Intubation Forces: A Study of a Joint Airway Simulator

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ABSTRACT

Simulation-Based Training (SBT) provides consistent, experiential learning opportunities for students throughout the medical domain. One of its benefits is the ability to measure learning outcomes with sensor-based equipment without risk of harm to real patients. Current airway simulators have shown deficiencies including inappropriate pharyngeal airspace, lack of anatomical structures, and tissue rigidity. These attributes require users to exert excessive force during intubation, an intervention used to create an airway adjunct if the existing airway is compromised. When excessive force is translated to real patients the risks for harm (dental damage and vocal cord injury) could be drastically increased. The aforementioned shortcomings in airway simulators prompted the research and development of the Joint Forces Airway Simulator (JFAS), by the U.S. Army Research Laboratory-Human Research and Engineering Directorate, Advanced Training and Simulation Division (ARL-HRED ATSD). This simulator was created with life-like tissues, improved anatomical fidelity, and pressure sensors throughout the oral cavity and airway with the intention of bridging the gap between current simulators and the human patient. The purpose of this study was to use the JFAS to evaluate forces applied to the oral cavity and airway during intubation, as well subjective measures related to ability and usability.

In the present study, the JFAS prototype was tested by 15 Emergency Medical Technician-Paramedics. Each participant completed three intubation trials. Self-reported intubation ability, intubation time, and force applied were examined to evaluate training impact. Preliminary data showed a strong positive correlation between self-reported pre- and post-simulation comprehension of intubation skill ($r = 0.889$, $p < 0.001$) along with confidence to demonstrate the appropriate intubation forces ($r = 0.855$, $p < 0.001$).

Key words: airway, intubation, forces, high fidelity, live tissue

ABOUT THE AUTHORS

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INTRODUCTION

Reducing medical errors to improve patient safety is a primary focus of the Institute of Medicine's (IOM) Quality of Health Care in America project and the Joint Commission through their National Patient Safety Goals. According to the IOM report "To Err Is Human," medical errors contribute to between 44,000 and 98,000 deaths per year costing billions in healthcare associated costs. Medical errors also impact the health care system from overall patient health and satisfaction to employee morale and productivity (Kohn, Corrigan, & Donaldson, 1999).

One recommendation to reduce medical errors is the use of simulation training (Kohn, Corrigan, & Donaldson, 1999). Simulation-Based Training (SBT) is already widely used in medical education to provide consistent, repetitive practice in a controlled learning environment to improve individual skill and competency, without the risk of patient harm (Issenberg, McGaghie, Petrusa, Gordon, & Scalese, 2005; Chen, et al, 2009). Invasive procedures, such as airway management, have inherent risks which are further compounded by human error and inadequate skill. SBT has been found useful for training these essential and invasive skills to improve individual competency, knowledge, and retention (Kennedy, Cannon, Warner, & Cook, 2014).

Securing and managing an airway by means of endotracheal (ET) intubation is a critical skill needed by numerous medical professions. ET intubation is the establishment of an airway adjunct, or method of passing air if the real airway is compromised. Due to the need for quick and skillful intervention, quality education is necessary to develop and maintain the competency of these skills. SBT has helped to drastically improve airway management skills, resulting in many facilities turning to SBT to provide quality instruction. This form of hands-on education has demonstrated improvements in knowledge, skill, and user satisfaction, along with increasing skill retention over time (Lorello, Cook, Johnson, & Brydges, 2014; Mileder, &, Schmolzer, 2014). SBT also allows for simulation of difficult airways or intubating within complex scenarios. Allowing ample practice time without risk of harm to patients has resulted in increased confidence of medical professionals' individual technical skills as well as lessening performance anxiety which may reduce human error during times of increased stress (Chen, et al., 2009; Pian-Smith, et al., 2009). One alternative to using a simulator for airway management training is the use of living patients. Although living patients are the gold standard and provide optimal experience, it is difficult to provide consistent training between multiple learners and measure learning outcomes without sensor-based equipment. Additionally, initial skill development on living patients carries the risk of harm to the patient due to inexperience (Kennedy, Cannon, Warner, & Cook, 2014). However, it is necessary to make improvements in airway simulators to create more realistic training prior to treating live patients to further improve patient safety and outcome.

