Design of Airway Management Training System

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Abstract - Airway management is done by emergency medical technicians (EMT) or anesthetists in order to save unconscious patients who can not breathe by themselves in case of an emergency or during a surgery. In particular, during Tracheal Intubation (TI), EMT who has little experience may damage inner skins or tissues (such as larynx, pharynx, tongue, vocal cord, and trachea) through the application of excessive force. Moreover, when the laryngoscope places excessive pressure on the front teeth, they can be easily broken. As a result, the patients suffer from trauma after TI causing patients to develop complications. In order to prevent any complication, trainees should practice TI to improve their skills using Airway management devices (i.e. mannequins). The airway management mannequins have been developed by many companies in order to train EMT to perform TI. However, such devices can not provide any quantitative information of trainees' performances during TI; which greatly limits the understanding of their progress. In this paper, we propose the Airway Management Training System (AMTS), which not only realistically represents human tissues, but it may also provide information about how trainees are performing the task. The design concept of the AMTS will be described as well as the way sensor were placed in different configurations to detect the force applied by trainees. We expect the ATMS will play an effective role in providing useful information about how to train better trainees.

Keywords- Airway Management, Tracheal Intubation, Emergency Medical Technicians, Mannequins

I. INTRODUCTION

A. Necessity of Airway Management Training

Airway management is a basic skill in an emergency situation such as cardiopulmonary arrest, multiple injury, unconscious condition, and general anesthesia. Airway management should be not only managed in order to supply oxygen into the lung, but also prevent the lung from gastric foreign body and bleeding due to an external wound [1].

Airway management is normally managed by anesthetists due to their highly experience. In contrast, emergency medical technicians are able of operating the Airway management only by the supervision of a doctor. However, many patients’ life could be saved by emergency medical technicians if they were able of performing Airway management before patients are operated. Quite in the contrary, many patients may die if unskilled persons manage Airway management. One of the most critical problems while administrating Airway management is the esophageal intubation. Esophageal intubation occurs in case the vocal cord in the larynx is not visualized by the operator’ sight when pharyngeal portion of tongue is lifted up through Laryngoscope. As a result, oxygen cannot reach into the lungs and patients died due to lack of oxygen [2].

Different complications may be found after a tracheal intubation (TI) is done by an unskilled person [3]. In fact, TI may cause damages to skins or tissues such as larynx, epiglottis [4]. Furthermore, cuff’s excessive pressure on the trachea made mucous membrane of airway traumatized. Finally, the application of laryngoscope may break the front teeth and oral cavity such as tonsil and tongue to be injured [5].

B. Problems of Airway Management Mannequins

Fig.1 Airway Management Training with mannequin [6]

Fig.2 Mannequin for Airway Management (Laerdal co., Ltd.)
As a result, in order to prevent all of these problems; Airway management is performed only by skilled and experienced anesthetists (Figure 1).

Emergency medical technicians are trained to operate Airway management by using mannequins (Figure 1). Actual mannequins, which have been developed by several companies (Figure 2), have realistic anatomy, tissue, and skin. Expensive mannequins (Figure 3) have a lot of functions such as difficult airway, they provide realistic situation, and it is possible for them to keep their hand in operating airway management.

Even if mannequins can simulate nearly the human body; such devices cannot provide any kind of information about how trainees are actually developing their skills. Such information can be useful for understanding better how they should be trained to avoid any mistake during their operation with patients.

For that reason, we have proposed the addition of sensors to the mannequins as a mean for understanding quantitatively how they are performing the task. In particular, it is important to detect when trainees may damage, while performing tracheal intubation, inner skins or tissues such as larynx, pharynx, trachea, tongue and vocal cord; as well as the incisor teeth while performing laryngoscope [8]

In order to develop the developed Airway Management Training System, in this paper, the design of a sensor system which is embedded to a mannequin is presented. The sensor system will enable the detection of the force applied by trainees to the simulated organs of the human while performing tracheal intubation and laryngoscope.

II. DESIGN CONCEPT

The prototype of the Airway Management Training System (AMTS) is shown in Fig. 4. A mannequin which is normally employed by EMT was used as a base for the development of the AMTS. Such mannequin simulates the anatomy of the human body.

