FOCUS ON AIRWAY MANAGEMENT

DEFINING THE “LEARNING CURVE” FOR PARAMEDIC STUDENT ENDOTRACHEAL INTUBATION

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ABSTRACT

Background. Proficiency in endotracheal intubation (ETI) is assumed to improve primarily with accumulated experience on live patients. While the National Standard Paramedic Curriculum recommends that paramedic students (PSs) perform at least five live ETIs, these training opportunities are limited. Objective. To evaluate the effects of cumulative live ETI experience, elapsed duration of training, and clinical setting on PS ETI proficiency. Methods. The authors used longitudinal, multicenter data from 60 paramedic training programs over a two-year period. The PSs reported outcomes (success/failure) for all live ETIs attempted in the operating room (OR), the emergency department (ED), the intensive care unit (ICU), and other hospital or prehospital settings. Fixed-effects logistic regression was used to model up to 30 consecutive ETI efforts by each PS, accounting for per-PS clustering. For each patient, the authors evaluated the association between ETI success and the PS’s cumulative number of ETIs, adjusted for clinical setting, elapsed number of days from the first ETI encounter, and the interaction (cumulative ETIs × elapsed days). Predicted probability plots were constructed depicting the “learning curve” overall and for each clinical setting. Results. Between one and 74 ETIs (median 7; IQR 4–12) were performed by each of 802 PSs. Of 7,635 ETIs, 6,464 (87.4%) were successful. Stratified by clinical setting, 6,311 (82.7%) ETIs were performed in the OR, 271 (3.6%) in the ED, 64 (0.8%) in the ICU, 86 (1.1%) in other in-hospital settings, and 903 (11.8%) in the prehospital setting. For the 7,398 ETIs included in the multivariate analysis, cumulative number of ETI was associated with increased adjusted odds of ETI success (odds ratio 1.067 per ETI; 95% CI: 1.044–1.091). ETI learning curves were steepest for the ICU and prehospital settings but lower than for other clinical settings. Conclusions. Paramedic student ETI success improves with accumulated live experience but appears to vary across different clinical settings. Strategies for PS airway education must consider the volume of live ETIs as well as the clinical settings used for ETI training. Key words: intubation; intratracheal; emergency medical services; learning; allied health personnel.

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The acquisition of procedural competence is a challenge faced by students in all areas of health care. During training, paramedic students (PSs) must acquire proficiency in endotracheal intubation (ETI), a difficult and challenging procedure. PSs may learn ETI using a combination of mannequin practice and clinical experience on live patients. Live ETI experience is traditionally gained under the guidance of anesthesiologists under controlled conditions in the operating room (OR). However, many factors limit the opportunities for PSs to acquire this type of training. Opportunities for PSs to perform ETI in other in-hospital or prehospital settings are also limited.

The National Standard Paramedic Curriculum recommends that PSs successfully perform at least five ETIs prior to graduation. However, empiric links between PS ETI proficiency and accumulated “live” experience (i.e., the “learning curve”) do not exist. In this study, we sought to determine whether PS ETI success is associated with accumulated live ETI experience, adjusted for elapsed duration of training and clinical setting.
METHODS

Study Design
The University of Pittsburgh Institutional Review Board (IRB) approved this secondary data set analysis. The original collection of PS data for research purposes was governed by a preexisting IRB approval from Inver Hills Community College, Inver Grove Heights, Minnesota.

Study Setting and Population
Data for this study were drawn from clinical performance data compiled by the FISDAP system (FISDAP, Inc., St. Paul, MN). FISDAP is a proprietary Internet-based system used to log PS clinical and procedural experience. PSs use the program to self-report information for each patient encounter, including the patient’s chief complaint and demographic information, the results of physical assessment, and the results of procedures attempted by the student. FISDAP is presently used by more than 175 paramedic training programs in North America. All FISDAP data are pooled on a national basis.

Study Protocol
For this analysis, we included data on PS encounters involving ETI for the study period May 1, 1999, to December 31, 2003. We included only data for students who consented to data release for research purposes. FISDAP contains a system for site instructors to internally audit PS entries. While there are no specified systemwide methods for such auditing, site instructors usually ensure that students’ Internet entries are consistent with those recorded on paper logs. We included only data that had been audited by site instructors.

