The Effect of Cross-Training with Adjustable Airway Model Anatomies on Laryngoscopy Skill Transfer

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BACKGROUND: A problem with learning endotracheal intubation on airway mannequins is poor transfer of direct laryngoscopy skills from model to patient. We developed an airway model with adjustable anatomic features and investigated whether practicing on a model with frequent adjustments improved laryngoscopy skills transfer.

METHODS: Fifty-one paramedic students and 18 medical students with minimal previous experience practiced laryngoscopy 25 times with either the novel model with static features, the novel model with variable features, or a Laerdal Adult Intubation mannequin. For the variable group, the configuration changed after every 5 attempts. After training, all subjects performed 10 laryngoscopies on 2 new mannequins to test their competence at skills transfer. A mixed linear model analyzed various predictors of success as a binary outcome, including training group and change in laryngoscopy model.

RESULTS: The odds ratio for success after a recent change in mannequin was 0.69 (0.49, 0.96 [95% confidence interval]). Compared with the Laerdal group, subjects with the static trainer did worse (odds ratio 0.46 [0.23, 0.94]), and subjects in the variable group were no different (0.74 [0.36, 1.52]). Change in laryngoscopy model decreased success rate by approximately 30% for all training groups.

CONCLUSION: The results verify that proficiency on one model does not guarantee success on another. However, subjects who trained with a laryngoscopy mannequin in multiple configurations did not show better skill transfer than subjects practicing on fixed configuration airway models. (Anesth Analg 2011;113:862–8)

Direct laryngoscopy performed by an expert practitioner results in successful intubation in 99.9% of patients.[1] Trainees must perform the procedure in 20 to 60 patients to attain a 90% success rate.[2–4] Approaching an expert status probably entails several times that amount of experience. Access to training opportunities is not a problem for anesthesiology residents who perform laryngoscopy daily in the course of their instruction. However, nonanesthesiologists have limited access to patients requiring laryngoscopy, and finding clinical opportunities for developing their technique can be a challenge.[5]

The alternative to patient experience is to practice on mannequins or patient simulators. However, laryngoscopy on currently available mannequins does not feel like laryngoscopy in patients and is generally more difficult than in real life.[6] Another disadvantage of learning with a model is that students develop skills that are specific for the configuration and anatomy of the mannequin. After mastering laryngoscopy on one specific model, trainees do not sustain the same intubation performance success rate on a different mannequin or a patient. Additional training is generally necessary in the new situation.[7] Airway dummies could be superior training tools if the head, neck, and airway were adjustable so that students could practice on a wide range of airway anatomies with varying degrees of difficulty, much as they would encounter working with real patients. Trainees, even anesthesiology residents, have a higher incidence of complications than more experienced personnel while learning laryngoscopy on patients.[8] Thus, a training model that substituted for patient practice could improve patient safety.

Toward this end, we have developed a laryngoscopy model with multiple adjustable settings for several variables, including face length, mandible length, presence and condition of the teeth, and mouth opening. We hypothesized that practicing laryngoscopy on a model in multiple configurations would enhance a trainee's ability to transfer learned technical skills to laryngoscopy on a new model. Medical and paramedic students with minimal previous laryngoscopy experience trained on 1 of 3 models: the adjustable mannequin in multiple configurations, the same model maintained in a single anatomy, or a commercial nonadjustable mannequin.

METHODS

Subjects

The subjects were medical and paramedic students receiving training in airway management, laryngoscopy, and

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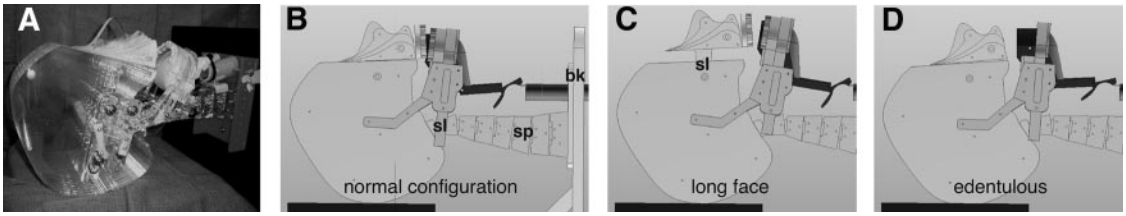

