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An intubation method for mono-pulmonary ventilation in patients with difficult airway

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Abstract. – OBJECTIVE: This study aimed to compare the clinical effect between thermal softening PVC double-lumen tube (DLT) and single-lumen tube (SLT) guided by laryngoscope and bronchoscopy in patients with difficult airways.

PATIENTS AND METHODS: 72 patients with chest surgery in need of mono-pulmonary ventilation, aged 20-70 years old, with ASA rating I-III and Arné scoring ≥ 11, were enrolled. Patients were categorized randomly into two groups with 36 patients in each: the D group (DLT was used) and the S group (SLT was used). Bronchoscopy was used for guiding the intubation and aligning in both groups. Laryngoscope would also be used immediately after failure in two trials of intubation. Intubation resistance, intubation success rate, laryngoscopy assist rate, time for intubation, time for alignment, incidence of catheter dislocation, VAS score for post-operative throat pain, and the damage extent of vocal cord were recorded.

RESULTS: No significant differences were seen between two the groups in terms of intubation resistance, intubation success rate, laryngoscopy assist rate, time for intubation, VAS score for post-operative throat pain, and the damage extent of vocal cord. However, shorter time for alignment and lower incidence of catheter dislocation were observed in the D group than in the S group (both $p < 0.05$).

CONCLUSIONS: For intubation in patients with difficult airway, the thermal softening DLT was as safe as the SLT, but simpler in alignment and had a lower dislocation incidence. Meanwhile, video laryngoscope could increase the success rate of intubation with either tube.

Key Words:
Difficult airway, Thermal soften, Double-lumen endotracheal tubes, Single-lumen tubes, Bronchoscopy.

Introduction

The establishment of lung isolation with double-lumen tube (DLT) could be particularly challenging for patients with airway difficulties, including poor opening (Mallampati 3 or 4), protruding front teeth and/or back of the jaw, restriction in neck movement, history of head and neck trauma, history of radiotherapy or tumor removal (semi-retinal excision or root-and-branch neck sweep)[1]. Currently, no common algorithm or standard is established for predicting the risks of difficult airway, therefore only basic recommendations are included in the guidelines instead of standards or requirements. The Arné score is one of the most detailed multivariate risk indicators clinically available for pre-operative evaluation of difficulty in laryngoscopic intubation[2]. When the Arné score exceeds 11, difficulty in intubation should be predicted[3]. Bronchoscopy guidance has also been demonstrated to be safe and effective in intubation with either expected or unexpected difficult airways[4-6].

Comparing with the single-lumen tube (SLT), PVC DLT is longer, with a thicker diameter and poorer flexibility, making it more difficult to be guided directly with bronchoscopy due to the potential damage caused[4,7-11]. Therefore, it has been suggested that for patients with difficult airways who need pulmonary isolation, the safest way is to use a SLT intubation through mouth under the guidance of a fiber bronchofiberscope, and then replace with DLT with a pipe changer or place a bronchial blocker for single lung isolation[8,9]. Previous studies have also reported that the intubation process of DLT guided by bronchofiberscope may be more complex than using SLT due to its large diameter and relative lack of compliance[7,9-11], mainly due to the physical property of commonly used PVC materials[12]. It had been studied that PVC trachea ducts would have good flexibility at 60°C through heat-reinforced treatment without causing any burn[13]. Meanwhile, similar intubation difficulty was observed between heated PVC tube and the iron catheter[4]. Reduced risk of post-operative sore throat and vocal cord damage was also

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observed in patients with normal airways after the use of heat softened DLT[14]. Furthermore, successful usage of video laryngoscopes has been reported in exposing the glottis, and subsequently bronchoscopy is used for the guidance of the catheter into the airways[15-17]. Therefore, we speculate that with the aid of video laryngoscope, the bronchofiberscope guided intubation with thermal-softening PVC DLT might be as safe as SLT and could serve as another safe option for lung isolation among patients with difficult airway.

Patients and Methods

Study Design

This study was a prospective pilot trial with single-center, single-blind (participant) and parallel group. The whole program was approved by the Ethics Committee of the First Hospital in Qinhuangdao City, Hebei Province (with the permit number 2019D004).

Participants

Patients who had chest surgery at Qinhuangdao City First Hospital, affiliated with Hebei Medical University, from 2018 to 2021, aged 20-70 years old, with ANA grade I-III and Arné score ≥ 11 points, were enrolled. Potential candidates who met the inclusion criteria were recruited during pre-operative enquiry and information for the study was obtained. The purpose, procedure, potential risks and benefits of the study were explained by the anesthesiologist to each participant and written informed consent was obtained from the participants. Participants held the right to withdraw from the study at any time without any consequences. All participants were evaluated for the difficulties of airway before intubation, according to the Arné score (refer to **Appendix I**).

