Comparison of endotracheal intubation learning curves with tracheoscopic ventilation tube for simulated difficult intubation between expert and novice anesthesiologists.

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Abstract

Background: Tracheoscopic ventilation tube (TVT) is a specially designed single-lumen endotracheal tube with a camera. It was developed to facilitate endobronchial blocker insertion without bronchoscopy; its ability to explore anatomy received attention for difficult intubations. To clarify the feasibility of TVT in difficult intubation, we evaluated the learning curves of intubation between novice and expert. Methods: 182 patients who presented as Cormack-Lehane (CL) grade IIb and III with cervical in-line stabilization, and 4 trainees (2 novices, 2 experts) at single tertiary care teaching university hospital. All trainees performed intubation with TVT during laryngoscopy. Intubation attempts were limited to two times, each within 30 seconds. For every attempt, trainees visualized an imaginary pathway from the teeth to vocal cords and then shaped the stylet. Intubation was confirmed by three successive ETCO 2 measurements > 30 mmHg. Using CUSUM analysis, the trial was continued until every trainee reached an acceptable failure rate. Results: Patients were constituted with 94.5% CL grade IIb and 5.5% grade III. The median number of acceptable performances (10% of the acceptable failure rate) was 36. Overall failure rate was 5.5% (95%CI: 2.2-8.8%), with 6.9% (95%CI: 2.0-11.8%) for novices and 3.7% (95%CI: 0.0-7.8%, P=0.165, Cohen's h=0.14) for experts. Intubation time was longer in novices by about 3 seconds compared to experts (mean difference=2.8, 95%CI: 1.3-4.3, P<0.001, Cohen's d=0.57). Conclusions: Intubation with TVT in CL grades IIb and III was easy to learn and could be an alternative for difficult intubation. It required small cases to reach acceptable performance, and provided a short learning period even for novice anesthesiologists, with failure rates similar to those of experienced anesthesiologists.

Introduction

Difficult intubation is one of the most disastrous situations for anesthesiologists. Various endotracheal intubation tools have been developed to overcome unexpected difficult intubation, yet no single tool has been accepted as the gold standard [1–4]. Among these, video-assisted endotracheal intubation devices are frequently recommended because of their ease of use [2, 3]. Several types of video-assisted devices have been developed over the decade including laryngoscopes with video incorporated in flexible or rigid viewing stylets [5–7]. Since the development of flexible fiberoptic scopes, endotracheal intubation with a flexible fiberoptic scope has been a high-end technique that can be used only by a qualified anesthesiologist [1]. Flexible fiberoptic scope-guided intubation requires much longer learning periods compared to intubation using other video-incorporated laryngoscopes [8]. Other types of intubating scopes have been introduced, but most of them are rigid. Tracheoscopic ventilation tube™ (TVT; ETView Ltd. Germany) has been developed to assist endobronchial blocker insertion without flexible bronchoscopy (Fig. 1). Its ability to overcome difficult intubation situations was introduced by several case reports [9, 10]. However, they presented only the ability of TVT, and not its feasibility. One article maintained that the camera imbedded in TVT could guide tracheal intubation without a direct laryngoscopy [11], and other reports mentioned useful roles of TVT in difficult intubations [12].

The objective of this study is to prove the feasibility of using TVT in difficult intubation situation for novice anesthesiologists. We hypothesized that using TVT in difficult intubation is as easy for novice trainees compared to experts. To prove our hypothesis, we compared the learning curves of using TVT in simulated difficult intubation situation between novice and expert anesthesiologists.

Methods

Following institutional review board approval (MD13021-002) and registration on the clinical research information service (CRIS, KCT0000908), this study was conducted in a single resident training university hospital. Two anesthesiology residents and two anesthesiology faculty members participated in this study. Residents (novices) were in the first-year anesthesiology residency program; their experience with endotracheal intubation with a conventional laryngoscope was equivalent to less than 300 cases. Two faculty members (experts) had experience of more than 10 years following their anesthesiology boards.

Manikin training

Following a short briefing about the features of TVT by one trainer who was in charge for intubation training with TVT and did not participate in the trial, all trainees were trained in endotracheal intubation with TVT using the airway management manikin until successfully completing 5 continuous endotracheal intubations. The criteria for successful manikin intubation with TVT was defined as a single attempt, within 20 seconds, and confirmed by bilateral artificial lung inflation when manually inflated through the intubated endotracheal tube using a bag-valve system. The intubations were performed as follows. With the airway management manikin placed in a supine position, manual cervical immobilization was applied by an assistant (cervical in-line stabilization). Then the anesthesiologist inserted the direct laryngoscopy and confirmed the tip of the epiglottis. The preformed TVT tube with a "J" shaped stylet (rounded and angulated more compared to hockey stick shape, Fig. 2) was inserted below the epiglottis. Identifying the glottic area and vocal cords, trainees advance TVT into the trachea until the tracheal rings are insight. While railroading TVT over the preformed stylet, all cautions were made not to introduce the stylet into the trachea. After introducing TVT until carina visible in the monitor and checking the adequate depth of TVT, then the cuff was inflated with an adequate volume of air, bag and valve system connected, and inflation of the lung was initiated.

Study Populations

The study included patients who were 19 to 64 years of age, scheduled to receive general anesthesia with endotracheal intubation, were Mallampati grade III to VI on physical examination during pre-operative visit, were scheduled for surgery in the supine or lateral position, and had Cormack-Lehane classification grade (CL grade) IIb and III with in-line stabilization. Exclusion criteria were as follows: surgery requiring double-lumen endotracheal tube or wire-reinforced endotracheal tube; Mallampati grade I and II; anatomical or pathological abnormalities in cervical area; teeth problems at the incisor, canines, and premolars; risk of aspiration during anesthesia induction; and difficult mask ventilation during anesthesia induction; CL grade I and IIa, IV, and patients who refused to participate.