Current airway simulators have room for improvement in realism and transfer of learned skill to the living patient. Inadequate simulators may lead to the development of inept skills which could affect both procedure and patient outcome success. Two main areas of focus in current literature include anatomy and tissue reproducibility in airway simulators. Research has revealed that current simulators from companies such as Laerdal, Ambu, CAE Healthcare (formerly METI), and Gaumard, have demonstrated deficiencies in some aspects of human anatomy (Schebesta et al., 2012; Jordan, Silsby, Bayley, & Cook, 2007). Difficulty has also been met with developing realistic simulated airway tissues capable of recreating the compliance of living tissue. Compliant tissue, in addition to inadequate anatomy, requires users to exert excessive amounts of force on the oral cavity and airway during intubation (Lee, Russell, Firat, & Cooper, 2013). When excessive force is translated and exerted on a real patient, the risks for harm could be drastically increased.

Although ET intubation is performed by trained staff in the hospital and in first-responder settings, it comes with some associated risks that can be compounded by unrealistic training with the current standard of airway simulators.

Two of the most common risks of ET intubation include dental damage and vocal cord injury (Hagberg, Georgi, & Krier, 2005). Damage to maxillary incisors most often results from excessive pressure by the laryngoscope during intubation (Mourão, et al., 2013). Vocal cord injury can vary from mild hoarseness to vocal cord paralysis, resulting from trauma during placement of the ET tube (Pacheco-Lopez, Berkow, Hillel, & Akst, 2014). While all risk cannot be eliminated from this procedure, numerous studies have shown a correlation between improved patient outcomes with adequate training (Pian-Smith, et al., 2009; Gordon, Wilkerson, Shaffer, & Armstrong, 2001; Al-Elq, 2010).

The aforementioned shortcomings in SBT have led to the creation of a new airway simulator, the Joint Forces Airway Simulator (JFAS), by the U.S. Army Research Laboratory Human Research and Engineering Directorate Advanced Training and Simulation Division. This simulator was created with realistic tissues, improved anatomical fidelity, and pressure sensors throughout the oral cavity and airway.

The purpose of this study was to use this new simulator as a training tool to evaluate forces applied to the oral cavity and airway during intubation with a laryngoscope. Using a cadre of paramedics, intubation forces were recorded over three intubations. A usability and self-efficacy survey evaluated realism and responsiveness of the simulator as compared to their experience with live human tissue, along with the perceived impact the simulator had on participant skill improvement. Intubation forces and time as well as completed surveys were used to evaluate the effectiveness of the simulator providing a realistic model to teach appropriate intubation forces.

METHODS

Simulators

Two JFAS models using the same design specifications were used for this study, further referred to as “Simulator A” and “Simulator B” (Figure 1). The JFAS contains embedded pressure sensors that continually measured forces during the intubation process. A total of six sensors were embedded in tissues located throughout the oral cavity and airway to include throat, vocal cords, epiglottis, esophagus, teeth, and trachea. Additionally, one sensor was located externally in a throat plug on the anterior neck of the simulator, which was not used in this study.

Figure 1. JFAS Model

Participants

The subject population included 15 Emergency Medical Technician-Paramedics (EMT-P), hereafter referred to as paramedics, from Orange County and the City of Orlando, Florida. Two females and 13 males were included. Experience levels ranged from 3-33 years within the profession and 0-4 intubations performed on living patients. All study participants were selected to participate in the Orange County Fire Department preceptor training academy. These individuals were selected from the Central Florida area as the top of their field to train other paramedics on skills that fall within the scope of their licensure.

Materials

The JFAS prototype was used to assess intubation forces. Two simulators with the same design specifications were used: Simulator A and Simulator B (Figure 2). Each simulator was placed on opposing ends of a six-foot table. The simulators were secured to the table using ratchet straps to prevent any movement. Materials provided for each simulator included an 8.0 mm ET tube and a lighted laryngoscope with a Macintosh size three laryngoscope blade (Figure 3). The airways of both simulators along with the ET tubes were lubricated using synthetic saliva.