Figure 1. New, adjustable laryngoscopy model. Photograph (A) and computer-aided design diagrams (B–D) are shown. The diagrams show a normal configuration (B), a mannequin with a lengthened maxilla and face (C), and an edentulous version (D). Other possible adjustments, which are not shown here, are changes in jaw length, mouth opening, ability of the jaw to sublux, and tension on the mouth or jaw. The diagrams depicting the tongue, larynx, and trachea are shown in a cartoon format, rather than an actual representation. The symbols mark the sliders (sl) for adjusting the maxillary and mandibular lengths in B and C, the backboard on which the model is mounted (bk), and the cervical spine (sp).

endotracheal intubation. Medical students and paramedic students were studied on different days. The appropriate IRB approved the study. Written informed consent was obtained from all subjects. A power analysis was performed before the study to estimate the necessary sample size. The assumptions were a laryngoscopy success rate during the evaluation phase of 0.9 for students with the variable anatomy training versus 0.5 for students with 1 configuration training, based on a literature report that a change in model decreased success by almost 50%.[7] A χ^2 test would need 24 subjects per group to detect that difference as significant at the 0.05 level with 80% probability, or 72 subjects altogether across the 3 study groups. The total number was 3 short of the target because 3 subjects who had been recruited were unable to participate. They were not replaced for reasons of convenience.

Adjustable Airway Mannequin

The prototype for the mannequin was a 2-dimensional (2D) movable and adjustable laryngoscopy model that has been described previously.[9] The model portrayed a sagittal view of the human head, neck, and spine. The dimensions, proportions, and range of motion data were extracted from human cephalometric literature[10] and represented a realistic facsimile of the adult airway anatomy. The mechanical engineers involved with the project designed several joints and sliding parts to allow movement and adjustability. The 3D model was created by adding layers to the 2D model, extruding thickness into the transverse dimension (Fig. 1). The 3D airway components consisted of a commercial model of the tongue, epiglottis, larynx, and trachea from Laerdal (Wappingers Falls, NY). Our model includes a cervical spine with 7 levels and physiologic range of motion, a mandible that rotates, subluxes, and has a tension device to close on its own, and removable upper and lower teeth. The mandible and maxilla can be lengthened or shortened independently, and mouth opening or jaw subluxation can be limited by adjusting tension elements.

Study Protocol

Students attended a 15-minute didactic session that reviewed airway anatomy, discussed general principles of airway management, and explained the procedure for laryngoscopy. They watched a short movie illustrating laryngoscopy and observed a demonstration of the procedure on a mannequin. Subjects answered questions on a survey form about their current and previous medical occupations and prior exposure to laryngoscopy instruction.

After the didactic session, students were assigned sequentially to 1 of 3 experimental groups by order of enrollment. The Laerdal group practiced with the Laerdal adult intubation model. The static group used the new laryngoscopy simulator maintained in the standard configuration (normal face and jaw length, normal dentition, and normal head and spine range of motion), and the variable group practiced on the laryngoscopy simulator changing the anatomy after every 5 intubation attempts. The first configuration was standard except that the teeth were removed. Subsequent changes were to replace the teeth, lengthen the face to 0.5 cm more than normal, shorten the mandible by 0.5 cm, and finally increase the tension on the mandible slider (i.e., movement in a prognathic direction). These variations were chosen because they target anatomic features known to affect laryngoscopy difficulty. The change in length was limited to 0.5 cm because we did not want to make laryngoscopy so difficult that most trainees would fail. The order of configurations progressed from easiest to most difficult in our estimation. The rationale for this sequence was based on data from Plummer and Owen[7] indicating that trainees learn more from a successful laryngoscopy attempt than a failed attempt. Thus, moving from easy to more difficult configurations might facilitate laryngoscopy training.

