ORIGINAL RESEARCH

Impact of Pulmonary and Critical Care Fellow Participation during Advanced Diagnostic Bronchoscopy

Ara A. Chrissian[1], Sevwandi De Silva[1], Erin Wiltchik[4], Brian Furukawa[5], Nico S. Rizzo[2], Elliot Ho[1], Dafne Moretta[1], and Gregory Cheek[3]

[1]Division of Pulmonary, Critical Care, Hyperbaric, and Sleep Medicine, [2]Division of Interdisciplinary Studies, School of Behavioral Health, and [3]Critical Care Center, Department of Anesthesiology, Loma Linda University Health, Loma Linda, California; [4]Scripps Memorial Hospital, La Jolla, California; and [5]Baylor Scott and White Medical Center, Temple, Texas

ABSTRACT

Background: Pulmonary and critical care medicine (PCCM) fellows frequently participate in advanced diagnostic bronchoscopy (ADB) procedures.

Objective: To investigate the impact of PCCM fellow involvement during ADB on various procedural outcomes in a real-world setting.

Methods: This was a retrospective observational cohort study analyzing prospectively collected registry data of consecutive ADB procedures performed between February 2018 and December 2021. Procedure duration, safety, breadth, and diagnostic performance of ADBs performed by PCCM fellows supervised by interventional pulmonologists (IPs) were compared with those completed solely by IP faculty.

Results: Among 628 ADBs, fellows participated in 379 (60.3%). With unadjusted analysis, fellow-involved cases were a median 11.5 minutes longer for convex-probe endobronchial ultrasound bronchoscopy (95% confidence interval [CI], 6.0–14.0;

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Correspondence and requests for reprints should be addressed to Ara A. Chrissian, M.D., Loma Linda University Medical Center, 11234 Anderson Street, MC, Room 1516-D, Loma Linda, CA 92354. E-mail: achrissian@llu.edu.

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$P < 0.001$) and 10.5 minutes longer for peripheral bronchoscopy (95% CI, 2.0–18.0; $P = 0.016$). Compared with ADBs performed by IP faculty alone, procedures with second-year (post-graduate year 5) fellows had the largest duration differences. These included convex-probe endobronchial ultrasound bronchoscopy (+14.5 min; 95% CI, 7.0–18.0 min; $P < 0.001$), cases not using rapid on-site evaluation (+14.0 min; 95% CI, 8.0–21.0 min; $P < 0.001$) and those performed with moderate sedation (+12.0 min; 95% CI, 7.0–18.0 min; $P < 0.001$). After multivariate adjustment, fellow-involved procedures overall were 7.2 minutes longer in duration (95% CI, 3.8–10.5; $P < 0.001$), and 8.8 minutes longer when performed by post-graduate year 5 fellows—an approximate 16% decrease in efficiency. Bronchoscopies performed with fellows were also more likely to experience complications (38.7% compared with 25.8% with faculty procedures; adjusted odds ratio [OR], 2.0; 95% CI, 1.3–3.0; $P < 0.001$) and be prematurely terminated (adjusted OR, 4.95; 95% CI, 1.44–17.02; $P = 0.011$). Diagnostic performance and occurrence of major complications were similar between fellow and no-fellow bronchoscopies.

Conclusion: Participation of PCCM fellows during ADB increases procedure duration and the risk for minor complications compared with cases completed solely by IPs. Procedures performed with fellows on the steepest portion of the ADB learning curve are the least efficient. Fellowship directors and faculty bronchoscopists should acknowledge these potential impacts on ABD practice while optimizing the approach to bronchoscopy training.

Keywords:
advanced diagnostic bronchoscopy; bronchoscopy training; bronchoscopy complications; bronchoscopy efficiency; pulmonary fellowship

Advanced diagnostic bronchoscopy (ADB) is essential for the evaluation of thoracic disease. Tissue sampling guided by convex-probe endobronchial ultrasound (cEBUS), radial-probe EBUS (rEBUS), electromagnetic navigation (EMN), and robotic-assisted platforms allow bronchoscopists to comprehensively and efficiently characterize both malignant and nonmalignant disorders (1–10). Consequently, proper training for performing ADB in modern-day bronchoscopy practice is of utmost importance. In the United States, the rapid expansion of a dedicated interventional pulmonology (IP) fellowship infrastructure has helped focus ADB training standards (11, 12).

