ARTICLE

Quantifying the educational benefit of additional cataract surgery cases in ophthalmology residency

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Purpose: To quantify the resident learning curve for cataract surgery using operative time as an indicator of surgical competency, to identify the case threshold at which marginal additional educational benefit became equivocal, and to characterize heterogeneity in residents' pathways to surgical competency.

Setting: Academic medical center.

Design: Large-scale retrospective consecutive case series.

Methods: All cataract surgery cases performed by resident physicians as primary surgeon at Massachusetts Eye and Ear from July 1, 2010, through June 30, 2015, were reviewed. Data were abstracted from Accreditation Council for Graduate Medical Education case logs and operative time measurements. A linear mixed-methods analysis was conducted to model changes in residents' cataract surgery operative times as a function of sequential case number, with resident identity included as a random effect in the model to normalize between-resident variability.

Results: A total of 2096 cases were analyzed. A marked progressive decrease in operative time was noted for resident cases 1 to 39 (mean change −0.17 minutes per additional case, 95% CI, −0.21 to −0.12; $P < .001$). A modest, steady reduction in operative time was subsequently noted for case numbers 40 to 149 (mean change −0.05 minutes per additional case, 95% CI, −0.07 to −0.04; $P < .001$). No statistically significant improvement was found in operative times beyond the 150th case.

Conclusions: Residents derived educational benefit from performing a greater number of cataract procedures than current minimum requirements. However, cases far in excess of this threshold might have diminishing educational return in residency. Educational resources currently used for these cases might be more appropriately devoted to other training priorities.

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Cataract surgery is one of the most commonly performed operative procedures in the United States and is a cornerstone of general ophthalmology practice.[1] Achieving competency in this procedure is a key component of ophthalmic surgical education, with residency programs devoting considerable time and faculty support to cataract surgery instruction.[2]

Ophthalmology trainees are required by the Accreditation Council for Graduate Medical Education (ACGME) to complete at least 86 cataract procedures during residency; however, nearly all U.S. residents exceed this threshold by increasingly significant margins.[3] In 2002, the median cataract caseload for a graduating U.S. ophthalmology resident was 100; by 2013, more than 42% of residents reported completing more than 150 cases, with 16% of residents completing more than 200 procedures during training.[4,5] Some residents now report completing in excess of 300 cataract cases during residency. This increase in resident-performed cataract cases is partly due to demand from current and prospective trainees, who might consider cataract surgery caseload to be a surrogate for the quality of a program's surgical training.[6,7]

The pressure to achieve ever-greater cataract surgical numbers has helped to precipitate an "arms race" among residency programs seeking to keep surgical volumes at pace with one another. Yet, despite this intensive focus on cataract surgical numbers by applicants and residency programs alike, the number of cataract surgeries that a

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trainee needs to perform to achieve competence is unknown. Ophthalmology residency programs must balance cataract surgery education with a competing imperative to impart a broad clinical and surgical knowledge base within a fixed timeframe. An optimized curriculum would tailor its surgical case mix to the learning needs of the trainee, allotting sufficient time to achieve proficiency in cataract surgery without displacing other important training opportunities. At present, there is little evidence to guide ophthalmology educators seeking to identify this optimal cataract surgery caseload.

We, therefore, sought to characterize the resident learning curve for cataract surgery by tracking case-by-case surgical performance for a 5-year complete sample of ophthalmic residents enrolled in a large U.S. residency training program. Our primary objective was to construct an aggregate learning curve model of residents' progression toward surgical competency as a function of case volume, with a goal of identifying the case threshold at which trainees' marginal decrease in operative times became equivocal. Our secondary objective was to characterize the degree of heterogeneity in different residents' performance and learning rates.

METHODS

Study Approval

Institutional Review Board approval was obtained through the Massachusetts Eye and Ear (MEE) Human Studies Committee, and a waiver of patient consent was obtained given the retrospective nature of the study. All work was performed in accordance with the Health Insurance Portability and Accountability Act of 1996, the Declaration of Helsinki, and all applicable federal and state laws.

