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ORIGINAL RESEARCH

Manikin Laryngoscopy Motion as a Predictor of Patient Intubation Outcomes: A Prospective Observational Study

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INTRODUCTION

The rate of endotracheal intubation complications with laryngoscopy is high for novice operators and decreases with training and acquisition of skill. For example, clinical anesthesia year 1 (CA1) residents have more complications with intensive care unit (ICU) intubations than do CA2 residents.[1] Failed intubation and multiple laryngoscopy attempts predispose patients to complications.[2–7] First-pass success rates for ICU intubations are low for junior residents and improvement occurs over 2 to 3 years,[1,8] suggesting that anesthesiology residents may experience laryngoscopy complications at all stages of training.

Since people vary in the rate at which they master laryngoscopy,[9,10] a method of discerning a trainee's skill would be useful to ascertain whether residents were ready for assignments with greater independence in airway management and help residents develop proficiency. Simulation is a possible venue for quantifying real-world skill, and performance on simulated surgical tasks predicts technical skill at laparoscopic cholecystectomy in patients.[11,12] Thus, assessment of clinical performance at laryngoscopy might be feasible with an airway simulator.

To address the laryngoscopy question, we compared motion between CA1 residents and anesthesiologists at a CA3 or Attending level performing laryngoscopy on a manikin. We then correlated CA1 manikin performance with their outcomes when intubating patients. The hypotheses were that motion would differ between groups and that one or more metrics measured in a manikin would be a prospective indicator of CA1 performance at intubating patients.

MATERIALS AND METHODS

Overview

Two observational studies, Experiment 1 and Experiment 2, evaluated manikin laryngoscopy motion in UC San Diego CA1 residents. Experiment 2 correlated manikin findings with subsequent outcomes in patients. Flow charts for both are presented in "Supplemental Digital Content 1."

The novice subjects for the two experiments came from different residency classes, with CA1 class beginning in 2011 and a class beginning in 2013. Variables and analysis plans were established before each study commenced. This manuscript adheres to the applicable Equator guidelines for transparency.

The study was approved by the University of California San Diego (UC San Diego) Human Research Protection Program. A study team member who had no position of authority recruited subjects, explained the study purpose and procedures, answered questions, and obtained written informed consents. Patients gave written informed consents plus HIPAA authorization for collection of data on their airway exam and intubation outcomes. Measurements of manikin laryngoscopy by subjects were incorporated as one of the training exercises in a simulation-based skills laboratory provided to all residents, regardless of study participation. Data were collected from subjects who gave consent and were used solely for research purposes. The information was stored in a secure location as de-identified data.

Experiment 1 Plan

Subjects performed laryngoscopy on a Medical Plastics Airway model (Mass Group Inc, Miami, FL) using a Macintosh 3 laryngoscope outfitted with sensors to measure motion and force data (Figure 1). Two papers describe the instrumented laryngoscope in depth[13,14] (see "Supplemental Digital Content 2" for the one article available only in print format).[13] Metrics were laryngoscopy duration, maximum axial force on the laryngoscope handle, handle angle relative to horizontal, and position coordinates of the tip of the laryngoscope blade at the end of laryngoscopy when the subject had achieved his or her best view of the glottis.

The intended analysis was to compare force and motion parameters in 10 CA1 residents versus a group of 6 anesthesiology attendings plus 2 CA3 residents. Historically, individuals in these two groups differ on average in outcomes when performing endotracheal intubation in patients. For example, anesthesiologists at a CA3 level or above achieve first-pass patient intubation success rates of over 90% under emergent conditions, while those with less than 6 months training in anesthesiology operate at less than 70%.[8]

Experiment 2 Plan

On the first day of their residency, 12 CA1 residents completed a questionnaire about

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their previous experience with laryngoscopy and performed a manikin laryngoscopy test similar to the test in Experiment 1. Residents were observed in the operating room every day for the next 4 weeks to obtain intubation outcome data on all attempted patient laryngoscopies. The data collection period was kept short to study resident performance in patients close to the time of the manikin test. Statistical considerations (see "Multilevel Modeling Methods" section, below) suggested that robust statistical estimates would require data from 5 to 10 patients.[15]

One analysis for Experiment 2 compared manikin laryngoscopy motion between CA1 residents and faculty, parallel in concept and hypothesis with Experiment 1. A second analysis evaluated the odds of successful patient intubation outcome in relation to manikin motion metrics, subject characteristics, and patient factors, the independent variables. The dependent variables focused on intubation outcome and consisted of first-pass intubation success, overall success regardless of number of attempts, and number of failed attempts. The statistical analysis was performed with a multilevel modeling approach (MLM) because the data were organized hierarchically with intubation outcomes from multiple patients nested within each resident.[16]

Experiment 2 included a new manikin laryngoscopy motion metric, Attending Route %, that had not been developed at the time we conducted Experiment 1. Attending Route % quantified the extent to which the resident moved the laryngoscope blade over the route used by attending anesthesiologists in a standard airway manikin. This metric is based on the premise that experienced anesthesiologists consistently succeed at intubation, in part because they move the laryngoscope in a well-defined, common pattern that enables successful intubation.[13] Trainees who move the laryngoscope in the same pattern would facilitate their own chances of success. Thus, we predict that the extent to which a trainee follows the attending manikin laryngoscopy route (Attending Route %) will predict the trainee's odds of intubation success in patients.

Manikin Test Procedures

The manikin laryngoscopy test took place in a classroom. It consisted of three laryngoscopy attempts on the Medical Plastics manikin with the instrumented laryngoscope. The manikin was returned to a horizontal orientation at the start of each attempt. In Experiment 1, laryngoscopy was timed until the trachea was intubated and the laryngoscope was removed. In Experiment 2, the test ended when the subject reported achieving the best view of the glottis without performing tracheal intubation. The protocol was changed in Experiment 2 to focus on laryngoscopy over intubation. Procedures were otherwise identical in the two experiments.