Conducting practice of intubation with TVT

After obtaining informed consent from all included patients, premedication with 0.2 mg glycopyrrolate and 2 mg midazolam IM were administered 30 minutes prior to anesthesia induction. When the patient arrived in the operation room, preoxygenation with 100% oxygen for 3 min was applied to establish denitrogenation. Standard patient monitoring was applied to all patients including 3-leads electrocardiography, non-invasive blood pressure measurement, peripheral oxygen saturation, end-tidal CO_2 ($ETCO_2$), Bispectral index score (BIS), train-of-four (TOF) neuromuscular monitoring. Anesthesia was induced by the anesthesiologists in charge using their preferred anesthetics and neuromuscular blocking agents. Manual mask ventilation was continued until the adequate depth of anesthesia was achieved by confirming a BIS below 60 and 0 counts of TOF monitoring. While attempting mask ventilation, oral airway or two-hand technique were applied as required to guarantee adequate ventilation confirmed using $ETCO_2$ and expired tidal volume monitoring incorporated in the anesthesia machine. Patients with failed adequate mask ventilation during the whole process was excluded immediately, then managed following difficult mask ventilation and difficult tracheal intubation protocol of our hospital. With the adequate mask ventilation, a screening laryngoscopy by one trainer was performed, and the CL grade was checked for inclusion or exclusion. Screening laryngoscopy was performed with cervical in-line stabilization provided the anesthesiologist in charge. The laryngoscope was inserted as usual without neck extension; CL grade was evaluated when the tip of laryngoscope reached at valeculae without upward movement. When the patient met the CL grade IIb to III, endotracheal intubation with TVT was attempted. Immediately after CL grading, one of 4 trainees was selected to perform intubation by opening an opaque, sealed envelope containing randomization results and prepared. Block randomization method was applied, and these envelopes were prepared before the first patient was included according to serial order by a non-participant in the study. We prepared randomization systems; of all 4 trainees used from the start of the investigation, of 3 trainees when one trainee reached at the acceptable failure rate, of 2 trainees using when another trainee reached the acceptable failure rate. When one trainee remains without fulfilling the acceptable failure rate, consecutive eligible patients were allocated to this trainee. Endotracheal intubation with TVT was performed using a similar method described in manikin training, except for shaping the stylet and number of attempts. In every case prior to intubation, each trainee made their own curvature according to the expected airway pathway by inspecting the patient's lateral view (Fig. 3). The inspecting points were an imaginary pathway from teeth to glottis, which was inferred from the surface anatomy of the thyroid cartilage, angle of mandible, and the edge of lips. A direct laryngoscope with a Macintosh blade was inserted until the mouth and the tip of the epiglottis was identified. Number 3 or 4 blades were used in accordance patient’s sex, height and weight. At this time, the anesthesiologist in charge maintained a manual in-line stabilization until the end of the whole intubation process. When the tip of the epiglottis was not identified by a trainee, only one chance to advance the tip of the laryngoscope blade to the vallecular through the base of the tongue without upward movement was permitted. Under the vision of epiglottis with a laryngoscope, TVT with preformed curvature was inserted below epiglottis until vocal cords are visualized in the monitor, then TVT was railroaded into trachea over preformed guidewire by the assist of the anesthetic nurse. At this moment, the trainee and trainer did every effort to ensure that the stylet would not introduce into trachea. Adequate depth of TVT was confirmed by visualized carina on video monitor system connected to the TVT and checking the number of depths printed on TVT. Successful intubation was defined when an end-tidal CO_2 over 30 mmHg was confirmed successively for 3 times through the sidestream capnography connected at the end of intubated TVT, within 30 seconds from the cessation of mask ventilation. If the first attempt failed, mask ventilation was re-started, and stable vital signs were confirmed, then a second attempt was made. Only 2 attempts were permitted for each trainee. If unsuccessful, airway management including endotracheal intubation was performed by the anesthesiologist in charge. After successful endotracheal intubation, anesthesia was maintained by the anesthesiologist in charge.

Study End Point and Complications

The primary end-point was defined as performance number needed to reach an acceptable failure rate for endotracheal intubation with TVT. The secondary end-point was defined as the success rate of the first attempt. Other variables including time laps for successful intubation, the incidence of a sore throat at the recovery room, teeth injuries, and blood-tinged tracheal or intraoral secretions after intubation were also recorded.

Statistical analysis

R statistical software package (version 3.5.2, 2018, The R Foundation for Statistical Computing) was used. Normality and equal variance tests were applied to continuous variables including age and BMI. According to test results, parametric or nonparametric statistical analysis was applied to each parameter. Chi-square test for categorical data, z-test for ratio comparison, and t-test to compare other continuous variables. $P<0.050$ was considered as significant results. Data presented as mean ± SD, a number for descriptive and mean (95%CI), ratio (95%CI) for estimated values. To evaluate the successive performance of endotracheal intubation with TVT, CUSUM (Cumulative sum control chart) was used to analyze each trainee as advocated by Kestin [13-16]. CUSUM analysis is a simple and intuitive method to determine the performance status of a trainee at that point. According to pre-determined acceptable and unacceptable failure rates (α and β, respectively), type 1 and 2 failure rates (α and β, respectively), trainee's performances were under control within a limited range (Equation 1). At each attempt, the CUSUM value was determined by the results of the performance, success or failure. That is, the CUSUM value is the running sum of the decrement (with success) and the increment (with failure). The decrease or increase as the result of each performance was determined by the pre-defined acceptable and unacceptable success rates. According to general performance [14], we assumed a 10% acceptable failure rate, 20% unacceptable failure rate, and 10% type 1 and 2 failure rates. By the CUSUM graph formula (Table 1), the result of each performance was plotted on the CUSUM graph decrement (-0.205) or increment (1.205) from 0.

