Analysis of Medical Students' Success Performing Endotracheal Intubation (ETI) and Predictive Model for Success Probability

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ABSTRACT

Introduction: Endotracheal intubation (ETI) is a critical skill every medical student should master during their education, at least on the basic level. Today, approaches in training and evaluating medical students regarding ETI vary, each with its benefits and drawbacks. The aim of this analysis was to comparatively evaluate different components of medical students' education regarding ETI.
Materials and methods: From the PubMed database, we selected 16 studies that reported on medical student ETI success rates with various training and evaluation techniques. The variables observed were time period of study, evaluation setting, evaluation technique, and training type, while the primary outcome was average intubation success rate (ASR).
Results: The analysis included 1610 medical students. A statistically significant superior score was noted in the indirect laryngoscopy subgroup compared to direct laryngoscopy, the mannequin model subgroup compared to operating room patients, and the standard training subgroup compared to advanced simulator training. Additionally, the trend of ASR change from the 1980s to today was shown to be significantly positive. Finally, as a form of result validation, we used machine learning modelling for intubation success prediction. Based on the provided variables, the model had a > 90% accuracy in predicting which student might have a higher than 70% probability of success.
Conclusions: In conclusion, this study demonstrates a significant improvement in student intubation skills over time, as well as a clear superiority of indirect laryngoscopy scores, and provides a contribution to the determination of an optimal educational program for ETI skill acquisition.

Keywords: Artificial intelligence; Intubation, Intratracheal; Students, Medical

Sažetak:

Analiza uspjeha studenata medicine u provođenju endotrahealne intubacije (ETI) i prediktivni model vjerojatnosti uspjeha

Uvod: Endotrahealna intubacija (ETI) ključna je vještina koju bi svaki student medicine trebao savladati tijekom svog obrazovanja, barem na osnovnoj razini. Danas se pristupi u obuci i evaluaciji studenata medicine u vezi s ETI razlikuju, a svaki ima svoje prednosti i nedostatke. Cilj ove analize bio je usporedno procijeniti različite komponente obrazovanja studenata medicine u vezi s ETI. Materijali i metode: Iz baze podataka PubMed odabrali smo 16 studija koje su izvještavale o stopama uspjeha ETI studenata medicine s različitim tehnikama obuke i evaluacije. Promatrane varijable bile su vremensko razdoblje studija, okruženje evaluacije, tehnika evaluacije i vrsta obuke, dok je primarni ishod

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This article was submitted to RAD CASA - Medical Sciences as the original article

Conflict of Interest Statement:
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 18 April 2025
Accepted: 29 May 2025
Published: 25 June 2025

Citation:
Brenner E, Bulić L, Vrbanović Mijatović V. Analysis of Medical Students' Success Performing Endotracheal Intubation (ETI) and Predictive Model for Success Probability
567=70-71 (2025): 8-17
DOI: 10.21857/90836c2zly

bila prosječna stopa uspjeha intubacije (ASR). Rezultati: Analiza je obuhvatila 1610 studenata medicine. Statistički značajno superiorniji rezultat zabilježen je u podskupini s indirektnom laringoskopijom u usporedbi s izravnom laringoskopijom, podskupini s modelom lutke u usporedbi s pacijentima u operacijskoj sali i podskupini sa standardnom obukom u usporedbi s naprednom obukom na simulatoru. Osim toga, pokazalo se da je trend promjene ASR-a od 1980-ih do danas značajno pozitivan. Konačno, kao oblik validacije rezultata, koristili smo modeliranje strojnog učenja za predviđanje uspjeha intubacije. Na temelju navedenih varijabli, model je imao točnost > 90% u predviđanju koji bi student mogao imati vjerojatnost uspjeha veću od 70%.
Zaključci: Zaključno, ova studija pokazuje značajno poboljšanje vještina intubacije studenata tijekom vremena, kao i jasnu superiornost rezultata indirektne laringoskopije te doprinosi određivanju optimalnog obrazovnog programa za stjecanje vještina intubacije.