Instrumentation to Measure Laryngoscopy Movement

The laryngoscope was equipped with a miniBird Model 800 magnetic position sensor (Ascension Technology Corp, Burlington, VT) and a 6-axis (3D force plus torque) force transducer (ATI Industrial Automation, Apex, NC; Figure 1B). A miniBird sensor on the manikin head monitored rotation and lift of the head during laryngoscopy. The laryngoscope sensor was situated on the handle close to the blade and did not interfere with the field of view.[13] The manikin and a magnetic field generator were anchored in close proximity on a table surface. Changes in magnetic field strength detected by the sensors were transformed into 3D spatial coordinates and angles. Position, force, and torque data were processed with a MATLAB program (MathWorks, Natick, MA). The coordinates at the tip of the blade could be calculated from the coordinates measured by the sensor based on the fixed geometry of the sensor, laryngoscope blade, and handle.

The instrumented handle was used only for manikin tests. A standard handle without sensors was used for patient laryngoscopy.

Calibration and Collection Procedures

A sagittal midline profile of the manikin and an outline of its mouth were traced with miniBird sensor on a stylus. The outlines were used to register laryngoscope motion in space relative to structures in the manikin. The location of points on the table surface were acquired to define a coordinate system. The origin was positioned just cranial to the manikin occiput. The y-axis ran horizontally along the sagittal midline of the manikin. The x-axis denoted left to right and the z-axis represented the vertical direction. Force and torque measurements were calibrated by hanging known weights from the blade.

Patient Intubation Procedures and Data

The patients were adults ≥18 years of age who presented for elective surgery in a wide range of surgical specialties. They had been assigned through the standard scheduling process to receive anesthesia from a CA1 resident.

Each patient underwent airway management in the operating room by one CA1 resident, who conducted the anesthetic under supervision of an attending anesthesiologist. When endotracheal intubation was unsuccessful, the attending had the discretion of allowing the resident to repeat the laryngoscopy or switch operators for patient safety. Residents had their choice of laryngoscope blade and size, but they universally selected a size 3 Macintosh blade. The supervising anesthesiologist recorded study data about each patient's airway exam, whether the resident succeeded at intubation information, and the number of failed laryngoscopies by the resident. Each time the laryngoscope blade entered the patient's mouth was a new attempt. Intubation was deemed successful if endotracheal placement was verified. A research team member collected data sheets daily and retrieved missing data from the medical records, from the anesthesia records, or by interviewing the anesthesia team.

The airway exam data consisted of a Mallampati score using the Samsoon and Young 4-point scale,[17] head range of motion, mouth opening, thyromental distance, and ability to move the mandible in a prognathic direction. Rose and Cohen reported that these characteristics were related to intubation difficulty.[18] We took Mallampati score >2, head range of motion <120°, mouth opening <4 cm, thyromental distance <5 cm, and inability to move the mandibular teeth or gums anterior to the maxilla as predictors of difficulty. Rose and Cohen found that 2 or more unfavorable characteristics represented an odds ratio (OR) for difficult endotracheal intubation of 7.4.[18]

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Statistical Analysis

Manikin motion parameters in Experiment 1. Group averages for manikin test metrics were analyzed by *t*-test or repeated measures analysis of variance. The difference in mean values between the CA1 residents and CA3/Attending group was divided by the pooled standard error to calculate effect size. The correlation between metrics was evaluated with Pearson correlation coefficients.

Multilevel modeling methods for Experiment 2. The contribution of potential predictors to patient intubation outcomes was analyzed with multilevel modeling used HLM 7.01 (SSI Inc, Chicago IL) and Stata software (StatCorp), as previously described.[19,20]

Independent variables. The independent variables (ie, potential predictors) were separated into two levels: Level 1 variables were specific to the patient and included "Patient Factors" and "Patient Order." Patient Factors was a binary variable derived from characteristics of each patient's airway exam regarding the likelihood of intubation difficulty (see "Patient Intubation Procedures and Data," above). Patients received a score of 1 if they had two or more unfavorable characteristics and a score of 0 otherwise. "Patient Order" referred to a patient's ordinal number in the list of the patients a resident attempted to intubate. It accounted for the possibility that a resident's success rate might improve due to experience accumulated between the first patient and the last patient intubated during the experiment.

Level 2 variables pertained to the resident subjects. These included the manikin test metrics and an experience variable based on the subjects self-reported history of patient intubations before the study. Experience was an ordinal variable (1, 2, or 3) corresponding to previous intubation experience in 6–20, 21–60, and ≥61 patients, respectively. The lowest number of previous intubations reported by any subject was 6. The manikin test metrics were continuous variables, and values were averaged over the three trials performed by each resident.

Dependent variables. The dependent variables included first-pass success at patient intubation, overall success regardless of the number of attempts, and the resident's number of failed laryngoscopy attempts on the patient. The number of failed attempts was a count ranging from 0 to 3, while the success variables were binary.

Analysis details. The first step in MLM was to fit the data to the unconditional model, meaning a model with no independent variables, to calculate the intraclass correlation coefficient (ICC).[16] The ICC measures the variance between Level 2 resident clusters (ie, patients intubated by the same resident) as a fraction of the total variance. A value of 0.05 or more is thought to represent a significant degree of heterogeneity between clusters and justification to pursue the MLM analysis.[16] When this criterion was satisfied, the next step was to fit the data to a full model that included the Level 1 and Level 2 independent variables as predictors of outcome. Binary outcomes (first-pass success, overall success) and count outcomes (number of failed attempts) would not meet linear model assumptions.[21] Hence, a generalized modeling approach was used that matched outcomes to the proper link function, logit for binary outcomes, and natural log for counts.[22–24] An iterative method called penalized quasi-likelihood (PQL) was used to reach a solution for parameters in the nonlinear model equations.[23] Cluster-specific estimates were reported rather than population-averaged estimates since the study objective focused more on between-resident differences as opposed to population generalization.[24] Data were reported as OR for the binary outcomes and incident rate ratios (IRR) for the failed attempt count outcome, accompanied by corresponding CI, and probabilities were provided.

