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The accuracy of anaesthetists in the depth of oral endotracheal tube placement in an academic hospital

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The accuracy of anaesthetists in the depth of oral endotracheal tube placement in an academic hospital

Ryan Jonathan Campbell

A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfillment of the requirements for the degree of Master of Medicine in Anaesthesiology, Johannesburg, 2017

DECLARATION

I, Ryan Jonathan Campbell declare that this research report is my own work. It is submitted for the admission to the degree of Master of Medicine in Anaesthesiology by the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

…… (Signature of candidate)

10th day of February 2017

ABSTRACT

Background: Endotracheal intubation is currently the proverbial “gold standard” for securing and protecting a patient’s airway. However, endotracheal tube (ETT) misplacement is a recognised complication of intubation and can result in significant patient morbidity and mortality. The aims of this study were to describe anaesthetists accuracy at placing oral ETTs to the correct depth, factors which influenced this accuracy and the methods used by anaesthetists to confirm correct ETT placement.

Methods: A prospective, contextual, descriptive research design was used. The sample included 138 adult patients presenting for elective surgery requiring oral ETT insertion, and the anaesthetists intubating these patients. Recorded variables included patient age, gender, height, ETT position at the front upper incisors, ETT tip to carina distance and the methods used by anaesthetists to confirm correct ETT placement.

Results: Only 45.7% of ETTs were accurately placed with 34.8% being too deep. There were significantly more deep ETT misplacements in females ($p=0.0231$), and patients with deep ETT placement were significantly shorter than those with accurate ETT placement ($p<0.05$). The number of methods used by anaesthetists to confirm correct ETT placement did not influence accuracy ($p=0.4014$). Neither the 21/23 cm nor the 20/22 cm methods were shown to improve the accuracy of ETT placements. Endotracheal tube distance measured at the front upper incisors was weakly correlated to the ETT distance measured above the carina in female patients but not in males.

Conclusion: Endotracheal tube misplacement is a frequent event in the intraoperative period, and potential risk factors identified included female gender and extremes of height. Endotracheal tube placement should be individualized. Airway ultrasound is a point of care test that could potentially help confirm correct ETT placement.

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ABREVIATIONS

ETT: Endotracheal tube

AIMS: Australian Incident Monitoring Study

CHBAH: Chris Hani Baragwanath Academic Hospital

ASA: American Society of Anesthesiologists

Wits: University of the Witwatersrand

ICU: Intensive care unit

C spine: Cervical spine

T spine: Thoracic spine

ED: Emergency department

SD: Standard deviation

IQR: Interquartile range

CHAPTER 1. Overview of the study

1.1. Introduction

This chapter will provide an overview of the study. The background to the study, problem statement, aims and objectives, research assumptions, demarcation of the study field, ethical considerations, research methodology, significance of the study and research report outline will be presented.

1.2. Background to the study

At present, an endotracheal tube (ETT) is still the proverbial “gold standard” when it comes to securing and protecting a patient’s airway (1). It is imperative that every person practicing anaesthetics should be able to accurately place an oral ETT.

The dangers of misplacing an ETT have been well described (2-7). Unrecognised oesophageal intubation can lead to hypoxia, regurgitation, aspiration, arrhythmias and death (1). An ETT that is placed too deep can lead to unintentional endobronchial intubation, with associated hyperinflation of the affected lung, atelectasis of the contralateral lung, ventilation perfusion mismatch, hypoxia and pneumothorax (2, 6, 8-11). An ETT that is placed too shallow in the trachea can lead to inadvertent extubation, inadequate ventilation and hypoxia, aspiration, laryngospasm and laryngeal injuries (2, 6, 7, 9, 11, 12).

Several clinical methods are available to confirm ETT position at the bed side including visualisation of the tip of the ETT passing though the cords, misting inside the lumen of the ETT, auscultation of the chest and epigastrium, capnography, pulse oximetry and palpation of ETT bulb (1-3, 6, 13, 14). However, although these tests are useful to exclude oesophageal intubation,

they cannot accurately predict how far an ETT is placed within the trachea (1-3, 6, 14, 15).

Several formulae have been developed to aid in depth of ETT placement, although most have been validated only for children (3, 16-21). The recommendation that in adults an ETT should be placed from 20 to 21 cm at the upper incisors in females, and 22 to 23 cm in males is a good guideline (17, 22); however, there are several other factors which determine tracheal length, and therefore this method is not completely reliable (5, 15).

Although there is no consensus in the literature as to the exact recommended depth for ETT placement, most sources agree that in adults, a depth of 4-5 cm from ETT tip to carina is safe (2, 6, 13, 23-25). An ETT that is too shallow can cause trauma to the vocal cords and larynx, or become dislodged with excessive neck extension (2, 3, 5, 24). Alternatively, an ETT that is placed too deep can migrate down into a main stem bronchus with neck flexion (2, 3, 5, 24). The theatre environment is dynamic, and patients are continually being moved and repositioned on the operating table. This can further predispose to ETT movement, and a ETT that is sub optimally placed to begin with, is even more likely to migrate into an inappropriate position (24).

There are several factors mentioned in the literature to influence tracheal length and ETT placement depth. These include patient age (11), gender (26) and height (9, 11, 18-21, 27). The results of these studies have however been inconsistent.