Measurements or Key Outcome Measures
Parameters reported by PSs included the date of encounter, the type of airway attempted, whether the procedure was observed or performed by the PS, the clinical setting, the number of attempts, and the outcome of the airway placement effort (success or failure). Airway outcome was self-reported by the PS and was presumed to be verified by the instructor or clinical preceptor. Types of airway included ETI, laryngeal mask airway (LMA), Combitube, and cricothyroidotomy. Clinical settings were broadly categorized as prehospital, OR, ED, ICU, or other in-hospital.

We included only ETI cases; we excluded all non-ETI airway placements (LMA, Combitube, etc.). Because it is a specialized technique much different from and less utilized than orotracheal ETI, we also excluded all nasotracheal intubations. We excluded procedures performed on mannequins or cadavers and where the PS only observed the procedure. The definition of an ETI attempt (i.e., insertion of blade vs. insertion of tube) was not set a priori, and therefore this parameter was not used in the analysis.

The FISDAP system did not record data on many clinical covariates (for example, Glasgow Coma Score, level of consciousness, or degree of relaxation) or anatomic factors (for example, obesity, short neck). While basic physiology and chief complaint information were available for each patient in a separate database, we could not successfully link the airway and physiology data sets. Therefore, we could not further assess associations between the ETI effort and patient physiologic parameters. Student demographic data (age, sex, race, prior certifications, etc.) were available but frequently displayed missing values (more than 40%) and thus were not analyzed.

Data Analysis
We used fixed-effects logistic regression to model the hypothesized relationship. This approach is an accepted approach for modeling learning curves and permitted us to adjust for multiple relevant covariates while accounting for per-PS clustering effects. Ordinary logistic regression is not appropriate where the data are clustered; for example, in this data set, each PS performed multiple ETIs and accounted for multiple observations. We did not use generalized estimating equations (GEE) because this technique produces estimates that are population-averaged; we were interested in subject-specific estimates. GEE is also inappropriate when the cluster sizes are relatively large, as in this analysis. We did not use random-effects logistic regression because the regression estimates were sensitive to the number of quadrature points used in the approximation and violated the Hausman specification test. We elected not to use cumulative sum techniques, which describe performance trends for individual subjects only.

We modeled ETI success as the primary binary outcome. The key independent variable was cumulative ETIs, defined as the PS’s cumulative number of ETI encounters (including the current patient encounter). We adjusted for the covariate clinical setting (prehospital, OR, ED, ICU, or other in-hospital) because of the variations in clinical and training conditions in each of these locations.

We speculated that elapsed time, independent of the number of ETI encounters, may have positive effects (e.g., from additional didactic and clinical experience) or negative effects (e.g., skill decay due to the sporadic nature of ETI opportunities). We also hypothesized that elapsed time may interact with the number of ETIs attempted. Therefore, we incorporated as covariates elapsed days since first ETI encounter (calculated...
as the number of elapsed days from the first ETI encounter to the current encounter) as well as the interaction (elapsed days × cumulative ETIs).

Because only a small number of students (33, 4.1%) performed more than 30 ETIs, we modeled only the first 30 ETI encounters for each PS. The excluded cases accounted for only a small fraction (237, 3.1%) of the total ETIs. Because goodness-of-fit approaches for fixed-effects models are not well developed, as recommended by prior authors we applied the Hosmer-Lemeshow test on a model fitted with the same parameters but using ordinary logistic regression. We also examined ΔD and Δβ statistics of the ordinary logistic regression model. We considered higher-order parameterizations of predictors in the model by using fractional polynomial regression (fracpoly command in Stata).

To depict the “learning curve” (the graphical relationship between predicted ETI success and cumulative ETI encounters), we used parameter estimates from the regression analysis to calculate the predicted probability of ETI success for each successive ETI encounter. We assumed that the fixed effect was zero. We constructed similar plots stratified by clinical setting.

All analyses were conducted using Stata v.8.2 (StataCorp LP, College Station, TX).

RESULTS

Of 2,063 students from 120 programs, 891 students from 60 programs consented to the release of data for research purposes. Of these 891 students, 802 attempted a total of 7,635 ETIs. No ETIs were reported by 89 students.