If the CUSUM value of each trainee reached the boundary of the unacceptable failure rate (h_1), further trials did not proceed until acceptable re-education using the manikin airway management trainer. When the CUSUM value reached and crossed the boundary of the acceptable failure rate (h_0), the intubation training with TVT for the trainee was stopped. However, intubation attempts were continued until the number of attempts over 40 or 48 according to their achievements due to guarantee the acceptable statistical power described below.

After all 4 trainees' CUSUM values were reached over the acceptable failure rate and the number of attempts were enough to fulfil the pre-determined statistical power, overall success and failure rates were compared and analyzed using CUSUM graphs.

To determine the sample size, a power analysis was performed to calculate the required number of patients. We assumed a 10% acceptable failure rate, 20% unacceptable failure rate, and 10% type 1 and 2 failure rates. Under these assumptions, the sample size was decided using the CUSUM calculation and sample size estimation method (Table 1).

If each trainee achieved successive acceptable failure rates, the average sample size was 40 cases, and if they achieved successive unacceptable failure rate, the average sample size was 48 cases. Thus, the required sample size was a minimum of 160 cases and a maximum of 192 cases for 4 trainees.

Results

We screened 217 patients for eligibility for our study according to the inclusion criteria; and among them, 3 patients were excluded due to refusal prior to anesthesia and 2 patients were excluded due to difficult mask ventilation despite using airway devices. Remaining 212 patients were evaluated for CL grade. Under direct laryngoscopy with cervical in-line stabilization, 30 patients presented as CL grade I or IIa and were subsequently excluded from the study. Finally, a total of 182 patients were included in our study and analyzed (Fig. 4).

Demographic data of all included patients are presented in Table 2. The mean age of all patients was 48.4 ± 12.6 years old and the male to female ratio was 108:74. The mean average BMI of all patients was 24.92 ± 3.81 kg/m^2. Of all the patients, 171 were Mallampati grade III (94.0%), and 11 were grade IV (6.0%). CL grade IIb was represented in 172 (94.5%) patients and grade III in 10 (5.5%) patients.

All participating anesthesiologists achieved acceptable performance without crossing over the limit of the unacceptable failure rate (h_1). The median number of acceptable performances was 36. The expert trainees reached acceptable performance (CUSUM values crossed over h_0) after 26 and 32 cases, and the novice trainees did so after 40 and 48 cases. The number of failure cases before reaching acceptable performance for all trainees was 3 for the experts and 7 for the novices. Figure 5 summarizes the overall performance of all 4 trainees.

The overall failure rate was 5.5% (95% CI: 2.2–8.8%). The failure rate for novice trainees was 6.9% (95% CI: 2.0–11.8%), while that for expert trainees was 3.7% (95% CI: 0.0–7.8%, z = 0.976, P = 0.165, Cohen's h = 0.14). The overall failure rate at first attempt was 30.8% (95% CI: 0.2–0.4%), 26.3% (95% CI: 16.7–36.0%) for the experts and 34.3% (95% CI: 25.1–43.5%) for novice trainees (z = 1.160, P = 0.877, Cohen's h = 0.17).

The intubation times between novice and expert trainees were statistically different. Mean intubation time of novice trainees was 24.9 ± 5.0 sec, and greater than that of expert trainees with a medium effect size (22.1 ± 4.8 sec, $t = 3.682$, $df = 169$, mean difference = 2.8 (95% CI: 1.3–4.3), $P < 0.001$, Cohen's $d = 0.57$).

There were neither cases of teeth injury nor of blood-tinged tracheal or intraoral secretions. Seven patients in the expert group (8.6%, 95%CI: 2.5–14.7%) and 14 patients in the novice group (13.9%, 95%CI: 7.2–20.6%) presented with sore throat in the post-anesthesia care unit ($z = 1.112$, $P = 0.133$, Cohen's $h = 0.17$).

Discussion

Tracheal intubation with TVT in CL grade IIb and III limited the failure rate to 5.5%. Even though we included novice residents, their failure rate reached only 6.9%. According to the manikin study [17], when they applied cervical collars to the manikins, all of their CL grades were II and III, and the intubation success rate reached 100% with TVT compared to 84% with direct laryngoscopy. These results imply that endotracheal intubation with TVT under assist of direct laryngoscopy provides easier intubation conditions and a higher success rate. In fact, we preformed “J” shaped TVT with a stylet, rather than a traditional hockey stick shape (Fig. 2). Endotracheal tube insertion over a slightly rounded angle is easy compared to an acutely angled “hockey stick” shape. Furthermore, a slightly upward movement of the tube tip while inserting allows one to make precise movements toward the vocal cords.

The median number of acceptable performances was 36 and ranged from 26 to 48. In consideration of the experiences of novice persons, not many intubation experiences were required to reach the smaller failure rate of 10% compared to other literatures[18, 19]. It was not a similar situation with this trial, only 60% of novice trainees were fulfilled the 20% acceptable failure rate within the mean 45 attempts [18]. In other systematic review [19], to reach at least 90% success rate within 2 attempts, more than 50 cases of intubation experiences were required with a direct laryngoscope. Considering we simulated moderate grade of CL classification, our results indicate that TVT could provide another excellent intubating method when anesthesiologists encounter an unexpectedly difficult intubation situation. With a rigid video stylet, successful intubation rate at first attempt was reported as 73.3% in patients with Mallampati grade I and II [20]. A semi-rigid video stylet, the Clarus video system is another type of video stylet which allows a custom angle to be made by the user. The overall successful intubation rate using this device was reported to be 95.7% in patients with Mallampati grade I to III [21]. In our study including only CL grade IIb and III, we achieved an overall successful intubation rate of 94.5% and reached nearly 93% even in novice trainees. These promising results could be evidence of an alternative method for overcoming difficult intubation situations.

