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ORIGINAL ARTICLE

The learning curve for laryngoscopy: Airtraq versus Macintosh laryngoscopes

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Abstract
Purpose Airtraq use by inexperienced personnel has been evaluated in simulator studies, but little is known about the learning process in real patients. This prospective study was designed to compare learning curves for laryngoscopy with the Airtraq or Macintosh laryngoscopes in patients under general anesthesia.
Methods Ten medical students with no prior experience in airway management were recruited on a voluntary basis and underwent training in Macintosh and Airtraq laryngoscopy. Patients with no difficult intubation criteria were enrolled after consent. Each student performed laryngoscopy with either device on ten consecutive patients. Success was defined as Cormack–Lehane grading ≤ 2. We also recorded subjective difficulty scores on an 11-point numerical rating scale. Learning curves were drawn using cumulative success rates and 95% confidence intervals calculated with bootstrap procedures.
Results The mean (95% CI) success rates for the procedures were 86.0% (76.7–93.3%) for the Airtraq and 64.0% (52.0–75.0%) for the Macintosh laryngoscope. Differences in success rate were significant from the fourth attempt and were 22.0% (8.2–36.5%) after the tenth. Seven students achieved success rates $\geq 90\%$ using the Airtraq, versus one using the Macintosh ($P = 0.022$). Median (25th–75th percentile) difficulty scores were 2 (1–4) and 4 (2–6), respectively ($P < 0.001$).
Conclusion Students achieved higher success rates using the Airtraq laryngoscope during early training on live patients. The Airtraq may be a useful choice for teaching advanced airway management, especially to professionals who will not perform laryngoscopy on a regular basis.

Keywords Laryngoscopy · Anesthesia, general · Laryngoscopes

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Introduction

Although accurate simulators exist to aid in airway management training, live experience is a core part of the curriculum for anesthesiology and emergency medicine residents; because of practical considerations, this is not always the case for other professionals for whom orotracheal intubation (OI) is not expected to be a routine maneuver, such as other medical specialists, nurses, respiratory therapists, or emergency medical service (EMS) personnel. Any device granting a steeper learning curve may be preferable in the training of professionals who may not perform tracheal intubation on a regular basis, as it may grant easier re-acquisition of manual abilities lost over time because of infrequent practice.

The Airtraq (Teleflex Medical S.r.l., Varedo, MB, Italy) is a single-use indirect laryngoscope with a tight blade curvature and a channel that guides the endotracheal tube into place. Glottic visualization is achieved through mirrors that reflect light from the tip of the instrument to a viewfinder at the opposite end. As the tip is placed in the vallecula, the resulting image is similar to that seen during direct laryngoscopy; once proper alignment of the instrument is attained, the endotracheal tube is advanced through the channel until it is seen passing through the vocal cords.

In the hands of experienced anesthesiologists, the Airtraq has been found to compare favorably to the Macintosh laryngoscope in routine OI of patients at low [1] and high [2, 3] risk of difficult laryngoscopy. Advantages in terms of subjectively reported ease of use have been reported in manikin studies involving inexperienced trainees [4, 5] or expert physicians [6]. Little is known about Airtraq laryngoscopy performance by inexperienced operators in real patients.

This study was designed to outline learning curves for inexperienced personnel after brief but commonplace training in Macintosh and Airtraq laryngoscopy. Cumulative success rates and progressive performances on real patients were analyzed and compared.

Materials and methods

The study involved ten senior medical students and 100 elective surgical patients meeting enrollment criteria. After Internal Review Board (IRB) approval, participating students were trained in July 2007, and patients were enrolled between July and September 2007. The study took place at the Azienda Ospedaliero-Universitaria of Parma (Italy), a tertiary 1,300-bed university hospital serving about 1,500,000 people, where senior medical students and residents are routinely involved in different levels of clinical care.

