



A multidisciplinary, video-based, curriculum for management of the intubated and surgical airway patient for a pediatric hospital in El Salvador

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ABSTRACT

Objective: Primary objective is to determine the rate of intubation with inappropriately sized endotracheal tubes (ETTs) in a pediatric intensive care unit (PICU) in El Salvador. Secondary objective is to determine effectiveness of a video-based curriculum to teach local providers on pediatric advanced airway management and surgical approach to patients requiring airway reconstruction.

Methods: Data for 296 intubated pediatric patients was collected over a six month period in a 16-bed PICU in El Salvador. Results of a learning behavior assessment survey completed by local healthcare workers informed a curriculum to complement on-site education during annual surgical airway mission trips. The video-based curriculum addressed proper sizing and use of cuffed endotracheal tubes, care of the intubated child and peri-operative considerations of the surgical airway patient. Providers completed pre and post-curriculum quizzes to measure knowledge acquisition.

Results: Over 6-months, 281 patients were intubated. Sixty-three percent had improperly sized ETTs. Thirty-one percent had a failed or accidental extubation. All-cause mortality was 24%. One hundred and fifty-nine Salvadorian providers completed a learning behavior survey informing a video-based curriculum. Sixty-four providers completed the curriculum. Post-curriculum quiz scores increased by 18.7%. Surgeons, anesthesiologist, intensivists and speech pathologists demonstrated significant improvement ($p < 0.05$).

Conclusion: Nearly two-thirds of intubated patients in a PICU in El Salvador have improperly sized ETTs and one-third require reintubation following planned or accidental extubation. The development of this first of its kind video-based curriculum for critical care and surgical training regarding how to properly care for the intubated child is coupled with the development of a longitudinal database to record pediatric airway related morbidity and mortality in the largest pediatric hospital in El Salvador. This model and system can be used to track the reduction in airway related morbidity and mortality directly related to a systems based intervention both in El Salvador and then elsewhere.

1. Introduction

One of the main pillars of the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, is

to ensure healthy lives and promote well-being for all. Goals have been set to reduce maternal and child mortality, provide universal healthcare coverage, vaccinations, and medications and to end epidemics such as AIDS, tuberculosis, and malaria [1]. In alignment with these initiatives,

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Table 1
Aggregate pre and post-educational curriculum assessment score.

	Mean pre-curriculum assessment score	Mean post curriculum assessment score	p-value
Surgery	4.25 (SD 1.83)	6.62 (SD 0.9)	0.008
Anesthesiology	6.14 (SD 1.67)	7.72 (SD 1.25)	0.04
Intensive Care	6.37 (SD 2.2)	9.21 (SD 1.34)	0.0001
Nursing	40.7 (SD 6.3)	46 (SD 2.75)	0.6
Speech Pathology	3.2 (SD 0.77)	4.8 (SD 1.2)	0.02

The overall head to head analysis of all healthcare providers who took a pre and post-test also showed a significant increase in their knowledge base by two-tailed, paired, *t*-test analysis ($p < 0.05$).

The Lancet Commission on Global Surgery has created a framework for addressing disparities in surgical care worldwide through the creation of local partnerships and longitudinal educational programs [2].” However, the details on how to train thousands of surgeons and physicians to care for surgical and intensive care patients in under-resourced areas remain elusive. Drs. Paul Farmer and Jim Kim have coined surgery to be the “neglected stepchild of global health [3].” The reason for neglect is straightforward: providing safe and effective surgery to this population is a large problem with tightly intertwined obstacles both known and unknown to providers. Beyond teaching surgical techniques, improvements in intensive level care, multidisciplinary preoperative evaluation and postoperative management of the surgical and intensive care unit (ICU) patient are needed. Surgical and medical education must, therefore, extend beyond learning surgical techniques and include a multidisciplinary model that serves to improve knowledge, communication and teamwork throughout the surgical continuum and ICU setting (see Table 1).