Most experiments using TVT in cases of difficult intubation were performed with manikins [5, 11, 17]. Manikin studies in airway management have been advocated due to lack of real-life settings [22]. A clinical trial was mandatory to evaluate the efficacy of tracheal intubation with TVT. Difficult intubation is a situation which is closely related to airway anatomy. Using a classic laryngoscope, the visual field of the naked eye is significantly affected by structures from the teeth to the glottic area. These include the large and thick tongue, elongated floppy epiglottis, limited angle between oral, pharyngeal, and laryngeal axis, and so on. Because subtle variations in these structures could create different intubation conditions, preparation for difficult intubation should be personalized. In addition, most general anesthetics decrease upper airway tone, therefore the anticipated pathway for intubation should be mapped prior to the attempt. Most commercial video stylets are supplied with a fixed angle. A fixed angle with a rigid stylet could provide superior handling ability during tracheal intubation [23, 23]. Tracheal intubation with these is possible without a midline approach. On the other hand, the most flexible intubating stylet is an intubating bronchoscope. Because of its flexibility, the user can manipulate the bronchoscope advancement toward where one wants to. However, it is hard to find adequate anatomical landmarks because the bronchoscope cannot make its own way due to its flexibility, especially when the patient is fully relaxed. The airway of a relaxed patient is almost totally obstructed by the base of the tongue. The midline should be kept during bronchoscope advancement to easily find the glottic area [25]. Keeping midline during bronchoscope insertion is a simple principle but not easy to achieve; bronchoscope-guided intubation requires delicate training programs and various assisting devices to establish acceptable performance even in standard intubation situations [26–28]. Predicting and making an adequate angle of the stylet almost depends on personal experience; it is not difficult to perform. It is required only expecting the pathway of an endotracheal tube according to the surface anatomy from teeth to thyroid cartilage (Fig. 3). During the study period, even a novice trainee could do this within a few attempts. Customizing the endotracheal angle is the most important feature of TVT. This may make handling during an intubation procedure easier compared to a flexible fiberoptic guided intubation. Glottic area approaching could also be enhanced by a customized stylet angle. Facilitation by making a customized stylet angle could also be possible in a semi-flexible video stylet.

Using a laryngoscope to make enough space and to identify the target glottis area enhanced TVT handling in anesthetized patients. It made it possible for us to find the pathway to the glottic area easily through relaxed structures. The only thing to do was inserting the tip of TVT under the epiglottis. By doing this, high CL grade with the naked eye became low CL grade in the view of the TVT (Fig. 6). Customized stylet shape and laryngoscope assist could maximize the likelihood of successful intubation with less effort and less seeking movement which is a cause of intubation-related trauma.

TVT was initially designed for tracheal surveillance during endobronchial blocker insertion. After its introduction, many articles presented its usefulness in difficult intubation situations [9, 12, 29, 30]. Its ability to manage difficult intubation was reported in unexpectedly difficult bag-mask ventilation [9], difficult intubation caused by tracheal injury [30], and high CL grade [12]. Compared to other rigid or semi-rigid intubating video stylets and the flexible intubating bronchoscope, TVT provided superior aspects in several ways. Firstly, it can deliver high flow and a large volume of oxygen during the intubation procedure. During the intubation process, oxygenation could prolong the apnea time [31]. Some intubating stylets are also designed with oxygen insufflation through the tube during intubation. However, TVT has another small route for lens clearing lumens; their ends are pointed toward the lens surface. Oxygen through these holes enables clear sight during procedure against secretions and fog. Secondly, tube passage over the glottic area is easier because of its bevel appearance. Usual single-lumen endotracheal tubes have a leftward bevel on their tips with right-sided Murphy's eye. This design ensures both lungs are ventilated when the endotracheal tube tip has reached the carina. In contrast, the TVT has a downward bevel and a camera on its upside tip. The midline placed TVT camera could enable inserting most of the end of the tube between the vocal cords and simultaneously enable confirming adequate depth of the endotracheal tube [32]. With the intubating video stylet or flexible intubating bronchoscope, railroading endotracheal tube into trachea usually follows confirming the scope is in the trachea. In this step, the left-sided bevel could get caught in the glottis because this is performed in a blind manner over the scopes as a guide. In addition to several other advantages, customizing its curvature to each patient is the supreme advantage. This diminishes the number of attempts, decreasing the chance of trauma around the airway which is another cause of difficult intubations. If the first attempt fails, one can modify the curvature to the most likely shape for that patient, then the possibility of success with the next attempt can be increased.

Most clinical trials about the feasibility of various intubation devices tested intubation time as their trial objective [6, 21, 31]. They tested and reported the feasibility of intubation devices with mean intubation time. Intubation time in most previous clinical trials is defined from the insertion of intubation devices to visual confirmation of endotracheal tube insertion through the vocal cords. A visual check by an experienced person is almost exact but sometimes provides the wrong information, especially for the novice anesthesiologist. In this trial, we regarded intubation to be successful only when 3 successive end-tidal CO_2 concentrations over 30 mmHg were confirmed. Also, we included this testing period in the measurement of the intubation time, which is why mean intubation time in this trial reached around 25 seconds. However, the mean difference of intubation time between novice and expert trainees was only 2.8 seconds. This small difference means that tracheal intubation with TVT in CL grade IIb and III is easy to learn and overcomes difficult intubations.

Complications during the intubation process were not so different compared to other devices in the literature [7, 32]. The incidence of sore throat after tracheal intubation for general anesthesia is reported from 30–70% [33]. The incidence of postoperative sore throat in this trial was numerically lower (8.6% for expert, 13.6% for novice trainees) than reported results. Because we used commercially available and FDA-approved stylets, and all participating anesthesiologists exercised not to do too many manipulations near the glottic area by individual stylet shaping before intubation, there were decreased factors of mucosal injury. However, sore throat developed nearly twice as much in the patients of novice trainees as in the patients of expert trainees. This means small injuries during intubation could be developed more frequently in novice trainees, although their mean intubation time is only different by 2 seconds. A sore throat could be caused by forced movement around the glottic area or vigorous endotracheal tube advancement which can cause tracheal injury. Cuff volume and pressure also contribute to sore throat development [33–35]. We guess that the cause of sore throat in this trial was inadvertent railroading of the endotracheal tube. Expert trainees could be more skilled in smooth advancement of the endotracheal tube into the trachea.