Most of the research on ETT misplacement has focused on the pre-hospital and ICU settings, and the incidence of ETT misplacement in these settings has been found to range from 5 to 25% (7, 8, 28-33) and 8 to 15.6% respectively (10, 26, 34-36). The prevalence of ETT misplacement in the intraoperative period is difficult to predict. An analysis of the American Society of Anesthesiology Closed Claims database between 1985 and 1990 showed

that respiratory events accounted for the majority of adverse outcomes (34%); while oesophageal intubation and endobronchial intubation accounted for 18% and 1% of these complications respectively (37, 38). Of these patients that developed respiratory complications, 85% either died or developed permanent brain damage as a result, and it was estimated that 72% of these complications could have been avoided with better monitoring (37). Analysis of the first 2000 reports from the Australian Incident Monitoring Study (AIMS) showed that problems with the ETT accounted for 9% of all incidents reported by anaesthetists. Of these, endobronchial intubation was the most commonly reported incident (42%) and oesophageal intubation accounted for a further 18% of cases. (39).

1.3. Problem statement

Incorrect placement of ETTs can have disastrous or even fatal consequences for patients (2, 6-12). Anaesthetists working in the Chris Hani Baragwanath Academic Hospital's (CHBAH) Department of Anaesthesiology are currently using clinical methods to decide on how deep to place ETTs. It was not previously known how accurate these anaesthetists were at placing ETT's to the correct depth.

1.4. Aims and objectives

1.4.1. Aims

The aims of this study were to describe the accuracy of anaesthetists at CHBAH in placing oral ETTs to the correct depth. Secondly, to describe how selected variables influenced the correct placement of ETTs. Lastly to describe the various methods used by these anaesthetists to confirm correct ETT placement.

1.4.2. Objectives

The objectives of this study were:

- to describe the accuracy of anaesthetists in placing oral ETTs to the correct depth in adults based on the distance from ETT tip to the carina, and to compare this between male and female patients;
- to describe the influence of patient height on the accuracy of ETT placement;
- to describe the various methods used by anaesthetists to confirm correct ETT depth on intubation;
- to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to either 20 cm or 21 cm at the front upper incisors in females;
- to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to either 22 cm or 23 cm at the front upper incisors in males;
- to correlate the depth of ETT placement based on the centimeter markings at the level of the front upper incisors with the ETT tip to carina distance in female and male patients.

1.5. Research assumptions

The following definitions were used in this study.

Anaesthetists: any qualified doctors who have completed their internship training, and are currently employed by the Department of Anaesthesiology; including medical officers, registrars and anaesthesiologists.

Primary anaesthetist: the anaesthetist who was performing the intubation.

Accurate oral ETT placement: for the purposes of this study, ideal ETT placement was defined as an ETT tip to carina distance of 4 cm. Measurements either 25% above or below this value (i.e. ETT tip to carina distance of 3 to 5 cm) where considered accurate ETT placements. All ETTs

placed less than 3 cm or more than 5 cm above the carina were considered to be misplaced. These values where chosen for safety reasons, in order to prevent any inadvertent endobronchial or shallow intubations with neck flexion or extension respectively. Conrardy et al. (24) showed that with the head in a neutral position, an ETT moves on average 1.9 cm towards and away from the carina with neck flexion and extension respectively. An ETT placed between 3-5 cm above the carina will allow the ETT to move by at least 2 cm in either direction with neck flexion or extension, without causing it to misplace.

Adult: any person 18 years to 65 years of age. The decision to restrict the sample to patients under the age of 65 was made based on the fact that Evron et al. (25) found the occurrence of misplaced ETTs to be significantly higher in patients older than 65 years (p=0.012). Although no other studies could be found to support this, it is reasonable to assume that the airway changes with advancing age. Cartilages calcify and the soft tissues become less elastic, which could potentially lead to changes in tracheal length. This could potentially lead to an increased risk of ETT misplacement in this population. In order to reduce potential variability within the studied population, patients over the age of 65 were excluded from this study.

American Society of Anesthesiologists (ASA) Physical Status Classification system: the ASA devised a scoring system for classifying co-morbid conditions and the extent to which they affect functionality, based on a scoring system from 1-6 (Appendix A).

1.6. Demarcation of the study field

This study took place in the general theatre complex at the CHBAH. The CHBAH is a central hospital affiliated to the University of the Witwatersrand (Wits). It is located in the Soweto area of Johannesburg and serves a catchment population of over 3.6 million people in the Gauteng district. It has

approximately 3200 beds and provides services to approximately 650 000 patients per year (40).

1.7. Ethical considerations

Approval to conduct this study was obtained from the relevant authorities (Appendix B, C and D). Both patients and anaesthetists who agreed to participate in the study were given an information letter and asked to sign informed consent (Appendix C and D). Any inaccurately placed ETTs were immediately reported to the primary anaesthetist so that the ETT position could be adjusted. This study was conducted in accordance with the Declaration of Helsinki (41) and the South African Good Clinical Practice Guidelines (42).

1.8. Research methodology

1.8.1. Research design

A prospective, contextual, descriptive research design was used.

1.8.2. Study population

The study population included:

- Adult patients presenting for elective surgery at the CHBAH general theatre complex, requiring oral ETT insertion as part of their anesthetic.
- The anaesthetist providing the anaesthetic and placing the ETT for these patients.

1.8.3. Study sample

Patient study sample

The patient sample determined the sample size and sampling method chosen. In consultation with a bio-statistician a sample size of 138 patients

was estimated. A non-probability, convenience based sampling method was used for patient selection. Inclusion and exclusion criteria were defined.

Anaesthetist study sample

No predetermined sample size or sampling method for the selection of anaesthetists was used.

1.8.4. Data collection

After induction of anaesthesia, ETT placement and verification, and once the patients were deemed to be stable by the primary anaesthetist, the relevant measurements were taken; including patient age, gender, height, position of the ETT at the front upper incisors, methods used by the anaesthetist to confirm correct ETT placement and the ETT tip to carina distance. Endotracheal tube tip to carina distance was measured using a flexible paediatric fiberoptic bronchoscope. The fiberoptic bronchoscope was cleaned and sterilised according to the recommended guidelines between patients (43). (Appendix H). All data was collected over an eleven-month period between April 2015 and February 2016.