Over the last several years, there has been a paradigm shift in medical education with widespread incorporation of web-based tools into surgical training and practice [4]. Students both in the United States and abroad are using computers, tablets, and mobile devices to complement traditional learning modalities, which has expanded education opportunities well beyond the classroom. While traditional modes of learning still predominate in medical education, both simulation and web-based curriculums continue to grow in use and popularity [5]. At the University of Wisconsin, a web-based surgical educational curriculum has been incorporated into the training of surgical residents and validated by a significant increase in surgical in-training examination scores [6]. Abroad, surveys of both Turkish and Nigerian medical students suggest that there is cultural, technological and content readiness for e-learning within their medical education systems [7,8].

There have been several initiatives to teach both medical and surgical curricula in the global arena. However, differences in the availability of resources, access to care and geopolitics, make simple translation and sharing of common practices difficult to replicate across geographic and cultural borders. Newer educational models have focused on transitioning traditional modes of teaching to include the use of technology for a new generation of learners. In a study evaluating online viewership for sinus surgery both at home and abroad, online videos were noted to be a growing media for educational content and distribution [9].” However, to date, global medical and surgical educational initiatives have been based on a single discipline rather than focused on a collaborative model encompassing the care of the surgical and intensive care patient from beginning to end.

Operation Airway was created to serve the airway needs of pediatric patients globally, particularly in under-resourced areas. Its mission is to provide lifesaving surgical airway care and train local healthcare teams to provide this care and function independently within 3–5 years. In 2014, we succeeded in creating one of the first sustainable autonomous surgical airway programs in a hospital in Ecuador [10]. To create a self-sufficient and sustainable environment, this encompassed the entire

multidisciplinary team, including anesthesiologists, intensivists, and nurses, and required training through the operative continuum from evaluation to case selection to postoperative care.

During a medical mission to a children’s hospital in El Salvador in 2017 to teach local providers how to perform and care for patients requiring laryngotracheal reconstruction, we noted a recurring theme of patients presenting with acquired subglottic stenosis following prolonged intubation during critical illness. We also observed many patients with oversized, uncuffed ETTs in the PICU. We therefore sought to quantify the rate of intubations with improperly sized ETTs and to develop and assess the impact of a video-based curriculum to teach surgeons, intensivists, nurses and respiratory therapists safe pediatric advanced airway management in addition to surgical considerations during airway reconstruction. This report details the development of a multidisciplinary approach to global medical and surgical airway education in LMICs with an online multimedia educational curriculum to achieve this goal. This first of a kind video-based curriculum for critical care and surgical training regarding how to properly care for the intubated child is coupled with the development of a longitudinal database to record pediatric airway related morbidity and mortality in the largest pediatric hospital in El Salvador. Together, this enables a model and system to track the reduction in airway related morbidity and mortality directly related to a systems based intervention both in El Salvador and then elsewhere.

2. Methods

2.1. Background and setting

Operation Airway falls under the Massachusetts Eye and Ear Institute (MEEI) 501(c)3 nonprofit and is comprised of a team of otolaryngologists, pediatric intensivists, anesthesiologists, speech and language pathologists, and nurses from MEEI and the Massachusetts General Hospital for Children (MGHfC) at Harvard Medical School.

Hospital de Niños Benjamin Bloom (Benjamin Bloom Hospital for Children) is an academic, tertiary pediatric hospital in San Salvador, El Salvador. The pediatric intensive care unit (PICU), is a mixed medical-surgical unit with 16 beds. This project was undertaken as a quality improvement project at Benjamin Bloom Hospital of Children with assistance from MEEI and MGH team members and was excluded from institutional review board review per policy as non-human subjects research.

2.2. Measures of success

Over a 6-month period, we developed a database to determine the mortality rate of intubated patients in the PICU at the Benjamin Bloom Hospital of Children. As our primary aim, this database served to determine how many patients had inappropriately sized endotracheal tubes (ETTs) and to identify the risk factors that may play a role in their high mortality rates. Our secondary aim was to design, implement, and field test a multidisciplinary, multimedia curriculum to address these root-cause issues, namely management of the intubated pediatric patient and perioperative management of the surgical airway patient.