Data Collection

The dataset was derived from the ACGME case logs of all residents enrolled in the Harvard Medical School Ophthalmology Residency Training Program. Case logs for all primary resident-performed cataract surgeries from July 1, 2010, through June 30, 2015, were reviewed. All cases performed by residents who entered the training program prior to the beginning of the study period were excluded because an accurate sequential case number could not be determined for these residents. Attending surgeon identity, anonymized resident identity, and the sequential case number were recorded. The dataset was inclusive of procedures performed at MEE and all affiliated clinical sites. Data concerning operative time were independently recorded by operating room staff at the time of the surgical procedure. Cataract surgery operative time was calculated as the elapsed time between initial incision and final wound closure. Operative time data were available only for cases performed at MEE—thus, resident cases performed at other clinical sites were maintained as placeholders for the case number count. For example, if a resident's 40th through 60th cases were conducted at another affiliated teaching hospital, the resident's next case with recorded operating time (on returning to MEE) was registered as case number 61. Operating time was selected as the variable of interest in this study because of its several attributes as a proxy for surgical competency: it is an objective measurement, can be easily obtained, and has been shown to be associated with surgical competency.[8,9]

Data Analysis

Mixed-effect linear regression models were used to evaluate the association between consecutive resident case number and mean operative time. The models included a fixed effect for case number and a random effect for residents to account for the correlation among cases by the same resident. Because the distribution of operative times were heavily right skewed, cases with operative times 2 standard deviations (SDs) longer than the mean operative time (58 minutes) were excluded because these cases tended to represent surgical complications, unusually complex procedures, or other extenuating circumstances for which operative time was not likely to reflect a resident's underlying degree of surgical competency. Because the association between consecutive case number and operative time was not expected to follow a linear trend, the slope for the association was modeled as 3 consecutive splines. Based on clinical experience and literature, the 50th and 150th cases were selected as the initial cutoff points for the splines. After initially fitting the models to the data, the cutoff points were adjusted to optimize model fit while maintaining clinical relevance, resulting in final cutoff points at the 40th and 150th cases.

To examine individual resident learning patterns, each resident's operative case times were individually plotted as a function of case number, and modeled best-fit second-degree polynomial curves for each resident.

RESULTS

A total of 6228 primary resident cataract cases performed by 40 residents were identified during the study period. A total of 2096 cases (33.7%) had available operative time data; 59 cases (2.8%) longer than 58 minutes were excluded because these cases were more than 2 SDs longer than mean operative time. Of the included cases, 5 were performed by residents at the postgraduate year (PGY)-2 level, 324 at the PGY-3 level, and 1709 were performed by PGY-4 residents.

Figure 1 depicts the distribution of operative times by case number with spline slopes from the mixed-effect model overlaid. The model intercept was 39.9 minutes (95% CI, 38.2 to 41.5). Table 1 depicts case-by-case changes in operative times as a function of sequential case number. For cases 1 to 39, the mean change in operative time was −0.17 minutes per case (95% CI, −0.21 to −0.12). For cases 40 to 149, the mean change in operative time was −0.05 minutes per case (95% CI, −0.07 to −0.04). For cases 150 and higher, no significant reduction in mean operative time was noted for each subsequent case (−0.02 minutes, 95% CI, −0.05 to 0.01).

From a qualitative perspective, 3 general resident learning "phenotypes" within the sample were noted—one group of residents who demonstrated early above-average surgical performance with steady progress, a second group who, despite a slow start, demonstrated rapid progress

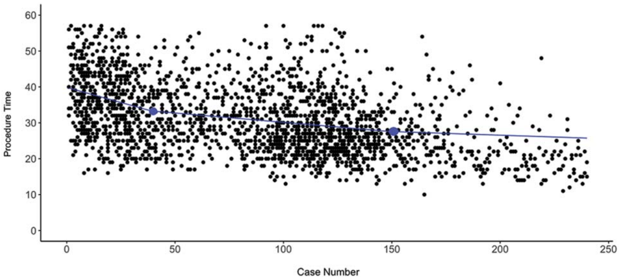

Figure 1. Operative time by case number with splines (cutoff points at 40th and 150th cases) from linear mixed-effect model overlaid.

Table 1. Mean (95% CI) change in operative time by case number.

Case Number	Change in Operative Time (min/case)	Lower Confidence Limit (min/case)	Upper Confidence Limit (min/case)
1 to 39	−0.17	−0.21	−0.12
40 to 149	−0.05	−0.07	−0.04
150+	−0.02	−0.05	0.01

midway through training, and a smaller third subset of residents who demonstrated prolonged inconsistent performance, even up through and beyond their 100th case. Figure 2 depicts examples of each of these learning phenotypes, whereas Figure 3 demonstrates individual learning curves for all study participants.