ADB training also occurs among the more than 100 Accreditation Council for Graduate Medical Education–accredited general pulmonary (GP) and pulmonary and critical care medicine (PCCM) fellowships. However, at this level the Accreditation Council for Graduate Medical Education does not specify a minimum competency standard or distinguish ADB from routine flexible bronchoscopy, even though ADB requires additional skill sets (13, 14). Nevertheless, the majority of GP and PCCM fellows perform 50 or more EBUS bronchoscopies and a number of other ADB modalities during fellowship; only an extreme minority get no EBUS exposure (15). Although simulator-based training leads to efficient acquisition of technical proficiency (16–20), the prevalence of organized multimodal bronchoscopy curricula among GP and PCCM fellowships is unknown. Therefore, to teach routine bronchoscopy, EBUS, and peripheral

navigation techniques, many programs likely rely to some extent on the "apprenticeship" model and a "minimum volume" competency standard. In addition, at a large majority of GP and PCCM programs, fellows are supervised in part by interventional pulmonologists (15). These factors highlight an expanding intersection between novice operators and advanced bronchoscopy within the training environment.

Learning curves for ADB vary widely, and proficiency can continue to evolve through 400 performed clinical cases (21–25). Therefore, involving novice trainees that are still learning basics of bronchoscopy during advanced procedures may influence important outcomes. A limited body of literature suggests such impacts within the context of routine bronchoscopy (26) or interventional training programs (27, 28). However, to our knowledge, data exclusively analyzing the influence of GP and PCCM fellow participation on advanced bronchoscopy do not exist.

Our goal was to investigate the impact of PCCM fellow involvement during advanced diagnostic bronchoscopy on procedure efficiency, breadth, diagnostic performance, and patient safety in a real-world setting. Similar to a growing number of practices in the United States, we manage an IP service at an institution without a dedicated IP fellowship. This provides PCCM trainees substantial exposure to our practice environment and, thus, combined with our prospectively collected ADB registry, offers a good data source for such analysis.

METHODS

Design and Patient Selection

This was a retrospective observational cohort study analyzing prospectively collected registry data of all consecutive ADB procedures performed between February 2018 and December 2021, supplemented by review of electronic medical records. The study hospital's institutional review board provided approval (#5210462), and individual consent for this retrospective analysis was waived.

Outcomes

The primary outcome was ADB duration. We hypothesized that procedures performed with fellows would take at least 10 minutes longer to complete than those performed by IP faculty alone. We chose 10 minutes as a clinically meaningful per-case delay for an average ADB practice performing about 4–6 procedures daily. Secondary outcomes included complications, procedure breadth, and diagnostic performance. Subgroup analysis was performed for all outcomes by procedure type and fellow training level.

Definitions

ADB was defined as a bronchoscopy performed with at least one of the following advanced-guidance modalities: cEBUS (BF-UC-180/190 F, Olympus America Inc.), rEBUS (UM-S20-17S, Olympus America Inc.), and EMN (Veran Medical Technologies). Procedure duration was recorded as time from first introduction of the bronchoscope into the lower airway to its final removal. Major procedure-related complications included pneumothorax requiring a chest tube; bleeding requiring a balloon blocker, ablation, embolization, or blood transfusion; respiratory failure requiring endotracheal intubation; escalation of disposition for any reason; cardiac arrest; and death. All other complications were considered minor. Indicators of procedure breadth were number of lesions sampled, number of diagnostic techniques used, and need for premature termination of a procedure

for any reason. Diagnostic techniques were any used for endobronchial, peribronchial (e.g., nodal), and/or peripheral lung sampling, as specified in Figure E1 in the online supplement. Specific diagnostic yield was defined as per-subject recovery of a specific actionable diagnosis, including malignancy, granuloma, organizing pneumonia, and infection (29). Diagnostic sensitivity for malignancy was the per-subject number of malignant cases diagnosed by ADB divided by the total number discovered by any means. For nonspecific sampling results, lesion regression or stability up to 2 years by imaging surveillance was required to suggest benignity.