Figure 2. Simulator Configuration

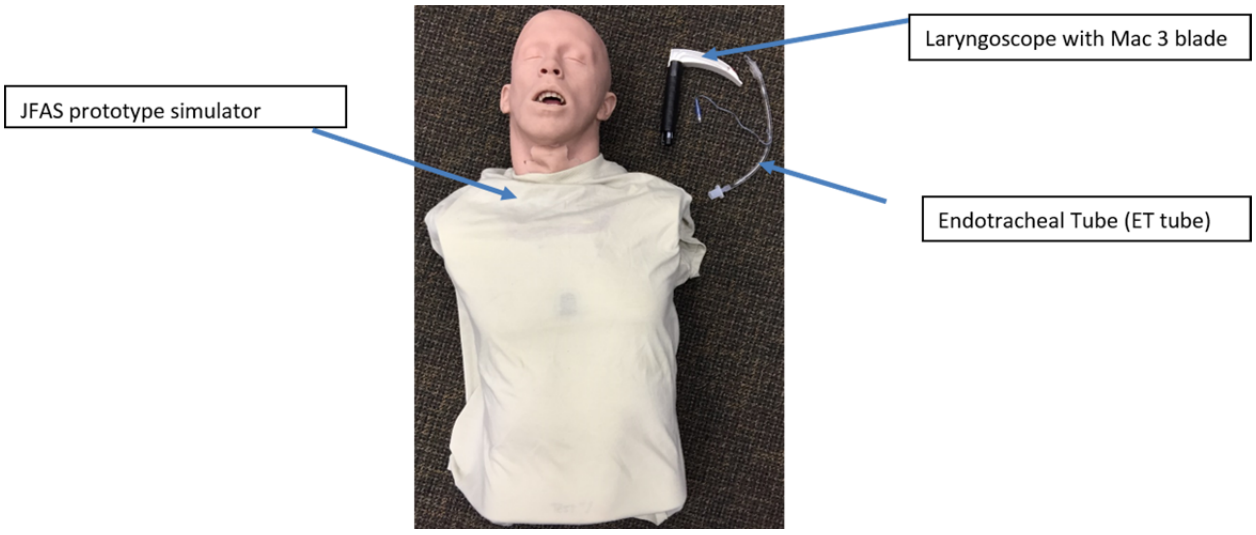

Figure 3. JFAS and Intubation Equipment

Demographic Survey

The demographic survey included years in profession, level of training/education in intubation, types of intubation equipment used, number of intubations completed on the following: living humans, cadavers, and simulators, along with time since latest intubation. The demographic survey also included questions to assess self-disclosed knowledge and ability about intubation prior to simulation. This portion of the survey consisted of five questions using a 6-point Likert scale ranging from no confidence at all to complete confidence, assessing each participant's knowledge about ET intubation and ability in performing the skill.

Usability and Self-Efficacy Survey

The usability survey consisted of a 7-point Likert scale which ranged from strongly disagree to strongly agree. This survey was used to evaluate features of the simulator to include realism, design, responsiveness of tissues, ease of use, and overall rating of the simulator. The self-efficacy portion of the survey included the same 6-point Likert scale questions about self-disclosed knowledge and ability as those asked within the demographic survey to compare post-simulation. A text box was available at the end of the usability and self-efficacy survey which allowed for written free response feedback from the participants.

Procedures

Participants were taken from the Orange County Fire Department preceptor training academy on July 31, 2015. The experimental study was completed over one day and took two hours. Participation was voluntary and no compensation or payment was provided. To begin the study, instructions were given regarding the procedure for the experiment (Figure 4). Participants gave informed consent and completed a demographic survey. Participants randomly selected a four-digit identification number to ensure all information collected was confidential and could not be traced back to any specific participant. Each participant was given a brief one-to-two minute period to ask questions and orient themselves to the simulator and equipment before beginning.