Patients with the following criteria were excluded for the study:

- Restricted in left side use of DLT and/or bronchial blocker;
- With twisted and/or lesions in the tracheal cavity;
- With predicted dyspnea in mask ventilation;
- With unpredictable difficult airway;
- With symptoms such as hoarseness and sore throat before surgery

Randomization and Blinding

A prospective pilot trial with single-center, single-blind (participant) and parallel group was used in the current study. 72 patients were included in the study and categorized randomly into two groups: the D group (DLT was used) and the S group (SLT was used). Participants were blind to their categorization. However, due to the significant difference between the two kinds of tubes, blindness could not be established for investigators in terms of patient assignment during the intubation. Follow-up questionnaires were performed double-blindedly by anesthetist nurse who didn't participate in the anesthetics.

Anesthesia and Preparation of Intervention

Disposable PVC left DLT (TUOREN Medical, Henan, China) was used for the intubation of patients in the D group. Model number was chosen based on the inner diameter of left trachea of the patient revealed by computed tomography (CT): 32 Fr for diameter ≥ 10.7 mm, 35 Fr for diameter ≥ 11.7 mm, 37 Fr for diameter ≥ 12.3 mm, 39 Fr for diameter ≥ 13.0 mm, while 41 Fr for diameter ≥ 13.7 mm. Heat softening of the PVC DLT was performed by an assistant, and 40°C turned to be the best softening temperature before intubation[18]. A thermostat was used for heating the disposable PVC tube at 60°C for 30 min. The temperature of the tube was measured by an infrared thermometer. The immediate temperature after taken-out was 46.5°C. 1 min later, it dropped to 46.5°C, while dropped to 41.2°C at 3 min. At 5 min after taken-out, the temperature of PVC tube dropped to room temperature. Therefore, the time between the taken-out of the PVC tube and entrance into the mouth of patients should be limited to 3 min.

Periterior venous channels were established for the patients, while invigilator, disposable bispectral index sensor (BIS) and intubation resistance monitoring device (Contec Medical Systems Co., LTD. **Appendix II**) were connected as well. Routine induction of anesthesia was used in this study: subsequently injected intravenously midazolam (0.05 mg/kg), lidocaine (40 mg/kg), propofol (2 mg/kg), and rocuronium (0.6 mg/kg), induced by sulfentanyl (1 μg/kg). Propofol (6 mg/kg) was used for maintaining the depth of anesthesia, when the BIS index reached 50. Direct laryngoscope was used by the anesthesia assistant to determine the Cormack-Lehane grading of the patient. After confirmation, the endotracheal intubation was started. The glottis and airway were observed with fiberoptic bronchofiberscope and photographed.

Intervention: Placement of DLT and Confirmation of DLT Position

The intubation process for the D group was performed as follow: heat softened DLT was taken out for the thermostat, and connected with the lubricated bronchofiberscope (MDH, A50, 2.8 mm, Zhuhai Mindhao Medical Technology Co., LTd.) at the left tube (the whole process should be controlled in 3 min). The patient was placed in a flat position, and the mandible was lifted by the anesthesia assistant. The intubation physician put the fiberoptic bronchoscope with the softened catheter into the mouth along the midline. The intubation time record started. The DLT touched epiglottis gently to pass through and then entered the airway. As the lens went deep, the catheter reached glottis following the fiberoptic bronchoscope and resistance appeared. The resistance intensity through the glottis was recorded, and the catheter was turned to allow the DLT to pass through the glottis (the DLT was withdrawn 1-2 cm for another try if the resistance was too high). The DLT was turned anticlockwise for 90 degrees. After the lens reached the tracheal carina, it entered the left main bronchus and stopped when the opening of the upper and lower lobes of the left lung was found. The fiberoptic bronchoscope was then fixed and the catheter was pushed until the distal end of the left catheter reached the left main bronchus. After confirming the opening of the upper and lower lobes of the left lung, the assistant helped to fix the catheter, withdraw the fiberoptic bronchoscope, and recorded the intubation time. The fiberoptic bronchoscope would then be manipulated to the right catheter to adjust the catheter position. After that, the alignment time and total time were recorded. The ventilator control was turned on, the CO_2 value and airway pressure were observed, and the effect of one lung isolation was confirmed.

In the group S, SLT was intubated under the guidance of fiberoptic bronchoscope, and the catheter was withdrawn from the main airway. The intubation time was recorded by fiberoptic bronchoscope. After successful intubation, the disposable occluder was used for alignment, and the alignment time and total time were recorded. During the operation, propofol, remifentanil and rocuronium were used to maintain the depth of anesthesia. After closing the pleura, PCA was given by intravenous infusion. PCA was composed of sufentanil and dexmedetomidine at the dose of 100 ml/48 h. After extubation, the glottis could be observed by fiberoptic bronchoscope, and the relevant results were recorded. VAS scores of pharyngeal pain were recorded at 1 hour, 4 hours, 12 hours and 24 hours after operation.