2.3. Data collection

Data was collected on all patients requiring intubation during admissions from June 2018 to January 2019. Variables included age, weight, sex, admission diagnosis, date of intubation and extubation, size and type (cuffed vs. uncuffed) of endotracheal tube (ETT), accidental extubations and reintubations, tracheostomy placement and ultimate patient disposition (including mortality). Data were stored in a password protected spreadsheet in Microsoft Excel. ETT sizes were compared to the age-based formula for proper sizing [11,12].

2.4. Online multidisciplinary multimedia curriculum and learning assessment

An online multidisciplinary, multimedia curriculum accessible from a mobile device, tablet or computer was created in English as well as in Spanish. Target audience included otolaryngologists, pediatric residents and attending physicians in the PICU, anesthesiologists, respiratory therapists, nurses, and patient parents Each content section was designed by members of that field with their local counterparts in mind (ie. US Otolaryngologists wrote the curriculum for local Otolaryngologists as they would sections to train medical students and residents, US ICU doctors wrote the ICU sections, etc). For the parent education curriculum, a focus group of parents were brought together to help build this curriculum in a way designed to be both understandable and informative. Before the mission, a list serve was used to recruit all potential learners by email. Participants were asked to complete an online learning behavior assessment survey to convey their preferred modes of learning centered around their needs. Respondents were asked which modes of learning they prefer (and were able to select all that apply) from a list of textbooks, medical journals, presentations, video modules, classroom and bedside teaching. During the mission, Operation Airway team members actively recruited learners to complete the curriculum with the aid of i-pads. After the mission, Salvadorian medical staff identified as “champions of change,” continued to recruit learners to complete the curriculum.

The curriculum was constructed in the form of PowerPoint presentations (Microsoft, Seattle, Washington) and video modules with embedded textbook and journal article references. These online modules were reviewed for accuracy by content experts at MGHfC and MEEI. Clinicians could select teaching modules most relevant to their area of practice. Although each module was targeted to a specific provider type (i.e bedside care of the intubated patient was labeled for nurses and RTs), pre and post-curriculum assessments did not vary between level of provider. Before initiating a module, a pre-curriculum assessment test was required and after module completion, a post-curriculum assessment test assessed knowledge gain with a score to track improvement. A two-tailed, paired, t-test was used to compare pre and post scores. A value of $p < 0.05$ was used to determine statistical significance. For quick bedside learning and reference, QR codes were posted to directly link the learner to the desired video module. The website material and videos are displayed and recorded in both English and Spanish.

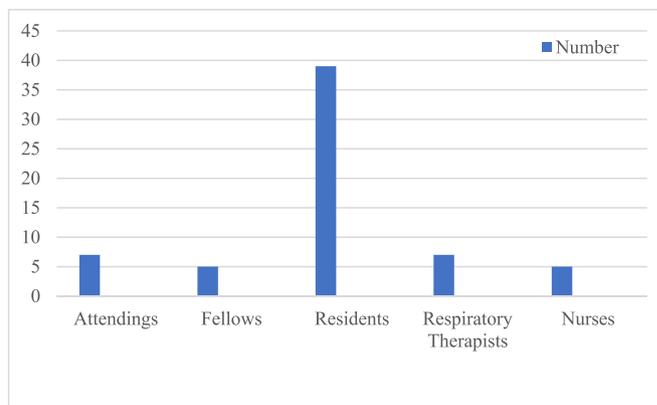
The curriculum focuses on care and management of the intubated pediatric patient in the intensive care unit. Specific modules are aimed at teaching management of cuffed ETTs (such as how to intubate with a cuffed ETT and measuring cuff pressures using a manometer). For the surgical curriculum, modules include operative and perioperative care of the surgical airway patient. The curriculum is available online at: <https://operation-airway.meei.harvard.edu/>.