Ten senior medical students, expected to graduate at the end of the current academic year and with no prior experience in advanced airway management, were recruited on a voluntary basis during their rotations in hospital wards. All students received a 45-min lecture on the relevant anatomy and the use of both the Macintosh and Airtraq laryngoscopes; they then proceeded to perform five attempts at laryngoscopy and OI under guidance, using both devices on a manikin set to simulate an easy procedure (SimMan; Laerdal Italia, Bologna, Italy). During this practice phase, students were instructed to center the glottic aperture in their field of view. Care was taken not to describe the Airtraq as a "novel" or "difficult-intubation" device, to reduce the risk of bias. They were also taught to grade glottic visualization using the four-point scale proposed by Cormack and Lehane [7]. Airtraq laryngoscopes comprised a video camera system, including an external monitor, which allowed the glottis view to be shared.

Patients were prospectively enrolled with their written informed consent. Senior medical students, interns, and residents routinely practice procedures (including orotracheal intubation) under specialist guidance at our hospital, with full insurance coverage if operating under supervision. It was thus convened with the IRB that the addition of a second laryngoscopy performed by a trainee, with topical anesthesia and under controlled conditions did not constitute a substantial deviation from current practice in terms of patient safety, as interns and junior residents are commonly allowed multiple attempts at procedures in uncomplicated cases. In accordance with IRB requirements, patients were informed that they would receive two laryngoscopies, and they were told about the rationale of the study; an increased risk for minor traumatic complications was explicitly mentioned, and presence of expert anesthesiologists was assured as usual. Inclusion criteria were age 18–85 years, ASA physical status class I–III, elective surgery under general anesthesia, and expected easy laryngoscopy as defined by an airway graded Mallampati class I or II and thyromental distance $\geq$6 cm. Patients were excluded in case of increased risk of aspiration, known allergies to study drugs, physical abnormalities of the head or neck, body mass index $\geq$30 kg/m^2, and/or a documented history of previous difficult intubation [Cormack–Lehane (CL) class >2]. In addition to these parameters, other anthropometric variables were recorded upon enrollment. Each patient was thus scheduled to receive two laryngoscopies by trainees after the induction of general anesthesia and before definitive OI, using both the Airtraq and Macintosh laryngoscope. The order in which the two devices would be used in each patient was chosen according to a preexistent randomization schedule based on a truly random number generator (Random.org, available at: http://www.random.org/, accessed Sep. 3, 2007), and then stored in envelopes to which students had no access.

On the day of surgery, patients were premedicated as indicated during preoperative evaluation. Upon arrival to the operating room, standard monitoring of vital parameters and bispectral index (BIS XP; Aspect Medical, De Meern, The Netherlands) was initiated. Patients were positioned in a neutral position and were given 80% oxygen in air through a face mask for 3 min. Anesthesia was then induced with propofol 2 mg/kg and fentanyl 2 μg/kg. Neuromuscular monitoring was then started at the ulnar nerve in the distal forearm and set to train-of-four (TOF) stimulation. After the attending anesthesiologist confirmed adequate bag-mask ventilation, myoresolution was induced using cisatracurium 0.2 mg/kg. Topical anesthesia of the pharynx was performed by injecting pre-warmed 4% lidocaine 5 ml through a pre-formed, multi-orifice cannula attached to a syringe, and the Airtraq was turned on to prevent fogging of the lenses. Laryngoscopy was attempted after absence of muscular twitches was verified on TOF stimulation, but no sooner than 3 min following cisatracurium injection. At that time the anesthesiologist communicated which device was to be used first. In cases where the second laryngoscopy (and thus intubation) was to be performed with the Airtraq, a nurse mounted and lubricated the endotracheal tube as recommended by the

manufacturer. The student then performed laryngoscopy attempts with both devices in the predetermined order; a 3-min interval was allowed between each attempt, during which the anesthesiologist ventilated the patient with 80% oxygen in air. Students could re-insert each instrument once, after which the attempt with that device was considered failed.