Paramedic student ETI characteristics are summarized in Figure 1 and Table 1. The PSs attempted between one and 74 ETIs. Of 802 PSs, 556 achieved ten ETI encounters, 175 achieved 20 ETI encounters, and 71 achieved more than 20 ETI encounters. Elapsed time from the first ETI encounter ranged from 0 to 552 days. Pooled overall ETI success was approximately 87.5% (95% confidence interval [CI]: 86.7–88.2%). ETI success rates were highest for ED, OR, and other in-hospital settings, and lowest for ICU and prehospital settings.

| TABLE 1. Characteristics of Paramedic Student Endotracheal Intubation (ETI) Efforts |
|---------------------------------|------------------|
| Parameter                        | Value            |
| Number of ETI encounters per student | 1–74             |
| Range                           | 9.5              |
| Mean                            | 7 (4–12)         |
| Elapsed days since first ETI encounter | 0–552           |
| Range                           | 9                |
| Median (IQR)                    | 6 (3–12)         |
| Intubation success, % (95% CI)   | Overall          | 87.5% (86.7–88.2%) |
| Operating room                  | (n = 6, 311)     | 89.3% (88.5–90.0%) |
| Emergency department            | (n = 271)        | 90.0% (86.4–93.6%) |
| Intensive care unit             | (n = 64)         | 68.8% (57.1–80.4%) |
| Other in-hospital               | (n = 86)         | 94.2% (89.1–99.2%) |
| Prehospital                     | (n = 903)        | 74.8% (71.9–77.6%) |

IQR = interquartile range; CI = confidence interval.
TABLE 2. Results of a Fixed-Effect Logistic Regression Model Depicting the Association between Paramedic Student Endotracheal Intubation (ETI) Success and Cumulative ETI Experience

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\beta$</th>
<th>Odds Ratio$^a$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative ETI experience (per patient)</td>
<td>0.065</td>
<td>1.067</td>
<td>(1.044–1.091)</td>
</tr>
<tr>
<td>Elapsed days since first ETI encounter</td>
<td>$7.995 \times 10^{-5}$</td>
<td>1.000</td>
<td>(0.998–1.002)</td>
</tr>
<tr>
<td>Elapsed days $\times$ cumulative ETI (interaction)</td>
<td>$1.000 \times 10^{-6}$</td>
<td>1.000</td>
<td>(1.000–1.000)</td>
</tr>
<tr>
<td>Clinical Setting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prehospital$^\dagger$</td>
<td>N/A</td>
<td>1.000</td>
<td>N/A</td>
</tr>
<tr>
<td>Operating room</td>
<td>1.368</td>
<td>3.927</td>
<td>(3.017–5.113)</td>
</tr>
<tr>
<td>Emergency department</td>
<td>0.967</td>
<td>2.638</td>
<td>(1.526–4.599)</td>
</tr>
<tr>
<td>Intensive care unit</td>
<td>−0.158</td>
<td>0.854</td>
<td>(0.335–2.175)</td>
</tr>
<tr>
<td>Other in-hospital</td>
<td>2.006</td>
<td>7.434</td>
<td>(2.232–24.758)</td>
</tr>
</tbody>
</table>

$^a$The odds ratio for cumulative ETI experience represents the incremental effect per ETI encounter (patient).

$^\dagger$Prehospital setting is the baseline value for clinical setting.

CI = confidence interval.

The multivariate model included 7,398 ETIs (Table 2). Adjusted for clinical setting, elapsed days from the first to the current ETI encounter, and the interaction (cumulative ETIs $\times$ elapsed days), cumulative ETI experience was independently associated with PS ETI success. The odds ratio of 1.067 (95% CI: 1.044–1.091) represents the incremental effect of each additional ETI encounter on predicted ETI success. Therefore, compared with the first ETI effort, the predicted odds of ETI success was 1.914 (95% CI: 1.534–2.390) after ten ETI encounters, 3.664 (2.352–5.710) after 20 ETI encounters, and 7.015 (3.607–13.644) after 30 ETI encounters. The main and interaction effects of elapsed days were not statistically significant.