Data Source and Collection

The primary data source was our advanced bronchoscopy quality improvement registry. The registry was designed in 2016 by an internal *ad hoc* committee, then vetted and refined through a modified Delphi survey of 16 external bronchoscopists. The final chosen metrics were incorporated into a raw data collection form, tested for 1 calendar year, and then deployed into clinical practice in 2018 (unpublished data, A. Chrissian and D. Moretta, 2018). Patient and bronchoscopy-related data are entered in real time during a team-collective preprocedure "time out" and a post-procedure debriefing session (Figure E1). Diagnostic outcomes and occurrence of delayed major complications are entered retrospectively.

All variables were defined at the time of study conception, and a data extraction form was created *a priori*. Each subject's medical record was reviewed and compared with the existing quality improvement database to ensure accuracy. Two separate investigators independently performed same-subject data extraction to ensure consistency. Discrepancies were adjudicated by a third investigator.

Bronchoscopy Procedures

ADB was performed using established techniques (30–34). Bronchoscopies requiring moderate sedation were completed in a dedicated bronchoscopy suite using our bronchoscopist-directed propofol infusion protocol (35). Procedures requiring general anesthesia were conducted either in the bronchoscopy suite or the operating room under the supervision of an anesthesiologist or certified registered nurse anesthetist.

Fellow Training, Participation, and Supervision

Pulmonary and/or critical care fellows performed ADBs during an assigned 4-week bronchoscopy/IP rotation. They were classified based on their level of training at the time of ADB participation (first, second, or third year: post-graduate year [PGY]-4, -5, or -6, respectively). Before the rotation, all fellows were provided supplementary reading material and completed assignments on a high-fidelity simulator (BRONCH Mentor, Surgical Science). During the rotation, fellows were given task-oriented instruction based on established bronchoscopy skills assessment tools (36, 37) and also trained via the apprenticeship model. Our concerted approach to bronchoscopy apprenticeship focuses PGY-4 fellows on basic elements (e.g., airway inspection, anatomy recognition, simple diagnostic techniques such as bronchoalveolar lavage), reserving more advanced and combined techniques for PGY-5 and -6. After the rotation, fellows took a multiple-choice exam and were provided comprehensive feedback on their overall performance. During the second half of PGY-4, pulmonary fellows also

attended a regional EBUS course that consisted of both didactic and simulation components.

Fellow involvement was dictated by usual clinical workflow, and fellows were expected to participate if available. A fellow was considered to have participated in an ADB if they were the primary operator for at least one key component of the procedure. Key components of a procedure included standard bronchoscope intubation and airway inspection, cEBUS scope intubation and peribronchial/mediastinal survey (with or without sampling), or advanced-guidance navigation to a peripheral lesion (with or without sampling). Although many fellows also assisted with or performed sampling, sampling alone did not qualify as participation. The extent to which a fellow performed a given ADB was at the discretion of the IP attending. A large majority of ADBs were performed and supervised by two of four IP faculty (A.A.C. and B.F., 57.3% and 34.7%, respectively), who had collectively completed more than 2,000 ADBs at the start of the study period.

Statistical Analysis

Based on a convenience sample of 30 ADB cases with a mean duration of 55 (±31) minutes, we estimated a per-group sample size need of approximately 200 ADBs to detect a 10-minute between-group difference with 90% power using a two-sided test and type I error rate of $\alpha = 0.05$.

Independent variables were chosen based on clinical relevance. *t* tests and the Wilcoxon rank-sum test were used to evaluate between-group differences for continuous variables, and chi-square tests were applied to categorical variables. Multivariate linear regression and binary logistic regression analyses were used to elucidate the adjusted impact of fellow involvement on procedure duration, complications, breadth, and specific diagnostic yield. Fellows were then stratified by year of fellowship (PGY 4–6), and the analyses were repeated to determine the influence of fellow level on the outcomes.

Analyses were performed using R Statistical Software (R version 4.3.1; R Core Team 2023) with RStudio Team (2023.09.1; RStudio: Integrated Development for R. RStudio, PBC).

RESULTS

During the study period, a total of 34 individual pulmonary and/or critical care fellows rotated on the IP service. Among 1,467 consecutive advanced bronchoscopies identified from the quality improvement registry, 628 (42.8%) were ADBs. Fellows participated in 379 (60.3%) of these procedures.

Patient demographics and procedure characteristics are summarized in Table 1. The majority of cases were performed in the outpatient setting (68.5%) and using moderate sedation (66.1%). At least one known risk factor for procedure-related complications was present in 114 (18.2%) patients. The most common ADB performed was cEBUS bronchoscopy (44.4%), whereas multiple guidance modalities were used in 38.9%.