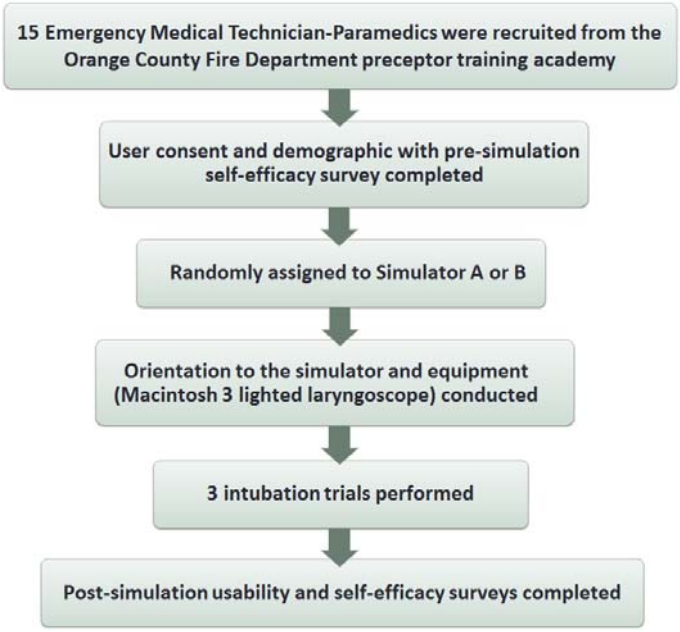

Figure 4. Experiment Flow

Participants were randomly assigned Simulator A or Simulator B. Once assigned, three intubation trials were completed on the respective simulator. The first intubation was considered an orientation to the simulator. Each participant then intubated the simulator for two additional trials. Neither feedback nor verification of correct ET tube placement was given following the trials. However, forces applied to various sensors throughout the oral cavity and airway were recorded. Following completion of the third trial, participants completed a usability and self-efficacy survey.

Statistical analysis

Categorical data (gender, years in profession, number of intubations performed, and time since last intubation) were represented in frequency and percentages. Ordinal data from a 6-point Likert scale (no confidence at all, a little confidence, a fair amount of confidence, much confidence, very much confidence, complete confidence) were represented as frequency and percentage. Continuous data (time to intubate, intubation force, and force per simulator) were represented as mean and standard deviation.

To assess the relationship between self-reported pre- and post-simulation confidence in intubation knowledge and skill, a Spearman Rho correlation was conducted. A paired-sample *t*-test was conducted to compare force applied to five airway locations over sequential trials. A Spearman Rho correlation was also conducted to assess the relationship between number of intubations previously performed on a living patient and force applied to five airway structures. All statistical analysis were two-tailed and *p*-values of 0.05 were considered statistically significant. Data were imported into Microsoft Excel 2016 and analyzed with SPSS for Windows version 23.0.

RESULTS

For data analysis trial one was considered as practice and orientation to the simulator and was therefore excluded. The following results and data analysis only includes data from trials two and three. The results reveal the impact of the JFAS as a training tool for ET intubation. The following measures were used to determine training impact: ability before and after intubation, time to complete intubation, and force applied during intubation.

Demographics

The demographics (Table 1) reveal 93.4% of participants have performed ET intubation on a living patient at least once, while 46.7% have intubated more than 20 times on a living patient. A large majority, 93.4%, of participants have intubated on a simulator at least four times while 66.7% of participants had more than 20 experiences. Finally, intubation on a cadaver was the lowest with 66.7% having no experience. This furthers the importance and need for an airway simulator that mimics the human airway anatomy and tissue compliance. After reviewing participant data, similarities were seen between years of professional experience and number of intubations performed on a living patient across the two groups. Also, 53.3% of participants had their last intubation within the previous 30 days.

Table 1. Participant characteristics

Characteristics	Participants (*n* = 15)
Gender	
Male	13 (86.7%)
Female	2 (13.3%)
Years in profession [a]	Mean = 11.4 (8.379 sd)
Number of intubations	
Living patient (*n* = 15)	
0	1 (6.7%)
1-3	2 (13.3%)
4-10	4 (26.7%)
11-20	1 (6.7%)
More than 20	7 (46.7%)
Cadaver (*n* = 13)	
0	10 (66.7%)
1-3	1 (6.7%)
4-10	2 (13.3%)
Simulator (*n* = 14)	
4-10	1 (6.7%)
11-20	3 (20.0%)
More than 20	10 (66.7%)
Time of last intubation (*n* = 11)	
Within 30 days	8 (53.3%)
Within 60 days	2 (13.3%)
60 days or more	1 (6.7%)

Categorical data presented here are displayed in frequency (%).
[a] Data displayed in mean (std. deviation).