Regardless of group, each subject attempted laryngoscopy with a Macintosh no. 3 laryngoscope and endotracheal intubation with a styletted 7.0 endotracheal tube 25 times. An investigator observed and scored the result of every attempt as success or failure. A successful laryngoscopy attempt was defined as placement of the endotracheal tube into the model trachea within 30 seconds. Exceeding the time limit, intubating the model esophagus, or handling the laryngoscope in a manner that could cause oral or dental injury in a real patient were grounds for failure on the attempt.

After training on the group-specific mannequin, all students attempted direct laryngoscopy with endotracheal intubation on the adjustable model with the mouth opening reduced from 5 cm to 3.5 cm, a new configuration for all subjects. In addition, the subjects performed laryngoscopy with a different airway mannequin that none had seen, a Medical Plastics Airway® model (Mass Group, Inc., Miami, FL). Five attempts were recorded on each of the 2 evaluation models. Success or failure for each attempt was assessed as in the training period.

Table 1. Subject Demographics

Factor	Laerdal	Static	Variable	χ^2	*P* value	Contingency coefficient
Total no.	22 (32%)	24 (35%)	23 (33%)			
Occupation						
Paramedic student	16 (32%)	18 (35%)	17 (33%)	0.03	0.98	0.02
Medical student	6 (33%)	6 (33%)	6 (33%)			
DL experience						
None	18 (33%)	19 (34%)	18 (33%)	0.24	0.89	0.06
Theory	1 (33%)	1 (33%)	1 (33%)			
Model	2 (25%)	3 (37.5%)	3 (37.5%)			
Patients	1 (33%)	1 (33%)	1 (33%)			

Data are *n* (% of row total).
DL = direct laryngoscopy.

Laryngoscopy Force and Torque

To obtain information on the amount of physical effort necessary for laryngoscopy on the different airway mannequins, one of the investigators with longstanding experience in laryngoscopy (RH) performed the procedure in the Laerdal, novel adjustable model, and Medical Plastics model using a Macintosh 3 blade with an instrumented laryngoscope handle.[11] The handle incorporates a 6-axis transducer (ATI Industrial Automation, Apex, NC) for simultaneous measurement of force and torque. The Medical Plastics model requires significantly greater force than the other 2 mannequins, 63 ± 3 Newton (N) vs 50 ± 1 and 45 ± 1 N for the adjustable and Laerdal models, respectively ($P < 0.001$ for Medical Plastics versus either of the other 2 models). Similarly, the Medical Plastics model demonstrated the highest torque, 16 ± 3 Newton-meters (N-m) vs 7 ± 0.3 and 5 ± 0.6 N-m in the same order ($P < 0.001$ for Medical Plastics versus either of the other 2 models). For comparison, laryngoscopy in adult elective surgery patients requires approximately 44 N (range, 10–60 N) and 4 N-m (range, 2–7 N-m).[12] Force and torque did not vary significantly for different configurations of the adjustable model (data not shown).

Data Analysis

A mixed linear modeling approach was pursued because of the hierarchical structure of the design; multiple measurements at different occasions were nested within each subject. With a multiple measures within subjects design, mixed level modeling can simultaneously analyze interindividual differences (e.g., how subjects differ between one another in their trajectory across time) and intraindividual variability (i.e., how each individual manifests a unique slope and intercept/starting point). The analytic methods afford the opportunity to break down variability at multiple levels: in this case, time at the micro level and subject at the macro level. The method's flexibility is amplified by the ability to add time-varying predictors (level 1), time-invariant predictors (level 2), and even to analyze interactions across levels. Similar to regression analysis, one can examine each of the predictors for significance and moreover ascertain whether the slopes and/or intercepts vary randomly between subjects.

The analysis used the HLM 6.08 software,[13] testing a succession of models (i.e., unconditional model, intercepts only free to vary, slopes and intercepts free to vary, etc.). The outcome variable was laryngoscopy success or failure. Given the nonlinear (i.e., binary) nature of the outcome, a penalized quasi-likelihood approach was used for parameter estimation with the logit link function. Moreover, the estimates were reported based on the population-average results because the overarching objective was averaging over all possible values of the stochastic parameter.[14] The logit (log of the odds), standard errors, *P* values, odds ratios (ORs) for success, and confidence intervals around ORs were interpreted and provided in table format.