The sensor system of the AMTS was designed to be as small and cheap as possible. The sensor system should be able of providing two kinds of information: force detection and position/object detection. The force detection is useful for detecting when a damage of the tongue, vocal cord or trachea is done while performing Airway management. Therefore, a Force Detection Sensor System (FDSS) was embedded into the tongue, vocal cord, epiglottis, incisor teeth and trachea of the mannequin.

The position/object detection is useful to detect whether the tracheal tube is inserted or not in the esophagus or bronchitis. Therefore, a Position Detection Sensor System (PDSS) was embedded into the esophagus and trachea of the mannequin.

One of the principal problems of embedding the sensor system into conventional mannequins is that such kinds of devices are not designed for having any kind of sensor. Therefore, we designed partially the mannequin’s upper airway such as trachea, vocal cord, and incisor teeth to be suitable for embedding the sensor system.
III. SYSTEM DESCRIPTION

A. Design of Sensor Systems

1) Design of Force Detection Sensor System (FDSS)

FDSS consists of 3 layers such as transparent gel, white adhesive tape, and photo interrupter as shown on Fig. 5. The SG-105 photo interrupter combines a GaAs IRED with a high-sensitivity phototransistor in a super-mini package with dimension of 2.7[mm] x 3.2[mm]. By using this sensor, we can reduce the installation space and increase the two-point-discrimination-threshold (TPDT) that is the minimum distance with which we can distinguish a two-point contact as two [9]. Light was emitted from GaAs IRED and reflected by the white seal of transparent gel placed above the photo interrupter because white adhesive tape reflects light from GaAs IRED. Then, reflected light will be collected by phototransistor. When the distance between photo interrupter and white adhesive tape become closer, reflected light volume become large. The electric current that flows inside the phototransistor will increase in proportion to the reflected light volume. By using this mechanism, we can sense the upward and downward movement of transparent gel due to the applied force from trainees. By using an A/D converter, the information obtained from the sensor can be processed by a computer. In our case, the A/D converter (from CONTEC) has a maximum conversion speed of 2[μm].

2) Design of Position Detection Sensor Systems (PDSS)

In order to detect the position of an object, it is required use of two photo interrupters as it is shown in Fig.6. At first, light is emitted from GaAs IRED of photo interrupter A; while the photo interrupter B collects the light emitting from the source, and vice versa. Based on this principle, the PDSS was designed. The PDSS works as follows: in the absence of any object between both photo interrupters, their electric currents that flow inside them will not change and be maintained because the light emitting from each of photo interrupter’s GaAs IREDs is collected by each of phototransistors without changing the light volume. On the contrary, when any object is place between the photo interrupters, the electric current that flows inside the phototransistor will change because the light emitting from each of photo interrupter is reflected by the surface of the object, and the electric current that flows inside the phototransistor will increase in proportion to the reflected light volume. By using this mechanism, we can sense the position of an object. The data obtained from the PDSS was also processed using an A/D converter from CONTEC.

B. Design of Upper Airway for Sensor Systems

1) The Vocal Cord

During Airway management, the vocal cord may be traumatized when is practice by unskilled persons. As a result further complications may appear such as hoarseness and vocal cord sequelae after tracheal intubation. Many patients appeal to hoarseness and vocal cord sequelae after extubating endotracheal tube [3]. Furthermore, when extubating the ET from the trachea, unskilled persons may extubate it with its cuff inflated. As a result, critical injuries may be caused to the vocal cord and trachea [3].

In order to avoid such situations, trainees during the training process are requested to intubate the ET into the vocal cord using a stylet. A stylet is made of plastic or gum-elastic and has a 1-cm, 30-degree deflection of distal tip (Figure 7). The tip deflection enhances the anterior movement of the distal tip underneath the epiglottis, maximizing the chance it will pass into the glottis and hence the trachea (Figure 8).

In order to understand better how trainees are performing improving their skills, it is desirable to detect the applied force on the vocal cord. Therefore, a FDSS should be embedded on the front and back sides of the vocal cord. However, the vocal cord of conventional mannequins has a complex structure which may require the use of a complex array of sensors. Furthermore, such a vocal cord has low stiffness which may difficult the correct measurement of the applied forces.

200mm
Therefore, we have designed a new vocal cord which has a more simply structure and it is made by acrylic resin which is characterized by its high stiffness (Figure 9).