Ključne riječi: Umjetna inteligencija; Intubacija, Intratrahealna; Studenti, Medicina

Introduction

A frequent preoperative procedure that can pose a challenge to many medical students and young physicians is endotracheal intubation (ETI). While this procedure is commonly performed, mistakes in its execution are costly and can even cause life-threatening complications for the patient. These include trauma, infection, hypoxia, hematoma, etc[1].

Many studies have deliberated on the best way to aid medical students in mastering this technique, as well as on how to best evaluate them. The long-term aim of these studies was to reduce complications regarding ETI, by devising an optimal educational protocol for clinical-year medical students. With the revolution of augmented reality and virtual reality technologies, this has been taken further than ever before. Students can now be taught and assessed in a virtual space and practice repeatedly with no limitations, an excellent example of which are the ‘smart glasses’[2]. Studies centred around this topic have often performed these assessments comparatively, usually with different groups of medical students or with groups of residents and even physicians who have completed residency[3]. Another aspect of comparison is between different instruments and techniques of ETI, such as the Macintosh laryngoscope or the flexible fiberscope[4].

The aim of this analysis was to compare different training and assessment techniques for medical students’ skills and success in performing ETI. By interpretation of the results, we hoped to discover and highlight the optimal training and assessment methods that might, in the future, result in physicians with a lesser number of complications.

Materials and Methods

An extensive search of the PubMed database was conducted using the keywords “medical students” and “intubation skill”. There was no specific range regarding the year of publication. The search yielded 208 results which included all types of scientific publications. All types of literature except original studies and meta-analyses were excluded from the analysis, leaving 42 results in the search. Each of the studies was analysed individually and only those with clearly defined objective student intubation success rates were taken into consideration (Figure 1). In the end, 16 scientific papers were included in the analysis[5-20].

The observed parameters were the time period of study conduction (or publication if not otherwise stated), number of students enrolled, evaluation setting (operating room patients vs mannequin intubation model), evaluation technique (direct laryngoscopy vs indirect laryngoscopy), type of previous training (standard training vs advanced simulator training), and average success rate (ASR). The ASR was considered to be the primary outcome for comparative statistical analysis. Statistical analysis was performed by the JASP statistical software (JASP Team (2024). JASP (Version 0.18.3)[Computer software]). Distribution differences between specific groups were evaluated using the Welch t-test. Distribution differences between time periods were evaluated using the Kruskal-Wallis test. The level of statistical significance was determined at $\alpha = 0.05$. The average success rate of each study was weighted according to the number of students enrolled. Studies that contained separate cohorts based on any of the observed parameters were treated as separate populations and added to their respective categories. In the case of comparative crossover studies, each student was counted once for each cohort they were part of at some point.

Based on the four independent variables (time period, evaluation setting, evaluation technique, and type of training), we trained a machine learning model for intubation success prediction. All entities in the database with an average success rate of 0.7 or over were classified as the “over 0.7” class, while the rest were classified as “under 0.7”. Considering predictions were made for individual entities, this value was no longer interpreted as an average success rate but rather as a derived intubation success probability. Having reduced the problem to a binary classification, we used the RandomForestClassifier algorithm. The model was trained and tested using 10-fold cross-validation. Model quality was evaluated based on accuracy, precision, recall, F-score, and confusion matrix analysis, with “over 0.7” regarded as the positive result. The WEKA workbench was used for model training and evaluation (Eibe Frank, Mark A. Hall, and Ian H. Witten (2016). The WEKA Workbench (Version 3.8.6)[Computer software]).