One of the limitations of this trial is the small number of trainees. If we tested more persons as trainees, it could decrease the inter-individual variance especially in the point of individual learning ability. To overcome these effects, every trainee did attempt enough cases and the results of each trainee fulfilled the normality test, which means that the data were neither skewed nor sparse. Second, Mallampati Grade III/IV and subsequent CL grade IIb/III with cervical in-line stabilization could not perfectly guarantee the difficult intubation situation. Real-difficult intubation situation could present more limited intraoral spaces to manipulated airway devices, could be harder to reach adequate tip position of a direct laryngoscope. Because of the ethical problem and rare incidence of these situations, a similar situation produced from simulation including cervical in-line stabilization and limited direct laryngoscope manipulation could enhance the personal technique of overcoming real difficult intubation situations. Third, we excluded patients with CL grade IV. Because all trainees were using TVT for the first time in high CL grade patients, we excluded CL grade IV patients to avoid accidental airway injury and "cannot intubation" status with unaccustomed devices. Fortunately, there was no patient presenting with CL grade IV during the trial.

In conclusion, tracheal intubation with TVT in CL grade IIb and III increases the chance to successfully and easily learn an alternative method to overcome unexpectedly difficult intubation situations. Tracheal intubation using TVT did not require many cases to reach an acceptable failure rate, even for novice anesthesiologists who uneventfully reached an acceptable level not very different from that of expert anesthesiologists.

Abbreviations

TVT: Tracheoscopic ventilation tube^{TM}.

CL grade: Cormack-Lehane classification grade.

$ETCO_2$: end-tidal CO_2

BIS: Bispectral index score

TOF: Train-of-four neuromuscular monitoring

CUSUM: Cumulative sum control chart

Declarations

Trial Registration: CRIS (http://cris.nih.go.kr/), identifier: KCT0000908. Registered 5 Nov 2013.

Human Research Ethics Committee approval number: MD13021-002, Korea Univ. Guro Hospital Institutional Review Board

Concent to participates: All patients participated in this study got an adequate explanation from researchers registered in ethics approval; they signed to the informed consent document by their own will.

Availability of data and materials: No additional data is available as participants have not provided consent for data sharing.

Competing interests: None of the financial and non-financial interests exist.

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Author contributions: DK Lee: conceptualization, study design, data collection tools, monitored data collection for the whole study, data analysis, revision of original draft and revised drafts. HZ Kim, CH Lee: data collection, writing original draft and revised the paper writing on the manuscript; DK Lee, HZ Kim: statistical analysis plan, cleaning of data and formal analysis, drafting and revision of original draft. MH Gong, JS Oh: study design, revision of original draft

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Tables

Due to technical limitations, the tables are only available as a download in the supplemental files section.

