Automatic Data Collection System and Video Laryngoscope Database

Gabrielle Hoyer, Sean Runnels, Samer Merchant, and Kai Kuck.
Departments of Anesthesiology and Biomedical Engineering, University of Utah

Abstract— **The aggregate intubation data collected by a network of video laryngoscopes can be processed to understand the quality of an individual's or a group of individual's practice(s). Currently, all data surrounding intubations is self-reported and not understood on an aggregate basis. We are developing a technology which can enable monitoring and benchmarking of intubations across a wide variety of practices.**

Index Terms **— intubation, laryngoscopy, trachea**

I. Introduction

Intubation is dangerous and frustratingly difficult to get right; Annually, a considerable amount of intubations in the U.S. require three or more attempts, and some of these difficult intubations may result in patient death. Complication rates increase dramatically with multiple intubation attempts; it is paramount that first-pass intubations succeed [1]. Laryngoscopy allows a health care provider a view of the throat, specifically the region of the vocal folds. The procedure is often performed to assist in intubation, the delivery of a tube directly to the airway through the vocal folds; this is used to provide mechanical ventilation to the patient. Laryngoscopy tools were developed over 75 years ago and were later augmented with a camera and a screen to allow the caregiver a visualization of the airway.

The additions of optics created a leap in laryngoscopy technology. The developments ameliorated the critical weakness of traditional laryngoscopes: the lack of visualization of the vocal cords and esophageal region during intubation [1, 2]. However, when comparing first-pass success rates (the ability of the health care provider to place a tube in the airway on the first try) using video vs. direct laryngoscopy, the outcomes vary. Some studies indicate an improved first-pass success rate [3] while others show little to no benefit [4, 5]. Furthermore, some studies have even indicated an increased risk of complications with video laryngoscopes [4, 6]. Effectively, studies have demonstrated that the core goal of laryngoscopy or "first-pass success rate" was not significantly impacted by these developments. It should be noted that the studies reporting positive results with the use of the video laryngoscope allowed users to choose their method, direct or video laryngoscopy; however, studies that assigned the intubation method randomly to users, reported decreased success rates.

Interestingly, studies have shown that video laryngoscopy led to a greater increase in first-pass success rate for inexperienced healthcare providers [3], such as emergency medical technicians (EMTs) and first- and second-year emergency room (ER) residents. Indeed, these individuals must often perform intubations in high-stress situations with limited guidance and must act as first-responders. Mistakes that often occur with inexperienced healthcare providers include insertion of the endotracheal tube into the esophagus or inserting the tube through the vocal folds at the incorrect depth leading to low levels of oxygenation for the patient. Additionally, a stressful situation may cause the healthcare provider to lose track of time when performing a difficult intubation; it is imperative that the intubation process is done promptly or the patient may suffer brain injury or death. Indeed, it is difficult to successfully perform an intubation on a first pass and patients are more likely to experience complications if intubation is not done correctly.

The risk of complications increases dramatically with every failed intubation [7], thus it is essential to correctly place the intubation tube into the trachea on the first attempt. Less significant complications, such as tracheal injuries, can cost a hospital $2,000, and a patient approximately $11,000 if readmission to the hospital is necessary [8]. Additional complications include brain damage or death, which may cost hospitals millions of dollars in compensation [9]. This is in addition to the patient's suffering. Therefore, it is in the best interest of patients, hospitals, health care professionals, and insurance providers that intubations succeed.

A. Airway Data Retention

Currently, the data surrounding these millions of procedures cannot be collected or processed. The video laryngoscope is used to indirectly visualize the vocal cords during these procedures. The high-fidelity digital video used to visualize the procedure is used only tactically to intubate the patient. It is not recorded, archived, or processed. This project was aimed at automating the recording and archiving of video-assisted intubations and then processing the data for various documentation and educational purposes. Strategically, the recordings can be databased and processed to surveil intubation quality and quantity at any level ranging from individual performance over time to departmental, medical system, or even national or worldwide performance. Currently, there is no practical ability to surveil this critical procedure at any of these levels.

II. Methods

A. Data Collection Device

In order to build an airway management dataset, an automatic data collection system was designed and rolled out in the University of Utah hospital. The device was designed to be compatible with a variety of video laryngoscopy systems to collect high-fidelity video data without needing to interact with health care providers [15]. In this way, data is collected more consistently, and the workload of providers is not affected.

The device includes a microprocessor that can store only limited amounts of data at any one time. Hence, a system was developed to automatically upload the procedural data from the device to our server each day. The data from that day would then be cleared from the device, preparing it to collect new procedural data for the next day.

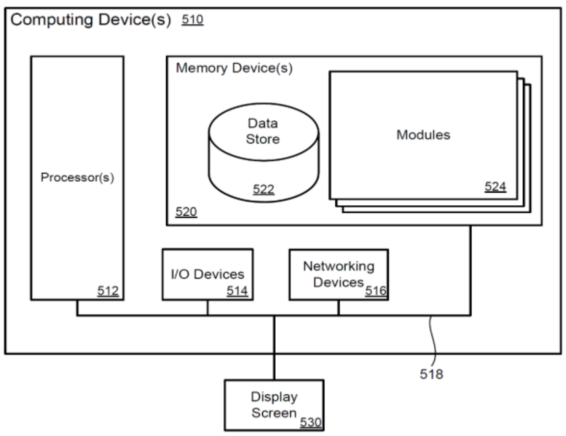

Fig. 1. System to collect, store, and send procedural data to data management system for future processing. System device connects to video laryngoscope tower.