1.8.5. Data analysis

All data was recorded in a Microsoft Excel® spreadsheet and analysed using descriptive and inferential statistical tests. Statistical analysis was done using the GraphPad InStat software program. P-values of ≤ 0.05 were considered statistically significant.

1.9. Significance of the study

Endotracheal tube misplacement is a well-described complication of intubation and can potentially result in significant morbidity and mortality. Unrecognised oesophageal intubation is a potentially life threatening emergency (2, 8, 17, 28, 44), the consequences of which can include gastric insufflation, regurgitation, aspiration, hypoxia, hypoxic brain damage, cardiac

arrest and potentially death (2). Placement of an ETT too high in the trachea can lead to inadvertent extubation, the formation of an inadequate seal, aspiration, hypoventilation, hypoxia, laryngeal injury and vocal cord paralysis (2, 6, 7, 12, 44, 45). An ETT that is placed too deep can lead to endobronchial intubation (2), which is in itself associated with a host of complications (2, 6, 8-11). Over-distension of the intubated lung can predispose to the development of a pneumothorax or tension pneumothorax. The raised intra-alveolar pressure, along with the hypoxic vasoconstriction in the under-ventilated lung, can lead to an increased afterload on the right ventricle and subsequent decrease in cardiac output and systolic blood pressure. The ventilation perfusion mismatch that results can lead to hypoxia, hyperventilation, hypocapnoea and subsequent respiratory alkalosis. (2, 5, 7, 9, 10, 44). Hypocapnic alkalosis has been associated with undesirable physiological changes such as decreased cardiac output, bronchoconstriction, increased airway resistance, decreased lung compliance, increased ventilation perfusion mismatch and increased right to left shunting (10, 46, 47).

Endotracheal tube misplacement is a common problem. The prevalence of ETT misplacement in the pre-hospital setting ranges between 5.8-25% (7, 8, 28-33), and in the intensive care unit (ICU) between 8-9% (10, 34-36). There is little evidence in the literature documenting the incidence of inaccurate ETT placement in the intraoperative period.

It was not known how accurate anaesthetists working at the CHBAH general theatre complex were at placing ETT tubes to the correct depth. By understanding the prevalence of ETT misplacement in this setting, and by examining the factors associated with it, anaesthetists working at the CHBAH will be made more aware of the problem, and can potentially change their intubating practices in order to prevent it and hence improve patient safety.

1.10. Validity and reliability of the study

Various methods were put in place to ensure the validity and reliability of this study.

1.11. Research report outline

This research report will be structured as follows:

Chapter 1: Overview of the study

Chapter 2: Literature review

Chapter 3: Methodology

Chapter 4: Results and discussion

Chapter 5: Summary, limitations, recommendations and conclusion

1.12. Summary

In this chapter an overview of the study was described. The literature review will be presented in Chapter 2.

CHAPTER 2. Literature review

2.1. Introduction

In this chapter the literature pertaining to oral endotracheal intubation will be discussed. A brief history of endotracheal intubation will be presented followed by an overview of the relevant airway anatomy, the complications of ETT misplacement, the prevalence of ETT misplacement, the definition of ideal ETT placement, the effects of patient movement on ETT position, the various formulae for predicting depth of ETT placement and finally the various methods for confirming correct ETT placement will all be discussed.

2.2. The history of intubation

Some of the earliest descriptions of emergency airway management can be found in ancient Hindu, Egyptian and Greek texts, and can be traced as far back as 2000 BC (48). The earliest reliable description of human intubation can be attributed to the Arab physician Avicenna, who lived between 980 and 1037 AD (49). The first modern day example of endotracheal intubation comes from the obstetrician, Benjamin Pugh, who, in 1754, described the use of ETTs in securing the airway of neonates during obstructed labour (48, 49). In 1847, the Scottish surgeon, William Macewen, was the first to use endotracheal intubation during elective surgery, where he used the technique to protect the airway of a patient coming for resection of an oral tumor (48, 49). Franz Kuhn described the process of nasal intubation, and published a paper on the topic towards the end of the nineteenth century. He was also the first person to describe topicalisation of the airway with local anaesthetic in order to facilitate intubation. The work of Sir Ivan Whiteside Magill during the First World War, and the subsequent introduction of muscle relaxants into anaesthetic practice by Harold Griffith in 1942, made endotracheal intubation routine practice. In 1930, Ralph Waters, pioneered the field of lung isolation and described this technique in thoracic surgery. (48)

The introduction of the fiberoptic bronchoscope by the Japanese Kensuke Ikeda, in 1968, revolutionised the approach to the management of difficult airways (48). As understanding of airway pathophysiology has grown, new methods for airway management have been developed, and continue to develop to this day. However, despite all these advances in airway management, endotracheal intubation remains the definitive method of airway protection in critically ill patients (1, 7).

2.3. Airway anatomy

In order to proficiently intubate any patient, a clinician must have a sufficient working knowledge of normal airway anatomy (50, 51).

The human airway starts to develop around the fourth week of gestation, and reaches maturity by 8 to 10 years (52). There are several ways to classify airway anatomy; however, for the purposes of describing the intubation process, the classification of upper versus lower airway is most appropriate. The upper airway can be defined as all the structures above the vocal cords; including, the oral cavity, nasal cavity, pharynx and the laryngeal structures above the vocal cords. The lower airway includes all the laryngeal structures below vocal cords, trachea and the bronchi with all their subsequent divisions. (50). The relevant anatomy of each of these structures will briefly be described below.