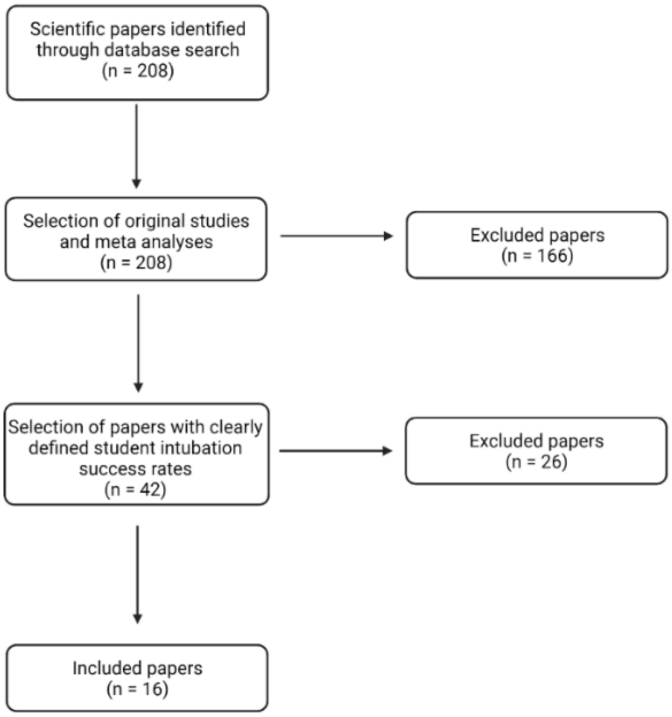

Figure 1. Study selection chart

Results

The selected papers provided a total of 1610 students for analysis. Using descriptive statistics, the distribution of students was determined for each category (Table 1). The Kolmogorov-Smirnov test for the distribution normality regarding ASR produced a p-value < 0.001, indicating a non-normal distribution (Figure 2).

After the initial analysis, comparative statistics for each category were done based on the ASR variable. The first observed comparison was between students tested by direct laryngoscopy and those tested by indirect laryngoscopy (Table 2). When observing the categories in total, there was a statistically significant difference between the ASR scores (p < 0.001), with indirect laryngoscopy being superior. The comparison could not be made among the students who were evaluated on operating room patients, while a statistically significant difference was noted in the mannequin intubation model subgroup (p < 0.001). When observing the type of training students had received, a difference was seen among students with advanced simulator training (p < 0.001) and students with standard training (p < 0.001). Both had a significantly superior score on the indirect laryngoscopy method. Regarding the year of study, the comparison could not be made in the period of 1981-2000. From 2001 to 2015, students showed superior success rates in using indirect laryngoscopy (p < 0.001) and the same result was noted in the period 2016 to today (p < 0.001).

The second observed comparison was the type of training students had received beforehand (Table 3). When observing the differences based on training, standard training in total yielded significantly better scores (p < 0.001). Statistically significant differences were in the mannequin intubation model (p < 0.001), while a comparison of operating room patients could not be done. When compared based on the evaluation method, students demonstrated significantly superior success rates in standard training with direct laryngoscopy (p < 0.001) and indirect laryngoscopy (p < 0.001). Finally, in the time periods 2001-2015 and 2016-today, standard training yielded significantly superior success rates (p < 0.001).

Thirdly, we observed differences between students who performed intubation on the mannequin model and operating room patients (Table 4). The general comparison and comparison in the standard training group demonstrated a significantly lesser success rate in operating room patient intubation than in the mannequin model (p < 0.001). The ASR means in the direct laryngoscopy group were equal and the difference was statistically insignificant (p = 0.649). Regarding time period, the mannequin model group had a significantly superior score in the 1981-2000 period (p < 0.001), while the operating room patient group had a significantly superior score in the 2001-2015 period (p < 0.001).