Procedure Duration

ADBs performed with fellows were overall longer in duration than those completed solely by IP faculty (median, 58.0 vs. 52.0 min, respectively; difference in medians 95% confidence interval [CI], 3.0–11.0 min; $P < 0.001$; Table E1). With unadjusted analysis, procedure duration differentials were largest overall for cEBUS bronchoscopy (+11.5 min; 95% CI, 6.0–14.0 min; $P < 0.001$) and rEBUS or EMN-guided peripheral bronchoscopy (+10.5 min; 95% CI, 2.0–18.0 min;

Table 1. Baseline characteristics

Characteristic	Overall ($N = 628$)	Fellow ($n = 349$)	No Fellow ($n = 279$)	*P* Value
Patient				
Age, mean ± SD	62.9 ± 14.2	63.1 ± 13.8	62.0 ± 14.6	0.34
Female sex	311 (49.5)	181 (51.9)	130 (46.6)	0.19
Severe or decompensated lung disease	43 (6.8)	23 (6.6)	20 (7.2)	0.78
Severe or decompensated cardiovascular disease	18 (2.9)	13 (3.7)	5 (1.8)	0.15
Airway concerns*	42 (6.7)	20 (5.7)	22 (7.9)	0.28
Coagulopathy†	18 (2.9)	10 (2.9)	8 (2.9)	1.00
Any medical risk factor	114 (18.2)	63 (18.1)	51 (18.3)	0.94
Body mass index ≥ 30 kg/m^2	188 (29.9)	110 (31.2)	78 (27.6)	0.33
Chronic sedative or narcotic use‡	56 (8.9)	36 (10.3)	20 (7.2)	0.17
Procedural				
Inpatient status	198 (31.5)	128 (36.7)	70 (25.1)	0.002
ICU status	40 (6.4)	25 (7.2)	15 (5.4)	0.36
cEBUS used only	279 (44.4)	161 (46.1)	118 (42.3)	0.34
rEBUS or EMN used only	105 (16.7)	62 (17.8)	43 (15.4)	0.43
Combined modalities used	244 (38.9)	126 (36.1)	118 (42.3)	0.11
General anesthesia	213 (33.9)	110 (31.5)	103 (36.9)	0.16
ROSE used	268 (42.7)	144 (41.3)	124 (44.4)	0.42
Start delayed >30 min§	318 (50.6)	168 (48.1)	150 (53.8)	0.16
IP faculty #1 performed procedure	360 (57.3)	223 (63.9)	137 (49.1)	<0.001

Definition of abbreviations: cEBUS = convex-probe endobronchial ultrasound; EMN = electromagnetic navigation; ICU = intensive care unit; IP = interventional pulmonology; rEBUS = radial-probe endobronchial ultrasound; ROSE = rapid on-site cytologic evaluation.
Data are given as *n* (%) unless otherwise noted.
*Includes known or anticipated difficult airway for any reason, sleep apnea.
†Active anticoagulant or antiplatelet therapy, uncorrected serum platelet count of <50,000/μl or prothrombin time and international normalized ratio levels greater than two times upper limit of normal.
‡Use for most days for at least 2 weeks before procedure date.
§After originally scheduled time.

$P = 0.016$). Among training level strata, ADBs performed with PGY-5 fellows were consistently the least efficient across various procedure types when compared with faculty-only cases (Figure 1). The largest median time differentials were seen with cEBUS bronchoscopy (+14.5 min; 95% CI, 7.0–18.0 min; $P < 0.001$), procedures not using rapid on-site evaluation (ROSE) (+14.0 min; 95% CI, 8.0–21.0 min; $P < 0.001$), and cases performed with moderate sedation (+12.0 min; 95% CI, 7.0–18.0 min; $P < 0.001$).