2.3.1. Oral cavity

During oral intubation, the ETT passes over the lips, teeth and tongue to enter the oropharynx posteriorly (6). The palatoglossal folds separate the oral cavity and oropharynx (50). The oral cavity is separated from the nasal cavity by the hard and soft palates (6). Although the anatomy of the nasal cavity is important for nasal intubation, its description is beyond the scope of this paper. The anatomy of the upper airway, including the oral cavity, is depicted in Figure 2.1.

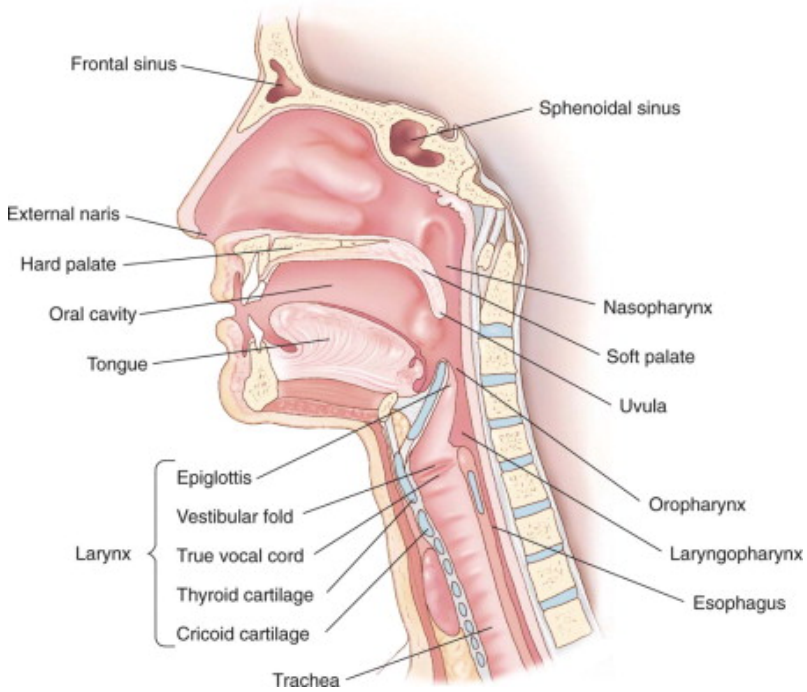

Figure 2.1 Anatomy of the upper airway (53)

2.3.2. Pharynx

The pharynx is a cone shaped tube consisting of three parts; namely, the nasopharynx, oropharynx and laryngopharynx (6). In adults, it extends from the base of the skull to C6 (50). The anatomy of the pharynx is depicted in Figure 2.1.

The nasopharynx extends from the base of the skull to the soft palate (C1). It communicates anteriorly with the nasal cavity via the nasal choanae, and houses the pharyngeal tonsil or adenoids. (50)

The oropharynx extends from the soft palate to C3, and communicates anteriorly with the oral cavity. The posterior pharyngeal wall is a soft muscular structure, which can appose with the base of the tongue and soft palate in the supine patient during general anaesthesia, causing airway obstruction. The negative airway pressure applied during inspiration can exasperate this situation. (50)

The laryngopharynx extends from C3 to the larynx (C6) (50). It is bordered posterior and caudally by the cricopharyngeus muscle, which forms the upper oesophageal sphincter. Anteriorly and caudally, it forms the vallecula and piriform recesses that surround the opening to the larynx. (6, 50)

2.3.3. Larynx

The larynx is located between C3 and C6 (6, 51). Its size, shape and exact position vary with age and gender. Adult females tend to have a smaller larynx with a less noticeable laryngeal prominence, more obtuse angel of fusion of the thyroid cartilage and shorter vocal cords when compared to their male counterparts. The larynx in an adult female also tends to be located slightly higher than in males. (51) The anatomy of the larynx is depicted in Figures 2.2 – 2.5.

Structurally, the larynx is comprised of nine cartilages and the hyoid bone (50, 51). The hyoid bone is a U-shaped structure from which the larynx is suspended via the thyrohyoid muscle and membrane (51). The nine laryngeal cartilages include: the epiglottis, thyroid, cricoid, and the paired arytenoid, corniculate and cuniform cartilages (50, 51).

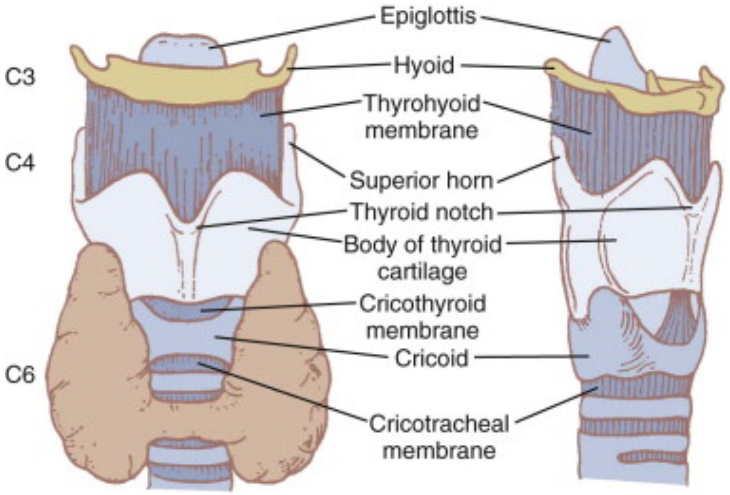

Figure 2.2 External frontal (left) and anterolateral (right) views of the larynx (54)