After two failures of bronchofibroscope-guided intubation, full mask ventilation would be given immediately, and video laryngoscope (Madian e.an-la. Tianjin Madian Medical Electronic Technology Co., Ltd.) was given to assist in bronchofibroscope-guided intubation with either DLT or SLT. The anesthesia assistant exposed the glottis with video laryngoscope, and then intubated with video laryngoscope to record the assistance of video laryngoscope. If intubation failed again in the group D, video laryngoscope assisted fiberoptic bronchoscope would be used to guide SLT intubation, but the use of SLT intubation in group D would be considered as a failure of fiberoptic bronchoscope guided left DLT intubation.

Outcome Measurements

Main results: the intubation resistance represented the maximal resistance of the distal end of the catheter through the glottis measured by the resistance monitor (Figure 1). The intubation success rate was represented as the ratio between the number of patients who successfully inserted DLT or SLT and completely aligned and the total number of patients in the group. The laryngoscopy assist rate represented the ratio of the number of patients using video laryngoscope after two times of bronchofibroscope-guided intubation failure to the total number of patients.

Minor results: the intubation time (T_1) represented total time required for the establishment of intubation from the fiberoptic bronchoscope entering the oral cavity. The time for alignment (T_2) represented the time required for the alignment. The incidence of tube dislocation represented ratio of the number of patients that required the adjustment of location of tube. VAS scores were recorded at 1 h, 4 h, 12 h, and 24 after operation. The damage extent of vocal cord represented the condition difference of vocal cord compared before and after the intubation. Graphics were taken and separated into mild (mucosal edema and congestion), moderate (mucosal erythema and bleeding), and severe (mucosal granuloma), as presented in Figure 2.

Withdrawal, Dropout, and Discontinuation

All patients had the right to withdraw from the study at any time. If patients refused to continue, withdrew their consent, or violated the inclusion criteria or trial protocol, participation could

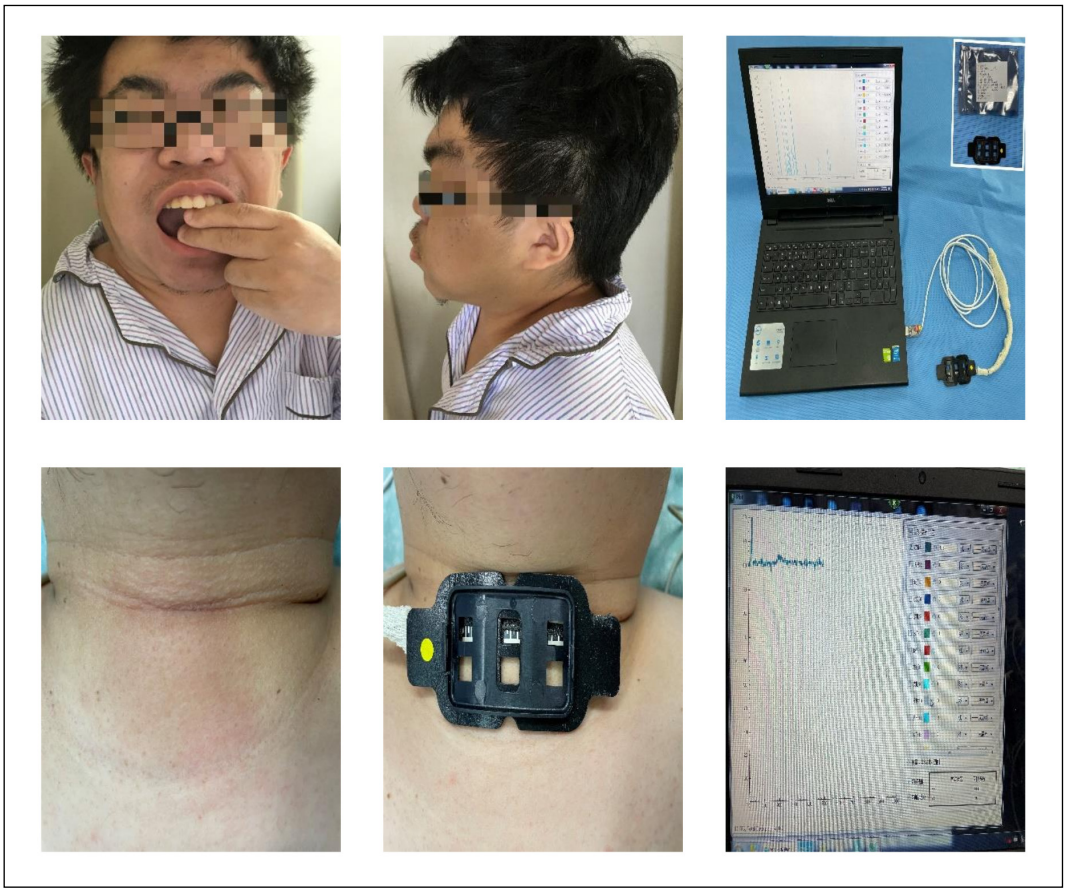

Figure 1. Details for the resistance monitoring before and during intubation.

be terminated at any stage. Participants withdrew from the study if they were unable to use the bronchoscope due to instrument failure. The reasons for withdrawal were recorded on the case report form.