3. Results

3.1. Database of patients

A total of 296 patients were intubated in the reviewed period. There were 180 boys and 116 girls (mean age: 3.58 years; standard deviation 4.06). Fifteen patients were excluded for incomplete data. The most common diagnoses were pneumonia (n = 142), sepsis (n = 41) and traumatic brain injury (n = 39). Twelve patients during this time period necessitated tracheotomy placement.

Of the 281 included, 242 were intubated with an uncuffed ETT and 39 with a cuffed ETT. A total of 177 patients (63%) had improperly sized ETTs which were generally oversized by half a size or more. Of the patients that were intubated with a cuffed ETT (39), 19 (49%) were improperly sized. Reintubation was required in 86 patients (31%) for failed or accidental extubation. All-cause mortality was 24%, with the



Graph 1. Total respondents of learning behavior assessment.

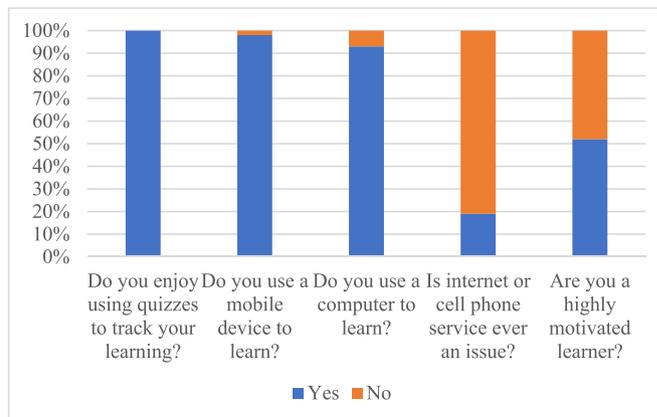
majority of deaths due to pneumonia (n = 36) and sepsis (n = 23). Eighteen of the 70 mortalities had a history of multiple intubations.

3.2. Learning behavior assessment

A total of 211 Salvadorian providers were emailed to register for the curriculum via an automated notification feature from the Operation Airway website. A total of 62 clinicians completed the learning behavior assessment survey as noted in Graph 1. Approximately 90% reported two hours or less of learning per day, with the majority (37%) reporting 30–60 min spent learning per day. Only 8% reported multiple hours learning per day. All reported utilizing multiple modes of learning; 51 (82%) video modules, 41 (66%) textbooks, 35 (56%) presentations, 32 (52%) medical journals, 27 (43%) bedside teaching and 20 (32%) classroom.(Graph 2)

3.3. Pre and post-curriculum assessment results

Of the 211 providers emailed, 159 of the multidisciplinary staff took the pre-curriculum assessment with an average knowledge score of 62.5%. While staff may then have completed the associated learning modules, only 64 completed the post-curriculum assessment for an average score of 81% and average change of 18.7% (therefore the overall head-to-head analysis of all health care providers who took a pre and post-test also showed a significant increase in their knowledge base by two-tailed, paired, t-test analysis ($p < 0.05$). When the results for the 64 healthcare participants who completed both pre and post-curriculum assessments were evaluated, learners in the areas of surgery, anesthesiology, intensive care and speech pathology demonstrated significant improvement ($p < 0.05$).



Graph 2. Learning behavior assessment results.

4. Discussion

4.1. Risk factors for high mortality rates and morbidities associated with intubation

It is the overarching mission of Operation Airway to teach airway surgery across the operative continuum so that local medical teams can perform independently in 3–5 years. Through pre-operative screening evaluations, we have learned that the majority of patients in need of airway surgery have a history of prolonged intubation for a variety of reasons. This led us to create a database of intubated patients in this PICU to further understand this population. The database illuminates the fact that 24% of intubated patients die in this unit. This far exceeds the unadjusted mortality rates of less than 5% reported by PICUs in the United States and other developed countries [13–15].