Sample size considerations for multilevel modeling. Recommendations in the statistical literature vary on the sample size deemed necessary for MLM to produce robust estimates of fixed effects.[15,25] Fixed effects estimates in our study were the parameters used to calculate OR and IRR values along with the standard errors used to calculate confidence interval. One review article has suggested that accurate standard errors can be obtained when there are at least 10 Level 2 clusters and a grand total of 30 or more Level 1 units.[15,25] Our study met these criteria because we had 12 CA1 residents as Level 2 units and 117 patients at Level 1. However, another review has suggested that at least 15 clusters are necessary for accurate point estimates of fixed effect parameters and 30 clusters for accurate estimates of the standard deviations. This text recommended a cluster size of 5–10 patients.[15] Our study met the cluster size recommendation with 7–13 patients per group but was low on cluster number. The number of clusters was limited by resident availability, time frame, and resources.

Results

Experiment 1

Two of the CA1 residents in Experiment 1 reported having previously performed over 120 patient intubations in the course of internships at hospitals where house staff was responsible for airway management after hours. Two residents had performed between 6 and 20 intubations, and the rest claimed experience with 6 to 20 intubations. The eight anesthesiology attendings reported 4 to 35 years' experience in clinical anesthesiology, with a median value of 6.5 years. The CA3 residents each had 36 months of training in anesthesiology.

In the manikin test, CA1 residents differed significantly from CA3 and attending laryngoscopists in endpoint *x*-coordinate and *z*-coordinate values, in laryngoscope path length, and in maximum laryngoscopy force generated (Table 1). The CA1 residents could be distinguished from the other group when laryngoscope end points were plotted in the *x*-*z* plane (Figure 2). CA3 residents and attendings positioned the laryngoscope 2.7 ± 0.3 cm left of the midline along the x-axis (Table 1), significantly left of the average position for the CA1 group at 0.6 ± 0.3 cm ($P = .0003$). The more experienced group also lifted the laryngoscope to a height of 17.7 ± 0.2 cm above the table along the *z*-axis, roughly 2 cm higher than the CA1 residents at 15.6 ± 0.8 ($P = .033$). The *y* endpoint, laryngoscope angle, laryngoscopy duration and % intubation success in the manikin did not differ significantly between the groups.

Experiment 2

Determining Attending Route. Figure 3A–C illustrates the steps we developed to plot the Attending Route. When laryngoscopy is viewed from the side, the laryngoscope

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moves in a J-shaped trajectory through the mouth, around the base of the tongue, followed by a lift near the larynx to expose the vocal cords (Figure 3A). The shape of the trajectory is similar whether the laryngoscopy is performed in patients, as shown in Figure 3A, or in manikins, shown in Figure 3B and C (Figures 3 and 4 available in "Supplemental Digital Content 2" online[13]). Manikin laryngoscopy trajectories from different attendings varied somewhat, but the separation was small when they were plotted together (Figure 3B). A virtual tunnel was constructed by drawing circular boundaries around the cluster of trajectories at each point from the beginning to the end of laryngoscopy. The tunnel, which we termed "the Attending Route" (Figure 3C), is a map of the space through which the faculty anesthesiologists moved the laryngoscope on repeated laryngoscopy in the manikin. Figure 3A and B illustrate the concept with a small number of laryngoscopy trajectories for ease in viewing. The method for drawing the Attending Route is illustrated in Figure 3C. The boundaries of the Attending Route surrounded all the trajectories, so the individual paths taken by each attending resided 100% within the tunnel. The Attending Route was drawn from 18 laryngoscopy trajectories from three attendings with 3, 7, and 25 years' experience in clinical anesthesiology and anesthesiology education. Each attending provided 6 laryngoscopies to the Attending Route. This group was different from the attending group in Experiment 1.

To evaluate CA1 resident laryngoscopy motion, their trajectories were overlaid on sagittal and coronal views of the Attending Route to identify the portions that strayed outside the tunnel boundaries and the portions that remained within (Figure 3D). The parameter of Attending Route % was calculated as the percentage of a novice's trajectory by length that remained within the boundaries. Figure 3E displays how trajectories from all 12 residents (colored traces) compared with the Attending Route. A few residents moved through the route tunnel from beginning to end, but many deviated outside the boundaries, particularly in the latter stages of laryngoscopy. A number of residents traced a course below the terminal portion of the Attending Route. This result is similar to the finding in Experiment 1 that the endpoint z-coordinate values for CA1 residents were less than for the CA3 resident/attending group (Table 1).

Experiment 2 motion parameter comparison. Laryngoscopy duration in the manikin was significantly longer for the CA1 residents than for the faculty ($P = .011$) and their Attending Route % was significantly less than 100%, averaging 74.3 ± 3.7% overall ($P = .001$; Table 2). Over shorter segments, the average Attending Route % value for CA residents was greatest for the first third of laryngoscopy and decreased progressively in the middle and final thirds, consistent with the impression from Figure 3E noted in the previous paragraph. The laryngoscope path length was 5 cm greater for residents than for faculty ($P = .054$), an effect size of 1.4. Force and torque did not differ between the two groups.

Laryngoscope endpoint coordinates were not part of our original analysis plan. The low-lying resident trajectories in Figure 3E raised a question post hoc of whether laryngoscope endpoints also differed between CA1 residents and attendings, as we had seen in Experiment 1. When the data were plotted, the average laryngoscope endpoints for CA1 residents and faculty were 1.0 ± 0.3 versus -0.4 ± 0.2 cm for x, respectively ($P = .056$), 25.2 ± 0.2 versus 25.5 ± 0.1 cm for y ($P = .516$), and 15.9 ± 0.1 versus 16.5 ± 0.3 cm for z ($P = .032$). Negative x coordinates signify points to the left of midline, positive values to the right. Thus, the faculty lifted the laryngoscope higher than the CA1 residents on average and moved the blade more to the left.

Outcome variables for patient intubation. Every resident attempted 7 to 13 patients for a total of 117 attempted patients. First-pass success at tracheal intubation occurred in 69% of the patients, with rates for individual residents ranging from 27% to 90% (average 71 ± 5%). Overall success occurred in 81% of the patients, with a range from 36% to 100% (average 83 ± 5%). There were 50 failed laryngoscopy attempts out of 146 total procedures (34%), no more than 3 in any patient. The incident rate ratio for individual residents ranged from 0.1 laryngoscopy failure/patient to 11.8 failures/patient (average 0.4 ± 0.1).