Confidentiality

Personal information, including name, identity number or hospitalization number, was not collected. Only research code was collected and managed separately. The data collected was kept confidential until the investigators analyzed the data. After the study was completed, the collected data was encrypted and stored for three years, and then discarded.

Statistical Analysis

Kolmogorov-Smirnov test was used to determine the normality of data distribution. The measurement data in accordance with normal distribution were expressed as mean ± standard deviation, and the comparison between the two groups was performed by *t*-test. The data of non-normal distribution were shown as median (quartile range) and analyzed by Mann-Whitney-U test. Classification data were expressed as the number of patients (percentage) and analyzed by chi-square test or Fisher exact test. All comparisons were bilateral, $p < 0.05$ was considered statistically significant. Statistical analysis was performed using IBM SPSS statistical version 19.0.0 (IBM, Armonk, NY, USA).

Results

From March 2018 to December 2021, a total of 966 patients were hospitalized for thoracic surgery and needed lung isolation. Among them, 72 patients with Arné score ≥ 11 were included in the current trial, who were separated randomly into two groups. As shown in Tables I and II, no differences in general conditions and the extent of airway difficulty were seen between the D group and the S group, while the highest Arné score in the D group was 23, comparing with the highest in the S group of 19.

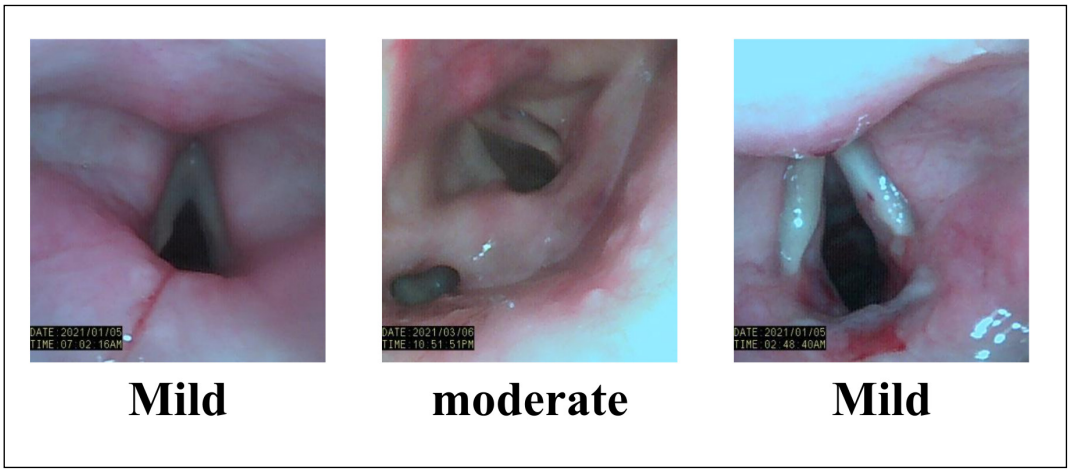

Figure 2. The categorization of damages of vocal cord after intubation.

The mean intubation resistance through the vocal cord in patients of the D group was 29, while the maximal value of 38.87953 N occurred in a patient with Arné score of 23. Comparatively, the average intubation resistance through the vocal cord in patients of the S group was 32, and the maximal resistance of 42.27648 N occurred in a patient with Arné score of 19 (Table III). The intubation success rate in the D group was 94.4% (34/36), in which 17 cases succeeded in the first trial and 8 cases succeeded in the second trial. Video laryngoscope assistance succeeded in 9 cases and failed in 2 cases (Figure 3), with the laryngoscope assist rate of 30.5% (11/36). An intubation success rate of 97.3% (35/36) was recorded in the S group, in which 24 cases succeeded in the first trial and 5 cases succeeded in the second trial. Video laryngoscope assistance succeeded in 6 cases and failed in 1 case (Figure 4), with the laryngoscope assist rate of 19.4% (7/36).

No statistical differences were observed in intubation time, post-operative VAS score, or damage extent of vocal cord. However, shorter time for alignment in the D group (average 32.75 s) was seen than in the S group (average 62.63 s), with $p < 0.05$. Consistently, the incidence of dislocation in the D group was 5.9% (2/34), lower than that in the S group of 31.4% (11/35). Among them, 2 cases of dislocation in the D Group occurred when the left bronchial tube was inserted too deep after changing position. In contrast, 7 cases of dislocation in the S group occurred after the position change and 4 cases occurred during surgery.