Figures

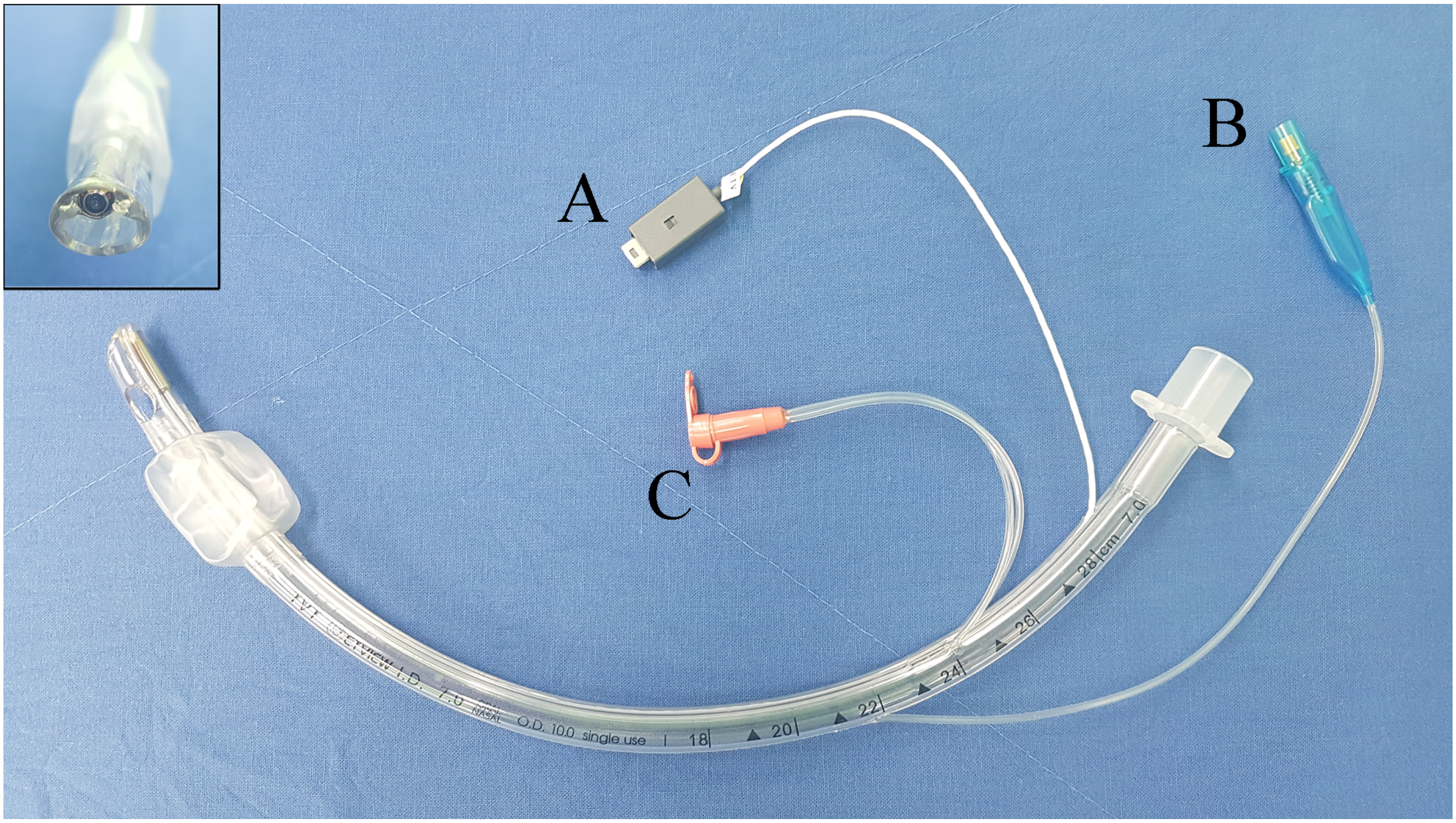

Figure 1

Gross appearance of the tracheoscopic ventilation tube. It has a small-sized camera on its tip (box) and the bevel is designed downward with two Murphy's eyes. It has 3 functional connectors, one for video signal transmission (A), another for cuff manipulation (B), the last for lens clearing (C).

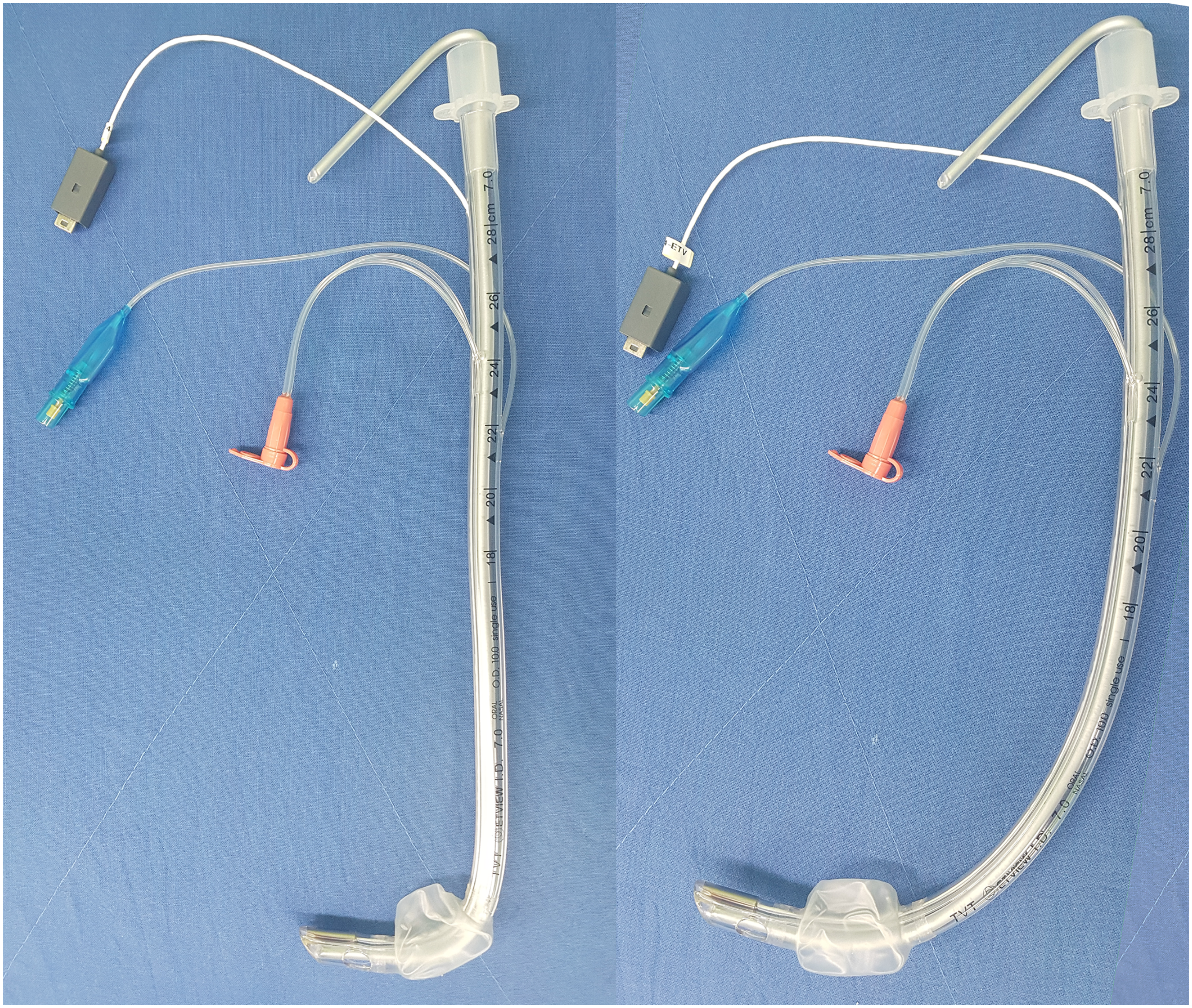

Figure 2

Traditional “Hockey-stick” (left) and new “J” shaped (right) endotracheal tube (tracheoscopic ventilation tube).

Figure 3

Drawing an imaginary “J” shaped pathway. According to the surface anatomy of the thyroid cartilage, angle of mandible, and the edge of lips, an imaginary pathway from teeth to glottis was established for every patient. Using stylet, endotracheal tube (tracheoscopic ventilation tube) were shaped as predetermined individualized curvature was applied.