For the linear model, the level 1 (time varying) variables were trial number, mannequin on which laryngoscopy was attempted, recent change in laryngoscopy model, and the number of previous changes in laryngoscopy model. The trial number was analyzed as either a fixed or random factor. Recent change was defined as a substitution of a new laryngoscopy mannequin or configuration for the current laryngoscopy trial or the previous trial; i.e., the variable was positive for the 2 trials after a change in mannequin. The rationale for designating the variable in this manner was our notion that a subject's performance would decrease after a change and that the subject would have to train for at least 2 laryngoscopy trials to recover the success rate obtained before the change. Level 2 (time-invariant) variables included subject occupation (medical student or paramedic student), history with laryngoscopy training, and the mannequin used for training.

Differences in proportions were compared in terms of χ^2 in a contingency table analysis. Force and torque were compared among groups by analysis of variance, and the Scheffé test was used for post hoc comparisons. The nominal level of significance was set at 0.05 for all tests.

RESULTS

Subject demographics divided by training group are presented in Table 1. The study population consisted of 51 paramedic students in their second month of training and 18 medical students, including 12 first-year, 3 second-year, and 3 fourth-year students. The majority of subjects had no previous exposure to laryngoscopy either in theory or practice. Eight subjects (12%) had practiced on models and 3 had attempted laryngoscopy on patients. Subject position and previous experience did not differ significantly among the 3 training groups.

On average, the subjects successfully intubated the model trachea in 88% ± 1% of the trials. Initial success rate on the first trial was on the order of 65% to 70%. From the third trial to the 25th trial, during the training run, the

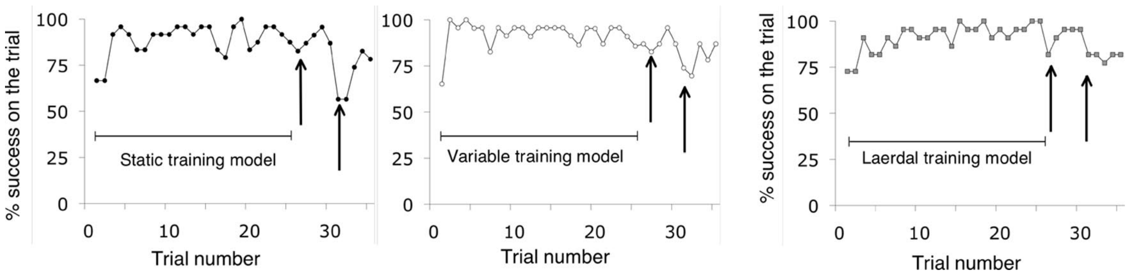

Figure 2. Laryngoscopy success rate versus trial number for the entire course of the study. Panels are labeled with the laryngoscopy training model used for the first 25 laryngoscopy attempts. The percent success refers to the success for the particular trial number averaged over 22 subjects for the Laerdal group, 24 for the variable group, and 23 for the static group. The left-most arrow at trial 26 on each diagram indicates the shift to the small mouth model. The arrow at trial 31 to the right in each panel indicates the shift to the Medical Plastics model. Success rate decreased substantially when subjects shifted to the latter mannequin.

Table 2. Effects of Level 1 and Level 2 Variables on the Odds of Success for Any Laryngoscopy Trial in a Population-Average Model