Discussion

In the current study, no significant differences in the resistance of intubation, success rate of intubation, assistance rate of video laryngoscope, intubation time, VAS score of postoperative sore throat and incidence of vocal cord injury were observed between video laryngoscope assisted DLT

Table I. General information of patients enrolled in the study.

	The D group (n = 36)	The S group (n = 36)	*p*-value
Age (year)	59.02 ± 8.53	57.79 ± 9.59	> 0.05
Sex (M/F)	15/21	18/18	
Height (cm)	163.46±6.80	165.67±8.18	> 0.05
Weight (kg)	65.67±9.80	65.79±9.85	> 0.05
ASA score			> 0.05
I	7	9	
II	21	17	
III	8	10	
operation time (min)	186±17.42	169±15.83	> 0.05

$p < 0.05$ was considered to be significant.

Table II. Arné score on the airway of patients before operation.

	The D group	The S group	*p*-value
History of airway difficulties	2 (5.56%)	4 (11.1%)	> 0.05
Airway difficulty related condition	8 (22.2%)	10 (29.6%)	> 0.05
Clinical condition of airway diseases	9 (25%)	10 (27.8%)	> 0.05
Incisor gap (IG) and maxillary luxation (ML)			> 0.05
IG = 5 cm or ML > 0	8 (22.2%)	11 (30.1%)	
3.5 < IG < 5 and ML = 0	27 (75.0%)	23 (63.9%)	
IG < 3.5 and ML < 0	1 (2.8%)	2 (5.6%)	
Modified Mallampati Score			> 0.05
1	N.A.	N.A.	
2	13 (36.1%)	14 (38.9%)	
3	21 (58.3%)	19 (52.8%)	
4	2 (5.6%)	3 (8.3%)	
Thyromental Distance < 6.5 cm	20 (55.6%)	21 (59.3%)	> 0.05
Lateral bend of head and neck			> 0.05
> 100°	4 (13.0%)	6 (18.5%)	
80 to 100°	24 (66.7%)	22 (63.0%)	
< 80°	8 (20.3%)	8 (18.5%)	
Arné score	15.62 ± 5.45	12.36 ± 4.73	> 0.05

$p < 0.05$ was considered to be significant.

and SLT intubation in patients with difficult airway.

Little definition or standard of difficult airway is provided in the current guidelines. Difficulties in mask ventilation, laryngoscope or tracheal intubation are mainly due to changes in the anatomical structure of the upper respiratory tract (the difficult upper respiratory tract). Pathophysiological changes in the tracheobronchial anatomy make the placement of the double lumen or other airway auxiliary devices difficult (difficulties in manipulation of the lower airway including lung isolation)[19]. In this study, patients with upper airway difficulty were enrolled. Many methods have been proposed to evaluate the difficult airway in clinic, which yielded certain sensitivity and specificity in predicting difficult airway. However, a single method could not predict all conditions in difficult airway, and thus should be used comprehensively in clinic. The Arné score is one of the most detailed clinical and multivariate risk indicators, which is commonly used to evaluate the hardiness in intubation by direct laryngoscope before operation[2]. If the Arné score exceeds 11, hard to intubation would be easily forecasted[3]. In the current study, the Arné score enabled us to identify patients known or most likely to have difficulty in intubation, therefore we chose patients with Arné score greater than 11 as the study subjects. Although the causes of difficult airway were different, data in Table I and II showed that there were no significant differences in the general situation and degree of airway difficulty between the two groups.

Fiberoptic bronchoscopy guided SLT intubation is considered to be the first choice for difficult airway during lung isolation[8]. In this trial, the clinical effect of fibrobronchoscope-guided heat softening DLT was studied. It has been demonstrated to be safe and effective to use fiberoptic bronchoscope to guide tracheal intubation in difficult airway. But for DLT, two main difficulties hinder its application: it is hard to find the glottis and insert the fiberoptic bronchoscope into

Table III. Summary of the results.

	The D group (n = 36)	The S group (n = 36)	*p*-value
Intubation resistance (N)	29	32	> 0.05
Intubation success rate	34 (94.4%)	35 (97.2%)	> 0.05
Laryngoscopy assist rate	11 (30.6%)	7 (19.4%)	> 0.05
Incidence of dislocation	2 (5.9%)	11 (31.4)	0.012
Intubation time T1 (s)	49.02 ± 8.54	46.36 ± 7.84	> 0.05
Time for alignment T2 (s)	32.75 ± 7.75	62.63 ± 8.42	0.001

$p < 0.05$ was considered to be significant.