After adjusting for multiple patient and procedure-associated variables, fellow

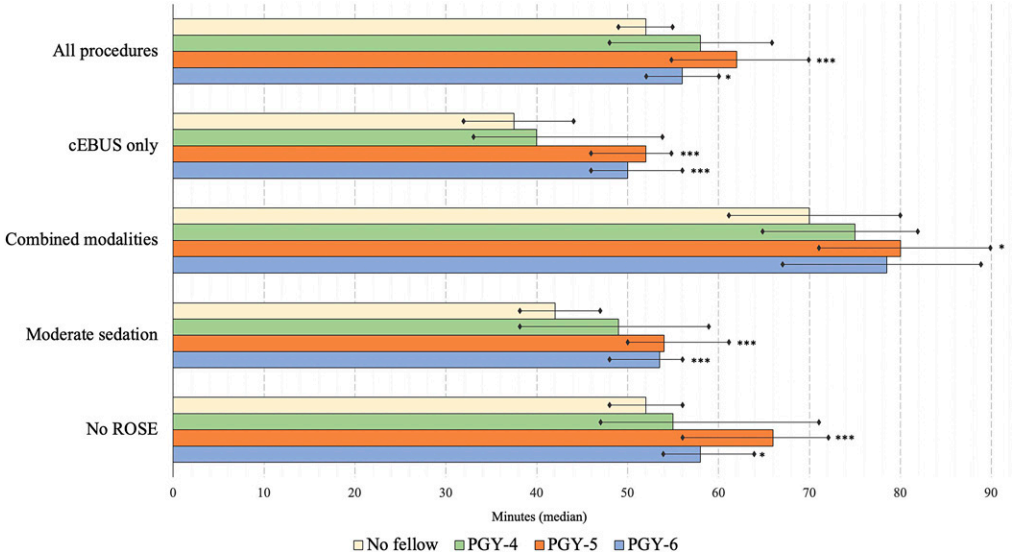

Figure 1. Univariate analysis showing procedure duration of various procedure types, per fellow training year level. Each fellow group compared with "no fellow" group for each procedure type using Wilcoxon rank-sum test. *$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$. Error bars represent 95% confidence intervals. PGY-4, 5, and -6 are first-, second-, and third-year fellows, respectively. cEBUS = convex-probe endobronchial ultrasound; PGY = post-graduate year; ROSE = rapid on-site cytologic evaluation.

participation remained a significant contributor to prolonging overall procedure time (mean difference of +7.2 min; 95% CI, 3.8–10.5 min; $P < 0.001$; Table 2). Other factors associated with longer ADB duration included use of general anesthesia, combined modalities, ROSE, more sampling techniques, and the occurrence of complications. After adjustment, PGY-5 fellows maintained the longest overall procedure duration differential among training levels compared with faculty-only cases (+8.8 min; 95% CI, 4.6–13.0 min; $P < 0.001$; Figure 2).

Complications

ADB complications were overall more common with fellow-involved procedures than with those completed by IP faculty alone (38.7% vs. 25.8%, respectively; $P < 0.001$; Table E2). However, major complications occurred with similar frequency in both groups (fellow, 3.4% vs. no fellow, 2.5%; $P = 0.50$). There was no major bleeding, cardiac arrest, or death in either group.

After multivariate adjustment, fellow participation remained a significant predictor for occurrence of any complication (odds ratio [OR], 2.0; 95% CI, 1.3–3.0; $P < 0.001$; Table 3). Other factors associated with complications included use of general anesthesia, patient age, the presence of an underlying medical risk factor, and procedure duration. Furthermore, a fellow-performed bronchoscopy had higher odds of experiencing a complication regardless of PGY level (Figure E2). Inpatient status did not correlate with adverse events (OR, 0.9; 95% CI, 0.6–1.4; $P = 0.66$).

Procedure Breadth and Diagnostic Performance

Overall per-patient specific diagnostic yield and sensitivity for malignancy were 74.5% and 89.7%, respectively. With univariate analysis, we found procedures performed with fellows were more likely to be

Table 2. Multivariate model evaluating factors associated with prolonged bronchoscopy duration

Characteristic	Bronchoscopy Duration Differential (min)	95% Confidence Interval	*P* Value
Patient			
Age	+0.09	−0.03 to +0.21	0.13
Female sex	+2.14	−1.12 to +5.39	0.20
Any underlying medical risk factor*	+2.29	−2.12 to +6.60	0.30
Chronic sedative or narcotic use†	−3.51	−9.30 to +2.29	0.24
Body mass index	−0.03	−0.30 to +0.23	0.80
Malignant diagnosis	−1.34	−4.75 to +2.06	0.44
Procedural			
Inpatient status	+3.54	−0.37 to +7.45	0.08
Combined modality‡	+12.13	+8.07 to +16.19	<0.001
Start delayed >30 min§	−0.57	−4.01 to +2.87	0.75
IP faculty #1 performing/supervising	−1.09	−4.54 to +2.37	0.54
Fellow participated	+7.16	+3.83 to +10.49	<0.001
General anesthesia	+18.16	+13.83 to +22.48	<0.001
ROSE used	+6.18	+2.75 to +9.61	<0.001
Number lesions sampled	+1.07	−0.72 to +2.87	0.24
Number techniques used	+5.44	+3.90 to +6.98	<0.001
Complication occurred	+4.79	+0.99 to +8.58	0.01