Thanks to this property, the force applied by the ET can be easily measured. The measurement can be done by placing one FDSS on the front side of the vocal cord and the other one on the back side. Using such array of sensors, we are able of detecting not only the force which is applied by the ET on the vocal cord, but also for detecting repeated intubations.

2) The Tracheal

After intubating the ET into the vocal cord, the cuff of intubation tube is inflated by the air pressure supplied by an injector (Figure 10, 11). The role of cuff is to prevent the lung from any gastric foreign body or bleeding from the oral cavity [1]. When unskilled persons realize this process, it may happen that the cuff is so inflated that the mucous membrane on the trachea may be traumatized [5]. Complications may appear when the cuff exerted pressure on the trachea and when the cuff is being inflated with the intubation tube which is leaning on one side of the trachea [5]; as it is shown in Fig. 11.

Before inflating the cuff, the ET’s tip is placed inside the trachea passing through vocal cord. As soon as the position of the ET’s tip reaches the black line marked on the tube, the cuff of the ET is inflated (Figure 10, 11). If the vocal cord is visualized by the operator through the laryngoscope, it is really simple to do this procedure. However, in practice, the vocal cord cannot be observed through the laryngoscope, so that unskilled emergency medical technicians often make the tip of tube positioned in one side of the bronchi. As a result, oxygen is supplied to the one side of the lung which is seriously damaged [1].

In order to avoid all the situations mentioned above, it is desirable to detect such conditions while trainees are learning by embedding sensors on the mannequin’s trachea.

However, the low stiffness of the material of the trachea of mannequins may affect the measurements obtained from both FDSS and PDSS due to external forces. Therefore we propose new design of the trachea which is shown in Fig. 12. Thanks to the design and arrangement of sensors, it is possible to detect the cuff’s pressure. The array of sensors is as follows: three FDSSs are placed at an angle of 120 degree on the inside surface of cylinder, and arranged in eight columns. When cuff is contact with the part of such sensors, it is possible to detect when the cuff is in contact with the trachea. Furthermore, by using PDSS, it is possible to detect the position of the tip of the ET. For that purpose, six PDSSs are placed along the trachea as shown in Fig. 13.

3) The Tongue and Epiglottis

In emergency situations, it is important to have a laryngoscope technique that is safe and simple to perform, consistent and universally applicable to every clinical situation. The airway course technique of laryngoscope and intubation that will be described below is traditionally
associated with the use of a straight blade (other shapes can be also considered). In the first stage of this technique, the laryngoscope blade is fully inserted blindly, but gently, into the esophagus. In the second stage, the blade is slowly withdrawn from the esophagus under direct vision to expose the glottis, then the epiglottis (which can be picked up with the tip of either blade, providing maximum laryngeal exposure for successful intubation), and finally the base of the tongue (Figure 14).

The traditional technique of inserting a curved blade into the vallecula and then, compressing it to flip the epiglottis forward while lifting the tongue into mandibular space [13]. This process may require several visual checkpoints when it is realized by unskilled persons and it may require more time to perform it, especially in an emergency [13]. Therefore, when emergency medical technicians with little experience make cause injuries to the base of tongue and epiglottis due to excessive applied force [3].

Mannequins have a simulated tongue which is fixed, so that is practically impossible to be controlled by using the laryngoscope like human’s tongue. As a result, it is difficult to measure the applied force on mannequin’s tongue by the laryngoscope. Therefore, we have design a new tongue and epiglottis similar to the human one which can enable the measurement of the forces applied on the base of the tongue and the epiglottis (Figure 14). For that purpose, an array of FDSS was placed on the surface of them (Figure 15).