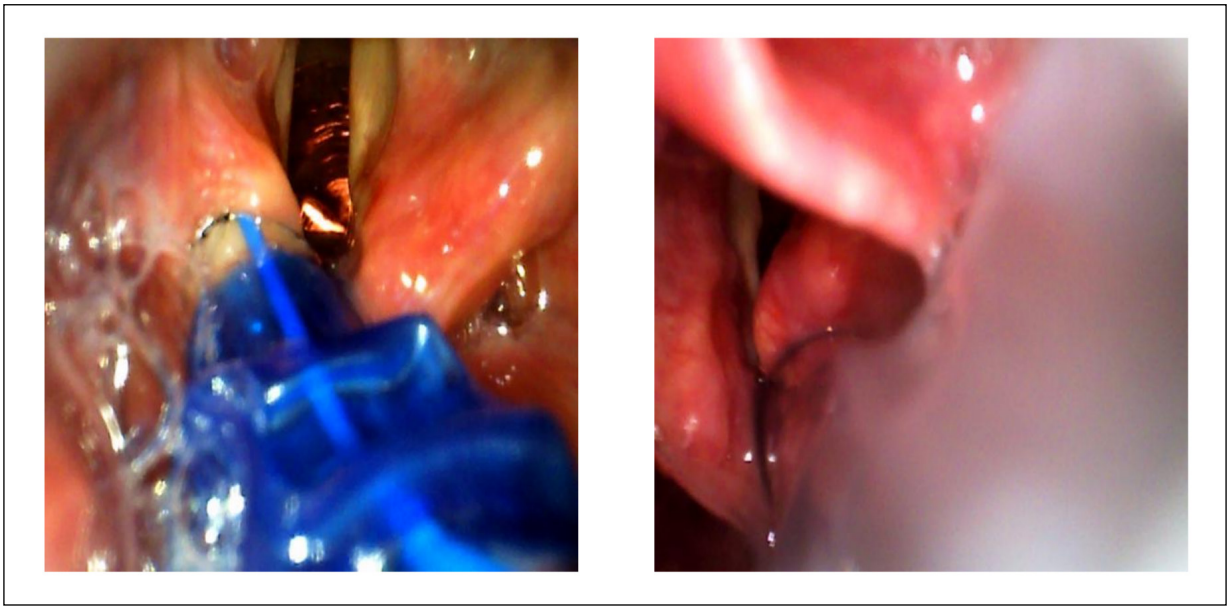

Figure 3. Video laryngoscope assisting the intubation process.

the trachea, and even succeeded in the insertion, large diameter and the hardiness of DLT material makes it harder for the tube to enter the airway. For the first difficulty, successful cases showed that video laryngoscope could be used to assist the exposure of glottis, and then fiberoptic bronchoscope was used to guide the catheter into the airway[15-17]. In contrast, few reports could deal with the second difficulty, that is, the placement of a catheter guided by fiberoptic bronchoscopy into the airway. Analysis of previous studies found that, the diameter difference between the catheter and the fiberoptic bronchoscope induced deviation of the front end of the catheter from the fiberoptic bronchoscope when it reached the larynx and moved towards the epiglottis, arytenoid cartilage, piriform fossa or esophagus, blocking the larynx and preventing it from entering the airway[4]. Indeed, in this trial, we also found 2 cases in the two groups requiring video laryngoscope assistance. One case in the D group and the other in the S group, both of which had entrance of fiberoptic bronchoscopy into the airway. However, the bronchial orifice was blocked in the larynx, by epiglottis, spoon cartilage or pyriform fossa. Therefore, we used the intubation resistance as the main observation index. Previous studies on intubation resistance were mostly based on indirect indicators, such as intubation time, intubation difficulty evaluation, postoperative vocal cord injury, or subjectively visual observation of resistance size under the laryngoscope image[14,20]. In this experiment, the resistance detector was used to detect the deformation of the tissue around the trachea caused by the pressure of the tube on the trachea wall, and the signal of tissue deformation was detected at the position of the glottis projected on the body surface, which was transformed into a mechanical value and directly reflected the pressure (as shown in **Appendix II**). As expected, the change in intubation resistance was directly proportional to intubation time, VAS score of postoperative sore throat and degree of vocal cord injury, and inversely proportional to success rate of intubation. With the increase in intubation resistance, the corresponding intubation time, VAS score of postoperative pharyngeal pain and degree of vocal cord injury increased, while the success rate of intubation decreased. We speculate that the intubation resistance causes catheter violence through glottis or repeated intubation operation, and thus prolongs intubation time, induces glottic edema, bleeding, and vocal cord injury, eventually leading to intubation failure.