Independent variables. Patient airway exam characteristics are summarized in Table 3. Sixteen of the 117 patients (14%) had a Mallampati class 3 oropharyngeal view but none had a class 4 view. Nine patients had head extension below 120° (8%), and one was restricted to less than 90°. Two or more unfavorable airway exam features were present in 13 patients (11%). One resident attempted intubation on 4 patients with multiple unfavorable features, while four residents encountered patients at the other extreme with no unfavorable characteristics. The other residents saw 1 or 2 patients in the multiple unfavorable characteristic category.

Path Length and Attending Route %—the Level 2 variables from the manikin test—are summarized in "Experiment 2 motion parameter comparison," above. For the experience Level 2 variable, 6 of the 12 residents in Experiment 2 had previously attempted intubation in 6–20 patients, 4 residents in 21–60 patients, and 2 residents in >60 patients. One of the residents had worked as a paramedic for 2 years before entering medical school and performed over 120 patient intubations. The other resident with similarly extensive experience had interned at a hospital that delegated after-hours emergency intubation responsibilities to internal medicine house staff. Patient intubation experience for most of the CA1 residents was accrued during anesthesiology clinical electives that lasted 2–6 weeks while in medical school.

Selected independent variables were analyzed as possible predictors of poor patient intubation outcomes. Force and torque were not used in the analyses because neither variable differed significantly during manikin laryngoscopy between CA1 residents and faculty in Experiment 2. Duration was excluded because the correlation coefficient between it and path length was 0.727. Correlations >0.7 may be an indicator of collinearity in our experience, which can reduce the power of MLM. Path length was selected instead of duration because it had a large effect size in Experiment 1 and because surgical literature suggests that instrument path length predicts success for laparoscopy.[12] We selected the overall Attending Route % for MLM rather than values over the shorter one-third segments because it represented the entire laryngos-

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copy performance. We omitted the endpoint coordinates because they were not included in the original analysis plan.

The complete data set used in MLM has been submitted as "Supplemental Digital Content 3."

MLM results. ICC values from the unconditional model were 0.167 for overall success and 0.078 for first-pass success, indicating that 16.7% and 7.8% of the variability, respectively, was attributable to between-CA1 resident differences. These ICC values were taken as definitive evidence of a clustering effect and justification to move to multilevel models with predictors. There are no methods to approximate ICC for variables that follow a Poisson distribution, such as the number of failed attempts. However, the variance component for fixed effects for number of failed attempts decreased from 0.311 in the unconditional model to 0.00006 in the full model, suggesting that hierarchical modeling improved the model fit. Hence, we proceeded to full-model analyses for all three variables.

Table 4 presents full-model parameter estimates. Attending Route % was a significant predictor of overall intubation success rate and the number of failed laryngoscopy attempts. The OR of 1.033 for overall success meant that the odds of success improved by 3.3% with each percentage point increment in Attending Route % ($P = .04$). The incident rate ratio of 0.982 for number of failed attempts signified a 1.8% decrease in failure rate for each point increase in Attending Route % ($P = .045$). Attending Route % carried an OR of 1.02 for first-pass success, but the result was not significant. The Level 1 variables and the other Level 2 predictors were not significant predictors of outcome.

Discussion

Laryngoscopy motion in a manikin differed in a number of aspects between CA1 residents and more experienced anesthesiologists, consistent with the first hypothesis presented in "Introduction." In Experiments 1 and 2, the end position of the blade was farther right and more posterior (ie, less lift) for CA1 residents than for advanced anesthesiologists. Experiment 2 also showed that many of the CA1 residents strayed significantly from the Attending Route and that the differences were magnified on average as they moved the laryngoscope from the mouth to the larynx. Given the systematic difference in blade placement compared to faculty at the end of laryngoscopy, CA1 residents might benefit from feedback about left-right placement and lift of the laryngoscope.

The mechanics of laryngoscopy establish conditions that could favor a relationship between an operator's motion patterns and procedural skill. Laryngoscopy is a sequential procedure that moves in an orderly fashion from the mouth to larynx, as shown in Figure 3A. The movement path, particularly in the final stage of the trajectory, is crucial for positioning the laryngoscope for a view of the vocal cords. The manikin laryngoscopy trajectories from several anesthesiology attendings clustered around a common and relatively direct path (Figure 3B), consistent with expectations that individuals who are skilled with a sensorimotor procedure will employ efficient, expeditious movement that favor success.[12] In contrast, many of the trainees had laryngoscopy trajectories with twists and detours into blind paths (Figure 3E). Exploratory movements convey the impression that the individual is unfamiliar with the procedure. Thus, a low score on Attending Route % could be a marker for inexperience at laryngoscopy.

There are reasons to suspect that an operator's laryngoscopy Attending Route % could also predict the chance of good intubation outcomes. First, inexperienced operators who are unfamiliar with how to conduct the procedure a priori would be less likely to perform the procedure to a successful end. Second, Attending Route % provides an estimate of procedural accuracy. The ability to see the glottic opening is an important factor in intubation success; inadequate visualization can lead to multiple attempts or failure.[26] Since anesthesiology attendings consistently succeed at intubation, the Attending Route % presumably reflects a range of motion trajectories resulting in sufficient glottic visualization. Thus, individuals who conform to the Attending Route attain a laryngoscope position conducive for exposing the vocal cords. Individuals who stray from the route may be outside that range, which could result lower intubation success rates.

Given this background, we hypothesized that a subject with unknown ability who maneuvered the laryngoscope in a way similar to attending anesthesiologists in a manikin would also follow a pattern in patients within the range used by attendings. Thus, the individual with a high Attending Route % would be more likely to succeed at patient intubation than would an individual who deviated from the faculty norm. Consistent with this hypothesis, Attending Route % was a significant predictor of a CA1 resident's subsequent odds of overall success in patient intubation and rate of failed laryngoscopy attempts. The test can be completed quickly, does not put patients at risk and, in this study, predicted future outcomes in patients. Our data provide no insight into why some CA1 residents had greater overlap with the Attending Route or achieved greater success at patient intubation than others. Some subjects had much greater experience than others and might have performed better for that reason. In addition, some people learn sensorimotor skills faster than others.