Self-efficacy

Prior to the simulation, using a self-reported five-question survey, 73% of participants reported confidence in their ability and skills in ET intubation reporting feeling very much confidence or complete confidence. Similar responses were seen on the same survey administered post-simulation training, with 85.6% of participants selecting very much confidence or complete confidence (Figure 5). Spearman Rho correlation demonstrated a large, positive correlation between the pre-simulation and post-simulation self-disclosed ability survey (Table 2). The 12.6% increase in self-

Table 2. Pre-simulation vs. post-simulation self-disclosed ability

Self-disclosed ability questions	*Rho*	*p*-value
Understand how to perform an endotracheal intubation with a laryngoscope.	0.889	< **0.001**
Identify the possible risk of harm for patients during the intervention of endotracheal intubation	0.578	**0.039**
Identify the possible risks of harm for patient from use of a laryngoscope.	0.608	**0.028**
Perform an endotracheal intubation with minimal harm to a patient.	0.521	0.068
Demonstrate the appropriate force needed to intubate a patient with a laryngoscope.	0.855	< **0.001**

reported confidence was seen following three intubations on the JFAS prototype.

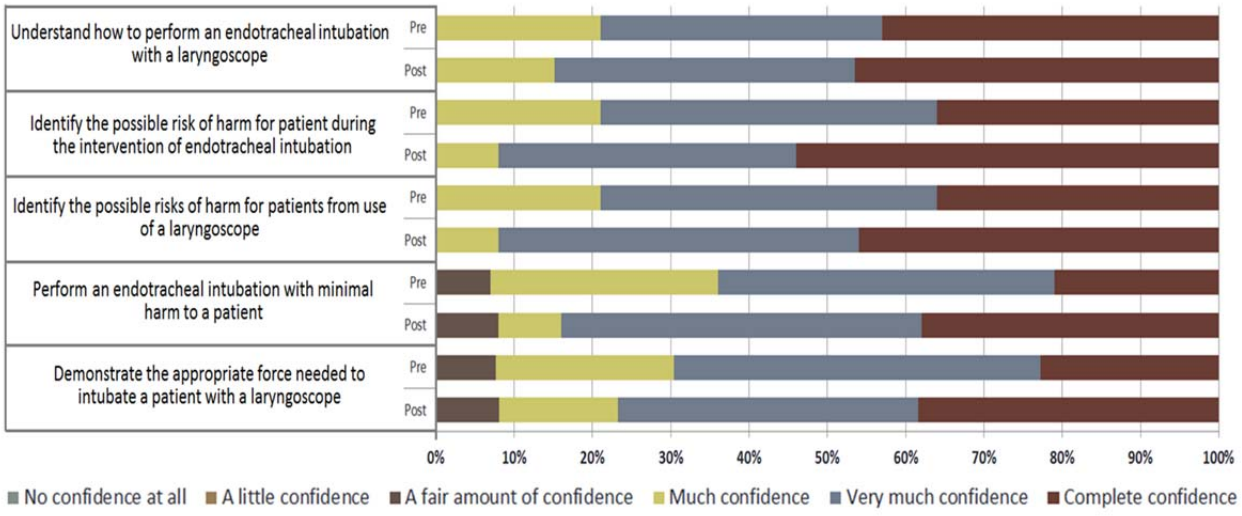

Figure 5. Pre- versus Post-Simulation Self-Reported Ability

Time to intubate

Average time to intubate decreased from trial two to trial three by 1.3 seconds (22.1 seconds to 20.8 seconds) as illustrated in Figure 6. It is important to note that time was not considerably different. However, the difference of 1.3 seconds could have clinical impact in an emergency room or traumatic, austere environment.