Throughout the procedure, propofol 0.5 mg/kg was administered for BIS ≥50; fentanyl 1 μg/kg was given for hypertension or tachycardia. The anesthesiologist could interrupt the study at any time if patient safety was deemed at risk, or in case of unexpected adverse events. During the second laryngoscopy, the instrument was handed to the anesthesiologist, who proceeded to intubate the patient.

At each attempt, students graded their laryngoscopic view according to the CL scale. The attending anesthesiologist confirmed the reported view with specific questions [e.g., "can you see anterior (posterior) commissure/epiglottis?"]. After intubation, the study protocol was concluded, and anesthesia was then managed as clinically indicated. Trainees were also asked to rate the difficulty of each laryngoscopy using a numerical rating scale ranging from 0 (="effortless") to 10 (="impossible"). The following variables were also recorded during the procedures: baseline mean arterial pressure (MAP) and heart rate (HR), immediately before the first attempt; need for instrument reinsertion, defined as the retraction of the instrument to the lips and subsequent repositioning; incidence of desaturation (peripheral oxygen saturation ≤90%), bradycardia (HR <50), hypo- or hypertension (MAP <60 or >110 mmHg); and incidence of trauma to the oropharyngeal mucosa or teeth (defined as visible lesions to the structures).

All data were immediately collected on paper case report forms by investigators not directly involved in patient care and were later input into a spreadsheet application.

Statistical analysis

The alternative hypothesis of the study was that there would be a difference in overall success rates between the Airtraq and Macintosh laryngoscopes. Success was defined as CL grade ≤2 on laryngoscopy as reported by the student. Overall success rates for each device were calculated by summing the number of successful laryngoscopies by all students and dividing by the number of all attempts performed.

According to a recent metanalysis, the incidence of unexpected difficult laryngoscopy (i.e., CL grade ≥3) as performed by anesthesiologists is about 4% in patients with Mallampati class I–II and normal thyromental distance (mean sensitivity of the combination test, 36%; actual mean prevalence, 6.6%) [8]. Based on these data and personal experience with Macintosh laryngoscopy, we arbitrarily hypothesized that the expected failure rate (i.e., pooled rates of laryngoscopies with CL >2) for unskilled students would be ten times the predicted incidence of unexpected difficult laryngoscopy in our screened population, or 40%.

The sample size required to detect a reduction in failure rate to 20% or less with the use of the Airtraq would thus be at least 81 attempts with each device (effect size = 0.44), with a risk of type I error $\alpha = 0.05$ and of type II error $\beta = 0.20$. Ten students were available for the study, and to construct more meaningful learning curves a total of 10 laryngoscopy attempts with each device was planned for each of them, bringing the total sample size to 200 laryngoscopy attempts on 100 patients.

To account for between- and within-subject (i.e., "learning") variation in the performance of students, we employed a cumulative sum ("cusum") analysis of the procedures. The cusum technique has been previously described in detail [9] (see also "Appendix"). Analyses were performed with risks of type I error $\alpha = 0.1$ and type II error $\beta = 0.1$. Using cusum data, we examined the following: (1) number of students having performance lines below the h_0 and/or above the h_1 threshold with each device, as the number of students attaining acceptable or unacceptable failure rates at the end of the series, respectively; (2) the pooled median cusum scores attained by students with each device, as a measure of the overall "learning" process, with lower values indicating higher cumulative success rates; (3) the number of students/lines crossing a performance threshold (including baseline) from below at least once over ten attempts, as a measure of "instability" of quality improvement. The values of the h_0, h_1, and s constants were 5.42, −5.42, and −0.71, respectively, calculating from an acceptable failure rate of 40% and an unacceptable rate of 80%. The comparison of median cusum scores was also repeated setting expected failure rates to half these values. For graphical clarity, the starting (zero) points of cusum lines were not plotted on the graphs shown in this article.