Definition of abbreviations: cEBUS = convex-probe endobronchial ultrasound; EMN = electromagnetic navigation; IP = interventional pulmonology; rEBUS = radial-probe endobronchial ultrasound; ROSE = rapid on-site cytologic evaluation.
*As defined in the text.
†Use for most days for at least 2 weeks before procedure date.
‡cEBUS plus rEBUS or EMN.
§After originally scheduled time.

prematurely terminated (6.3% vs. 1.8% with no fellow; $P = 0.009$). A majority of these (63.0%) were because of recurrent and/or persistent minor complications or patient agitation. This relationship persisted after multivariate adjustment (OR, 4.95; 95% CI, 1.44–17.02; $P = 0.011$; Table E3). Diagnostic outcomes were not influenced by fellow participation or training level.

DISCUSSION

Herein we demonstrate that participation of PCCM fellows during ADB prolongs procedure time and increases the risk for complications compared with cases completed solely by interventional pulmonologists. Procedures performed with fellows in the second year of their training (PGY-5) were the least efficient. Other procedural factors, such as use of

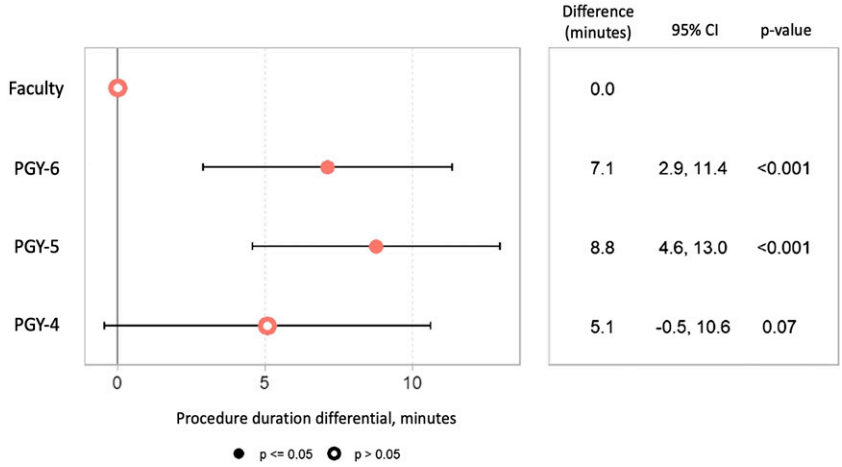

Figure 2. Adjusted procedure duration differentials of fellow-involved bronchoscopies compared with faculty-only cases, per training year. CI = confidence interval; PGY = post-graduate year.

general anesthesia, combined diagnostic modalities, ROSE, and using more techniques also increased ADB duration. Our findings can assist fellowship directors and advanced diagnostic bronchoscopists in managing the important interaction between novice operators and bronchoscopy practice within the training environment.

We found fellow participation during ADB increased overall bronchoscopy duration by 7.2 minutes, although time differences varied depending on PGY level and procedure type. The reason for such delays within this context is likely multifactorial. Most intuitively, novice operators take longer to complete a given procedure, as they are still acquiring relevant muscle memory and learning new techniques. Intraprocedural adverse events may also reduce efficiency, as the focus shifts to their management. Although we did not observe an increase in major complications with fellow-involved procedures, this is not surprising given the overall favorable safety profile of ADB (38, 39). However, even minor events, such as inefficiently controlled airway bleeding, can divert from procedural objectives. These did occur more frequently during fellow-involved cases. Furthermore, secondary effects, such as excessive coughing, can trigger a cascade of sedative administration and rescue maneuvers that contribute to further delays and patient risk. In support, we found that occurrence of complications also independently increased procedure time.