Residents do not achieve maximum success rates in their first few months of training.[1,8,27,28] A test that predicted the risk of complications would provide relevant information to decide when a resident was ready for patient intubation with indirect supervision. First-pass success rate, number of failed attempts, and overall success rate may be considered surrogate measures for risk of complications because both multiple attempts and failed intubation are associated with more frequent adverse outcomes.[2–6]

The data also showed differences between novices and more experienced anesthesiologists for force, duration, and laryngoscope path length, but the results are not consistent between experiments. Furthermore, the literature is divided on whether laryngoscopy force[29–31] and duration[32,33] vary with skill. The inconsistencies reduce confidence that these parameters reliably distinguish between novice and expert laryngoscopy performance.

Other investigators have compared the motion of experienced and novice laryngoscopists. Carlson and colleagues[34] reported that emergency medicine attendings differed from residents and beginners in smoother laryngoscope acceleration, less variability in movement patterns, and greater consis-

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tency in the angle of the laryngoscope handle.[32] Rahman and colleagues found that laryngoscope angle was a distinguishing feature with experienced anesthetists tilting the laryngoscope farther from vertical than did medical students.[33] We did not study acceleration or variability, and we did not find a significant difference in laryngoscope angle. The Carlson team and the Rahman collaborators tracked motion of the laryngoscope handle and of the operator's hand but did not record blade trajectories, as in our protocol. A large number of metrics would be reasonable to investigate as predictors of laryngoscopy expertise.

Study Limitations

The conclusion that increases in Attending Route % predict improvement in patient intubation outcomes would be strengthened if data were available from a broader group of subjects, not just beginning CA1 residents. A collection of findings from anesthesiology trainees at all stages would indicate whether Attending Route % increases progressively with experience and in parallel with improvement in patient intubation outcomes. The results could then be used for calibrating the relationship between Attending Route % versus expected outcome. It would also be worthwhile to collect outcome data in settings where intubation difficulty is increased.

The Attending Route in this study was set by only three faculty anesthesiologists, a relatively small number, creating some uncertainty about the generalizability of the route shown in Figure 3. Conceivably, some experienced individuals could deviate from the route shown in Figure 3. Further studies should also assess performance of attendings at patient intubations to test whether each attending performs up to expectations and provide an upper data point for calibrating Attending Route % versus patient outcome.

Although malposition of the laryngoscope with poor exposure of the vocal cords is a major cause of difficult or failed intubation, novices could achieve good glottic exposure and still fail for other reasons.[26] They could have difficulty maneuvering the endotracheal tube or problems recognizing the glottic opening.[26] Thus, some residents with a high Attending Route % on the manikin test could perform worse than anticipated with patient intubation. Anatomy recognition and ability to manipulate the endotracheal tube could also be studied as factors that affect patient intubation success.

Laryngoscopy in a manikin differs considerably from patient laryngoscopy in required force and some anatomic proportions,[14,35,36] so one might not expect a priori that motion in a manikin would predict outcomes in a patient. Despite this uncertainty, our results suggest that manikin simulation tests do, in fact, have value in predicting clinical laryngoscopy success (see Table 4). Manikin laryngoscopy is similar to patient laryngoscopy in the motion trajectory followed by the laryngoscope[13] in the dimensions, angle of manikin and human airways, and in the recognizable similarities between the anatomy modeled in a manikin and the actual anatomic structures in patients. Mastering sensorimotor tasks is characterized by the ability to adapt to changes in the environment and make appropriate corrections.[37] Thus, an anesthesiologist must adapt procedures to a wide range of patient sizes and anatomies.[14,38] Manikin laryngoscopy could be viewed as a case requiring substantial adaptation.

The size of our trainee population was relatively small for MLM. The major concern was the possibility of underestimating the parameter standard deviations due to a low number of Level 2 clusters, leading to confidence intervals that are too small and a type 1 error.[15,25] The PQL method for fitting multilevel models improves fixed effects estimates compared to other methods and may ameliorate the impact of the population size to some extent. Type 1 error rates are reported to fall between 0.01 and 0.08 when using PQL with a Level 2 sample size of 10.[25] We were encouraged that the analysis seen in the "Results" section revealed significant predictors but remain cautious pending further work.

Summary

This investigation used sensor technology to compare manikin laryngoscopy motion parameters between CA1 residents and anesthesiology faculty. Laryngoscope position and trajectory differed significantly between beginning CA residents and more advanced anesthesiology personnel. Attending Route %, a new metric, was a significant predictor of the odds that a new CA1 resident would be successful at patient intubation and with few attempts. A test that quantified laryngoscopy skill in advance of patient contact could be useful in following resident progress. Studies with larger subject populations are necessary to validate findings and test whether changes in manikin motion parameters track improvement in resident performance at patient intubation.

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Abstract

Background: The goal of this study was to determine whether motion parameters during laryngoscopy in a manikin differed with experienced operators versus novice trainees and whether motion measurements would predict trainee outcomes when intubating patients.

Methods: Motion, force, and duration of laryngoscopy on a manikin were compared in two separate experiments between beginning anesthesiology residents (CA1) and anesthesiologists with more than 24 months of anesthesiology training (CA3 or attendings). In one experiment, CA1 residents were also evaluated for the percentage of their laryngoscope path that followed the route used by attending anesthesiologists. The residents were then observed for patient intubation outcomes for 4 weeks after manikin testing. The relationship between manikin test metrics and patient intubation outcomes was analyzed by multilevel modeling.

