Original Research

An In Vitro Evaluation of Aerosol Delivery Through Tracheostomy and Endotracheal Tubes Using Different Interfaces

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BACKGROUND: Previous research reporting factors influencing aerosol delivery in intubated patients has been largely focused on the endotracheal tube (ETT) during mechanical ventilation, with little comparative analysis of effect of types of artificial airways and their interfaces on aerosol delivery during spontaneous breathing. The purpose of this study was to compare aerosol delivery via tracheostomy tube (TT) and ETT, using interfaces such as T-piece, tracheostomy collar, and manual resuscitation bag. METHODS: A teaching manikin was intubated with either an ETT (8.0 mm inner diameter) and TT (8 mm inner diameter). Both bronchi were connected to a collecting filter, attached to a sinusoidal pump simulating the breathing pattern of a spontaneously breathing adult (tidal volume 450 mL, respiratory rate 20 breaths/min, inspiratory-expiratory ratio 1:2). Albuterol sulfate (2.5 mg/3 mL) was nebulized through a jet nebulizer, using each airway and interface as appropriate (*n* = 3). Drug on the filter was eluted and analyzed with spectrophotometry, and expressed as mean percent of loaded dose delivered. Descriptive statistics, the Student *t* test, and one-way analysis of variance were applied. RESULTS: A greater percentage of nominal dose was delivered via TT than ETT with both T-piece (13.79 ± 2.59% vs 9.05 ± 0.70%) and manual resuscitation bag (45.75 ± 1.8% vs 27.23 ± 8.98%, *P* = .038 and *P* = .025, respectively). Use of manual resuscitation bag with both TT and ETT increased lung dose more than 3-fold. Inhaled dose with tracheostomy collar was (6.92 ± 0.81%) less than T-piece with TT (*P* = .01). CONCLUSION: In this adult model of spontaneous ventilation, aerosol therapy through ETT was less efficient than TT, while the manual resuscitation bag was more efficient than T-piece or tracheostomy collar. *Key words: tracheostomy tube; artificial airways; endotracheal tubes; aerosols; tracheostomy collar; tracheostomy mask; t-piece; manual resuscitation bag; nebulizers.* [Respir Care 2012;57(7):1066–1070.

Introduction

Artificial airways such as the tracheostomy tube (TT) and endotracheal tube (ETT) are commonly used for aerosol therapy as part of long-term airway management in critically ill patients. Evidence indicates that artificial airways influence aerosol deposition during mechanical ventilation.[1-6] For instance, the efficiency of aerosol therapy through an ETT has been associated with the inner diameter of the airway. Delivery efficiency decreased with reduction of the inner diameter of the ETT and was significantly lower in the smaller-sized airways.[1-3] Because ETTs are 30–50% narrower than the internal diameter of the trachea, early work hypothesized that artificial airways would be a key factor in reducing aerosol delivery, compared to the normal non-cannulated airways. In addition,

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narrow inner diameters of ETTs increase airway resistance and are associated with losses in aerosol delivery.[5,7] However, others have suggested that the smooth interior surfaces of the artificial airways may create a more laminar flow path, compared to the structures of the upper airway, resulting in even greater aerosol efficiency.[5]

Previous research reported several factors influencing aerosol delivery in intubated patients, with a primary focus on aerosol delivery through an ETT during mechanical ventilation.[5,8-21] Comparative aerosol delivery efficiencies between artificial airways and their interfaces on aerosol delivery in spontaneously breathing patients with ETT or TT remain unclear. Using artificial airways and their interfaces effectively during aerosol therapy could lead to greater pulmonary deposition of drug in spontaneously breathing patients with artificial airways. It is important to make practical recommendations with the aim of helping clinicians in optimizing delivery of inhaled bronchodilators for the well-being of critically ill patients with artificial airways who do not or no longer require mechanical ventilation. It is not uncommon for patients to require airway protection with an ETT or TT post anesthesia or mechanical ventilation prior to extubation. Therefore, the purpose of this study was to compare aerosol delivery between ETT and TT, using different interfaces such as T-piece, tracheostomy collar, and manual resuscitation bag. The following 3 questions were addressed in this study:

How much aerosol is delivered with each interface using ETT and TT?

Is there any difference on aerosol deposition between ETT and TT when using T-piece and manual resuscitation bag?