We believe there are several factors contributing to the high rates of airway morbidity in intubated patients in the Salvadoran PICU studied. It has previously been shown that intubation complications such as acquired subglottic stenosis are associated with 1) prolonged, traumatic and multiple intubations; 2) uncuffed and improperly sized ETTs; and 3) under-sedation allowing patients to move excessively [16–22]. Our data suggest that patients intubated in this PICU are subject to many of these risk factors. Use of oversized, uncuffed ETTs, a high rate of accidental extubation and inadequate sedation all may contribute to airway damage that eventually necessitates airway reconstruction. Thirty-one percent of the patients in our database required reintubation for failed or unplanned extubation. In contrast, unplanned (accidental) extubation rates in the United States have been reported between 0.4 and 1.2 per 100 ventilator days and failed extubation rates have been described to be 8.3% [23–25]. Furthermore, of the 70 patients who expired, 18 (26%) had multiple intubations which may have contributed to the high mortality rate as tracheal intubation is a high-risk procedure known to result in significant morbidity and mortality.

Our preintervention data suggest that the majority of ETTs are improperly sized (63%). Further investigation reveals that the majority of ETTs are uncuffed (86%) and that uncuffed ETTs are often upsized to seal large ventilator circuit leaks preventing delivery of adequate tidal volume. The predisposition to use uncuffed ETTs can be attributed to cost and resource availability. Compounding this issue is the lack of other resources such as manometers to measure cuff pressure. Lastly, changing hospital-wide culture around the use of cuffed ETTs takes time and education.

4.2. Multidisciplinary, multimedia educational curriculum

The challenges of developing a global medical or surgical curriculum are multifactorial and include obstacles of time, language, distance, cultural barriers and sustaining learner motivation. We believe the solution to many of these obstacles is the development of an online curriculum to sustain learning even after a mission team leaves. After identifying risk factors such as widespread use of uncuffed ETTs, improper sizing of ETTs and high rates of unplanned extubations, we have created an educational curriculum to address these root causes of airway related complications. Our data suggests that this online, multimodal curriculum is an effective teaching tool that can compliment learning during and between mission trips. We hope that by focusing on management of the intubated patient we can prevent airway related complications that may necessitate future airway surgery. We are currently developing a database that will help determine the incidence of subglottic stenosis in this population.

While being cognizant of available resources, the curriculum focuses on 1) proper use and sizing of cuffed and uncuffed ETTs; 2) best practices for securing the ETT and preventing dislodgement during care; and 3) proper use of sedation to minimize head movement. For those patients requiring airway surgery, our curriculum also teaches the preoperative, operative and postoperative care of these patients.

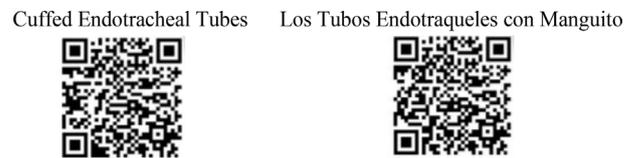


Image 1. QR codes for cuffed endotracheal tube teaching (English and Spanish).

Examples of current modules include airway reconstruction surgical technique, operating room set-up (surgical and anesthesia), and post-operative PICU care considerations. We believe this online multimedia, multidisciplinary educational curriculum will address knowledge gaps identified by the local healthcare team and, coupled with efforts to acquire and utilize cuffed endotracheal tubes, may improve outcomes.

4.3. QR codes

The use of QR codes is an easy way to quickly access material. QR codes can be posted in resident rooms, nursing stations and OR suites. Videos and presentations can be viewed multiple times to consolidate learning. For patients requiring tracheostomy, we have also created simple teaching videos on topics such as suctioning and changing the trach. These videos empower parents and patients to be involved in their own healthcare and we believe are an essential and novel way to impact lasting change. (See [Image 1](#))