Results: CA1 residents positioned the laryngoscope blade farther right and with less lift than did experienced anesthesiologists. Endpoint position was 0.6 ± 0.3 cm left of midline for residents ($n = 10$) versus 2.7 ± 0.3 cm for advanced anesthesiologists ($n = 8$; $P = .0003$), and 15.6 ± 0.8 versus 17.7 ± 0.2 cm above the table surface, respectively ($P = .033$). On average, only 74 ± 6% of the CA1 laryngoscopy trajectory coincided with the Attending Route ($P < .001$ versus 100%). For each percentage point increase in Attending Route match, residents' odds of intubating a patient's trachea improved by a factor of 1.033 (95% confidence interval [CI] 1.007–1.059, $P = .040$), and their rate of failed laryngoscopy attempts decreased by a factor of 0.982 (0.969–0.996, $P = .045$).

Discussion: Laryngoscopy motion in manikins may predict which trainees can complete a patient intubation successfully in a few attempts. The assessment could help determine readiness for intubating patients with indirect supervision.

Figures

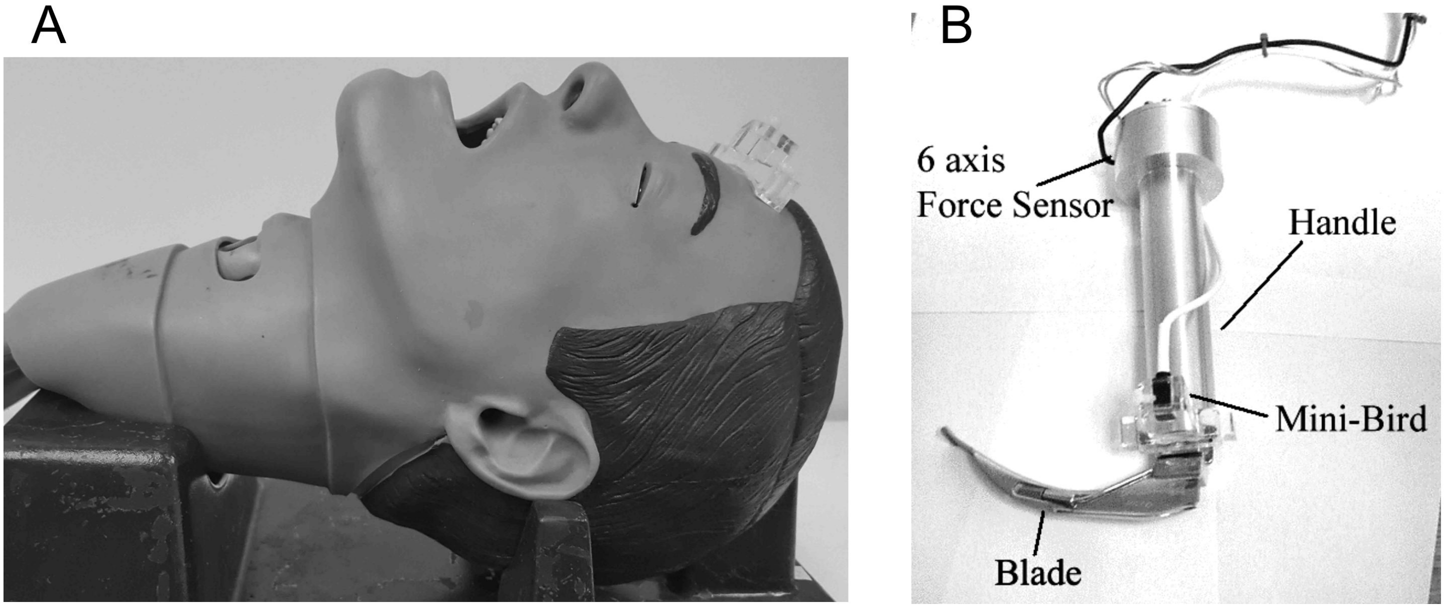

Figure 1. *Photographs of equipment: The manikin test was performed in a Medical Plastics Airway Model (A) using a laryngoscope handle with an axial force transducer (ATI Industrial Automation, Apex, NC) and a miniBird position sensor (Ascension Technology Corp, Burlington, VT). (B) Panel B is used with permission of the publisher.*[12]

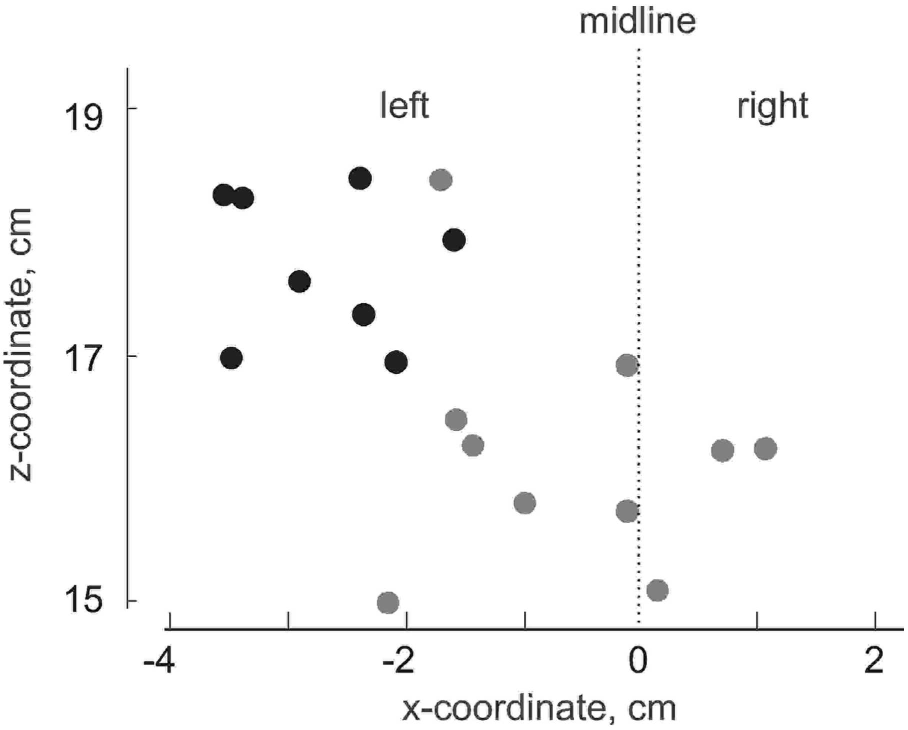

Figure 2. *Plot of endpoint coordinates for the tip of the laryngoscope blade. Data show the vertical coordinate graphed versus the left-right coordinate, both in cm, for the position of the laryngoscope at the point where operators had their best view of the vocal cords. Negative numbers for x-coordinate signify that the blade was to the left of the manikin midline. The z-coordinate indicates height above the table on which the manikin rested. On average, CA1 residents (gray circles) positioned the blade lower and to the right of the location selected by CA3 resident and attending anesthesiologists (black circles). The two groups did not differ in placement along the y-axis, the direction from the occiput toward the trachea (data not shown).*