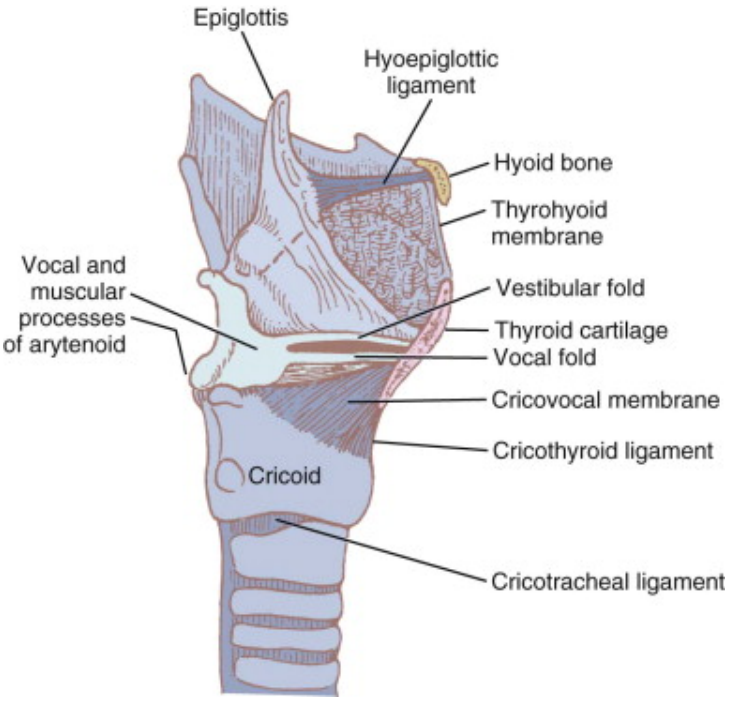

Figure 2.3 Lateral view of the larynx (54)

The epiglottis is a leaf shaped structure that covers the glottis during swallowing to prevent aspiration of food contents (51). The vallecula is the space formed between the base of the tongue anteriorly and the epiglottis posteriorly, and it forms an important anatomical landmark during laryngoscopy. (6, 50, 51)

The thyroid cartilage is a prominent shield like cartilage that forms the laryngeal protuberance, or Adam's apple, in the neck. It articulates with the cricoid cartilage below to form the cricothyroid joint. Movement at this joint is facilitated by contraction of the cricothyroid muscle, which serves to maintain tension on the vocal cords while they change in length. (51) The relatively avascular cricothyroid membrane connects the space between these cartilages anteriorly, and serves as a convenient site for emergency cricothyroidotomy, jet insuflation, translaryngeal local anaesthetic infiltration and retrograde wire-guided intubation (50, 51). Posteriorly, it is attached to the

vocal processes of the arytenoid cartilages, and is responsible for forming the cricovocal ligament and vocal cords on its superior medial surface (51).

The cricoid cartilage is the only complete ring-like cartilage in the larynx, and its strength and structure are useful clinically in the application of cricoid pressure, to prevent regurgitation and aspiration during a rapid sequence induction (51).

The arytenoid cartilages are paired, pyramidal shaped cartilages that articulate with the cricoid cartilage posteriorly at the cricoarytenoid joints. As these joints are synovial in nature, they can potentially be involved in any pathological process that involves the synovial joints, and cause subsequent airway obstruction. Movement at the cricoaryteniod joints controls tension in the vocal cords and subsequent phonation. The arytenoid cartilages are connected with the epiglottis anteriorly via the aryepiglottic folds, which house the corniculate and cuneiform cartilages. (51)

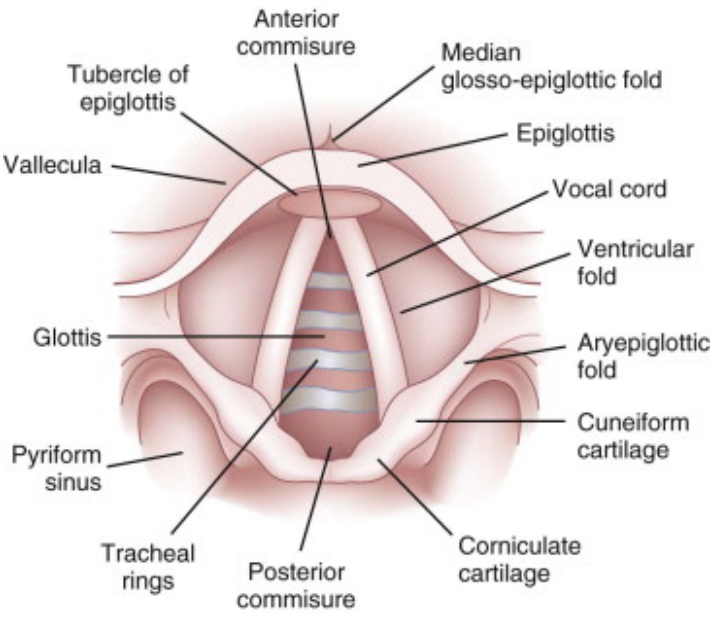

Figure 2.4 Larynx viewed from above (54)

The nerve supply to the larynx comes from the vagus nerve via the superior and recurrent laryngeal nerves (50, 51). The internal branch of the superior

laryngeal nerve supplies all sensory function the larynx above the vocal cords, while the external branch supplies motor function to the cricothyroid muscle. The recurrent laryngeal nerve supplies motor function to all the rest of the intrinsic muscles of the larynx, as well as sensory function to the larynx below the level of the cords. (51)