DISCUSSION

Across our multiyear sample of 40 residents from a large U.S. residency program, we found that sequential operative times tended to improve rapidly through residents' 40th cataract surgery cases as primary surgeons. We noted further case-by-case improvement well beyond the ACGME-mandated minimum of 86 cases, up through 150th cases, although case-by-case improvement in this range tended to be more gradual. Beyond this threshold, we were not able to demonstrate further significant improvements in operative times. We additionally noted significant heterogeneity in the progression of individual residents' operative times, demonstrative of the diverse individual pathways different residents take as they progress toward surgical competency.

It stands to reason that residents' initial cases would tend to garner rapid sequential improvement because trainees learn and begin to practice the various operative maneuvers necessary for successful and efficient case completion. It is notable that this trend continues well beyond the minimum required threshold for graduation, albeit with attenuation in the rate of case-by-case improvement. Given that residents are typically introduced to increasingly complex surgical cases as they progress through residency, it is likely that this leveling-off in operative times partially reflects senior residents encountering more difficult cases as they progress through their training. Case-by-case learning might still be quite substantial in later cases if trainees are learning to tackle increasingly challenging pathologies. This might also be reflected in the continued variability of operative times still noted in residents' later cases, highlighting the importance of tracking operative times as a trend rather than as a point measurement when used as a proxy for assessing competency.

In our aggregate model, we did not observe a statistically significant improvement in operative times beyond the 150th case. This is not to suggest a lack of educational benefit to caseloads in excess of 150; surgical learning continues throughout an entire career, and a continuing dose–response relationship between surgical volume and clinical outcomes has been documented in the literature more than a decade beyond graduation from residency training and for caseloads extending well into the thousands.[10,11] Rather, our findings suggest that the marginal educational benefit of additional cases beyond this threshold might be lower than for earlier cases—especially for residents already demonstrating competency at this threshold. This finding might help to guide curriculum planning when programs must decide how to optimally allocate residents' educational time, especially if there is a choice between additional cataract experiences far in excess of this threshold and exposure to other surgical techniques. Recent surveys have shown that although most residents feel prepared to perform unsupervised cataract surgery on graduation, many feel that their exposure to other important and common procedures has been inadequate. Yeu et al., for example, noted that more than 50% of residents

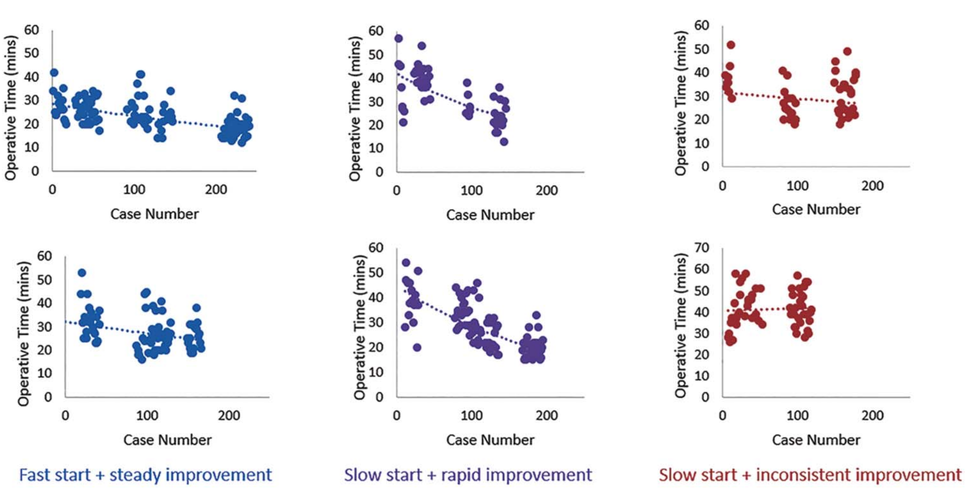

Figure 2. Interresident heterogeneity and learning phenotypes. Each graph depicts continuous case data for a single resident, selected to illustrate differences in between-resident rates of improvement in operative time.