What is the most efficient interface of aerosol therapy for simulated intubated patients with ETT and TT?

QUICK LOOK

Current knowledge

Aerosol deposition during mechanical ventilation is significantly reduced by the presence of an artificial airway. As internal diameter of the artificial airway diminishes, aerosol deposition in the artificial airway increases.

What this paper contributes to our knowledge

During simulated spontaneous breathing, the presence of a tracheostomy tube results in less impediment to aerosol deposition than a similar internal diameter endotracheal tube. The use of manual ventilation enhanced aerosol deposition in this model.

Methods

Experimental Setup and Research Design

All experiments with TT (Portex, Smith Medical, Dublin, Ohio) and ETT (Mallinckrodt, Boulder, Colorado) used an anatomical teaching manikin (Medical Plastic Labs, Gatesville, Texas), with both bronchi attached to a collecting filter (Respirgard II, Vital Signs, Totowa, New Jersey), using a Y adapter. The cuff of both the TT and ETT were inflated to minimal occluding pressure. A jet nebulizer (eValueMed, Trianim Health Services, Sylmar, California) was operated at 8 L/min to deliver albuterol sulfate (2.5 mg/3 mL) to the lung model via tracheostomy mask (AirLife Adult Tracheostomy Mask, Cardinal Health, McGaw Park, Illinois), aerosol T-piece, and standard manual resuscitation bag (manual resuscitation test lung, Ohmeda, Harlow, Essex, England) and run until sputter at each condition tested in this study (n = 3). While the TT was tested with all of the interfaces, only the T-piece and manual resuscitation bag were utilized with ETT. Figure 1 represents the scheme of study design of this research, including study variables, experiments, and sample size.

Lung Model Used With the T-Piece and Tracheostomy Collar

As shown in Figure 2, an anatomical teaching manikin was first intubated with an ETT (shown) and then a TT (not shown), both with 8 mm inner diameter. Each mainstem bronchi of the model was connected to a Y adapter attached to a collecting filter. The teaching manikin and filter were attached to a sinusoidal pump set to simulate a spontaneously breathing adult (tidal volume 450 mL, respiratory rate 20 breaths/min, inspiratory-expiratory ratio 1:2) for all experiments with the T-piece (shown) and tracheostomy collar (not shown) (see Fig. 2). Since the large-volume nebulizer is typically used to provide humidity to intubated patients, aerosol was administered from a jet nebulizer in line with a large-volume nebulizer that was kept off throughout the experiments.

Lung Model Used With the Manual Resuscitation Bag

Figure 3 shows the lung model and filter attached to a passive test lung with an electronic respirometer (Anesthesia Associated, San Marcos, California) in line, with an manual resuscitation bag attached by 22 mm inner diameter tubing to a jet nebulizer, connected to a sealed T-piece attached to the airway, using both TT and ETT (see Fig. 3). In order to be consistent with the spontaneously breathing model, breaths were delivered via manual resuscitation bag by a single operator, with volumes monitored using

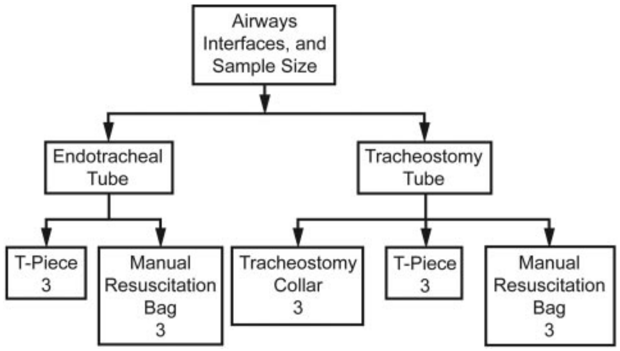

Fig. 1. Graphical representation of the study design, including the sample size, the type of airways, and the interfaces used in this study.