Table 1. Distribution of students for each variable

CATEGORY	NUMBER OF STUDENTS	PERCENTAGE
Total	1610	100%
Evaluation setting		
Mannequin intubation model	1307	81.2%
Operating room patients	303	18.8%
Evaluation technique		
Direct laryngoscopy	1312	81.5%
Indirect laryngoscopy	298	18.5%
Training type		
Standard training	1248	77.5%
Advanced simulator training	362	22.5%
Year		
1981-2000	95	5.9%
2001-2015	1002	62.2%
2016-today	513	31.9%
CATEGORY	**MEAN**	**STANDARD DEVIATION**
Average success rate	0.76	0.16

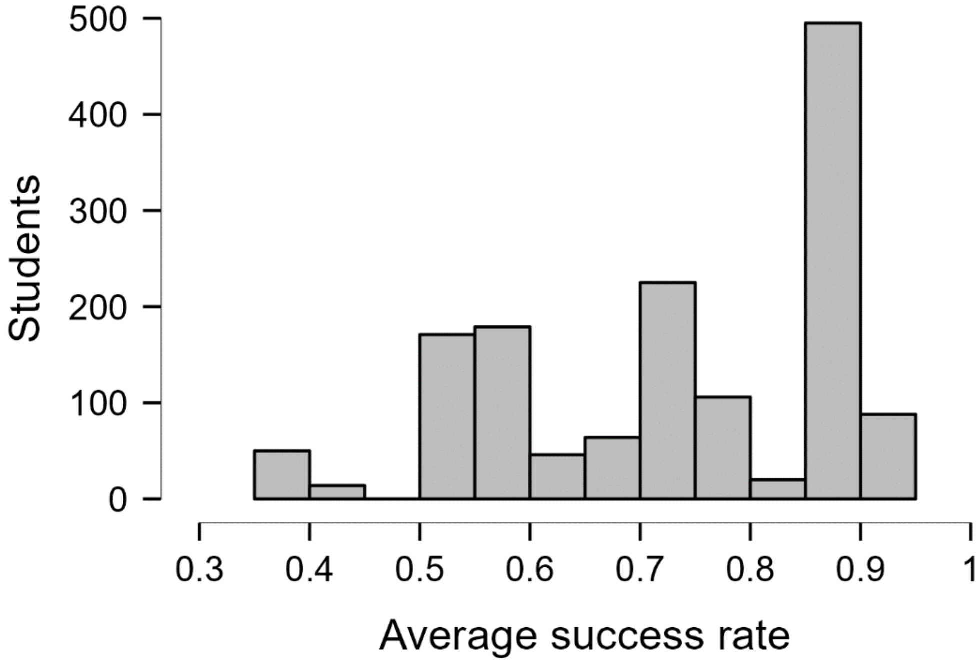

Figure 2. Distribution of ASR

Table 2. Comparison of mean ASR between direct laryngoscopy and indirect laryngoscopy

Stratification	Mean ASR		p-value*
	Direct laryngoscopy	Indirect laryngoscopy	
Total	0.74	0.85	**<0.001**
Evaluation setting			
Operating room patients	0.74	N/A	N/A
Mannequin intubation model	0.74	0.85	**<0.001**
Training type			
Standard training	0.80	0.87	**<0.001**
Advanced simulator training	0.58	0.72	**<0.001**
Year			
1981-2000	0.67	N/A	N/A
2001-2015	0.69	0.80	**<0.001**
2016-today	0.87	0.91	**<0.001**

**Welch t-test; N/A - not available*

Table 3. Comparison of mean ASR between standard training and advanced simulator training

Stratification	Mean ASR		p-value*
	Standard training	Advanced simulator training	
Total	0.81	0.59	**<0.001**
Evaluation setting			
Operating room patients	0.74	N/A	N/A
Mannequin intubation model	0.83	0.59	**<0.001**
Evaluation method			
Direct laryngoscopy	0.80	0.58	**<0.001**
Indirect laryngoscopy	0.87	0.72	**<0.001**
Year			
1981-2000	0.67	N/A	N/A
2001-2015	0.77	0.60	**<0.001**
2016-today	0.89	0.43	**<0.001**

**Welch t-test; N/A - not available*

Table 4. Comparison of mean ASR between mannequin model and operating room patient intubation