Compared with the baseline linear model, fractional polynomial regression did not identify any higher-ordered models with superior fit. The Hosmer-Lemeshow test indicated acceptable model fit ($p = 0.70$).

The “learning curve” for ETI success increased from 77.8% to 95.8% over 30 ETI procedures (Figure 2). Learning curves stratified by clinical setting are depicted in Figure 3. Predicted ETI success appeared to increase with cumulative ETI experience across all clinical settings. The largest ETI success increases were observed for the prehospital and ICU settings, but initial predicted success rates for these settings were low (<60%). In contrast, while the learning curves of OR, ED, and other in-hospital settings began at higher levels (on the order of 75–90%), improvements in predicted ETI success were lower.

![Figure 2](image-url)

**Figure 2.** Relationship between endotracheal intubation (ETI) success and cumulative experience—all clinical settings pooled. Curve depicts the predicted probability of successful ETI (**solid line**) and 95% confidence interval (**dashed lines**). Only the first 30 ETI efforts were modeled.

**DISCUSSION**

We found that PS ETI success is associated with accumulated live ETI experience. This relationship exists even when adjusted for elapsed duration of training and the clinical setting of each ETI. Our analysis also suggests that elapsed time from the initiation of live ETI training is not related to PS ETI success.

The concept of “learning” presumes that performance improves with repetition of a task. ETI is both
a key and complex procedure. While it is important that PSs achieve minimal proficiency in ETI prior to certification, many barriers may prevent students from attaining adequate live experience. Paramedics and PSs have only limited opportunities for ETI in the clinical setting. OR training is ideal but is difficult to obtain because of competition from other students (such as medical students and residents) and medicolegal concerns. Even if a PS achieves “mastery” of ETI, once in clinical practice only a few select paramedics have opportunities to return to the OR for skills maintenance.

Even when presented with ETI opportunities, PSs may be constrained by other factors that impede the learning process. For example, PSs may not be permitted to attempt ETI on patients who have difficult airways. Thus, while PSs may learn basic ETI technique, they may not acquire skills necessary for managing more difficult airways, conditions likely to be encountered in clinical prehospital practice. Clinical considerations (for example, the deterioration of a patient) may also constrain the number of ETI attempts permitted to the PS. In addition, the clinical techniques used to manage the airway may also impact the learning experience; for example, ETI conditions may be very different depending on whether an instructor chooses to use neuromuscular-blocking agents or a sedative agent only.

An interesting observation was that the PS ETI learning curves differed when stratified by clinical setting. These trends may be explained by the different patient populations, clinical techniques, and teaching conditions present in each setting. For example, in the OR setting, most patients are clinically stable and deeply sedated or paralyzed prior to ETI. These patients may be easier to intubate, and PSs may be afforded opportunities for repeated attempts if initially unsuccessful. In the ED, rapid-sequence intubation (RSI—the use of neuromuscular-blocking agents) is used widely, but this population may include “ill” patients with some degree of instability. Therefore, while the PS may face airway relaxation similar to the OR, he or she may be allowed fewer attempts to achieve successful ETI. Likewise, the markedly lower ICU and prehospital curves may be explained by the nature of these patients and the limited array of pharmacologically assisted ETI techniques used in these settings.

Most importantly, PSs may have acquired very different learning experiences given the heterogeneity of instructors and patients across these varied clinical settings.

We did not have adequate information to determine why the “other in-hospital” curve rests higher than the other curves. However, only 20 PSs performed the 86 ETIs in this subset, and thus this may simply reflect the skills of this student subset. We emphasize that this data set contained information concerning neither the clinical condition of the intubated patient nor the techniques and drugs used to facilitate ETI, and thus we could not control for these factors, which may be relevant to PS ETI success.
An interesting question is whether PSs should be exposed to a particular sequence of clinical settings for ETI training. The slope of the learning curve depicts the degree of skill gained per additional ETI in each clinical setting. The learning curves for the OR and ED settings appear to plateau after 20–25 ETIs. In contrast, the prehospital and ICU learning curves appear steeper and do not plateau across the span of 30 ETIs. However, the initial predicted ETI success rates for prehospital and ICU settings are low (50–60%); these levels may represent unacceptable risks to live patients. Therefore, PSs in this cohort may need to acquire baseline experience with 15–20 ETI encounters in the OR or ED prior to attempting more difficult ETIs in the prehospital or ICU settings.

