Poorly placed tracheostomy tubes: Effects on flow and resistance

Joshua Moorhouse¹, Tahir Ali², Tobias Moorhouse³ and David Owens³

Abstract

This study aimed to investigate the effects of an incorrectly positioned tracheostomy tube on flow resistance. A laboratory-based model of the trachea was used with both cuffed and uncuffed tracheostomy tubes inserted to variable depths. With a constant metered flow through the model, the pressure for given depths of insertion was recorded. The model was then re-run to test the effect of different flow rates on the system. A total of 468 individual results were grouped and statistically analysed. They showed that both over- and under-insertion increase the pressure within the circuit and that a cuffed tracheostomy tube offers a degree of protection against this. These results were statistically significant with $P < 0.05$ demonstrating that incorrect positioning has a greater resistance to flow. These results provide an essential scientific basis for further work to assess the clinical significance of incorrect positioning as well as suggesting the need to monitor tube position.

Keywords

Airway resistance, flow, malposition, tracheostomy

Introduction

Tracheostomy tube insertion is a common procedure with an estimate of over 12,000 undertaken in the UK each year.¹ Tracheostomy tubes are typically of a basic design with majority consisting of a rigid fixed 90 degree curvature enabling the tube to simultaneously lie perpendicular (and upon) the skin of a patient's neck yet also within and parallel to the patient's trachea. Tracheostomy tube selection has traditionally been based upon the ratio between tracheal diameter and the distance between the tracheal wall and the cutaneous surface of the skin. In clinical practice, however, it is recognised that there is a natural anatomical variation in the skin to trachea:trachea diameter ratio² and in the gross dimensions of patient's necks.^{3,4} Additionally, the national trend of increasing body habitus⁵ together with the natural variation of the population have affected the previously accepted ratio used in tracheostomy tube selection thus complicating sizing. This has led to the postulation; one size does not fit all.

Considering the rigid fixed curvature of traditional tracheostomy tubes, the position of the external portion of the tube directly affects the position of the internal portion, specifically the terminal meatus and its parallel relationship to the tracheal wall. Loss of

this parallel relationship risks complete or partial occlusion of the tube thus increasing airflow resistance and ventilatory effort. This concept was described in clinical practice with a case report postulating that intra-operative ventilation difficulties were encountered when a tracheostomy tube's internal position was altered and partially obstructed by the tracheal wall.⁶ In addition, chronic complications have been described due to variation in tube position. For patients with tracheostomies being weaned off mechanical ventilation, almost 10% were malpositioned (of which 90% were partially occluded by the tracheal wall) and these patients experienced almost double the time to be weaned from mechanical ventilation.⁷ While the article mainly examined the risks associated with surgically inserted tracheostomies, it could be argued that the current risk of malpositioning will be lessened by the trend towards routine percutaneous

¹Anaesthetics Department, Wycombe Hospital, High Wycombe, UK

²Anaesthetics Department, John Radcliffe, Oxford, UK

³ENT Department, University Hospital Wales, Cardiff, Wales, UK

Corresponding author:

Joshua Moorhouse, Anaesthetics Department, Wycombe Hospital, Queen Alexandra Road, High Wycombe, Bucks HP11 2TT, UK.

Email: joshua.d.moorhouse@gmail.com

tracheostomies followed by bronchoscopic verification. This verification does allow for the early correction of any obstructive positioning of the tube but it does not account for a theory that the majority of malpositioning occurs days to weeks post insertion.

Although the consequences of tracheostomy tube malpositioning have been postulated theoretically and described clinically, little evidence exists as to the objective consequences with regard to airflow and resistance.

This study examines the effect tracheostomy tube malposition has on airflow and ventilatory effort, using flow resistance as objective evidence. By using a laboratory model of the airway within a controlled environment, quantifiable values could be obtained for this theorised circumstance providing objective data and evidence to further base clinical interpretation.

Method

The study design involved creating a model in which a tracheostomy tube could be placed into an artificial trachea and held static at varying degrees of insertion. A flow could then be introduced through the model, allowing the change in resistance with insertion depth to be recorded. The experiment could then be repeated for both cuffed and uncuffed tracheostomy tubes. This could then be followed by multiple repeats of the experiment and stratifying the data into groups allowing for statistical analysis.

Study equipment

Tracheal/neck model. Standard bore anaesthetic ventilation tubing was used to act as a model trachea. A fenestration was cut within the ventilation tubing for the tracheostomy tube to be inserted (Figure 1). Once

inserted to the required depth (measured using a straight rule) the tracheostomy tube was held static using a clamp. Size 10 Shiley tracheostomy tubes with internal diameter of 8.9mm and a length of 81.0mm were used throughout the study with both cuffed and uncuffed varieties tested. The cuffed tube was inflated with 10 mL of air when it was in use.