Factor	Logit	Standard error	*P* value	Odds ratio	95% CI
Level 1 variables					
Trial no.	0.057	0.01	<0.001	1.06	(1.03, 1.08)
Mannequin on which laryngoscopy was performed					
Medical Plastics				1	
Laerdal	1.80	0.36	<0.001	6.1	(3.0, 12.2)
Static	2.35	0.37	<0.001	10.5	(5.1, 21.5)
Variable	2.00	0.31	<0.001	7.4	(4.0, 13.8)
Small mouth	1.06	0.21	<0.001	2.9	(1.9, 4.3)
Model change					
None				1	
Recent change	−0.38	0.17	0.03	0.69	(0.49, 0,96)
No. of previous changes	−0.05	0.08	0.58	0.95	(0.81, 1.13)
Interaction of model change and training model					
Laerdal × recent change				1	
Static × recent change	−0.1	0.5	0.79	0.9	(0.3, 2.4)
Variable × recent change	−0.5	0.6	0.35	0.6	(0.2, 1.8)
Level 2 variables					
Occupation					
Paramedic student				1	
Medical student	−0.99	0.26	0.001	0.37	(0.22, 0.63)
Mannequin on which subject trained					
Laerdal trainer				1	
Static trainer	−0.76	0.35	0.03	0.47	(0.23, 0.94)
Variable trainer	−0.31	036	0.40	0.74	(0.36, 1.52)
Previous exposure to laryngoscopy training					
None				1	
Theory only	0.83	0.39	0.04	2.3	(1.1, 5.0)
Model practice	1.28	0.38	0.002	3.6	(1.7, 7.7)
Patient practice	0.29	0.56	0.61	1.3	(0.4, 4.2)

Odds ratio is the quotient of the odds of laryngoscopy success for a group with a given condition holds divided by the odds of success in the reference group. For each comparison, the reference group is the first condition listed. The reference odds ratio = 1. The odds ratios for trial number and for number of previous changes are expressed per event.

CI = confidence interval.

success rate exceeded 80% for individuals training on any of the 3 laryngoscopy models, the new static model, the new variable model, and the Laerdal mannequin (Fig. 2).

The experimental design involved a time-related variable, the laryngoscopy trial number, nested within each subject. Thus, we performed mixed linear modeling to validate factors that could predict laryngoscopy success within the framework of the experiment. We included the significant predictors from the 2001 publication by Plummer and Owen in our set of variables because we had used that study as the template for the design.[7] We first analyzed an unconditional model without predictors and found that the OR for the fixed effects was significant at 9.7. The variance component for the intercept, 0.9, was also significant, and corresponded to an intraclass correlation of 0.215. Thus, 21.5% of the variability in the results was attributable to between-individual variation and we proceeded with the hierarchical model.

In the subsequent analysis, laryngoscopy trial number, subject occupation, previous experience with laryngoscopy training, training model, laryngoscopy model, and recent change in laryngoscopy model had a significant impact on the odds of success (Table 2). The table presents results

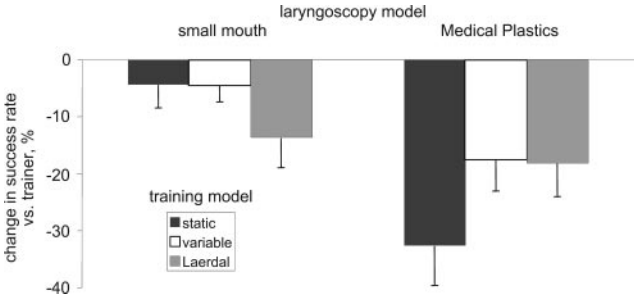

Figure 3. Effect of changing the laryngoscopy model in decreasing success rate. The ordinate shows the change in success rate over the first and second laryngoscopy trials after changing from the training model to either the small mouth or the Medical Plastics airway mannequin. The value was calculated as the success rate averaged for the 2 trials after the switch (trials 26 and 27) minus the success rate for the last 2 trials on the training model before the change (trials 24 and 25), both as percentages of the number of attempts across all subjects in the group. Negative numbers signify decreased success. The "laryngoscopy model" label on the abscissa denotes the results obtained when switching to the small mouth model or the Medical Plastics model. Black, open, and gray bars represent results for subjects training on the static mannequin, the variable mannequin, or the Laerdal mannequin, respectively. None of the changes was significant (χ^2 $P = 0.08$ for small mouth mannequin comparison, 0.23 for Medical Plastics). Subjects in the variable group did not perform significantly better when the airway model was changed than subjects who trained on a static configuration.