Collective learning curves were plotted using a bootstrap model to estimate confidence intervals (CI) and to allow inference on results [10]. Cumulative success rates for each device and each student were computed as the rate of successful visualizations to the attempts made at each time point. Cumulative success rates were calculated from each student's data and grouped by device; the mean was then calculated by resampling individual success rates with 50,000 iterations, allowing repetitions. Confidence intervals at the 95% level were computed using the adjusted bootstrap percentile method; these were also calculated for the difference in success rates (i.e., for each attempt, mean cumulative success rate for the Macintosh laryngoscope minus that for the Airtraq). Differences between success

rates were considered statistically significant if their 95% CI did not include 0.

All continuous variables were checked for departures from the assumption of normal distribution using the Shapiro–Wilk test, except difficulty numerical rating score (NRS) ratings and cusum scores, which were assumed to be nonparametric variables.

The R language and environment was used for all analyses [11]. The cusum analysis was run using custom functions in R. The bootstrap procedure was based on the boot package for R (original by Angelo Canty, R port by Brian Ripley) and computed using custom functions.

Continuous variables are presented as mean (95% CI) and were tested using Student's paired t test in case of normal distribution or as median (25th–75th percentile) and using the Wilcoxon signed-rank test otherwise. Categorial variables are presented as percentage (which equals the absolute count within each group) and were compared using Fisher's exact test or Pearson's χ^2 test as appropriate.

For all tests, a value of $P \leq 0.05$ was considered significant.

Results

A total of 116 screened patients were approached for informed consent to participation in the study, of whom 16 declined to participate. Twenty laryngoscopies were attempted by each of the ten students on 10 different patients (a total of 100 attempts with each device). The demographic and anthropometric characteristics of patients are illustrated in Table 1.

The overall success rate for the procedures was 86.0% (76.7–93.3%) for the Airtraq and 64.0% (52.0–75.0%) for the Macintosh laryngoscope. The distribution of final cumulative success rates is shown in Fig. 1. Seven of ten students had final success rates ≥90% with the Airtraq, as compared to 1 using the Macintosh laryngoscope ($P = 0.022$). A statistically significant difference in success rates is seen from the fourth attempt onward, with Airtraq values higher by 27.5% (5.0–48.7%). Success rates for Airtraq laryngoscopy were higher at all subsequent attempts, with a final difference of 22.0% (8.2–36.5%) at the tenth attempt (Fig. 2).

Table 2 summarizes the incidence of adverse events, which was not significantly different between the two devices. The Macintosh laryngoscope had to be re-inserted more frequently than the Airtraq to obtain a laryngeal visualization ($P = 0.004$). Students rated laryngoscopies with the Airtraq as significantly less difficult than those with the Macintosh blade, with NRS scores of 2 (1–4) and 4 (2–6), respectively ($P < 0.001$).

Table 1 Demographic and anthropometric characteristics of patients

Variable	$n = 100$
Age (years)	65 (47–73)
Weight (kg)	70 (61–80)
Height (cm)	168 (163–175)
BMI (kg/m^2)	24.1 (22.2–27.6)
Neck circumference (cm)	38 (35–42)
Interdental distance (cm)	5 (4–6)
Chin–hyoid distance (cm)	7 (5–8)
Chin–jugular notch distance (cm)	9 (7–12)
Able to protrude jaw	99
Baseline MAP (mmHg)	97 (94–100)
Baseline HR (bpm)	76 (72–79)
ASA physical status class (*n*)	
I	16
II	57
III	27
Mallampati class (*n*)	
1	65
2	35

Continuous variables are presented as mean (95% CI) or median (25th–75th percentile), according to data distribution. Categorial variables presented as number of patients, equivalent to percentage