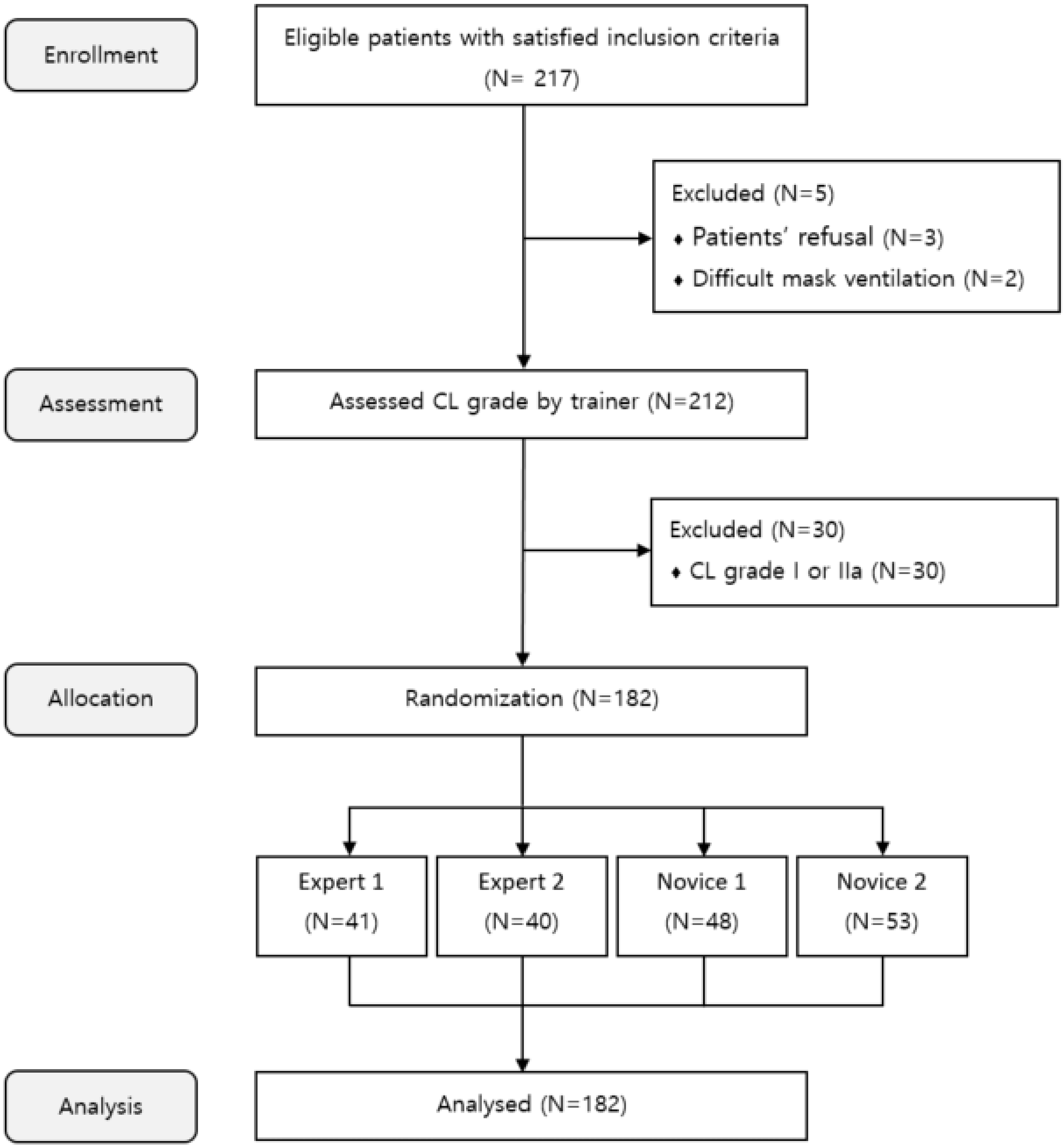

Figure 4

Study process diagram. CL grade: Cormack-Lehane classification grade. Assessment: CL grade evaluated using direct laryngoscope with cervical in-line stabilization. Randomization was prepared for; in cases of 4 trainees, 3 trainees, and 2 trainees. When the trainee 4 remained with not-reached the acceptable failure rate, consecutive cases allocated to the trainee 4.