4.4. Limitations

Only 64 of the 159 medical staff who completed the modules also completed the post curriculum assessment. We hypothesize that this may reflect an unfounded hesitation that post-curriculum scores would be reported to the head of each department. For future modules, we will include a statement that reiterates that all scores are kept confidential. Furthermore, the use of pre and post-curriculum test scores as a measure of success of our multidisciplinary, video-based, curriculum is limited as knowledge acquisition may not necessarily lead to change in practice. To address this challenge, we have identified “champions of change” in the areas of surgery, anesthesia, intensive care, nursing and respiratory therapy. These individuals not only serve to strengthen the bond between our two institutions but to help ensure what is being taught during our medical missions and through the online curriculum reaches the bedside. This study was designed as a pilot study or proof of study to demonstrate that local problems such as lack of education and multi-disciplinary team care could be identified as sources of increased morbidity and mortality and then that a multi-lingual, multi-disciplinary, video based curriculum could be designed, implemented, and be well-received. Since this implementation, we have supported continued systems bases, process, and educational improvement through monthly, multidisciplinary teleconferences with our partners to discuss difficult cases, identify patients who may benefit from early tracheostomy and promote team building. We take as a significant sign of success the local enthusiasm for the curriculum, how much additional content we have been asked to provide, and the local level of enthusiasm for this year's pending mission. All that being said, we recognize that the true impact of our interventions will be borne out over a longer period of time as we continue to track data on airway complications and PICU mortality.

We also realize that airway related complications do not occur solely in the PICU but also throughout the hospital and even in the homes of our patients. Home tracheostomy care is extremely limited in LMICs. In the U.S., we have published standards for home tracheostomy care that include learned suction techniques, frequent trach changes (to avoid plugging the cannula) and access to home equipment such as suction devices and catheters [26]. The lack of parental and patient

home education and limited home resources are risk factors for airway related complications that may occur at home. An educational curriculum that includes patients and families is a novel approach to establishing a more comprehensive model for overall airway care and may further reduce morbidity and mortality. Future work will be to collect epidemiologic data on the number of children in El Salvador who have tracheostomy-related airway complications at home. This data will help us understand the root causes of at-home complications and guide future interventions.

The impact of our multi-modal curriculum is limited by the current lack of a steady supply of cuffed ETTs at this institution. As previously mentioned, the cost of cuffed ETTs is higher than uncuffed ETTs and to date has precluded their widespread availability. Studies have shown that in both pressure and volume-regulated ventilation, uncuffed ETTs have a higher circuit leakage than cuffed ETTs and therefore cuffed ETTs have better ventilation characteristics compared with uncuffed tracheal tubes [27]. The Salvadoran intensivists frequently struggle with large airflow leaks around uncuffed ETTs leading to ETT upsizing in an attempt to “seal the leak.” This practice results in significant morbidity from repeated airway manipulation and decreased capillary perfusion causing ischemia and fibrosis of the airway from oversized ETTs. For these reasons, it will be important to help this institution acquire cuffed ETTs. Once again, while the cost of cuffed ETTs is higher than uncuffed ETTs, we believe this cost will be offset in the long run. We predict that the use of properly sized ETTs with low-pressure high-volume cuffs will reduce airway trauma leading to decreased costly morbidity and possibly reduce length of stay by improving respiratory mechanics. Together with our Salvadoran partners, we are currently working to change hospital purchasing practices and explore other sustainable solutions to this resource challenge.

4.5. Future directions

We believe that the future of global medical and surgical education lies in the development of an easily accessible, multimodal, online curriculum that can be used to supplement learning between mission trips. Future work will focus on expansion of our curriculum to include new teaching modules based on feedback from the local healthcare providers and identification of sustainable solutions for resource acquisition, including cuffed ETTs and manometers. While this is only the beginning of our journey documenting our experience in creating this curriculum, we will continue to collect data on the use of cuffed versus uncuffed ETTs, use of appropriately sized ETTs, rate of failed and accidental extubations as well as rate of acquired subglottic stenosis and mortality over time to know whether our interventions have led to true change. The development of this first of its kind video-based curriculum for critical care and surgical training regarding how to properly care for the intubated child, coupled with the development of a longitudinal database to record pediatric airway related morbidity and mortality in a the largest pediatric hospital in El Salvador, enables a model and system to track the reduction in airway related morbidity and mortality directly related to a systems based intervention both in El Salvador and then elsewhere.

Declaration of competing interest

None.

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