No significant differences in the success rate of intubation and the auxiliary rate of video laryngoscope were observed between the two groups. For patients with difficult airway, video laryngoscope was used to expose glottis, and then fiberoptic bronchoscope was used to guide the catheter into the airway. The use of video laryngoscope and fiberoptic bronchoscope at the same time could contribute to the success of difficult tracheal intubation[21,22]. In the D group of the cur-

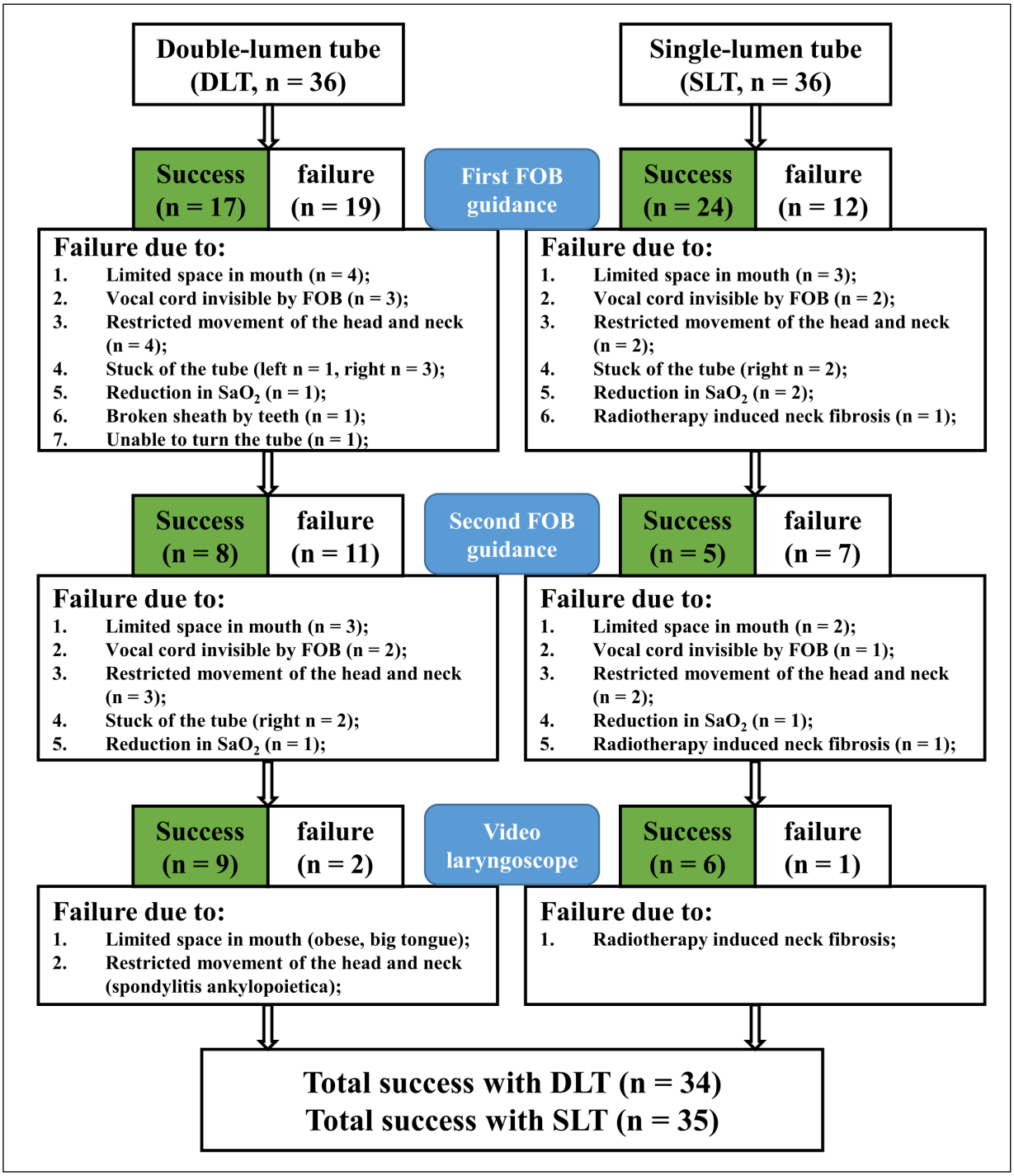

Figure 4. Overview of the current study.

rent trial, video laryngoscope was required for 11 patients (32.3%) to expose glottis, and 9 of them were intubated successfully. In an obese patient with BMI of 38, the tongue was too large, therefore the video laryngoscope could not be inserted into the DLT, where the DLT had been replaced with a 6.5 single lumen steel wire catheter and the occluder was used for one lung isolation. Another patient with mandatory spondylitis and flexion of head and neck, who was unable to lean back with a small oral operation space, and infantile epiglottis. The Arné score of this patient was 23. Two

Table IV. Summary of the minor results.