BMI body mass index, *MAP* mean arterial pressure, *HR* heart rate

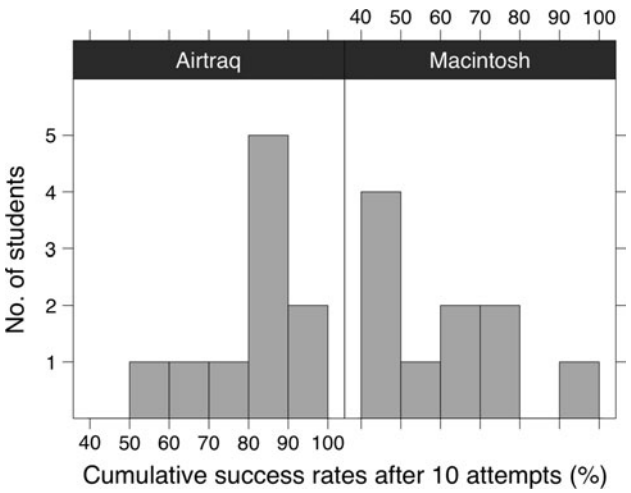

Fig. 1 Distribution of cumulative success rates at the tenth attempt for each device. Seven students attained rates ≥90% using the Airtraq as opposed to one using the Macintosh laryngoscope

All students' final cusums for the Airtraq device were below the h_0 threshold at the 40% acceptable failure rate level, i.e., had a success rate not significant of at least 60% with $\alpha = 0.1$ and $\beta = 0.1$, as opposed to 6 with the Macintosh laryngoscope. Four students' final cusums for Macintosh procedures were indeterminate (P= 0.093 vs.

none with the Airtraq). One student crossed the unacceptable failure rate (80%) boundary line using the Macintosh. The median cusum scores attained with the Airtraq device were significantly lower than those attained with the Macintosh laryngoscope at both acceptable failure rates ($P \leq 0.009$ in either case; Table 2). Fewer students crossed an unacceptable performance threshold from below when using the Airtraq (1 vs. 8; $P = 0.005$). Four cases of minor trauma (bruising) of the lips or pharyngeal mucosa occurred using the Airtraq as opposed to six cases with the Macintosh laryngoscope ($P = 0.810$). No dental lesions were recorded with either device. Hypertension developed in four patients during Airtraq laryngoscopy, as opposed to eight during Macintosh laryngoscopy ($P = 0.810$). No episodes of significant bradycardia or tachycardia were recorded. All patients were intubated on the first attempt by the anesthesiologist with the assigned instrument.

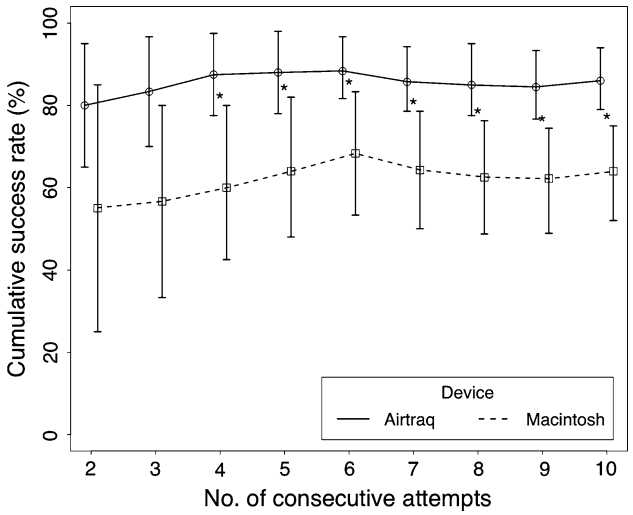

Fig. 2 Learning curves for the two devices. *Circles* represent mean cumulative success rates for the Airtraq series; *squares* represent those for the Macintosh laryngoscope. *Error bars* indicate 95% confidence intervals of the mean, calculated by bootstrapping individual values. *Asterisks* indicate differences greater than zero at the 95% confidence level. For clarity, data points have been slightly shifted along the *x*-axis

Discussion

We examined the performance of ten inexperienced medical students attempting laryngoscopy with the Airtraq and Macintosh devices in a population of patients screened for possible difficult tracheal intubation. We report higher rates of successful glottic visualization (CL grade $\leq$2) with the Airtraq with respect to the Macintosh laryngoscope. Students also reported greater ease of use with the Airtraq, as expressed by lower median NRS scores of difficulty.