B. Data Processing and Annotation

Once the data was collected by the device, the data was stored in a secure, HIPAA-compliant workstation, and ready for processing. Videos were split into frames, and redundant frames were removed. Furthermore, frames with patient identifiers were removed.

The image frames were saved in their raw form, and further prepared for analysis and machine learning techniques. An annotation team consisting of senior medical students, anesthesiology residents, and anesthesiologists was formed to annotate images from intubation videos. Each annotator would be assigned a set of images to identify and label features. These features include airway anatomy such as the epiglottis, arytenoids, vocal folds, as well as airway management tools such as an endotracheal tube and introducer. Additionally, features to be labeled included indicators of trauma such as blood and bruising.

Each image was classified by two annotators, one to identify anatomical features and place bounding boxes around them, and another to tighten or correct the location of the label bounding box. In this way, a database was created, and two datasets were developed for neural network training. There was a small initial dataset composed of 32 intubations which contained ~280 images with 4 classes, and a large dataset composed of 114 patient cases which had ~1700 images with 11 classes. The large dataset was composed of 1459 instances of the epiglottis, 1756 instances of the vocal cords, 963 instances of an endotracheal tube, 1689 instances of arytenoids, 190 instances of an introducer, 108 instances of the trachea rings, 142 instances of blood, 100 instances of an NG tube, and 108 instances of the esophagus.

Furthermore, a third dataset was formed by performing augmentation techniques on the large dataset. Specifically, the color, hue, and saturation of images within the dataset were randomly altered to introduce additional variability into the dataset, which could not be naturally collected from the intubation procedure. Such augmentation to the data could improve the performance of the object detection models, thereby leading to improved real-time guidance cues and assistance to healthcare providers. The datasets were split into training and testing sets composed of 90% and 10% of the datasets, respectively. Testing the predictive performance of a trained network was done on test set images, i.e., images not utilized in training.

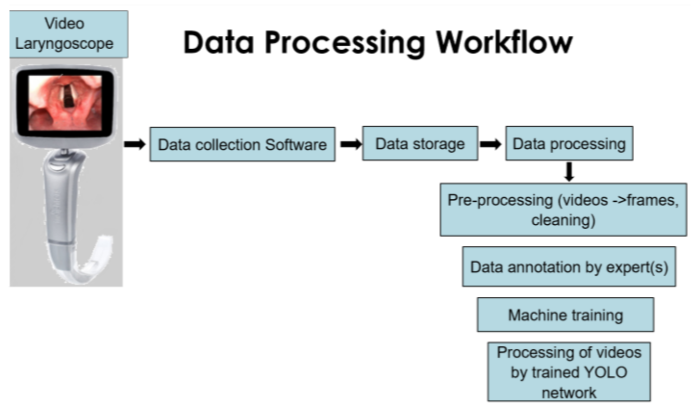

Fig. 2. Workflow of collecting, storing, and processing procedural, high-fidelity data from VLs for machine learning.

C. Intubation Database

The intubation database exists on a University Hospital secure server and includes intubation image data and associated metadata from each step of the analysis. The database includes raw video data without patient identifiers, raw image frames from these videos, and annotated image frames with labels. Moreover, the database maintains the data in a format compatible with machine learning and other statistical analysis tools. The database includes the annotated data with notes describing procedure events, as well as outputs of machine learning models; these outputs are stored and used for quality assurance, training, etc. This picture archiving and communication system was developed, and security measures were established to ensure proper data management.

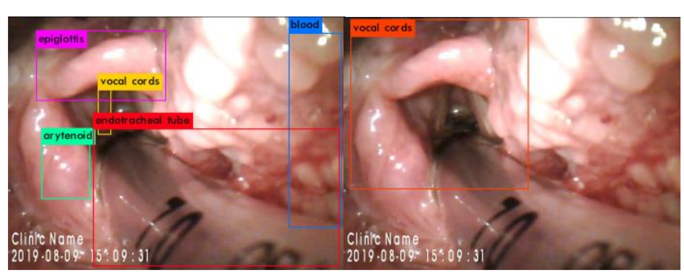

Fig. 4. Images displaying anatomical features with overlaid predictions made by deep learning network, trained on images within the intubation database. Images with predictions stored in database.

III. Conclusion

A. The Potential of Data

This project advances knowledge by enabling, for the first time, automated collection and archiving of high-fidelity data for tracheal intubation procedures in aggregate. This data will enable basic research to take place to improve intubation outcomes through better clinical research, quality assurance, training feedback, and execution of the procedure. The lack of data related to tracheal intubation is currently the rate-limiting step to rapidly advancing to higher quality outcomes. We aim to build this system as it is necessary to improve access to safe airway management at a lower cost worldwide. The key mechanism to attain this goal is to obtain consistent high-quality outcomes with less training and skills. Data is critical to achieving this goal.

B. Limitations

Amidst the COVID-19 pandemic, our team has been limited in its ability to further progress with the project, particularly in the building and implementation of our automatic data collection devices in the hospital system. As a result, our rate of data collection has decreased. When a particular data collection device requires upkeep, there may be an extended delay to when a member of our team can enter the hospital environment to ensure the automatic data collection and storage of said device. Our team continues to work remotely to create a better automatic data collection system and video laryngoscope database.

At the same time, the pandemic has shown the importance of broadening the personnel that is capable of performing safe and successful intubations.

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