Outcomes of Trainees Performing Coronary Artery Bypass Grafting: Does Resident Experience Matter?

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Background. **Outcomes after coronary artery bypass graft surgery (CABG) are known to be dependent on attending surgeon volume, but the impact of resident experience is unknown. Our objective was to assess the influence of resident experience to understand the learning curve for CABG.**

Methods. **From 2008 to 2014, all isolated on-pump CABG (n = 1,668) during which a resident performed the entire operation (including sternotomy, mammary artery harvest, coronary anastomoses, and closure) were reviewed. Operations were stratified by individual resident CABG experience. Primary outcomes included operative time, which was further divided into "opening time" (incision to bypass initiation), cardiopulmonary bypass times, cross-clamp times, and "closing times" (bypass termination to close). Secondary outcomes included 30-day mortality and major complications.**

Results. **Operative time was 29.7 minutes longer ($p < 0.001$) during residents' first 30 CABG, primarily driven by longer opening and closing times. After controlling for resident, attending physician, preoperative risk, number of grafts, and redo status, the completion of 30 operations improved operative time by 25 minutes ($p < 0.001$), the majority of which included opening time (13 minutes, $p < 0.001$). Minor differences in bypass and cross-clamp times were not clinically meaningful, and there were no differences in 30-day mortality or major complications with respect to resident experience.**

Conclusions. **Total operative time during CABG is dependent on resident experience, with significant improvement by approximately the 30th case. Importantly, these differences do not translate into worse outcomes. These data support trainees performing all components of CABG—even early in the residency experience.**

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Intense pressure on academic medical centers to increase efficiency and cut costs, as well as the perceived dichotomy between delivering the highest possible quality care and training residents, has focused considerable scrutiny on the influence of residents on patient outcomes [1–4]. Inexperienced trainees have been identified as a source of increased mortality and medical errors [5–7]. However, most of this evidence has relied on academic season, or the "July effect," as a crude proxy for resident experience and has focused on mortality at the hospital rather than at the subspecialty level. Notably, these trends have not been shown to exist in cardiac surgery, possibly owing to increased supervision and to many residents having already completed general surgery residency [8–12].

Cardiac surgery involves complex operations that require significant training and technical expertise. Therefore, it is unsurprising that the balance of evidence suggests that higher attending surgeon case volume and years in practice are associated with both improved 30-day mortality and long-term survival for most cardiac operations [13, 14]. Acknowledgement of these data has not only called into question whether graduating residents are prepared for independent practice but also led to increased recognition that mentorship in cardiac surgery should extend after residency [15].

Such findings also complicate defining the proper role of autonomy and make it difficult to identify truly achievable milestones in cardiothoracic residency, especially given that the influence of resident experience remains largely unknown. Our objective was to assess the influence of case-specific resident volume to understand the resident learning curve for coronary artery bypass graft surgery (CABG).

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Patients and Methods

Patients and Setting

This study was approved by the University of Virginia Institutional Review Board, including a waiver for the

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need to obtain patient consent. The University of Virginia Health System is a tertiary care academic medical center with an Accreditation Council for Graduate Medical Education accredited thoracic surgery residency program.

All adult patients undergoing isolated, on-pump CABG between July 1, 2008, and July 1, 2014, were identified using The Society of Thoracic Surgeons (STS) Adult Cardiac Surgery Database at our institution. Inclusion further required that a resident trainee perform and log the entire operation as primary surgeon (including sternotomy, internal thoracic artery conduit harvest, cannulation, majority of the distal coronary anastomoses, and chest closure). All trainees acting as primary surgeon during this time were in their final 2 years of cardiothoracic residency; no integrated 6-year residents at our institution had entered their final 2 years of residency during the study period and thus were effectively excluded from the study.

Operations were stratified by resident experience, dividing operations into two cohorts based on whether the resident had completed 30 cases. This threshold was obtained from the learning curve analysis, and therefore used to guide our selection of a reasonable case volume after which significant improvement should be expected.

Patient demographics, preoperative risk factors, operative surgeon, operative features, and postoperative outcomes were compared between the two cohorts. Preoperative risk was assessed by the prevalence of comorbid disease as described by standard STS variable definitions and established calculated STS predictive indices, including predicted risk of mortality (PROM) and predicted risk of mortality or morbidity (PROMM).

EDUCATION

Outcomes

Primary outcomes included total operative time, which was further divided into "opening time" (skin incision to initiation of cardiopulmonary bypass; likely also a proxy for sternotomy plus mammary artery harvest time), cardiopulmonary bypass time, cross-clamp time, and "closing time" (cardiopulmonary bypass termination to skin closure).

Secondary outcomes included 30-day mortality and major complications (stroke, renal failure, reoperation, prolonged ventilation, deep sternal wound infection). Thirty-day mortality was defined as all patient deaths occurring during hospitalization as well as those within 30 days of surgery regardless of discharge status. Standard STS definitions for complications were used, including, for example, prolonged mechanical ventilation (more than 24 hours) and renal failure (increase in serum creatinine level greater than 2.0 or a doubling of the most recent preoperative creatinine level).

Statistical Analysis

Learning curves for opening and closing were defined using best-fit power functions. The transition from an exponential to linear curve was used as a threshold to separate the learning phase from the consolidation phase. We also analyzed the learning curve in terms of the number of cases required to achieve proficiency, defined as achieving five consecutive operative times below the median of all trainee's times during the last academic quarter.

Univariate comparisons were performed using the Pearson χ^2 test for dichotomous variables and Student's t test for continuous variables. All categoric variables are expressed as a percentage of the group of origin; continuous variables are expressed as mean ± SD or median with total range.

To verify the univariate comparisons between the study cohorts and to control for confounding variables, multivariable linear and logistic regression were used to define the effect of case volume on operative times, mortality, and major complications. Variables for control included resident surgeon, attending surgeon, STS PROM, number of grafts, and redo sternotomy. Regression coefficients and odds ratios are reported as the mean impact of each variable with a 95% confidence interval.

All study outcomes and data comparisons were established a priori. Statistical analyses were designed to test the null hypothesis that no association existed between each cohort. The study was 90% powered to detect timing differences of more than 3 minutes. All reported p values are two-tailed, and a threshold p value of 0.05 or less was used to test for significance. Trend lines were estimated using the least squares fit through method. Data analysis was performed using Microsoft Excel (Redmond, WA) and open-source R statistical software (http://www.R-project.org).

Results

Learning Curve Analysis

During the study period, 1,668 patients underwent isolated on-pump CABG. There were 21 residents in the study supervised by seven attending surgeons. The total number of CABG operations performed by each resident ranged from 32 to 101 (median 91).

The data collected for operative times were used to create learning curves for opening and closing (Fig 1). Median opening and closing times were plotted against the number of CABG operations the resident had performed. Learning curves were fitted to the data using power functions with the generic formula $t_n = t_1 n^{\log(r)/\log(2)}$, where t_1 = expected time for the first CABG operation; n = the number of CABG operations a resident had performed; r = learning curve (%); and t_n = the expected time for the nth CABG operation. In this framework, more complex processes translate into lower learning curve percentages because more complex processes offer greater opportunity for improvement than do simpler processes.

Opening time was best described by the formula $t_n = 117n^{\log(90\%)/\log(2)}$, and closing time was best described by the formula $t_n = 65n^{\log(95\%)/\log(2)}$. For opening, the calculated learning curve of 90% signifies that a 10% improvement in opening time is expected for each doubling of the number of cases performed (ie, time falls