Cusum analysis, first introduced for quality assurance in industrial processes, has been employed in studies examining the performance of anesthesia residents in several procedures including tracheal intubation [9]. Although the number of students attaining the acceptable failure rates was not different, we found lower cusum scores and a lower number of students crossing performance thresholds from below when using the Airtraq.

Such results would indicate, both quantitatively and qualitatively, a steadier progression of skill building with this device as compared to the Macintosh laryngoscope, at least in the earliest phase of training on live patients.

The construction of cumulative learning curves confirms this impression, with higher cumulative success rates at each trial attempt and lower intersubject variability from the fourth attempt onward. The bootstrap approach allowed us to construct 95% confidence intervals around the mean success rates, so as to simulate a large population and verify the statistical significance of differences. This was the first study to examine the performance of personnel attempting laryngoscopy with the Airtraq on live patients after brief training. Although carried on in a favorable

Table 2 Cumulative sum (cusum) values and incidence of adverse events for each device

Variable	Airtraq ($n = 100$)	Macintosh ($n = 100$)	*P*
Cusum	−10.84 (−16.51 to −5.42)	−5.42 (−10.84 to −0.42)	<0.001
Alternative cusum	−4.68 (−4.68 to −2.86)	1.37 (−1.65 to 5.00)	0.009
Instrument reinsertions	4	17	0.004
Mucosal trauma	4	6	0.810
Dental trauma	0	0	1.000
Desaturation	2	0	0.155
Bradycardia	1	1	1.000
Any adverse event	7	7	1.000

Cusum values are presented as median (25th–75th percentile), using acceptable and unacceptable failure rates of 40 and 80%, respectively. Alternative cusum values are calculated based on a 20% acceptable failure rate and a 40% unacceptable failure rate. Other values are absolute counts, equivalent to percentage

environment, we presume this approach more closely simulates real-life conditions. It has been shown that experience on simulators does not necessarily ensure adequate skills on live patients, even under controlled conditions similar to those presented here [12]. The combination of higher overall success rates and reduced interindividual variability (i.e., narrower confidence intervals on learning curves) suggest that the Airtraq may require shorter training on live patients to achieve acceptable skills. The importance of quickly acquiring (or reacquiring) skills with an intubating device can be appraised, for example, when considering results from large database studies in the United States that show that 40–60% EMS personnel do not perform any OI annually and <5% perform more than five OI [13, 14], with high overall failure rates [15]. Although different airway management and ventilation strategies have been advocated as an alternative to expensive training programs for direct laryngoscopic OI [16], it may be argued that the ideal choice for emergency airway management is the combination of a cuffed endotracheal tube and an effective, easy-to-use device for its insertion. United States national guidelines for EMS paramedics require five OIs on simulators for certification [17], although this is clearly too low a number for proficiency with the Macintosh laryngoscope, as also shown by our results in live anesthetized patients; cumulative success rates for excellent/good glottic visualization ≥80% (lower 95% CI for the mean) were seen in all attempts on live patients with the Airtraq. Although the Airtraq is a disposable device with an acquisition cost of about US$80, there is a potential for reduction of the number of attempts required on real patients to achieve and "stabilize" skills. This reduction might translate to lower training costs if live practice in the operating room was chosen for training programs. Alternatively, we may hypothesize reduced costs for complications and increased effectiveness if the Airtraq was used for manikin training according to current guidelines. Patients tolerated the two laryngoscopies well, with an incidence of clinically relevant hemodynamic responses comparable to that seen during single Macintosh laryngoscopy [18]. The incidence of dental or pharyngeal trauma was similar between the two devices; however, significantly more instrument reinsertions were seen in Macintosh laryngoscopies. This difference may indicate a lower risk of lesions during training with the Airtraq, as already evidenced in simulator studies [4], which may have positive medicolegal implications with respect to training and clinical practice. Our results add to the studies by Maharaj and colleagues [4, 12], who report similar success rates, but shorter procedure times, when comparing inexperienced residents' or students' performance on manikins with both the Airtraq and Macintosh laryngoscopes. Although Maharaj et al. measured procedure-related variables such as performance time and subjective reports of confidence, we assessed the effectiveness of the maneuver in real patients and analyzed progressive success rates. Woollard and coworkers [5] also investigated the increase of OI success rates over three attempts on a difficult laryngoscopy model. In their study, experienced and novice users achieved better success rates using the Airtraq, although a clear rise in success rates, or a narrowing of confidence intervals, was not defined.