In our study, the overall 7.2-minute increase in procedure duration seen with fellow participation represented an approximate 13% compromise in efficiency compared with an average faculty-performed bronchoscopy. This did not meet our predefined clinically meaningful value of +10 minutes (an approximate 18% increase in procedure time). This somewhat arbitrary threshold was chosen based on the assumption that an average ADB practice performs about four to six procedures daily, and the cumulative impact of even a modest 15–20% per-procedure decrease in efficiency could sacrifice volume capabilities of at least one per day. For a practice with already limited access to resources, such as dedicated procedure space and/or anesthesia block time, this represents a

Table 3. Multivariate model evaluating factors associated with bronchoscopy-related complications

Characteristic	Odds Ratio	95% Confidence Interval	*P* Value
Patient			
Age	1.02	1.00–1.03	0.01
Female sex	1.20	0.82–1.76	0.34
Any underlying medical risk factor*	1.63	1.01–2.65	0.05
Chronic sedative or narcotic use†	0.95	0.47–1.92	0.89
Body mass index	1.03	0.99–1.06	0.10
Malignant diagnosis	1.23	0.0.83–1.84	0.29
Procedural			
Inpatient status	0.91	0.56–1.43	0.66
Combined modality‡	1.30	0.82–2.29	0.32
Start delayed >30 min§	1.10	0.73–1.65	0.64
IP faculty #1 performing/supervising	1.27	0.85–1.89	0.24
Fellow participated	1.99	1.34–2.96	<0.001
General anesthesia	3.53	2.19–5.69	<0.001
ROSE used	0.96	0.65–1.42	0.83
Number lesions sampled	1.06	0.92–1.22	0.46
Number techniques used	1.01	0.82–1.25	0.93
Procedure duration	1.01	1.00–1.02	0.006

Definition of abbreviations: cEBUS = convex-probe endobronchial ultrasound; EMN = electromagnetic navigation; IP = interventional pulmonology; rEBUS = radial-probe endobronchial ultrasound; ROSE = rapid on-site cytologic evaluation.
*As defined in the text.
†Use for most days for at least 2 weeks before procedure date.
‡cEBUS plus rEBUS or EMN.
§After originally scheduled time.

substantial impact on operations. In addition, longer procedure times may increase labor needs and various other fixed costs, thus reducing the cost efficiency of ADB.

Our results still have value, given the considerable procedure time variation we observed depending on fellow training levels and ADB type. For example, overall procedure duration differences between fellow and faculty cases were smallest with PGY-4 fellows (5.1 min) and largest with PGY-5 fellows (8.8 min). This represents a decreased efficiency range between 9% and 16%, solely based on fellow training level. The differences were most stark with cEBUS bronchoscopy, with fellow cases prolonged between a range of 2.5 minutes (PGY-4) and 14.5 minutes (PGY-5), compared with a 37.5-minute faculty-performed cEBUS (Figure 1). This

represents a decreased efficiency range between 7% and 39%. Therefore, the magnitude of the impact incurred by fellow involvement will depend on a particular bronchoscopy practice's ADB case mix and trainee profile. Furthermore, when prioritizing operational efficiency within a training environment, bronchoscopists should also consider other factors that may independently prolong procedure duration. Per our data, these include use of general anesthesia, rapid on-site evaluation, and case breadth and complexity.

The variations in procedure duration differentials seen among training level strata are consistent with our ADB training approach. We focus PGY-4 fellows on basic bronchoscopy aspects (e.g., airway inspection, anatomy recognition, mucosal biopsies, etc.), while introducing and developing more advanced techniques (e.g., EBUS-guided sampling, peripheral bronchoscopy) at the PGY-5 and -6 level, when fellows have had more exposure to ADB-specific curricula. Consequently, the ADB learning curve at our program is steepest for PGY-5 fellows. This could explain their long procedure times across multiple procedure types, but especially cEBUS bronchoscopy, which is the primary focus of ADB education for our PCCM fellows. Procedure efficiency and complication outcomes both improved slightly in PGY-6, suggesting some acquisition of real-world ADB proficiency toward the completion of the fellowship. A similar pattern was previously reported with routine bronchoscopy in another study (26). Therefore, to adjust both training and operational expectations, PCCM programs should identify fellows at the steepest portion of the ADB learning curve at their respective institutions. Aggressive supplemental simulation may be most important at or just before this stage to help enhance uptake of technical skill and optimize the transition to real-world apprenticeship training (16, 17, 40, 41).