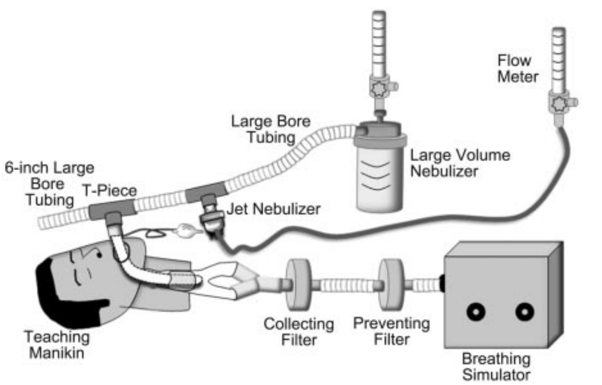

Fig. 2. Experimental setup used with the T-piece, using tracheostomy tube and endotracheal tube.

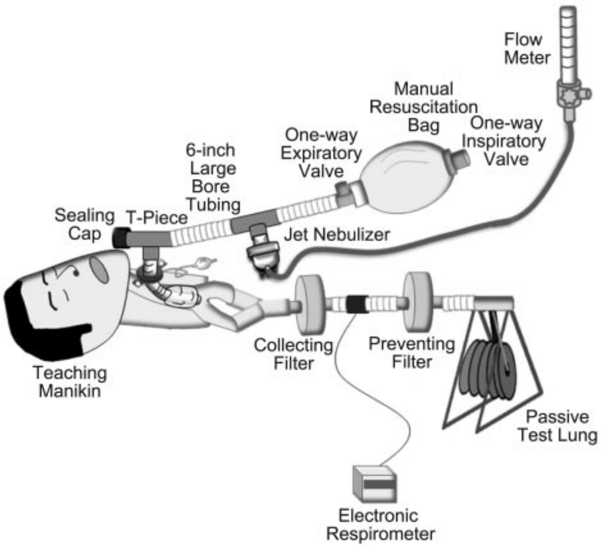

Fig. 3. Experimental setup used with the manual resuscitation bag, using tracheostomy tube and endotracheal tube.

Table. The Amount of Albuterol Expressed as Percent of Total Dose Deposited Distal to the Main Bronchi of the Model With Each Airway and Interface Used in This Study

	Tracheostomy Collar	T-piece	Ambu Bag
TT	6.92 ± 0.81	13.79 ± 2.59	45.75 ± 1.80
ETT	NA	9.05 ± 0.70	27.23 ± 8.98

Values are mean ± SD.
TT = tracheostomy tube
ETT = endotracheal tube
NA = not applicable

the respirometer. The beginning of each inspiration was synchronized with the breaths given by the sinusoidal pump that was run independently during each run.

Data Analysis

After each nebulizer treatment, deposited drug was eluted from the filter and analyzed by spectrophotometry to quantify inhaled drug quantity, and expressed as a mean ± SD percentage of the nominal dose placed in nebulizer. Descriptive statistics were calculated to determine mean and standard deviation of each condition. Comparisons of inhaled dose percent between interfaces used with the TT were made using repeated measures analysis of variance and Scheffé post-hoc comparisons. Differences of the inhaled dose percent obtained with the T-piece and manual resuscitation bag using ETT were compared with the paired sample *t* test. Independent sample *t* tests were performed to identify significant differences on inhaled dose percent obtained from each interface used with ETT and TT. A P value of < .05 was considered to be statistically significant.

Results

Inhaled drug delivery beyond the bronchi of the model was expressed as mean ± SD of percent of nominal dose (Table). Significant differences were found between interfaces used with the TT and ETT ($P < .001$). Aerosol deposition was significantly greater with the TT than with the ETT, with both T-piece and manual resuscitation bag ($P = .038$ and $P = .025$, respectively). When using the TT, inhaled dose with the tracheostomy collar was lower than the T-piece or manual resuscitation bag ($P = .01$ and $P < .001$, respectively). Use of the manual resuscitation bag during aerosol therapy increased lung dose more than 300% with TT ($P < .001$) and ETT ($P = .008$) in this simulated adult model.