The Airtraq has been positively evaluated in terms of ease of use in patients at high risk of difficult OI [3], and several case reports illustrate successful employment of the device in cases where Macintosh laryngoscopy failed [19]. Because learning may be faster for experienced professionals than novice personnel [20], the success rates shown here may be in accordance with current manufacturer's recommendations for providers to practice two to four times before using the Airtraq as a backup device in difficult OIs. Such a role, however, is yet to be confirmed by systematic evaluation.

Previous studies of Airtraq use by inexperienced personnel in "easy laryngoscopy" scenarios used tracheal intubation of the manikin as the main outcome variable [4, 12], whereas we report success based on laryngoscopy grading according to the scale developed by Cormack and Lehane. Differences in success rates between the two devices, which were in general lower here as compared to previous works, may be attributed to the choice of outcome variable: OI may be performed even during suboptimal laryngoscopy, especially when performing under experimental conditions without additional sources of stress and anxiety for the trainees.

Although OI is clearly the clinically relevant endpoint in these settings, it has been reported that correct laryngoscopy (i.e., instrument insertion and manipulation) is the major determinant of successful intubation with the Macintosh laryngoscope [21]. Moreover, endotracheal tube placement is the major determinant of stress responses to the whole procedure [22]; by limiting our analysis to two laryngoscopies, one of which has been found to cause minimal hemodynamic variations [3] and carries only minor risk of trauma, we were able to employ both techniques on the same patients, thus reducing uncontrolled interpatient variability between attempts with each device. We cannot exclude that learning curves for actual OI with the Airtraq are different than those that were shown here, but success rates are similar to simulator studies in which OI was included [4, 5, 20].

Although care was taken in instructing students to perform laryngoscopy with criteria required for proper intubation, such as centering the larynx within the field of view, the learning curve for Airtraq OI may be different. In fact, better view does not mean easier intubation, so current

results do not guarantee the better success rate of tracheal intubation by Airtraq.

However, an improved glottis view can be related to improved intubation skills during early training. In fact, endotracheal intubation is a complex psychomotor skill traditionally passed from mentor to student by long apprenticeship, usually without the aid of a video system, so that teaching laryngoscopy occurs with indirect feedback to the instructor. As properly described by Shulman et al. [23], in case of students' difficulty instructors give advice according to external cues and limited feedback. If verbal guidance is insufficient, instructors are forced to take over the laryngoscopy, thus limiting the learning experience for students and prolonging the training period. Looking for a possible solution, Shulman et al. [23] noted that use of a video system is effective to quicken the process of learning Bullard laryngoscopy, at least during the early learning experience. The authors justified their results arguing that video camera systems allow for individualized feedback when teaching laryngoscopy.

Moreover, dividing a challenging procedure into small steps can speed up skill acquisition because success comes more quickly in these small stages than when attempting to learn the skill all at once. Howen and Plummer [24] found that deconstructing the laryngoscopic technique is important to avoid cognitive overload among students.

An essential step during endotracheal intubation is the ability to properly visualize glottis anatomic structures, that is to say, to perform a correct laryngoscopy. Thus, breaking down a complex skill such as endotracheal intubation into smaller steps and committing time to achieve a proper glottis view may positively affect the whole process of intubation training. Consistently with this hypothesis, Ovassapian et al. [25] showed that dividing the procedure into smaller steps allows students to learn what anatomy looks like and to be readily able to identify structures in the later steps.

Kaplan et al. [26] already stated that video-assisted laryngoscopy provides an improved view of the larynx, suggesting that the technique could be useful for teaching laryngoscopy and intubation. However, no students were involved in the study, so that their conclusion was merely speculative.