Airflow model. Compressed air from the laboratory's regulated main supply was directed into the model via an adjustable tap which enabled the rate of flow to be varied from the constant output main supply. This supply was then directed through the first RT-200 calibration analyser to record the flow before being channelled into the tracheostomy tube. A small 'T' piece outlet after the calibration analyser was directed to a second RT-200 calibration analyser, which recorded the pressure within the circuit. All connections within the circuit were attained using universal connectors and standard bore anaesthetic tubing.

RT-200 calibration analyser. The RT-200 (Figure 2) (Timeter Instrument Corporation; now Allied Healthcare Products, St Louis, Missouri, USA) is used to check and calibrate ventilation systems and is capable of measuring the flow, pressure and volume of both air and oxygen. The functions used were air high flow (L/min, accuracy $\pm 2\%$), airflow pressure (cm H₂O, accuracy $\pm 1.6\%$). Two machines were used to enable simultaneous monitoring of both flow and pressure. The analysers are checked and calibrated annually.

Study procedure

Airflow and resistance through the tracheostomy/neck model were assessed by first inserting and

Figure 1. Neck model configuration showing the tracheostomy tube clamped and inserted through a fenestration within the anaesthetics tubing.

Figure 2. Pair of RT-200 calibration analysers.

clamping the tracheostomy tube at a pre-determined and measured depth. The range of insertion depths used was between 2 and 8 cm, with 0.5 cm intervals. Each insertion depth was assessed at a range of flow rates to simulate the different stages of ventilation. The flow rates used were: 5, 10, 15, 20, 25 and 30 L/min. For each flow and depth scenario, the pressure before the tracheostomy tube was recorded. This procedure was carried out for both the cuffed and uncuffed tracheostomy tubes with each measurement being repeated three times to give a mean result.

Statistical analysis

Statistical analysis was performed by grouping the results of each airway/airflow scenario into three categories of insertion depth to assess for changes in flow resistance. These categories were: (1) over-insertion (2) mid-insertion and (3) under-insertion. The null hypothesis states that there would be no statistical difference in resistance between the three groups. To test for statistical significance a Student's t-test was applied between each data set.

Results

A total of 468 individual data recordings were taken during the study and the means results were plotted graphically (Figure 3).

Assessment of pressure in relation to insertion depth

Mean results show that as the depth of tracheostomy tube insertion approaches either extreme the pressure within the system increases. These trends were similar for both the cuffed and uncuffed tracheostomy tubes.

The data set was grouped into three different categories according to depth of insertion of the tracheostomy tube. The depth categories were based upon observations of pressure variations between different insertions and were defined as: (1) over-insertion (2–3.5 cm), (2) mid-insertion (4–5 cm) and (3) under-insertion (5.5–8 cm). At each flow rate, the raw data from the three insertion groups were compared for statistical significance. The results showed that, for flow rates above 10 L/min, a statistically significant difference existed between the pressure variations for the correct (mid-insertion) and incorrectly placed tracheostomy tubes ($P < 0.05$). The only instance where this was not true was for a cuffed tracheostomy tube comparing over-insertion to correct positioning; the results were significantly different ($P < 0.05$) for flow rates of 25 and 30 L/min.

Analysis of the difference between cuffed and uncuffed tubes

The data sets were then compared for differences between cuffed and uncuffed tubes. Analysis highlighted that, at high rates of flow, a cuffed tube provided less resistance when malpositioned compared to an uncuffed tube. Statistical analysis using the same categories for level of insertion demonstrated that this finding was significant ($P < 0.05$) at flow rates of 15 L/min and above for over-inserted tubes and at 20 L/min and above for under-inserted tubes.

Discussion

This study examined the relationship between resistance to flow and tracheostomy tube insertion depth within a trachea/neck model. Specifically, the study examined whether malpositioning of the tracheostomy tube had an effect on resistance to airflow.

Figure 3. Line graphs showing the depth of insertion of the tracheostomy tube and the resultant pressure variation while being segregated for flow rate and type of tracheostomy tube.

The results collected show that the incorrect positioning (over or under insertion) of a tracheostomy tube increases the required pressure to maintain a constant airflow; incorrect positioning increases the resistance to flow (extrapolated from the principle of Poiseuille's law). These results were statistically significant when comparing incorrect against correct positioning. These findings have a direct clinical consequence as this resistance would require greater effort of self-respiration or mechanical ventilation to maintain

adequate oxygenation and carbon dioxide removal. It could be hypothesised that this difference in resistance to flow upon incorrect positioning is due to a change in the flow through the model verging towards turbulent from laminar. Further analysis of the data does appear to suggest this to be the case but further work would be required to make a valid extrapolation.