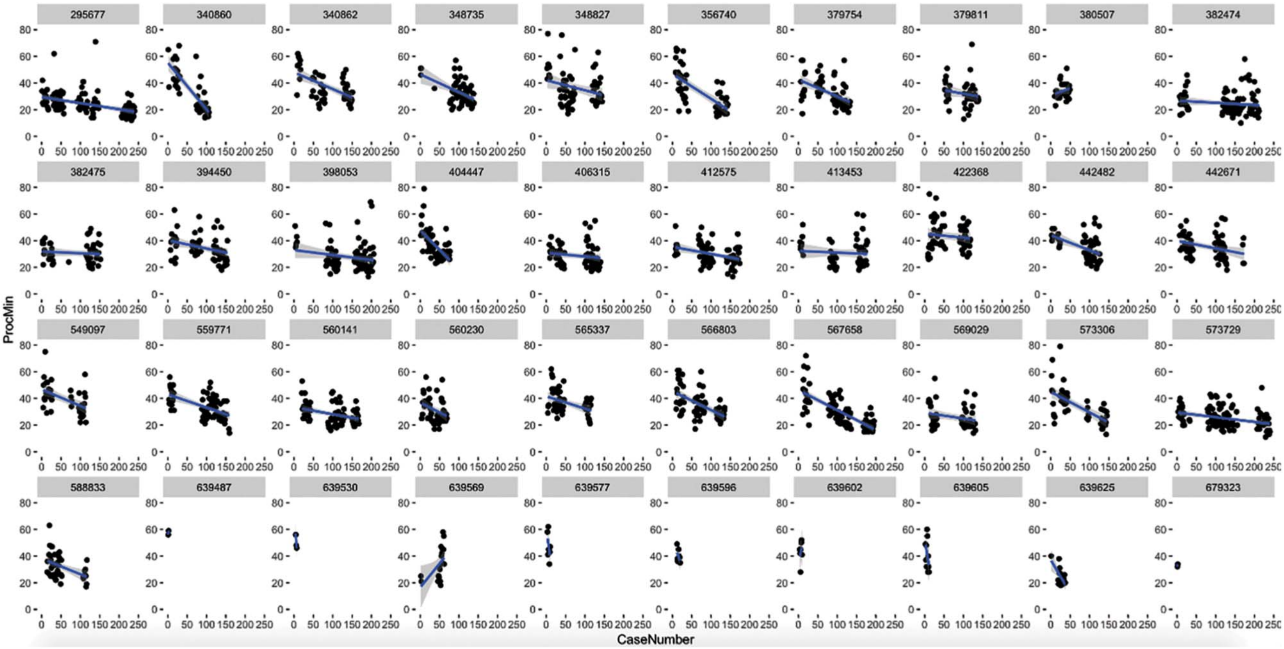

Figure 3. Individual resident's operative times. Each graph depicts continuous case data for a single resident (identity anonymized).

had never performed corneal relaxing incisions and 75% had not performed LASIK or surface ablation procedures.[5] Residency programs might, therefore, find value in diverting some of their competent residents' time presently devoted to additional cataract surgery instead toward other surgical teaching objectives to fully capitalize on the unique opportunity residency offers to impart a wide range of surgical training.

Our findings additionally highlight the heterogeneity that exists between residents in their individual pathways to surgical competency. Whether this heterogeneity is driven by innate differences in hand–eye coordination and manual dexterity or by variable prior experience and comfort with microscope-assisted manipulations, it is apparent that residents follow different trajectories to achieving competency with cataract surgery. We note, for example, at least 3 phenotypes among our sample of residents, with some trainees attaining operative times indicative of competency at substantially above-average rates, some demonstrating slower starts with rapid improvement that comes later in development, and a smaller third set who seemed to struggle even into their later cases. As such, although the aggregate learning curve model we report is useful in gauging residents' progress and identifying a reasonable default procedure target, it is best viewed as a guideline rather than a mandate because some residents will attain competence well before their 150th case, whereas others will substantively benefit from procedures well in excess of this mark. Taken together, these data might most strongly support the pursuit of individualized "competency-driven" cataract caseloads for trainees, with case volume varying as a function of each resident's individual learning needs rather than a uniform caseload goal for all residents.

Our findings build on those from previous studies that similarly used data on operative times to assess the resident cataract learning curve. Randleman et al. demonstrated a significant decrease in phacoemulsification time between residents' 1st through 80th cases compared with cases 81+ and a plateau in rates of posterior capsular tear and vitreous loss at residents' 160th cases (N = 680 cases; 15 residents).[9] Hosler et al. noted a decrease in senior residents' phacoemulsification case times from 63 minutes to 27 minutes from the beginning to the end of the academic year (N = 473 cases; 6 residents).[12] Wiggins and Warner found significant decreases in operative times between residents' 45th and 86th cases, with a plateau at the 121st case (N = 375 cases; 25 residents).[8] Our study presents congruent findings, now drawn from a large sample of more than 2000 cases and 40 residents over a multiyear time horizon. Our findings are additionally consistent with those from studies that have used different proxies for assessing residents' surgical competency, such as surgical complication rates. For example, a review by Ament and Henderson found that complications of resident-performed cataract surgery declined by 50% after trainees' 40th case, similar to our findings of an attenuated proficiency curve at this threshold.[13] Kaplowitz et al. found an inflection point in complication rates at an average of 70 ± 20 cases based on 5 previous studies.[2]