Figures *continued*

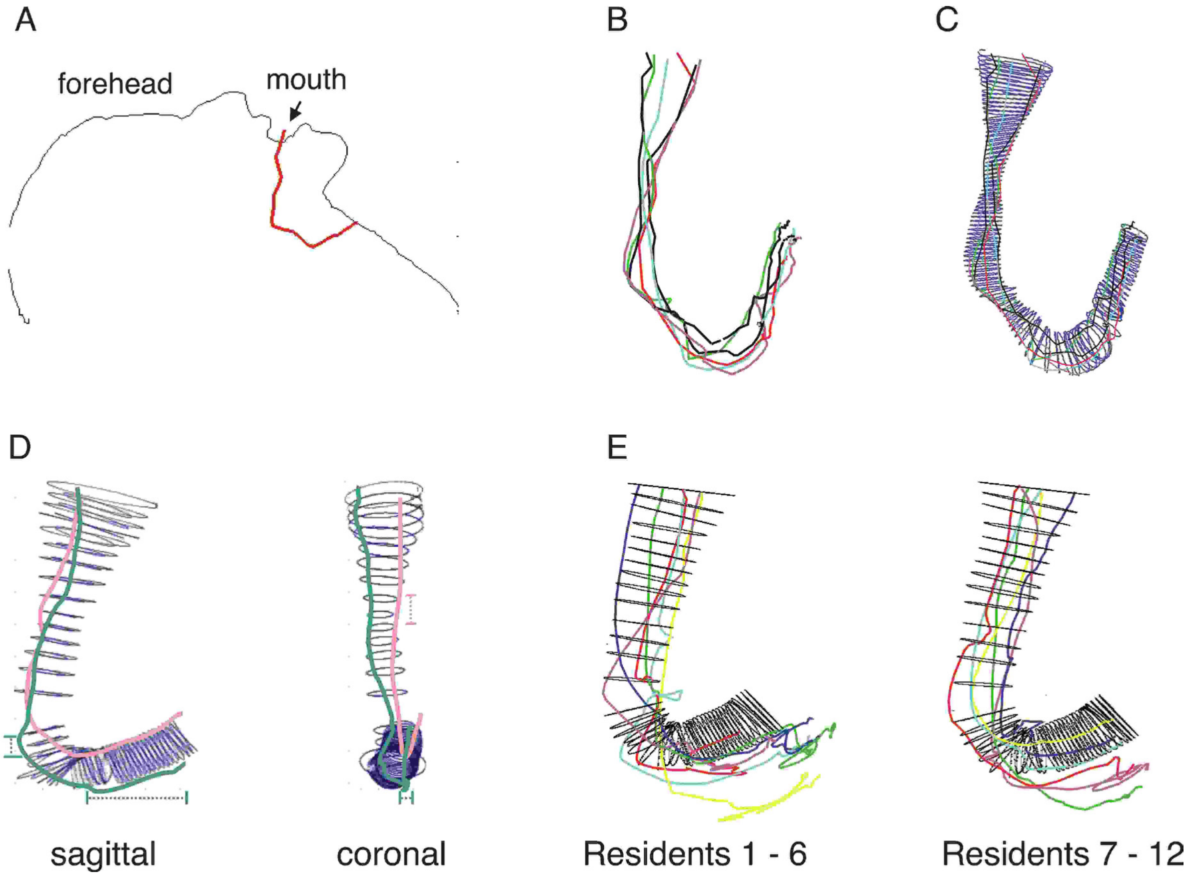

Figure 3. *Procedure for plotting and using the Expert Route. (A) In a side view, the trajectory of a curved laryngoscope blade in a supine human takes a "J"-shaped path. The laryngoscope enters the mouth at the arrow, moves to the back of the throat, bends around the base of the tongue, and then lifts the tongue and jaw when close to the larynx. (B) Trajectories of laryngoscopies by attending anesthesiologists in the Medical Plastics Airway model also follow a "J"-shaped path, similar to the path in patients (A). Trajectories from different attendings cluster closely when they are plotted on the same graph. (C) Circular boundaries have been drawn around the clustered trajectories at each point along the way. The boundaries outline a virtual 3-dimensional tube, the Attending Route. The Attending Route is a map of the laryngoscopy path followed in general by attending anesthesiologists. It surrounds all the attending trajectories. (D) Two CA1 trajectories (color traces) are superimposed on the Attending Route to compare novice and faculty performance. Views are shown from the sagittal and coronal (back) perspective. The overlap of novice trajectories with the Attending Route can be calculated as the percentage of the novice path (by distance) that lies inside the tunnel, a variable we label "Attending Route %." The line segments in the panel denote segments of CA1 path that have strayed outside the tunnel. (E) Laryngoscopy trajectories for each of the 12 CA1 residents have been plotted with the Attending Route, using two graphs for ease of viewing. Some residents stay inside the tube and follow the Attending Route to the end. However, many residents stray outside the Attending Route in the latter portions of their procedure. Resident trajectories tend to take a course lower than the Attending Route.*

Tables

Table 1. Differences in laryngoscopy kinematic parameters between CA1 residents and more Advanced Anesthesiologists, Experiment 1. Data represent mean ± SE