Consistently with previous findings, present results may strengthen the recommendation for a teaching model aimed at obtaining a proper glottic view as a first step, possibly by using a video-laryngoscope such as the Airtraq in the early training.

It should be noted that attending anesthesiologists, per our protocol, would prevent students from levering back on patients' upper teeth if they deemed their patient's safety was at risk; our results may thus be biased toward increased safety, especially during Macintosh laryngoscopy, and the observed number of instrument reinsertions has probably been affected by this. The learning curves reported in our study are relatively flat for the Airtraq and especially the Macintosh laryngoscope. We might have seen a more definite growth of success rates by increasing the number of attempts for each student, which was not possible for practical and ethical reasons. However, although previous studies have already shown that five attempts are too few to achieve an adequate success rate in real patients with Macintosh laryngoscopy [12, 27], the confidence intervals for success attained by inexperienced students on their tenth attempt with the Airtraq (79–94%) are similar to suggested endpoints for personnel training. Such results were obtained after very limited simulator training. Another limitation of the study was that we did not record CL gradings by the attending anesthesiologists upon OI to account for unexpectedly difficult laryngoscopies; this would have been inconvenient in our study design, as the repetition/adjustment of each laryngoscopy by the attending anesthesiologist would have added additional apnea time for patients. Furthermore, CL gradings by a skilled (as opposed to novice) operator were not the focus of the analysis.

In conclusion, after brief training, inexperienced personnel attempting laryngoscopy on live patients under general anesthesia attained better success rates with narrower interindividual variability using the Airtraq as compared to the Macintosh laryngoscope.

Future investigations could clarify whether full-fledged training programs for advanced airway management providers may benefit from employing this device, and if there are advantages in settings where skill retaining and reacquisition is an issue.

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Conflict of interest The authors have no conflicts of interest.

Appendix

Cusum analysis

Cumulative sum ("cusum") analysis has been developed to analyze and control industrial process. It is based on cumulation of differences from a pre-established standard, and allows one to assess deviation from the "acceptable" limit both in a qualitative and quantitative way. The main

result of the analysis is a quality assurance chart plotting cusum scores on the ordinate and the consecutive trial number on the abscissa.

Movement of the plotted line above or below prespecified limits defines an unacceptable and, respectively, an acceptable performance.

The main variables to be specified a priori in cusum analysis are the acceptable (p_0) and unacceptable (p_1) failure rates, and reasonable risks of type I and type II statistical errors (α and β; both typically set to 0.1 for sake of clarity).

Parameters for the actual analysis are calculated from these variables. The initial parameter is s, the amount to be subtracted from an individual's score in case of success.

In case of failure, the amount $1 - s$ is added to the relevant score. Each individual's cusum chart takes the form of a line starting from zero and joining points, which represent their cumulative score at each consecutive trial.

Horizontal lines are also added to the chart at values of h_0 and h_1. These values represent the thresholds for statistical inference, and thus quality assessment, on an individual's performance. When an individual's line crosses the h_1 line (or its multiples) from below, then their actual failure rate can be said to be equal to or higher than the unacceptable failure rate, with $\alpha = 0.1$ and $\beta = 0.1$. When the line crosses the h_0 threshold (or its multiples) from above, that individual's performance can be said to be acceptable, with failure rates not significantly different from p_0. If the line stays between the same set of boundary lines, no inference can be made, and monitoring should continue.

Analyses and inference can be performed individually on different portions of an individual's line, by selecting segments delimited by intersections with the h_0/h_1 boundaries or their multiples.

The pre-set variables are calculated as:

$$a = \ln[(1-\beta)/\alpha] \qquad b = \ln[(1-\alpha)/\beta]$$
$$P = \ln(p_1/p_0) \qquad Q = \ln[(1-p_1)/(1-p_0)]$$
$$h_0 = -b/(P+Q) \qquad h_1 = a/(P+Q)$$
$$s = Q/(P+Q).$$

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