using a population-average model. The findings with a unit-specific model were similar, but have not been shown. Based on OR, the Medical Plastics and Laerdal mannequins appeared to present the most difficulty for laryngoscopy, whereas the small mouth model and the static model seemed easiest. Success was more likely at later trial numbers and if subjects had previous experience with laryngoscopy theory or practice on mannequins. Medical students had lower odds of success than paramedic students. In addition, ORs were lower for those who trained on the static trainer (versus the Laerdal trainer), or those who experienced a recent change in laryngoscopy model (versus no change). We calculated the interaction term between training model and the recent change variable to investigate whether method of training affected the impact of change in model. The interaction term was insignificant (data not shown), suggesting that method of training did not affect the extent to which success decreased after a change.

We also evaluated training model as a factor by examining the decrease in success rates when the subjects shifted to new mannequins after the 25 attempts on their original training model. The decrease in performance was marginal when changing to the new model with limited mouth opening: 35% for subjects training on the static or variable new mannequins and a 16% decrease for subjects training with the Laerdal model (Fig. 2, left arrow in each panel). The change in success was substantially greater when subjects switched to the Medical Plastics airway dummy (right arrows in Fig. 2), consistent with the observation that laryngoscopy was more difficult with that model. Subjects training with the static model had a 90% ± 4% success rate for the last 2 trials on that model but decreased to 57% ± 7.4% success for the first 2 trials on the Medical Plastics model, the biggest change for any of the groups (Fig. 3). Subjects who trained with the other 2 models experienced an approximately 15% decrease in performance going to the Medical Plastics model. However, the change in success did not differ among the 3 groups when analyzed by χ^2.

DISCUSSION

In a previous study, Plummer and Owen[7] examined the rate at which medical personnel develop laryngoscopy skill in mannequins. One of their major findings was that trainees demonstrated a decrement in performance if they shifted to a new airway model after training on another mannequin. Thus, the skills developed on the first mannequin did not generalize completely to the new setting and additional training was needed. The goal of our study was to investigate whether a novel, adjustable laryngoscopy model could improve a subject's ability to transfer skills across different settings. The desired long-term benefit would be to aid students in transitioning from laryngoscopy in mannequins to live patients and to improve their preparation for performing the technique in patients with differing airway anatomies.

The new training paradigm was to expose students to laryngoscopy on a mannequin whose configuration could be changed, reasoning that forcing a trainee to adapt to multiple varying anatomies would improve his or her ability to adjust to new or novel circumstances. If training on multiple anatomies improved skill transfer, we expected that subjects in the variable group would outperform the subjects in the other 2 groups who each trained on an airway mannequin with a fixed configuration. In addition, we expected a significant interaction between training group and the effect of recent change. Nevertheless, neither prediction was borne out. Similar to the findings by Plummer and Owen,[7] a recent model change decreased the odds of laryngoscopy success (OR 0.7, Table 2). However, trainees in the variable model group performed no better that those in the static or Laerdal group after switching mannequins (Fig. 3). Furthermore, the linear modeling analysis indicated that the training model did not affect the impact on success rate after a change in model; the interaction between training group and recent change was insignificant.

One factor did seem to affect the degree of skill transfer: which model was introduced when the configuration changed. Subjects maintained their success rate to a greater extent when they shifted to the small mouth model compared with the Medical Plastics model. The defining characteristic might be the difficulty of the new model. Laryngoscopy was more difficult on the Medical Plastics model than on any other model and required more force and torque, as well. Plummer and Owen[7] similarly found that the Medical Plastics intubation head was more difficult for students than the Laerdal mannequin.

Although the study was unable to show that training with multiple model anatomies improved laryngoscopy skill transfer compared with training on 1 configuration, the data do provide evidence for a cross-training effect. In particular, subjects with previous laryngoscopy practice on airway models had better success than subjects with none. More than half the laryngoscopies in our study were performed on a novel model that none of the subjects had seen before. Thus, improved performance with prior experience suggests skills learned on one model do transfer to some extent to another laryngoscopy model and those skills persist for some time after training.