The thresholds for ETI “proficiency” have been defined differently for different medical specialties. For example, the anesthesia literature has recommended that anesthesia residents perform 20–57 ETIs to reach 90% success. Nurse anesthetists are required to perform 200 ETIs, prior to graduation. Emergency medicine residents are recommended to perform at least 35 ETIs prior to graduation. The National Standard Paramedic Curriculum recommends that PSs perform at least five successful ETIs prior to graduation. While this analysis was not expressly designed for this purpose, our data suggest that PSs may require exposure to more than 15–25 live ETI encounters across a range of clinical settings to achieve success rates above 90%. This potential skill threshold may be affected by heterogeneity in the clinical settings used for training. We emphasize that this analysis depicts how ETI skill improves with cumulative experience—not the minimum thresholds that denote “ETI proficiency.” However, if this minimum experience figure were adopted, only 10–15% of the students in this series would have achieved this standard. We note that in the current series 255 PSs (31.8%) did not attain the national paramedic curriculum standard of five successful ETIs.

Of note, our analysis may depict the true learning curve for novice intubators. Prior depictions of ETI learning curves have been based on anesthesia residents, many of whom may have obtained at least minimal ETI experience during medical school studies. Since PSs typically do not have prior training in advanced life support techniques, our series likely represents a group with no prior ETI experience.

LIMITATIONS

We did not have data regarding clinical or anatomic factors that may have affected the difficulty of the ETI effort. As discussed previously, we could not successfully link our ETI data to the data set containing basic physiologic data. We similarly did not have access to data regarding program demography. We encountered large numbers of missing values for PS demography and therefore could not assess their potential relationships. We accepted these limitations since there was no other similarly large data set suitable for testing the hypothesized relationship. Prospective efforts to validate our findings must consider these factors.

All outcomes in this study were self-reported and may have been subject to self-reporting bias. However, most of the ETIs performed in this series occurred in controlled (i.e., OR) settings where ETI placements were likely verified by an instructor or a preceptor. We note that the pooled ETI success rate in this cohort (87.5%) appears similar to those reported by prior studies of paramedic ETI.

This analysis is based on a data set with a low subject participation rate. Also, students who were more adept intubators may have performed more ETIs and reported information more diligently. Despite these facts, we still had access to more than 7,600 ETIs performed by more than 800 PSs. A data set of this magnitude would be extremely difficult to replicate on a prospective basis. Furthermore, our intent with this data set was strictly to model a hypothesized relationship between ETI success and cumulative live ETI experience. We did not seek to describe the epidemiologic aspects of PS ETI training.

This analysis assumes that acquisition of ETI skill results primarily from experience on live patients. However, students may acquire ETI skill using a variety of other platforms such as mannequins, human simulators, and cadavers. Evaluation of the effects of these training modalities and their interactions with live ETI experience was beyond the scope of this study. We found that elapsed time, and its interaction with ETI encounters, was not a significant predictor of ETI success. However, in this series most of the ETI encounters occurred within a relatively short time frame. Therefore, we cannot make inferences regarding skill retention from these data.

Finally, the learning curves in this analysis represent predicted trends in this population for a defined range of ETI experience. While this analysis accounts for a PS’s number of prior ETI encounters, it does not account for the student’s quality of performance on those encounters. While we defined ETI proficiency in terms of ETI success, ETI proficiency may be potentially described in other dimensions. For example, avoidance of technical errors (prolonged or multiple laryngoscopy, tube misplacement or tube dislodgement, etc.) is important during ETI. Manner of laryngoscopy and appropriate decision making are other important dimensions of ETI, but measures for these constructs have not been developed. These intermediate measures are likely important but must be studied prospectively. We elected to defer modeling of these conceptual constructs because of the preliminary nature of this analysis and the recognized limitations of the data set.
CONCLUSIONS

Paramedic student ETI success improves with accumulated live experience but appears to vary across different clinical settings. Strategies for PS airway education must consider the volume of live ETIs as well as the clinical settings used for ETI training.

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References