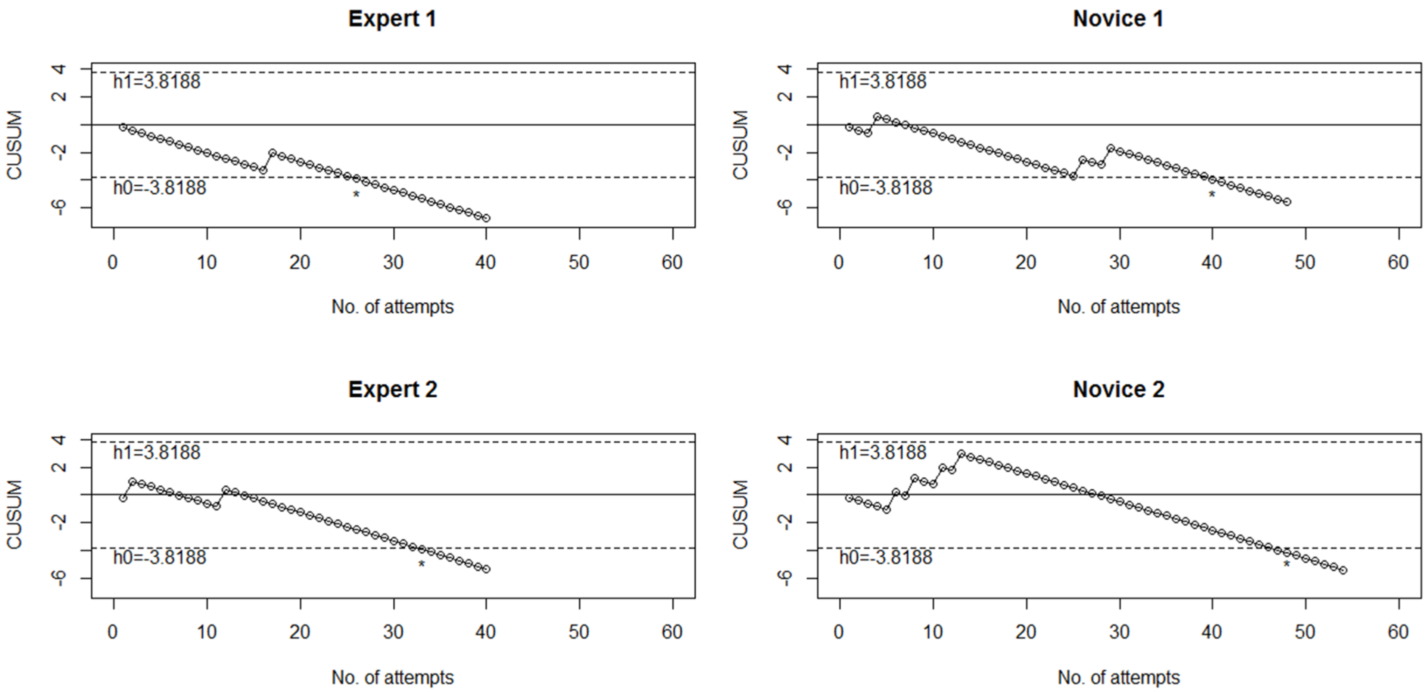

Figure 5

CUSUM graphs of all 4 trainees. According to each performance result, CUSUM value increased (failure) or decreased (success) by a predetermined amount. If successive failures occurred and the CUSUM value crossed over the upper boundary (h1), the applicable trainee immediately ceases the trial and conducts retraining. When the CUSUM value is less than the lower boundary (h0), we regarded that the trainee reached an acceptable performance.

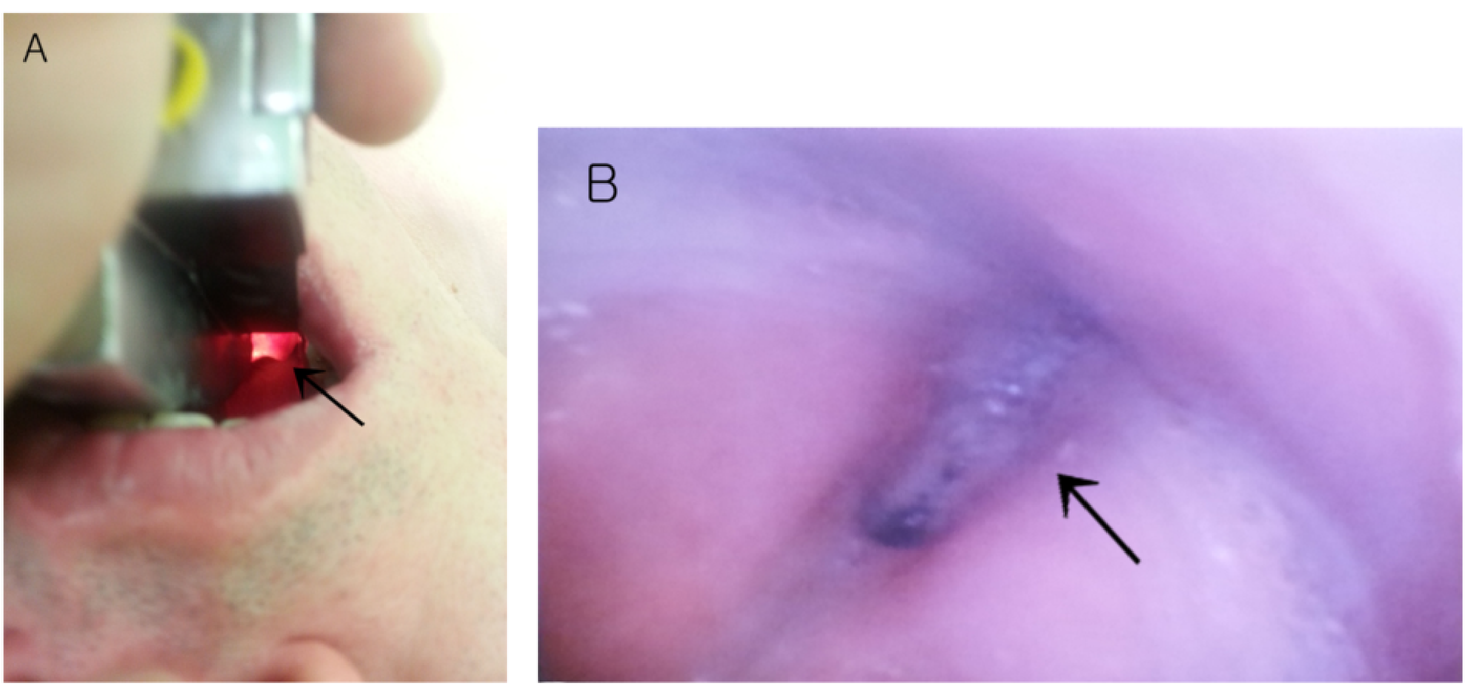

Figure 6

Cormack-Lehane (CL) grade under laryngoscope and the view of tracheoscopic ventilation tube (TVT) in the same patient. A: View under laryngoscope. Patient presented CL grade III. The black arrow indicates epiglottis. B: View of TVT. TVT was inserted below epiglottis then relatively small area of vocal cords were identified (black arrow).

Supplementary Files

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