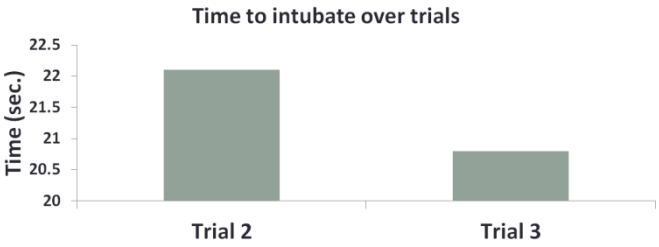

Figure 6. Intubation time

Airway intubation forces

Average force applied to the throat, vocal cords, epiglottis, esophagus, and trachea were very similar between trials two and three. A paired-samples *t*-test was conducted to evaluate the force applied to these five airway locations varied over sequential trials. The results indicated there were no significant differences in force applied between trials (Table 3). However, the sample size was extremely limited to determine if this trend would occur with larger numbers using a redesigned prototype. Although data trends showed little significance, consistency of the mean force data standard deviation was noted across trials two and three. It is important to note that the forces presented throughout this study are represented in relative terms and not correlated to any specific unit of force. The numbers recorded are a derived unit of force based on the sensor output reading.

Table 3. Average (derived) forces applied

	Trial 2	**Trial 3**	***p*-value**
Throat	59.44 (24.95)	56.55 (25.49)	0.128
Vocal cords	22.79 (19.12)	23.11 (22.30)	0.826
Epiglottis	76.17 (34.74)	76.46 (38.36)	0.880
Esophagus	91.55 (10.25)	92.38 (10.00)	0.655
Trachea	38.73 (50.96)	36.89 (50.11)	0.597

Data presented here are displayed in mean (std deviation).

The relationship between number of intubations previously performed by participants on a living patient and force applied during this experiment was investigated using a Spearman Rho correlation (Table 4). Similar trends were

seen across trials two and three for all anatomical locations except the throat. These trends include possible correlations to examine with future prototype development. Spearman Rho correlation was also used to evaulate the time since last intubation on a living patient and force applied during this experiment. Fewer trends were seen across trials two and three for this data (Table 4). Conclusions drawn from this data are very limited and future studies with larger sample size are needed.

Table 4. Number of intubations and time since last intubation vs. force applied

			Throat	**Vocal cords**	**Epiglottis**	**Esophagus**	**Trachea**
Intubations on living patients	Trial 2	*Rho*	-0.025	0.133	-0.166	-0.057	0.314
		p-value	0.930	0.636	0.555	0.840	0.254
	Trial 3	*Rho*	0.019	0.017	-0.101	-0.287	0.364
		p-value	0.946	0.952	0.721	0.299	0.183
Time since last intubation on living patient	Trial 2	*Rho*	0.162	**-0.766**	-0.592	**0.673**	-0.435
		p-value	0.633	**0.006**	0.055	**0.023**	0.181
	Trial 3	*Rho*	0.046	-0.331	-0.435	0.232	-0.203
		p-value	0.892	0.320	0.181	0.492	0.549

Usability

Overall, participants were satisfied with the JFAS with 75% of participants rating the simulator as good or extremely good. Participants commented that overall the simulator appeared very realistic and life-like. Comments on the simulator's strengths included "very lifelike, realistic appearance" and "the simulator was the best one I have seen in relation to weight of head and flexibility of neck." Some improvements to the durability of internal tissues and realism of the vocal cords were recommended. Comments regarding improvements included "torn pieces of the JFAS prohibited proper (ET tube) placement" and "the tissue began to tear in the simulator leading to an unrealistic experience."

DISCUSSION

This study examined the impact of the JFAS as a training tool for ET intubation. Participant ability before and after intubation trials, time to complete intubation, and amount of force applied during intubation were examined, as well as self-efficacy and usability measures to determine the impact on training.

During this study two simulator prototypes with the same design specifications were used to minimize wear and tear on the simulators and extend usability. It was determined that three trials would be used to also reduce wear and tear on the prototypes. Although more trials were preferred, the durability of the prototype was the major limiting factor in number of trials and participants. Future studies with a larger sample size are needed before any conclusions can be drawn. Moreover, we recognize implementing a cross design study where each participant intubated both simulators would provide better comparison of force application between simulators. Minor discrepancies between the two simulators were expected due to their construction with hand-made parts. With awareness of these differences, the researchers recognize there may be a difference in prototype wear and durability, possibly affecting participant experience and forces applied among the two study groups.