Stratification	Mean ASR		p-value*
	Mannequin intubation model	Operating room patients	
Total	0.77	0.74	**<0.001**
Training type			
Standard training	0.83	0.74	**<0.001**
Advanced simulator training	0.59	N/A	N/A
Evaluation method			
Direct laryngoscopy	0.74	0.74	0.649
Indirect laryngoscopy	0.85	N/A	N/A
Year			
1981-2000	0.70	0.61	**<0.001**
2001-2015	0.69	0.76	**<0.001**
2016-today	0.88	N/A	N/A

**Welch t-test; N/A - not available*

Finally, the statistical difference in ASR between the three time periods was analysed (Figure 3). There was a statistically significant difference in ASR between the three time periods ($p < 0.001$). Analysis revealed that the ASR has been increasing over time, from the 0.65-0.7 range in the 1980s and 1990s, to the 0.85-0.95 range today.

The machine learning model for the prediction of intubation success probability was successfully trained using our cohort and the RandomForestClassifier. The overall predictive accuracy of the model was 90.93%, with a precision of 0.905, recall of 0.976, and F-score of 0.939. The confusion matrix showed the true positive, true negative, false positive, and false negative absolute counts (Table 5).

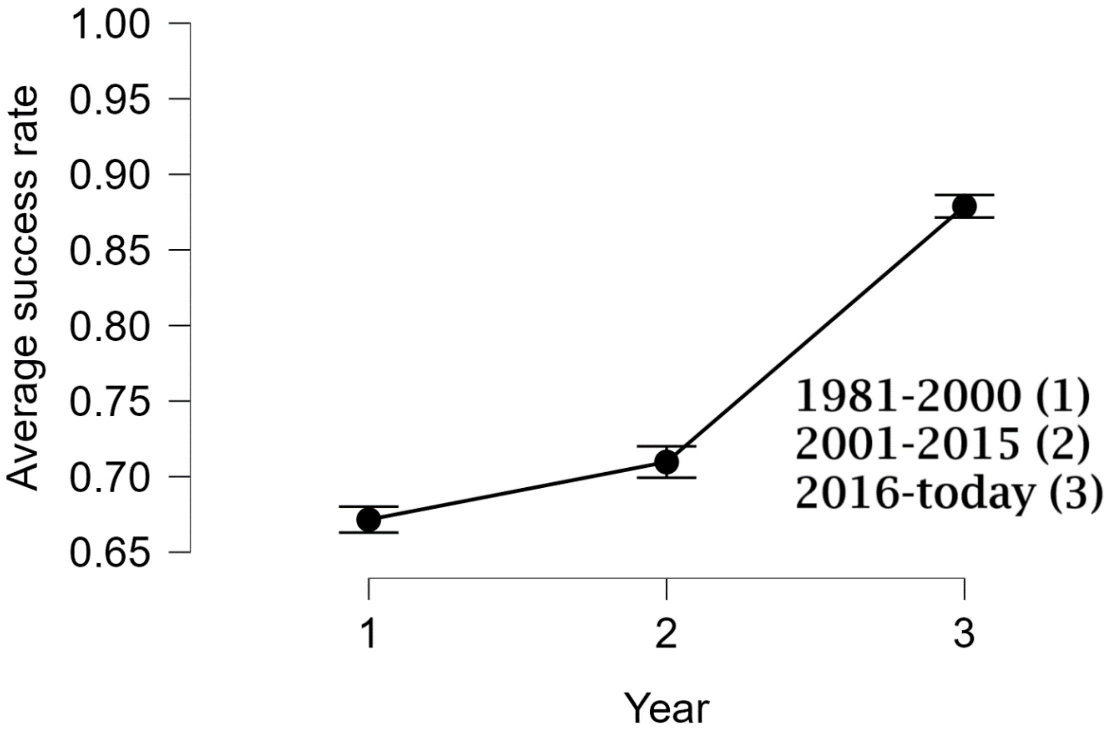

Figure 3. Distribution analysis of ASR in different time periods

Table 5. Predictive model confusion matrix for "over 0.7" class

Predicted value / True value	**Over 0.7**	**Under 0.7**
Over 0.7	1121	28
Under 0.7	118	343

Discussion

Our analysis was conducted on a population of 1610 medical students who were evaluated on endotracheal intubation skills after receiving previous training. Statistical analysis showed many significant differences between different groups of students based on the observed categories.