Additionally, the results demonstrated that cuffed tracheostomy tubes were, to a degree, protective

against the effect of tube malposition with significantly lower resistance noted at both over- and under-insertion compared to uncuffed tubes. This again may have clinical consequence, specifically when there is a decision to change from a cuffed to an uncuffed tracheostomy tube during disease resolution as this may inadvertently affect patient outcome.

Within the operative setting, case reports highlight that obstructions⁸ or structural abnormalities⁹ with the breathing circuits have significant clinical impact on the anaesthetised patient. For intensive care patients, malposition of a tracheostomy tube increases the average time for a patient to be weaned off ventilation.⁷ In conjunction with the results from this study it could be suggested that the effects of tracheostomy tube malposition could lead to increased resistance of breathing and be a cause of a clinically observable effect on a patient. The results obtained in this study are from a laboratory bench model using a minimally compliant, open-ended corrugated tube to model the trachea. This does limit the total significance of the data as the absolute pressure values obtained would not be translatable to the *in vivo* clinical setting. However, an *in vivo* apparatus would be complex to establish and a more advanced *in vitro* model lacks the necessary compliance and characteristics to significantly increase the validity of the model.¹⁰ Although lacking in the ability to extrapolate the absolute pressure values, this simple model addresses the main objective that we set out to investigate: determining whether positioning has an effect on the resistance to flow.

Clinically, the effects of an increase in resistance could mean that tracheostomy tube malposition would reduce the positive pressure delivered to a mechanically ventilated patient, potentially reducing the treatment effects from this ventilation. It could also suggest that spontaneously breathing patients would have to increase their work of breathing to accommodate an incorrectly placed tracheostomy tube. This could potentially result in an increase in the time required to wean the patient off a ventilator, or render such attempts unsuccessful. A direct clinical application of these results could be the regular monitoring of tube positioning, especially in patients requiring higher than expected ventilation pressures. This could expose and correct any malpositioning before it is detrimental to the patients. Further studies introducing animal models or *in vivo* apparatus would help to add directly applicable pressure values in order to assess whether the findings are translatable to the theorised clinical consequence.

In conclusion, incorrect positioning of a tracheostomy tube leads to an increased resistance to flow within a tracheal/neck model with this finding being present irrespective of a cuffed or uncuffed tube being

used. Cuffed tracheostomy tubes do, however, convey some protection against this effect. Theoretically, this finding may have consequences on clinical care and the need to monitor tube position; however, further research is required to assess the actual clinical significance.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

References

1. Gwinnutt C. The national tracheostomy project. The emergency management of tracheostomy and emergency management of laryngectomy. *Resuscitation Council Newsletter* (UK). www.resus.org.uk/newsletter/nletr12W.pdf (2012, accessed 28 March 2015).
2. Griscom NT, and Wohl ME. Dimensions of the growing trachea related to body height. Length, anteroposterior and transverse diameters, cross-sectional area, and volume in subjects younger than 20 years of age. *Am Rev Respir Dis* 1985; 131: 840–844.
3. Muhammad JK, Major E, and Patton DW. Evaluating the neck for percutaneous dilatational tracheostomy. *J Craniomaxillofac Surg* 2000; 28: 336–342.
4. Szeto C, Kost K, Hanley JA, et al. A simple method to predict pretracheal tissue thickness to prevent accidental decannulation in the obese. *Otolaryngol Head Neck Surg* 2010; 143: 223–229.
5. Finucane MM, Stevens GA, Ezzati M, et al. National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. *Lancet* 2011; 377: 557–567.
6. Abola RE, Tan J, Wallach D, et al. Intraoperative airway obstruction related to tracheostomy tube malposition in a patient with achondroplasia and Jeune's syndrome. *Middle East J Anaesthesiol* 2010; 20: 735–738.
7. Schmidt U, Hess D, Kwo J, et al. Tracheostomy tube malposition in patients admitted to a respiratory acute care unit following prolonged ventilation. *Chest* 2008; 134: 288–294.
8. Sprung J, Bourke DL, Harrison C, et al. Endotracheal tube and tracheobronchial obstruction as causes of hypoventilation with high inspiratory pressures. *Chest* 1994; 105: 550–552.
9. El-Khatib MF, Husari A, Jamaledine GW, et al. Changes in resistances of endotracheal tubes with reductions in the cross-sectional area. *Eur J Anaesthesiol* 2008; 25: 275–279.
10. Walenga RL, Longest PW, and Sundaresan G. Creation of an in vitro biomechanical model of the trachea using rapid prototyping. *J Biomech* 2014; 47: 1861–1868.