All study participants were selected to participate in the Orange County preceptor training academy. These individuals are selected from the Central Florida area as the top of their field to train other paramedics on skills that fall within the scope of their licensure. In addition to providing training to other paramedics, these participants are also required to complete biannual Emergency Medical Technician-Paramedic (EMT-P) licensure recertification which requires frequent training on life-saving interventions including ET intubation. According to the National Registry of Emergency Medical Technicians, paramedics are required to complete a minimum of 48 hours of continuing education training to renew their licensure with 16 of those hours focusing on airway, breathing, and cardiology (National Registry of Emergency Medical Technicians, 2016). With training frequency and participant

characteristics noted in Table 1 considered, this population was expected to be highly confident and competent in ET intubation.

It is important to note that the small sample size had an impact on overall result significance and trends. Due to this, it is difficult to predict if similar trends will be seen over a larger sample size and future studies are needed. There is potential for future studies to show significance and correlation between time since last intubation and force profiles. This information could necessitate revising training guidelines on the frequency of airway training to maintain ET intubation skills.

The first indicator of training impact evaluated was self-disclosed ability assessed before and after intubation trials. It was unknown if an increase in confidence would be seen after training with the JFAS due to the advanced skill level and demographics of the study population. As noted previously, prior to the simulation 73% of participants reported feeling very much confidence or complete confidence in their ability and skills in ET intubation. Although participants reported a high level of confidence pre-simulation, the level of confidence increased by almost 13% post-simulation with 85.6% selecting very much confidence or complete confidence. These results suggest that the JFAS had an impact as a training tool on perceived confidence. Of greatest interest were two self-disclosed ability survey questions, asking about confidence in completing the following tasks: “demonstrate the appropriate force needed to intubate a patient with a laryngoscope” and “understand how to perform an endotracheal intubation with a laryngoscope.” There was a strong, positive correlation for both of the aforementioned questions. This positive correlation suggests a positive impact on training by the JFAS as part of intubation skill knowledge, education, and assessment of appropriate intubation forces (Table 2).

Next, time to intubate was examined as an indicator of training impact. Overall, time to intubate decreased by 1.3 seconds over sequential trials, suggesting that continued training with this simulator could help medical professions reduce time to successfully complete this life-saving intervention. Although time may not be the most important factor in evaluating intubation proficiency, it has an effect on patient outcomes. Increased intubation time or multiple intubation attempts can lead to oxygen desaturation, ultimately resulting in hypoxemia without intervention. Hypoxemia and its resulting complications have been directly linked to increased patient morbidity and mortality (Bodily, Webb, Weiss, & Braude, 2016).

Lastly, force applied during ET intubation was correlated to several participant characteristics. It was hypothesized that a greater number of intubations previously performed on a living patient would correlate with lower forces applied to oral structures with the laryngoscope and ET tube. Moreover, reduced time since an intubation was last performed on living patients was expected to better correlate with lower force profiles than the total number of intubations performed. Correlations in this data could not be drawn due to lack of statistical significance, likely due to small sample size. Although statistical significance was demonstrated for forces applied to the vocal cords and esophagus, there were major inconsistencies within this force data preventing significant correlations from being drawn (Table 4).

Force profiles of five of the seven sensor locations (throat, vocal cords, epiglottis, esophagus, and trachea) were analyzed. Originally, forces applied to maxillary incisors and vocal cords were of main interest as these structures are easily damaged during ET intubation. However, sensor data was excluded from the teeth and throat plug. The data from the teeth sensors were unusable due to composition of the teeth and sensor placement within the teeth. Current design revealed an unrealistic amount of force to recognize any force applied on this sensor. Using such force on a living patient would likely result in damage to the maxillary teeth. Therefore, force data collected from the teeth sensor was not used. Force data was also excluded from the throat plug since it was an external component of the simulator design used for cricothyrotomy training. The data from the five sensors were analyzed through the second and third participant trials. The first trial was considered as practice and orientation to the simulator and was therefore excluded from data analysis. It was hypothesized that sequential trials would demonstrate less force applied to the simulator. Although there were some differences between the simulators as noted above, paired *t*-test analysis of all force data showed there was no significant difference in force applied to these structures over sequential trials as shown in Table 3. Although data trends showed little significance, consistency of the mean force data and standard deviation was noted across trials two and three, potentially indicating uniformity of sensor response across participants.