Our study uses operative time as a surrogate indicator of surgical competency. Although operative times do correlate with surgical competency, this endpoint is not a perfect proxy because case duration is influenced by such factors as case complexity, attending teaching style, and intraoperative complications. Although the ability to respond promptly and appropriately to intraoperative complexities is a key component of surgical development, we elected not to measure surgical complication rates as our primary outcome, and we excluded from our model cases with completion times greater than 2 SDs above average because our objective was to track residents' baseline surgical performance in nonextenuating circumstances. Spot-check analyses of the small subset of excluded extreme outlier cases confirmed that these cases involved significant intraoperative complications or unusually complex procedures. As such, operative times in these unusual cases were not deemed to be representative of a resident's contemporaneous competency level. Furthermore, because the overall resident cataract surgery complication rate is quite low (recently found to be 1.4% at MEE), we believed use of surgical complications would not produce a sufficient number of datapoints with which to generate robust resident-level learning curves.[14] By contrast, because operative time data are both easy to measure and continuous in nature, we reasoned such data could generate high-fidelity learning curves for the purpose of our study and could be quite readily incorporated into any residency program's existing performance review system (ideally in concert with a monitoring system for unexpectedly high complication rates).

There are limitations to this study. Our data are restricted to residents at a single residency program; as such, it is possible that the learning trajectories depicted in this study are at least partially a function of this program's pedagogical approach. MEE residents, for example, partake in a robust simulation program and a structured graduated cataract surgery training curriculum relatively early in their clinical training. As such, our observed operative time progressions might not be generalizable to residents in programs with differing timing and techniques of surgical training.[15] There are incomplete elements to our dataset, namely, the dataset does not contain operative time data for procedures performed during MEE residents' offsite rotations. Residents in the Harvard Ophthalmology Residency Program are assigned to a sequence of 6 to 7 week rotations, some of which take place at MEE (where operative time measurements were recorded), whereas others occur at affiliated institutions (where case number was recorded, but operative times were not available). Because the ordering of these rotations varies randomly between residents and we were able to accurately track cumulative case numbers across all institutions, we do not believe a systematic bias is present. Nonetheless, this does preclude our ability to depict residents' uninterrupted case series, which might contain unmeasured variability.

Our analysis informs navigation of the tradeoff program directors face when balancing surgical volume and variety and provides context regarding the heterogeneity of residents' different learning rates and pathways to competency with cataract surgery. Future studies could evaluate the external validity of our findings by assessing cataract learning curves as a function of operative times across a broader range of residency programs. Given the heterogeneity we note in different residents' learning rates, future studies could evaluate quantitative predictors of early poor performance based on residents' initial cases, to better ascertain which residents would benefit from early supplemental instruction. Finally, future studies could combine our methodological approach with intraoperative performance metrics captured by phacoemulsification machine platforms to measure learning curve progression as a function of a composite metric encompassing both operative efficiency and intraoperative performance.

In summary, residents seem to derive benefit from performing a greater number of cataract procedures than stipulated by current ACGME minimum guidelines. Residents' surgical competency generally increases rapidly over their first several dozen cases and continues to gradually improve until at least their 150th case. However, cases performed beyond this threshold might yield diminishing educational return. For residents who demonstrate competency at this juncture, this time might be more appropriately devoted to other training priorities.

WHAT WAS KNOWN

- Residents' cataract surgical caseloads have risen dramatically above the Accreditation Council for Graduate Medical Education requirement of 86 cases in recent years because residency programs are pushed toward ever-greater cataract numbers.
- The number of cases necessary for a resident to achieve competency in cataract surgery is unknown and might vary by resident.

WHAT THIS PAPER ADDS

- Residents derive substantial educational benefit from each of their first 39 cataract surgery cases and moderate continued benefit for subsequent cases up through their 150th case; caseloads in excess of 150 seem to have diminishing educational return on invested time.
- Three common resident learning curves illustrate the heterogeneity in trainees' pathways to competency. These data help inform the optimal resident cataract surgical caseload to ensure proficiency without displacing other important residency training opportunities.

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