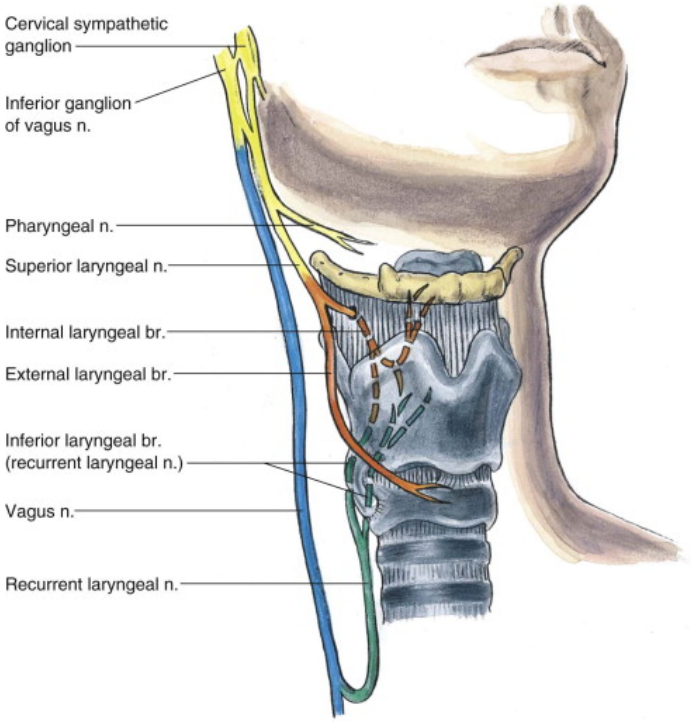

Figure 2.5 Anatomy of laryngeal innervation (55).

2.3.4. Trachea

The trachea is a hollow, elastic, tube-like structure extending from the larynx (C6) to the carina (T5), where it splits to form the right and left main stem bronchi (56). It is approximately 10 to 20 cm long in adults (50, 51), and has an internal diameter of approximately 1.2 cm (56). The anterolateral aspect is composed of incomplete C-shaped cartilaginous rings; while the flattened posterior wall is formed by the trachealis muscle. The trachea is a highly elastic structure, which lengthens with inspiration and shortens with expiration. The posterior fibromuscular wall can be seen on bronchoscopy to bulge anteriorly into the tracheal lumen, a phenomenon that is exaggerated by

expiration and coughing. The anterior and posterior pulmonary plexi innervate the trachea and bronchi, and are formed primarily by branches of the vagi, recurrent laryngeal nerves and sympathetic chains. (56) The anatomy of the trachea, carina and bronchi are depicted in Figure 2.6.

2.3.5. Bronchi

At the level of the carina, the trachea splits into two main stem bronchi. The right main stem bronchus is approximately 2.5 cm long in adults, and divides to form the right superior, middle and inferior lobar bronchi. The left main stem bronchus is approximately double this length (5 cm) and gives rise to the left superior and inferior lobar bronchi. (56) In adults, the right main stem bronchus is shorter, wider and less angulated than the left, making it easier for an ETT to inadvertently move into this side if placed to deep. (50, 51) The anatomy of the trachea, carina and bronchi are depicted in Figure 2.6.

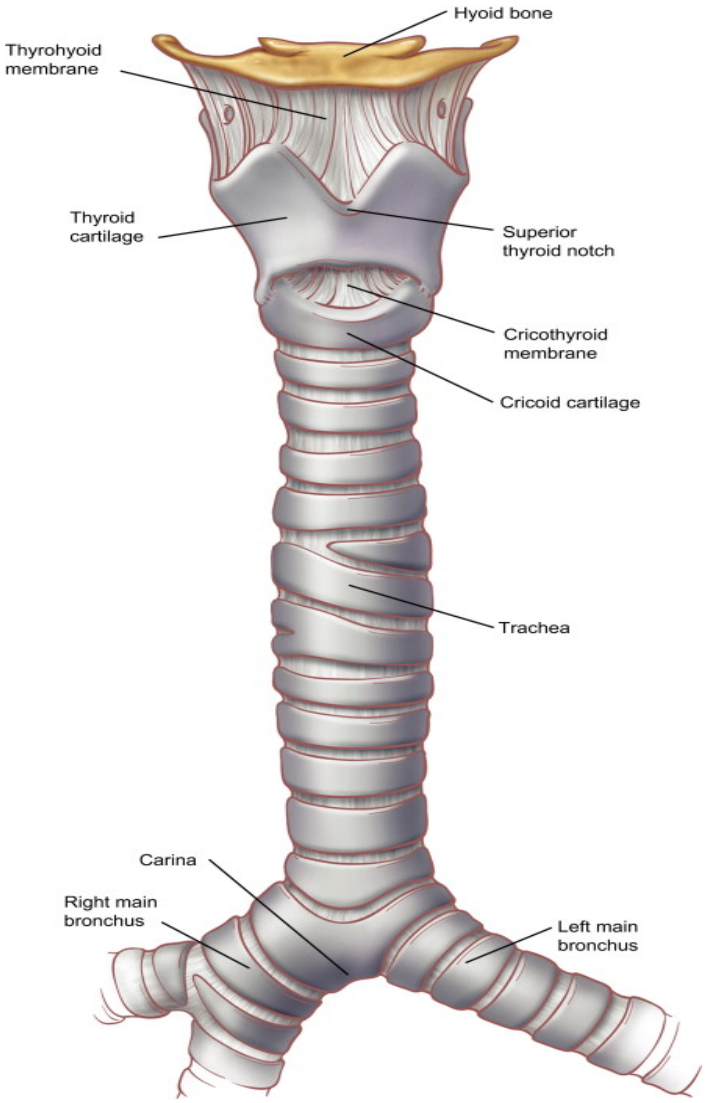

Figure 2.6 Anatomy of the trachea, carina, and bronchi (57)

2.4. Complications of inaccurate endotracheal tube placement

The complications associated with ETT placement have been well described. These can be classified as complications occurring during intubation, those occurring while the ETT is in place, those occurring during extubation, and those occurring after extubation (2). To describe all the complications of endotracheal intubation is beyond the scope of this study; and only the complication of inaccurate ETT placement, an event that typically occurs during intubation and possibly while the ETT is in situ, will subsequently be discussed.