Discussion

The findings indicate that aerosol delivery through the TT was up to 40% more efficient than the ETT with both the T-piece and the manual resuscitation bag. To our knowledge, at the time of this study no data comparing aerosol delivery between ETT and TT in spontaneously breathing patients were available in peer-reviewed literature. The majority of studies on aerosol deposition through ETT in the literature studied aerosol delivery during mechanical ventilation, with deposition to the filter distal to the ETT ranging from 1% to 37%, depending upon the type of nebulizer, measurement, and ventilator parameters used during mechanical ventilation.[8-17] However, the delivery of albuterol from a jet nebulizer through an ETT during spontaneous breathing has not been reported. The obvious variable to associate with improved aerosol delivery with similar internal diameters is the difference in length between an ETT and TT. This would agree with reports by O'Riordan et al that the TT is less of a barrier for aerosol delivery during mechanical ventilation, because only 2.6% of nebulizer output deposits in the TT during inspiration.[4]

We found that aerosol delivery via the T-piece was more efficient than the tracheostomy collar. This agrees with findings of Piccuito and Hess,[22] who evaluated bronchodilator delivery through a TT in vitro, using a nebulizer, different patient interfaces, bias flow, and humidification. They concluded that aerosol delivery with high gas flow and humidity was inefficient and use of a T-piece increased aerosol deposition significantly, compared to a tracheostomy collar.[22] Piccuito and Hess also reported that the amount of aerosol delivered to a filter distal to the TT using a tracheostomy collar was 12.9%, compared to 15.3% with the T-piece, when no additional flow and humidity were used.[22] The greater differences between TT and ETT in this study may be attributed to differences in lung models, nebulizer type, and setup. While Piccuito and Hess used a semicircular model that was attached directly to the collecting filter, our lung model consisted of an anatomical teaching manikin with both bronchi attached to a collecting filter, using a Y adapter. They used the Hudson Micro-Mist nebulizer, and the nebulizer setup was different. For instance, Piccuito and Hess attached the nebulizer to a T-piece in which one side was capped and the other was connected to a 15 cm large bore tubing that was attached to another T-piece connected to the tracheostomy collar. We directly attached the nebulizer to the tracheostomy collar, as this is the most common nebulizer setup used by respiratory therapists in the clinical setting.

In our study the inhaled dose ranged from approximately 7% to 46%, depending upon the type of interfaces utilized. Significant differences were found between interfaces used with the TT and ETT. When using the TT, aerosol delivery with the tracheostomy collar was the lowest, and the T-piece provided twice as much aerosol, compared to the tracheostomy collar. Use of manual resuscitation bag during aerosol therapy increased lung dose more than 3-fold with TT and ETT in our model of a simulated spontaneously ventilated adult. In experiments with the manual resuscitation bag we observed that the amount of aerosol lost during expiration was significantly less, as our model had a relatively closed system that minimized aerosol loss during expiration. This suggests that in some manner the manual resuscitation bag setup acted as an effective reservoir. Capping the end of the tubing may increase drug delivery with the manual resuscitation bag because of the charging effect of the closed circuit with drug. The increase in filter deposition is more likely due to charging the closed circuit than any reservoir effect of the manual resuscitation bag itself.

Further studies with other designs of valved manual resuscitator bags are warranted to better determine the variables associated with this increased efficiency. To the best of our knowledge, this is the first study testing aerosol delivery with the manual resuscitation bag in simulated spontaneously breathing patients with artificial airways; therefore, no comparisons could be made.

Limitations

Our study used a bench model in order to evaluate aerosol delivery through TT and ETT using different interfaces. To reduce variables in this study we used only one type of breathing pattern, one brand of nebulizer, and one size of artificial airway. Further research explaining the effect of these variables on aerosol delivery on spontaneously breathing adults with artificial airways is warranted.

Implications for Clinical Practice

This study provides several implications for clinicians. First, aerosol delivery via TT was 35–41% more efficient than ETT in spontaneously breathing patients with all interfaces tested. Second, aerosol delivery via the tracheostomy collar was substantially less efficient than the T-piece. Finally, these findings suggest that the greater drug delivery with the manual resuscitation bag with both types of artificial airways demonstrates potential for more efficient delivery of medical aerosols to passively breathing patients with artificial airways. This also raises concerns that such high doses may exceed the safety threshold for a specific drug and precipitate adverse effects. Based on these findings, clinicians should closely monitor patients for adverse effects, when "bagging" in medication. Using these simple but important strategies, clinicians can optimize delivery of inhaled bronchodilators for the well-being of critically ill patients.

Conclusions

In this adult model of spontaneous ventilation, aerosol therapy through ETT was less efficient than TT, while the manual resuscitation bag was more efficient than T-piece or tracheostomy collar. Further study is required to better understand whether these findings can be generalized to a broader number of manual resuscitation bag designs.

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