4) The Esophagus
In emergency situations, it is also important to understand how the esophageal intubation is realized. It often happens in difficult laryngoscope and intubation. In fact, operators have a limited view of the target (i.e. the
As a future work, depending from the results of the planning to embed more sensors in other parts of the
perform experiments in order to collect data from several
patient’s teeth may be broken [4]. If the broken teeth enter
positioned there, the voltage measured from the sensor
experiments realized, further improvements of the design
of the sensor system may be required. Furthermore, we are
have not yet perform experiments with the proposed
indexes that may be significant to understand the problems
of trainees while performing the task. From the analysis of the collected
way for quantitatively analyzing the human performance as
that from such experiments, we could figure out the best
anesthetists and medical students while performing the
have designed a new incisor tooth which contains
measured using the FDSS; however, the mannequin's teeth
to the glottis, serious complications may happen. Therefore,
device for measuring the applied force on the incisor
to the glottis (or esophagus) so operators use a stylus
to the laryngoscope blade, and exert excessive force on them (Figure 18). As a result, the
the patient’s teeth may be broken [4]. If the broken teeth enter
to the glottis, serious complications may happen. Therefore,
it is important to measure the applied force on the incisor
tooth while trainees are learning. Such a force can be
measured using the FDSS; however, the mannequin’s teeth
have no space for embedding a sensor. Consequently, we
have designed a new incisor tooth which contains two
FDSSs, as it is shown in Fig. 19. By using them, we can measure the applied force exerted on the tooth when the
laryngoscope blade is used.

5) The Incisor Teeth

Operators when actuating in an emergency situation,
they often lift the base of tongue in the wrong way of using
the incisor teeth as fulcrum for laryngoscope blade, and
exert excessive force on them (Figure 18). As a result, the
patient’s teeth may be broken [4]. If the broken teeth enter
to the glottis, serious complications may happen. Therefore,
it is important to measure the applied force on the incisor
tooth while trainees are learning. Such a force can be
measured using the FDSS; however, the mannequin’s teeth
have no space for embedding a sensor. Consequently, we
have designed a new incisor tooth which contains two
FDSSs, as it is shown in Fig. 19. By using them, we can measure the applied force exerted on the tooth when the
laryngoscope blade is used.

IV CONCLUSION

In this paper, the design of the sensor system as well as
the design of some of the parts of the upper airway system
of a mannequin has been detailed. The proposed sensor
system was designed to detect the position and applied
force by using arrays of photo interrupters.

At this moment, due to the busy schedules of anesthetists,
we have not yet perform experiments with the proposed
system. However; in the near future, we have scheduled to
perform experiments in order to collect data from several
anesthetists and medical students while performing the
Airway management with the proposed system. We expect
that from such experiments, we could figure out the best
way for quantitatively analyzing the human performance as
well as understanding better how trainees are actually
improving their skills. From the analysis of the collected
data, we will propose which are the principal performance
indexes that may be significant to understand the problems
of trainees while performing the task.

As a future work, depending from the results of the
experiments realized, further improvements of the design
of the sensor system may be required. Furthermore, we are
planning to embed more sensors in other parts of the
mannequin.

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REFERENCES

Basic Techniques,” 1st ed, Yodohya, 2005
Anaesth Intensive Care 1980;8:183 6
[3] William M. Keane, MD, James C. Denny, MD, Lee D. Rowe, MD,
Joseph P. Atkins, JR, M.D.”Complications of intubation”,Ann Otol
Rhinol Laryngol 1982;91:584-587
[4] Francis B. Quinn, Jr,M.D.,”Larygel injury as a result of endotracheal
intubation,”Grand Rounds Presentation, UTMB, Dept.of
Otolarygology, 1999, May, 1999
after operation: Influence of tracheal intubation, intracuff pressure and
type of cuff,” Br.J.Anaesth 1982;54, 453
[6] Emergency medical technician education association,”Debribrillation-
Tracheal Intubation,” 1st ed, Herusu, 2004
Caplan, M.D.,Frederick W. Chieney, M.D.,”Airway Injury following
Anesthesia,” Anaesthesiology, 1999;91:1703-11
[9] Yoshiharu Tojo, Naoya Asamura, and Hiroyuki Shinoda:”A study on
Tactile Resolution of Human Skin”; Proceedings of the 2002 SICE,
pp.3137-3139, 2002
[10] Peppard SB, Dickens JH,”Laryngeal injury following short-term
intubation,” Ann Otol rhinol Laryngol 1983; 92:327-30
Updated Report by the American Society of Anesthesiologists Task
Force on Management of The Difficult Airway,”Anesthesiology
Airway Management. 2nd ed, Lippincott Williams & Wilkins, 2005,
pp.52-54
Airway Management. 2nd ed, Lippincott Williams & Wilkins, 2005,
pp.62