The overall procedure duration differential between fellow and faculty cases of our study was considerably smaller than a previous report by Stather and colleagues (27), which found that fellow involvement prolonged procedures by 21 minutes (about a 36% decrease in efficiency). However, in contrast to our study, which focused on a heterogeneous group of PCCM fellows, theirs was conducted within an IP training program; the majority of cases were performed by an IP fellow and without the use of supplemental bronchoscopy simulation. Such factors imply different baseline fellow proficiencies, intraprocedural training goals, and the extent to which a trainee may be allowed and expected to independently perform a procedure. These and other workflow characteristics could account for the differences in our respective findings and dictate the varying needs of a given training model.

Collectively, our results emphasize the importance of acknowledging individual aspects of a given PCCM bronchoscopy training program and adapting to its strengths and limitations. At present, there is no nationally established competency requirement guiding fellow readiness for ADB techniques (14). We suggest fellowship directors establish internal milestone metrics within the context of a multimodal curriculum, recognizing that acquisition of bronchoscopy proficiency is highly variable and individualized (21–25). Meanwhile, bronchoscopy faculty should be mindful of fellows lacking basic bronchoscopy skills whose involvement with ADBs could hamper the various operational, performance, and cost-efficiency advantages of these essential

and often complex procedures (42–44). To more holistically evaluate fellow impacts on bronchoscopy operations, future investigations should incorporate not only the elements of our study but also components that may highlight patient-centered and logistical aspects to which fellows might positively contribute, such as obtaining informed consent, order entry, and follow-up practices.

Limitations

The main limitation of our study is its retrospective and single-institution design, although the data originated from a prospectively maintained quality improvement database and analyzed a consecutive cohort.

The supervising bronchoscopy faculty for our study were skilled interventional pulmonologists. This may have been part of the reason we did not observe a significant compromise in ADB diagnostic performance with fellow-involved procedures. The impact of trainee involvement at programs with less experienced bronchoscopy faculty is unknown. Regardless, our practice model of an IP service without a dedicated IP fellowship is increasingly common in the United States, with interventional pulmonologists frequently charged with training GP and PCCM fellows (15). Therefore, we consider our findings generalizable to and valuable for a substantial proportion of such fellowships.

We acknowledge that several fellow-related factors may have been unrecognized in our analysis. First, we did not factor the correlation inherent in procedures done by the same fellow. However, we believe the impact of this potential confounding would be limited, because most fellows rotated on our bronchoscopy service only once during their fellowship, thus minimizing the repeated measures effect across training level strata. In addition, we had a relatively large number of fellows (34) contribute data to the study, but individually they only performed a median of six ADBs to the extent required to meet our "participation" criteria.

Second, baseline fellow bronchoscopy experience and proficiency were not measured or controlled. Although all fellows were expected to complete a supplemental multimodal bronchoscopy curriculum, we did not rigorously verify the extent of their engagement before the rotation. Nevertheless, even fellows within a given training year with similar baseline experience have varying proficiencies (26). Furthermore, the ideal curriculum that best maximizes acquisition and assessment of bronchoscopy skill within a GP or PCCM program remains unknown (19, 20, 39, 45, 46). Our intent was to simulate a real-world interaction between modern bronchoscopy training and an ADB practice, and many of these variables are typical among such programs.

Finally, the arrival of the coronavirus disease (COVID-19) pandemic overlapped with a portion of the study period. Although we maintained our general approach to fellow training and supervision, it is unclear how specific modifications to our bronchoscopy operations (e.g., enhanced isolation practices, minimizing elective cases, etc.) and other intangible factors affected the outcomes of interest. It is possible that during peak surges supervising bronchoscopists allowed less latitude for fellows to independently complete a bronchoscopy. Consequently, the reductions in efficiency and increases in complications seen within the fellow groups may have been underestimated. Nevertheless, we consider our findings significant and consistent enough to support our conclusions.

Conclusions

We found that participation of pulmonary and critical care fellows during ADB increased procedure duration and frequency of minor complications, especially among trainees at the steepest portion of the learning curve. We hope our results help enhance collaboration between fellowship leaders and designated supervising bronchoscopy faculty to optimize bronchoscopy training while maintaining operational efficiency and patient safety.

Author disclosures are available with the text of this article at www.atsjournals.org.

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