An ETT can be misplaced in three scenarios:

- the ETT is placed in the oesophagus;
- the ETT is placed too high in the trachea, or in the hypopharynx;
- the ETT is placed too low in the trachea, or in the bronchi.

An unrecognised oesophageal intubation is a potentially life threatening emergency (2, 8, 17, 28, 44). The consequences of which can include, gastric insufflation, regurgitation, aspiration, hypoxia, hypoxic brain damage, cardiac arrest and potentially death (2). The high morbidity and mortality associated with inadvertent oesophageal intubation has been documented by several studies in the pre-hospital setting (8, 28, 58).

Placement of an ETT too high in the trachea can have severe complications. An ETT cuff that is inflated between the vocal cords will result in an inadequate seal being formed. This is due to the differences in the shapes of the relative structures. The opening of the vocal cords is typically pentagonal shaped, while the ETT cuff is circular (6). This suboptimal ETT placement could potentially result in inadvertent extubation, the formation of an inadequate seal, aspiration, hypoventilation, hypoxia, laryngeal injury and vocal cord paralysis (2, 6, 7, 12, 44, 45). Despite these severe complications, there is little literature pertaining to the incidence of high ETT misplacement, with the main focus being on oesophageal and endobronchial intubation (12, 45).

Inadvertent extubation, if unnoticed, can have potentially life-threatening cardiopulmonary sequelae, including hypoxia, arrhythmias, aspiration or death (59-61). The term “unplanned extubation” is broadly defined in the literature, to include unplanned self-extubation by the patient, or any other accidental form of extubation that occurs (2, 59-61). It is a common occurrence in the intensive care setting, and has been reported to occur in between 3-13% of intubated patients (61). Despite that fact that an ETT has been shown to migrate proximally in the trachea with neck extension and potentially dislodge

into the hypopharynx (2, 3, 5, 24), none of the studies reviewed looked at ETT position as a risk factor for unplanned extubation.

Laryngeal injury post intubation represents a significant proportion of the morbidity associated with airway manipulation (4, 62-64). Despite being a recognised complication of a misplaced ETT (2, 6, 7, 12, 44, 45), no literature could be identified that specifically looked at the position of an ETT as an independent risk factor for laryngeal injury. These injuries range in severity, and include laryngeal oedema, muscle dysfunction, vocal cord paralysis, vocal cord haematoma, peri-laryngeal infection, glottic and subglottic stenosis, vocal cord granulomas and synechae (2). Prospective studies in the ICU setting have demonstrated laryngeal injury in between 73 to 94% of patients intubated for longer than 24 hours (62-64). Although none of these studies looked at the position of the ETT as a risk factor for laryngeal injury. Domino et al. (4), in their analysis of the American Society of Anesthesiologists Closed Claims Project database, showed that 6% of all claims where related to airway injuries, and the majority of those claims (33%) where related to laryngeal injuries. The most common laryngeal injuries included vocal cord paralysis (34%), granuloma formation (17%), arytenoid dislocation (7,8%), and haematoma (3%). The majority of these injuries where associated with “non-difficult” intubations (80%), and with endotracheal intubation lasting less than five hours (85%). However, ETT position was not assessed as a risk factor for laryngeal injury in these claims.

An ETT that is placed too deep can cause injury to the carina or inadvertent endobronchial intubation (2). As the right main stem bronchus is shorter, wider, less angulated and more circular in shape compared to the left main stem bronchus, the tip of an ETT will most likely migrate to this side if advanced too far (50, 51, 65). The bevel of a normal ETT faces left, which will also tend to deflect an ETT into the right main stem bronchus (65). Few reported cases of left main stem bronchial intubation could be identified in the literature. Benumof and Brzenski (65), described one such case in a woman

with cryptogenic cirrhosis; where it was speculated that her massive ascites, hepatomegaly and right lower lobe lung collapse distorted her normal bronchial anatomy and predisposed her to left main stem bronchial intubation.

The complications of endobronchial intubation have been well described (2, 6, 8-11). They relate primarily to the hyperventilation and subsequent over-distension of the intubated lung; with relative hypoventilation or atelectasis of the opposite lung (2). Over-distension of the intubated lung can predispose to the development of a pneumothorax or tension pneumothorax. The raised intra-alveolar pressure, along with the hypoxic vasoconstriction in the under-ventilated lung, can lead to an increased afterload on the right ventricle, which may lead to a subsequent decrease in cardiac output and systolic blood pressure. The ventilation perfusion mismatch that results can lead to hypoxia, hyperventilation, hypocapnoea and subsequent respiratory alkalosis. (2, 5, 7, 9, 10, 44). Hypocapnic alkalosis has been associated with undesirable physiological changes, such as decreased cardiac output, bronchoconstriction, increased airway resistance, decreased lung compliance, increased ventilation perfusion mismatch and increased right to left shunting (10, 46, 47).

In a prospective study of the complications of assisted ventilation in the ICU, Zwillich et al. (10), found right main stem bronchial intubation to be significantly associated with increased mortality ($p<0.05$). Although the population group studied varied in terms of their ages (ranging from 15 to 95), type (included both medical and surgical patients) and severity of their conditions; only 45% of patients with right main stem bronchial intubation survived compared to 64% in whom ETT position was considered adequate. The findings that alveolar hyperventilation, pneumothorax and atelectasis where all significantly associated with right main stem bronchial intubation ($p<0.001$), are not surprising in light of the complications described above. In their study Zwillich et al. (10) found all cases of pneumothoraces associated

with endobronchial intubation occurred on the same side as the ETT placement, and were all tension pneumothoraces.