When discussing the selected evaluation method, the two in question were direct and indirect laryngoscopy. In total, as well as in all observed stratifications, students had better success scores when tested on the indirect laryngoscopy method. The difference between the total ASR for direct and indirect laryngoscopy had a difference of $\Delta = 0.11$. When analysing the studies of our selected pool which specifically observed differences between direct and indirect laryngoscopy, the range of success range differences was $\Delta \in \langle 0.0\text{-}0.2 \rangle$. The indirect laryngoscopy scores were equal to or superior to the direct laryngoscopy scores in all cases but one. In the study by Aghamohammadi H et al., the number of successful intubations was identical in all testing iterations but one, in which the direct laryngoscopy group had two more successful students[13]. However, it is worth noting that the study also greatly focused on intubation times and demonstrated that the intubation time results were significantly superior in the indirect laryngoscopy group. The following results greatly indicate that medical students perform better when evaluated using the indirect laryngoscopy method, rather than direct laryngoscopy. A study published by Prekker ME et al. further supports this finding[21]. The authors made the comparison on clinicians and critically ill patients in multiple medical centres. Video laryngoscopy provided a significantly greater number of successful intubations on the first attempt. Our results demonstrate an increase in ASR over time in both direct and indirect laryngoscopy groups. The ASR is especially high in the indirect laryngoscopy group in the most recent time period, reaching up to 94%. These trends might follow the evolution of intubation technologies which are becoming easier and easier to handle.

When discussing the training the students received before evaluation, we compared the success after training in advanced simulator settings to standard training modes. The students with standard training had a generally significantly higher ASR in comparison to the students trained with advanced simulators ($\Delta = 0.22$). The superiority of standard training was demonstrated in all compared subcategories. The advanced simulator training category involved high-fidelity systems with or without continuous quantitative feedback, complex fully equipped *in situ* simulations, and virtual computer programs for fibreoptic intubation. The two studies using *in situ* simulations (Minai F et al.) and virtual intubation programs (Boet S et al.) demonstrated a significantly superior score with this type of training in comparison to the standard group[19,20]. Furthermore, the scores of students trained with advanced systems were individually high (>80% for acceptable intubation). On the other hand, two studies comparatively used high-fidelity simulators with or without quantitative feedback. In the study by Hempel G et al., the training impact of high-fidelity simulators was compared with and without quantitative feedback[14]. The success rates of correct positioning of the endotracheal tube upon examination for both groups were in the 50%-60% range, but a slightly better score was noted in the group with additional quantitative feedback. Finally, the study by Yau SY et al. involved high-fidelity simulators for the training and evaluation of multiple groups, including medical students and clinicians[9]. Only the medical student group was taken into account in the analysis and their success rate was in the 40%-50% range. While the results in this analysis demonstrated a superiority of success rates following standard training methods, the great potential and utility of advanced technologies in this regard cannot be overlooked. A review by Duffy CC et al. emphasizes the importance of virtual reality in airway management training, stating the need for consensus and guidelines on the incorporation of these technologies into modern curriculums[22]. One important matter that must be kept in mind as simulation technologies advance is their fidelity to real-life situations, as training in unrealistically optimal conditions may negatively impact performance in real-life scenarios. On the other hand, as intubation technologies themselves are rapidly advancing, real-life intubation scenarios are also decreasing in difficulty (best demonstrated by the success rates in direct and indirect laryngoscopy).