	The D group (n = 36)	The S group (n = 36)	*p*-value
VAS score of throat pain			> 0.05
1 h	3.92 ± 2.22	3.39 ± 2.38	
4 h	2.19 ± 1.45	1.81 ± 1.60	
12 h	0.83 ± 0.94	0.61 ± 0.80	
24 h	0.25 ± 0.44	0.22 ± 0.42	
Damage extent of vocal cord	21	25	> 0.05
Mild	14	18	
Moderate	6	4	
Severe	1	3	

$p < 0.05$ was considered to be significant.

attempts of DLT failed in this patient, and a 6.5 single lumen tube was used with occluder to complete the operation. In the S group, video laryngoscope was used for 7 cases (20.0%) to expose glottis, and 6 of them were intubated successfully. One patient with neck radiotherapy had limited mouth opening (1.2 cm), with an Arné score of 17. Video laryngoscope assisted glottic exposure was performed for a successful intubation. The reason might be that video laryngoscope assisted the exposure of glottis, therefore the tip of fiberoptic bronchoscope could be manipulated into glottis hence the trachea could be exposed. The results showed that, for patients with difficult airway, the success rate of DLT guided by fibrobronchoscope was similar to that of SLT ($p > 0.05$), and video laryngoscope could improve the success rate of intubation with DLT.

The average time of alignment in the D group was 32.75 s, while the average time of alignment in the S group was 62.63 s, with statistically significant difference between the two groups. Consistently, the incidence of catheter dislocation in the D group (5.9%) was lower than that in the S group (31.4%) ($p < 0.05$). These results were in line with previous reports[23,24]. The reason might be due to the one-time achievement of the alignment with DLT, and it was relatively simple to adjust the catheter position through the main tube. Comparatively, after the completion of SLT intubation, the occluder needed to be inserted again, and the occlusion alignment had to be finished in two steps[25]. In the D group, one patient whose bronchial end stuck the tube in the carina toward the right bronchus. At this time, the fiberoptic bronchoscope had entered the left bronchus. After rotating the proximal end of the catheter for many times, the direction of the bronchial end remained unchanged, so we had to withdraw the fiberoptic bronchoscope and the catheter to the sub-glottis, adjust the direction and re-insert for the alignment. The reason might be that the tube wall temperature reached 45.2°C during intubation, and the intubation time was 43.7 s, therefore the temperature was higher when the tube reached protuberance, which resulted in a better elasticity of PVC and insufficiency of the hardness to turn. Therefore, the thermal softening temperature needed to be explored further.

Scholars[26] have shown that the incidence of pharyngeal pain and hoarseness after DLT (60%) is higher than that of occluded tube (13%) in non-difficult airway. No difference was observed between DLT and SLT in the current study (Table IV). We speculated that there might be two reasons: first, DLT was not inclined, and the round blunt bronchial end might pass through glottis more easily than the inclined tip of SLT. Meanwhile, the diameter of DLT (5 mm in 35 FR) was smaller than that of SLT (7.5 mm in 7.5 and 7.0 mm in 7.0), and it had a higher degree of fit with the fiberoptic bronchoscope making it less easy to be deviated from the fiberoptic bronchoscope during moving, which reduced intubation resistance. Second, due to the softness and plasticity of the heated DLT, the fibrobronchoscope was easier to pass through the physiological bending of the upper respiratory tract accompanying the DLT tube, making the DLT easier to pass through the glottis, which therefore reduced the intubation resistance, shortened the intubation time, and avoided the intubation related complications. These observations were also in consistent with previous report[14].

There were some limitations in this study as well. First, this was a preliminary study, and the sample size lacked detailed statistical consideration and references for the estimation. Due to the low incidence (0.2%) of patients with extremely difficult airway (C-L grade IV)[27], a to-

tal of 72 cases might not be sufficient to detect the clinically related differences. Secondly, the heating temperature of DLT cannot be unified at a constant temperature, with a range of 41 ± 2°C, which might affect the test results. Third, the evaluation of post-operative sore throat and vocal cord injury was subjective. Some other operations, such as extubation, oral sputum suction, video laryngoscope, could also affect post-operative sore throat and vocal cord injury. Fourthly, video laryngoscope in this trial was completed by an unfixed anesthesia assistant, which might affect the exposure degree of glottis as well.

Conclusions

In summary, for intubation in patients with difficult airway, the thermal softening DLT was as safe as the SLT, but simpler in alignment and with a lower dislocation incidence. Meanwhile, video laryngoscope could increase the success rate of intubation with either tube. Larger prospective clinical trials could be conducted in the future to further validate our findings.

Conflict of Interest

The authors have no conflict of interest to declare.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' Contributions

All authors contributed to data analysis, drafting, or revising the article, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

Ethics Approval Statement

This research was reviewed and approved by the Ethics Committee of the First Hospital in Qinhuangdao City, Hebei Province (with the permit number 2019D004).

Informed Consent

Informed consent was obtained from all participants.

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