Interestingly, the odds of success for medical students were significantly less than for paramedic students. Plummer and Owen[7] also reported that paramedic students outperformed medical students, with an OR of almost 8 for the paramedic students. In our study, the paramedic students and medical students did not differ in previous experience and there was no obvious explanation for the difference in success rates between the groups. Medical students and paramedic students trained on separate days, so didactic training could have differed or differences in how harshly the groups were graded might have been an issue. However, it is our impression that the difference in subjects' physical fitness between groups was unappreciated beforehand and could have contributed to the superior success of the paramedic students. Over the course of the experiment, some of the less-robust medical students had difficulty lifting the laryngoscope hard enough to get their view, but none of the paramedic students appeared to struggle with the lift. Paramedic students generally come from a population motivated toward maintaining fitness because of the demands of the chosen field. One of the standards for the study's paramedic students at their college is the ability to carry at least 125 lbs. No explicit physical ability standards are in place for medical students. We did not measure strength in this study, but the factor might be important for future investigations. Strength is certainly an issue for laryngoscopy in patients, as well. The force and torque can approach the limits of the relevant upper extremity muscles in a normal population of patients undergoing anesthesia.[12] The forces can increase with patient weight, laryngoscopy difficulty, or under special circumstances such as manual in-line stabilization for cervical spine protection.[15,16]

Study Limitations

A number of factors and limitations should be considered in interpreting the results of this study. Although we included a number of relevant factors that could affect laryngoscopy training in the analysis, other unmeasured or unrecognized variables could have influenced the results. In particular, we did not record the identity of the individual evaluating each subject. Results could vary among different graders depending on their assessment stringency, and the degree or quality of feedback could vary among individuals. Potential bias by a grader in favor of one trainer or another is also an issue, because the graders could not be blinded to the trainer used by individual subjects. Finally, the findings are specific for the conditions of the study and might have varied if different mannequins were used, if different changes in anatomic configuration had been selected, or if variables such as the length of training or the frequency of introducing new configurations had been different.

Summary

In this study, we investigated whether training on an airway model with multiple anatomic configurations improved a trainee's ability to transfer skills to new models and evaluated several other factors with potential impact on laryngoscopy success. A recent change in airway model reduced the odds of success to 70% of the odds without a change. Laryngoscopy success was increased with previous laryngoscopy experience and in paramedic students compared with medical students. Success differed among airway models, with some posing greater difficulty than others. However, practicing laryngoscopy in a new airway model adjusted into 5 different configurations did not improve the odds of success over practicing with only an airway trainer held in a fixed anatomy. Factors that might contribute to the ability to transfer laryngoscopy skill to new settings include the difficulty of laryngoscopy in the new setting and a subject's innate ability. ■

AUTHOR CONTRIBUTIONS

WW helped with study design, data analysis, and conduct of study; SK and ND helped with conduct of study and model design and construction; DG helped with data analysis and statistical methods description in manuscript; JM and DPD helped with conduct of study; and RHH helped with study design, data analysis, conduct of study, and manuscript preparation.

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Randolph H. Hastings statement on FAER funding: I applied for a Parker B. Francis/FAER Young Investigator Award in 1991 to continue studies on the mechanisms of alveolar protein clearance that I'd begun with my mentor, Michael Matthay. It was a wonderful surprise and a honor when I was selected for one of the grants. Looking back, the FAER support was instrumental in initiating my professional academic career at a number of levels. The favorable review and response boosted my self-confidence, letting me know that other scientists thought my career was promising and my project worthwhile. It also strengthened my stature as a physician-scientist within the department, justifying the nonclinical time I'd received. The research support gave me independence and was particularly generous, allowing me to complete the project and set-up the basic equipment I needed in my lab for future work. I published 3 papers, solved the question I had posed for the grant and set myself up with data and a publication record to seek larger scale funding. The basic research finding was that protein in pulmonary edema funding was cleared by passive diffusion out of the air spaces and not by active transcellular endocytosis as had been suspected before my work. I have subsequently received Veterans Affairs Merit Awards, National Institutes of Health funding and numerous foundation grants. My research direction has broadened and shifted considerably, but much of my success I owe to the start I received through FAER.

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