Due to the simulators being composed of cutting edge synthetic material, they were inspected frequently to ensure consistency between participants and additionally to assess their durability and potential longevity. The goal was to minimize changes in the simulators between each participant to limit the impact on the flow and quality of training provided by the JFAS. Between each participant the simulators were inspected for visible damage to ensure the integrity of the simulators and force sensors. The simulators were inspected for appropriate lubrication of the airway and ET tube along with tissue integrity. However, difficulties were still encountered during the study. Tissue durability of both simulators was a limiting factor for the number of intubations able to be conducted, restricting both the number of participants and trials. The posterior tongue in both simulators began to tear causing the laryngoscopes to get caught on this tissue. This damage prevented adequate advancement of the laryngoscope for proper vocal cord visualization, resulting in several participants commenting that this damage made it difficult to appropriately intubate the simulator.

Difficulties replicating normal human physiology were also experienced with the JFAS, mostly concerning the vallecula and epiglottis. The epiglottis is composed of cartilage and projects posteriorly from near the base of the tongue. When swallowing, the epiglottis covers the larynx ensuring solids and liquids pass into the esophagus, while preventing aspiration into the lungs. The vallecula is a depression between the base of the tongue and epiglottis used as a landmark during ET intubation. During intubation, the laryngoscope blade is advanced into the vallecula and upward pressure lifts the epiglottis to allow visualization of the vocal cords. The lift of the epiglottis is needed to advance the ET tube between the vocal cords to establish an adjunct for an external airway. Figure 7 (with permission of Aegis Anesthesia) illustrates airway anatomy associated with intubation.

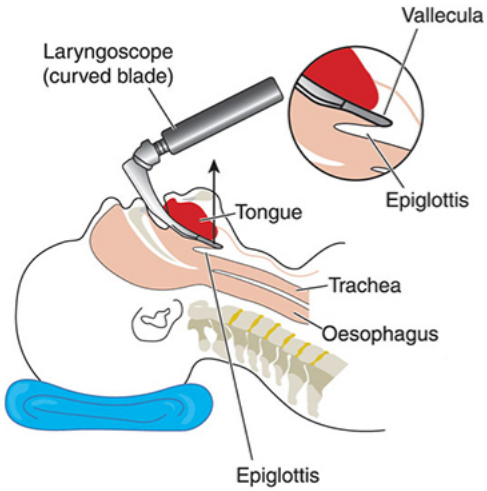

Figure 7. Airway Anatomy

Participants had difficulty visualizing the vallecula to appropriately place the laryngoscope and ET tube. Usability surveys revealed that the vallecula and epiglottis were not representative of normal human anatomy, with the epiglottis failing to rise when the participant placed upward pressure on the vallecula. Participant comments included that “there was no visualization of vocal cords which we do see on real patients” and “I was able to identify the vallecula but was not able to lift it. Never able to actually visualize the cords.” Several participants had the ET tube exit through the anterior of the trachea due to damage to the local tissues which is not representative of live patient intubation.

FUTURE WORK

This study revealed some areas of improvement for the Joint Forces Airway Simulator along with opportunities for future studies. There is a delicate balance between material durability and ability to replicate live tissue. To avoid negative training situations, further simulator design is needed to develop tissues that are durable but still life-like enough to respond similarly to normal human tissue. To improve durability and longevity of the simulator, exchangeable airway pieces would allow for easy replacement after damage from intubation. This would allow continued high fidelity training for any population size without affecting training due to equipment damage. For exchangeable airway pieces to be a reasonable consideration, cost and ease of replacement needs to be considered in future simulator design. Additionally, future design considerations with a feedback loop may be useful for students to receive automated feedback on appropriate intubation intervention placement and force parameters. Despite a few shortcomings of the JFAS prototype, there is exciting potential for this, and similar, simulators to bridge the training gap between live patients and harder, less malleable synthetic tissue alternatives.

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