoperative risk factors or extracardiac anomaly types, for example, not captured in the registry, that were making the early-career surgeons' patients lower risk than they appeared and the very senior surgeons' patients higher risk. This certainly fits with our clinical perception. Were this the case, however, one would assume that there would be other observable patient risk factors that were also decreased for junior surgeons and increased for the most senior. This might be consistent with our data for early-career surgeons who seemed to perform fewer STAT Mortality Category 5 and STAT Morbidity Category 5 procedures. It was not, however, what we found for the most senior surgeons. In fact, differences in observed characteristics across surgeon experience categories seem to indicate that, on average, very senior congenital heart surgeons operate on fewer of the highest risk patients than do their midcareer and senior colleagues (Figure 1). Extensive secondary analyses exploring the effects of unmeasured risk were also performed. None of these analyses support the hypothesis of confounding by unmeasured risk either. The addition of all observable risk factors to our multivariable models changed negligibly the point estimates for the magnitude of the effects of surgeon years of experience on outcomes, indicating that risk adjustment is unlikely to be driving our results.

In interpreting our data, we find it critically important to point out that seniority in this study was arbitrarily set with a cut point at 35 years post-medical school. This category incorporates surgeons 35 to 55 years out (≈60–80 years old). The differences in patient outcomes that we observed do not necessarily begin at exactly 35 years. It is possible that the true tipping point for patient outcomes in this cohort occurs closer to 30, or 40, or even 45 years post-medical school. In sensitivity analyses, we divided the very senior surgeon category into surgeons 35 to 39 and ≥40 years out from medical school. Our results remained statistically significant for the 35 to 39 year group, suggesting that our results were not driven by a select few surgeons with the most years of experience. Unfortunately, we do not have sufficient power to discriminate further within this age category. Certainly, the precise timing and impact of any age-related effects would also vary between individual surgeons. In addition, our data do not allow us to account for the possibility that high-volume very senior surgeons, even when listed as the surgeon of record, might allow trainees (or more junior surgeons) to perform larger portions of their cases than do their midcareer or senior colleagues. That having been said, Waljee et al[7] saw persistent effects of surgeon seniority in their cohort, even after controlling for hospital teaching status.

Our study has a few other notable limitations. It is possible that some of our subanalyses, such as the analyses of the lower and middle volume very senior surgeons, were underpowered, and that this prevented us from detecting meaningful differences in outcomes in these subgroups. Further, although we controlled for patient age and STAT Mortality Risk Category, there was not sufficient power to explore differences in the magnitude of the effects of surgeon experience on outcomes between age or Risk Categories. And finally, postoperative outcomes are related to several factors that might change with surgeon age, including, but not limited to technical proficiency, clinical decision-making, interaction with other members of the care team, and processes of care. This data source cannot discern which aspects of surgeon performance improve/decline with age.

Our study has several important implications. First, it is helpful in reassuring families and the pediatric cardiology and cardiothoracic surgery community that, in general, surgeon years of experience are not associated with patient outcomes, or, at least, that, given the current system of support and referrals, junior surgeons are able to achieve outcomes that are not appreciably different from those of more senior surgeons. Second, as surgeons near the extreme end of the spectrum of experience (and thus, age), our data suggest that the performance of some might suffer. The extent of this effect is likely variable, and undoubtedly some very senior surgeons continue to function at the highest levels. Nonetheless, our findings suggest that it might be prudent for the surgeons with the most years of experience to closely monitor their outcomes and to critically appraise their skills. Third, as medical boards rethink their approaches to training, continuing medical education, and maintenance of certification, there might be use in considering the needs of the most senior surgeons, as study by Waljee et al[7] previously suggested. This having been said, we feel strongly that any blanket policy restricting practice to younger generations would be misplaced, as our clinical impression is that these senior mentors might be the very reason why junior surgeons in the congenital heart community demonstrate such outstanding outcomes. Critical assessment and dissemination of these mentoring, support, and referral practices might benefit the medical community at large. Future studies that examine these practices systematically might help shorten provider learning curves and improve patient outcomes across subspecialties.

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Disclosures

None.

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Brett R. Anderson, Amelia S. Wallace, Kevin D. Hill, Brian C. Gulack, Roland Matsouaka,
Jeffrey P. Jacobs, Emile A. Bacha, Sherry A. Glied and Marshall L. Jacobs

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