When discussing the selected evaluation setting, we compared the evaluations performed on the mannequin intubation model and operating room patients. The ASR was significantly superior in the mannequin group when compared to the preoperative patient group ($\Delta = 0.03$). This trend was also noted in the subgroup comparisons, with two exceptions. Upon exclusion of the indirect laryngoscopy students, the difference between evaluation settings was insignificant. Secondly, when comparing only the time period 2001-2015, the preoperative patient group had higher ASR. Our analysis included no comparative studies which focused on this aspect of research. The studies which solely observed medical student intubation skills on preoperative patients reported success rates in the 60%-80% range[5,7,10]. This cohort of students had little diversity, as there were no students with advanced simulator training or students evaluated using indirect laryngoscopy in this cohort. A point that must be considered when evaluating students on mannequins is how this will translate into intubation skills in actual patients. To investigate this very question, a study was conducted by Lubin J et Carter R[23]. The authors concluded that daily practice on airway management mannequins did not translate into improved clinical performance regarding intubation.

Finally, the trend of general intubation success score was analysed over different time periods. While the score has consistently increased with time, a drastic difference can be noted between the 1981-2000 and 2001-2015 periods on one hand and the 2016-today period on the other. This might suggest that medical students are becoming more successful in acquiring intubation skills and successfully completing evaluations as technology evolves. In their study, Lin YF et al. analysed how the use of smart glasses impacted students' satisfaction with training and self-assessment of efficacy[2]. In their conclusion, the authors stated that both of these variables were positively impacted on account of implementing advanced technology, a fact that highlights the importance of continued development and utilization of simulation training technologies.

Machine learning predictive model training based on the provided data yielded excellent results, with a high accuracy of > 90%. Students from studies with average success rates over 0.7 were identified efficiently, while those from studies with average success rates under 0.7 were identified with a little more difficulty. This additional result not only serves as a positive mark of data quality but opens the idea for implementation of machine learning prediction for student intubation success probability. The practical use of such models is a thoughtworthy idea that should be explored in future studies in this field.

Limitations

The limitations of this analysis are significant and must be taken into account upon result interpretation. Firstly, the inclusion criteria in terms of study participants was that the participants were required to be medical students. Further than this criterion, the population variables were not controlled. For this reason, it is possible that different backgrounds, educations, nationalities, ages, etc. impacted certain differences in ASR between groups. Secondly, the ASR for each study was not always a product of the same procedures. Some studies tested students in multiple iterations and calculated the average success rate as an average of all attempts, while other studies gave students only one evaluation. Furthermore, the term 'success' was not uniquely defined, but rather varied from physically successful intubation to passing grade upon evaluation (this took into account other performance components aside from successfully positioning the device into the airway). Thirdly, the groups of standard and advanced simulation training proved difficult to define. The advanced simulation training group consisted of technologies that the authors emphasized in their studies, such as high-fidelity simulators and *in situ* complex operating room simulations. Other modes of learning were categorized into the standard training group, creating a great variance in what the term "standard" encompassed. In general, fitting the greatly heterogeneous data we had at our disposal into a homogenous categorical system for statistical analysis proved difficult. As for machine learning model training, the amount of bias and overfitting introduced with the accumulated data is questionable. The high-accuracy result that was achieved might be further evaluated on other datasets with the analysed variables.

Conclusions

Endotracheal intubation is one of the key procedures of anaesthesiology and emergency medicine and requires great skill and training. In order to secure the best performance of this procedure from healthcare providers, a consensus must be reached on the characteristics of an optimal curriculum. For the purpose of educating medical students, sophisticated airway management mannequins have been made. Furthermore, advanced technologies are being developed for training purposes, including high-level feedback simulators and virtual reality programs. Additionally, modern tools for easier intubation are also being developed for clinical but also educational use. This analysis provides a breakdown of the impact these components have on student intubation skills and hopes to contribute to the development of the aforementioned education guidelines.

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