Metric	CA1 n = 10	CA3/Attending n = 8	Effect Size	P-value
Endpoints, cm				
x -coordinate	-0.6 ± 0.3	-2.7 ± 0.3	2.2	0.0003
y-coordinate	22.9 ± 1.6	24.5 ± 0.4	0.4	0.398
z-coordinate	15.6 ± 0.8	17.7 ± 0.2	1.3	0.033
Laryngoscope Angle, °	62.3 ± 2.7	55.7 ± 3.7	0.7	0.157
Path Length, cm	44.4 ± 5.1	28.9 ± 3.9	1.1	0.035
Duration, sec	13.6 ± 1.7	10.3 ± 2.3	0.6	0.253
Force, N	53.3 ± 3.4	67.1 ± 2.9	1.4	0.008
Torque, N-m	3.0 ± 0.3	3.5 ± 0.3	1.7	0.483
Intubation Success, %	73.3 ± 9.7	91.7 ± 5.5	0.7	0.144

x-coordinate: positive numbers signify a position to the right of sagittal midline
y-coordinate: values increase with horizontal movement away from the head
z-coordinate: values increase with vertical movement away from the closer floor
Laryngoscope angle: positive values reflect backward tilt of the handle toward the operator

Table 2. Differences in laryngoscopy motion between CA1 residents and Attending Anesthesiologists, Experiment 2. Data represent mean ± SE

Metric	CA1 n = 12	Expert n = 3	Effect Size	P-value
Laryngoscope Angle, °	62.3 ± 2.7	55.7 ± 3.7	0.7	0.157
Path Length, cm	20.4 ± 1.1	15.5 ± 1.2	1.4	0.054
Duration, sec	7.9 ± 0.7	3.6 ± 0.6	1.9	0.011
Force, N	67.3 ± 6.2	66.8 ± 8.5	0.1	0.975
Torque, N-m	3.0 ± 0.3	3.5 ± 0.3	1.6	0.483
Attending route %				
overall	74.3 ± 5.7	100	4.5	0.001
beginning	92.9 ± 2.6	100	6.6	0.018
middle	73.7 ± 6.5	100	4.0	0.002
end	61.1 ± 9.6	100	4.1	0.002

Tables *continued*

Table 3. Outcome of patient intubations with level 1 patient airway predictors for each CA1 subject.

		Intubation Outcomes			Patient Airway Predictors					
CA1 Subject	Pts n	FP Success Pts, n (%)	Overall Success Pts, n (%)	DL N Failed Attempts n	OPV Class 1/2/3 n	Thyro-Mental Distance cm ± SE	Head Extension >120°/90-120°/<90°	Mouth Opening cm ± SE	Jaw Protrude Yes/No	Pts with ≥ 2 Risk Factors n
1	7	6 (86%)	7 (100%)	1	3/3/1	5.7 ± 0.3	7/0/0	5.0 ± 0.2	7/0	0
2	8	7 (88%)	8 (100%)	1	5/1/2	7.4 ± 0.4	7/1/0	5.1 ± 0.3	7/1	1
3	10	8 (80%)	8 (80%)	2	5/3/2	5.9 ± 0.3	10/0/0	5.8 ± 0.6	8/2	2
4	13	8 (62%)	9 (69%)	7	6/6/1	5.8 ± 0.2	13/0/0	4.9 ± 0.2	10/0	1
5	10	7 (70%)	8 (80%)	4	2/5/3	5.8 ± 0.3	10/0/0	6.1 ± 0.3	10/0	1
6	10	9 (90%)	9 (90%)	1	3/7/0	6.6 ± 0.4	10/0/0	5.4 ± 0.2	10/0	0
7	10	8 (80%)	10 (100%)	2	8/2/0	6.1 ± 0.5	9/1/0	5.2 ± 0.2	9/1	0
8	11	3 (27%)	4 (36%)	13	5/6/0	5.8 ± 0.4	6/4/1	4.8 ± 0.4	8/2	2
9	10	6 (60%)	7 (70%)	7	4/2/4	6.6 ± 0.4	9/1/0	5.0 ± 0.3	10/0	0
10	10	6 (60%)	9 (90%)	5	4/6/0	5.9 ± 0.1	10/0/0	5.0 ± 0.0	9/1	1
11	10	6 (60%)	8 (80%)	6	6/2/2	5.3 ± 0.3	9/1/0	4.9 ± 0.2	10/0	4
12	8	7 (88%)	7 (88%)	1	2/5/1	5.3 ± 0.2	8/0/0	5.1 ± 0.3	8/0	1
All	117	81 (69%)	94 (80%)	50	53/48/16	5.5 ± 0.2	108/8/1	5.2 ± 0.1	106/7	13

DL = direct laryngoscopy

OPV = oropharyngeal view, i.e. Mallampati assessment

Risk factors = factors predicting intubation difficulty; see text

“Jaw protrude” refers to movement of the mandibular teeth or gums anterior to the plane of the corresponding maxillary structure. Protrusion data were missing for 4 patients.

Tables *continued*

Table 4. MLM analysis of predictors of intubation outcome

	Factor	**Estimate**	**SE**	**p-value**	**OR**	**95% CI**
	Overall Success					
Level 1						
	Patient Factors	-0.394	0.406	0.334	0.675	0.304-1.494
	Patient Order	0.047	0.083	0.571	1.048	0.891-1.233
Level 2						
	Previous Experience	0.799	0.425	0.097	2.224	0.967-5.114
	Path Length	0.147	0.100	0.178	1.159	0.952-1.409
	Attending Route %	0.032	0.013	0.040	1.033	1.007-1.059
	Number of Failed Attempts					
Level 1						
	Patient Factors	0.346	0.226	0.129	1.414	0.908-2.201
	Patient Order	0.002	0.047	0.968	1.002	0.914-1.099
Level 2						
	Previous Experience	-0.396	0.237	0.134	0.673	0.423-1.071
	Path Length	-0.143	0.065	0.059	0.867	0.763-0.985
	Attending Route %	-0.018	0.007	0.045	0.982	0.969-0.996
	First Pass Success					
Level 1						
	Patient Factors	-0.223	0.339	0.512	0.800	0.412-1.555
	Patient Order	0.089	0.072	0.214	1.094	0.949-1.259
Level 2						
	Previous Experience	0.507	0.314	0.145	1.660	0.897-3.072
	Path Length	0.154	0.078	0.084	1.166	0.984-1.383
	Attending Route %	0.021	0.011	0.101	1.021	0.999-1.043