2.5. Prevalence of inaccurate ETT placement

The prevalence of ETT misplacement varies, and it is affected by a number of factors; including, the setting in which endotracheal intubation takes place, the urgency of the situation, the experience of the intubator, the methods used to detect ETT misplacement and the way that ideal ETT placement is defined (2).

2.5.1. Prevalence of inaccurate ETT placement in the pre-hospital setting

The occurrence of ETT misplacement in the pre-hospital setting varies between 5.8 to 25% (7, 8, 28-33). Inadvertent oesophageal intubation is the most common type of misplacement in this setting, and accounts for between 6.7 to 17% (8, 28-30). Endobronchial and hypopharyngeal intubation occur in the pre-hospital setting in between 2 to 10.7% (8, 30, 33) and 1 to 8% (28-30) respectively. There are several limitations that are common to all these studies, and that are inherent to the nature of studying pre-hospital intubation in general. Firstly, there is an element of reporter bias involved. Only patients who survive to hospital admission are generally included in these studies. Intubated patients that die on scene are not transported to hospital and ETT position is not confirmed. This could potentially lead to under-reporting of the number of oesophageal intubations; and initial oesophageal intubation may in fact be contributing to the deaths of these patients on scene. The Denver Metro Airway Study Group (32), tried to account for this by obtaining post mortem reports from intubated victims who had died on scene; however, they had problems obtaining complete records. Of the 15 patients in whom compete records where available, three (20%) had the ETT placed in the oesophagus. Secondly, there is a problem with paramedic compliance and data collection. Both the Denver Metro Airway Study Group (32) and Wirtz et

al. (28), list poor compliance and incomplete data collection for all participants as limiting factors in their studies. Thirdly, there is a delay between the time of intubation and the time of ETT confirmation in the ED. During this period of patient transport, there is a possibility that the ETT becomes dislodged or malpositioned in the airway. Excessive patient movement, especially involving neck flexion, extension or rotation, has been shown to be associated with ETT migration (2, 3, 5, 24), and this could contribute to the incidence of ETT misplacement observed after transport.

Geisser et al. (7) conducted a large retrospective study, including 435 intubated patients admitted to the trauma ED over a five year period. Patients where either intubated on scene in the pre-hospital setting (n=324); or transferred in after being intubated at another hospital (n=111). Either chest X-ray or CT scan were used to confirmed ETT position. Ideal ETT position was defined as an ETT tip to carina distance of greater than 2 cm, with the ETT cuff below the cords. ETTs where found to be inaccurately placed within the trachea in 20.5% of patients, and endobronchial intubation were identified in a further 5.7%. There where two reported cases of left main stem bronchial intubation, and no incidents of oesophageal intubation where noted. There was no significant difference reported in the incidence of inaccurate ETT placement between patients intubated pre-hospital and those transferred in from another hospital. The limitations in this study include reporter bias, where intubated patients that died on scene or before transport where not included, and possible ETT dislodgement during transport. Another limiting factor in this study is the fact that it was conducted retrospectively, and head position could not be standardised during X-ray or CT confirmation of ETT position. Conrardy et al. (24), showed that an ETT can migrate as much as 3.1 cm and 5.2 cm with neck flexion and extension respectively, and suggested that radiographic confirmation of ETT position could not be accurately determined without prior knowledge about head position.

2.5.2. Prevalence of inaccurate ETT placement in the ICU setting

ETT misplacement in the critical care setting is a common problem. Inadvertent oesophageal intubation following emergency airway management in the tertiary care setting has been estimated be as high as 8 to 9% (34, 35). Zwillich et al. (10), conducted a large prospective study of 314 intubated adult patients in the ICU setting, to determine the complications associated with assisted ventilation. Right main stem bronchial intubation was found in 9.6% of intubated patients post chest X-ray, and was significantly associated with increased mortality ($p<0.05$) and tension pneumothorax ($p<0.001$). Stauffer et al. (36), showed similar results in a prospective study of 150 intubated adults in the critical care setting. Right main stem bronchial intubation was found in 9% of patients and was reported as the fourth most common early complication of endotracheal intubation.

Schwartz et at. (26), conducted a prospective study of 271 intubated adult patients in the critical care setting in order to assess proper ETT placement. ETT position was confirmed by chest X-ray with the head in the neutral position, and ideal tube placement was defined as an ETT tip to carina distance of between 2 to 6 cm. Inaccurate ETT placement was found to occur in 15.5% of patients. The majority of these misplaced ETT's where placed too deep (78.6%), and of these 30.3% where located in the right main stem bronchus. All the remaining inaccurately placed ETT's (21.4%) where located too high within the trachea.

2.5.3. Prevalence of inaccurate ETT placement in the intraoperative setting

The incidence of inaccurate ETT placement in the intraoperative period is unknown. This is probably because a large number of inaccurately placed ETTs go unrecognised in this setting. The majority of anaesthetists rely on clinical methods to verify ETT position after intubation, as chest X-ray and fiberoptic bronchoscopy is not always practical in this setting. The use of clinical methods to verify ETT position within the trachea has, however, been

found to be inaccurate (1-3, 6, 14, 15). Brunel et al. (15) showed that 60% of patient with endobronchial intubations had equal breath sounds reported on physical examination. The theatre environment is dynamic, and as neck movement, patient positioning and abdominal packing have all been associated with ETT movement within the trachea (2, 3, 5, 24, 66, 67), ETT shifting and inadequate ETT placement can be expected to occur fairly frequently in this setting.

The ASA Closed Claims database is a compilation of anaesthetic records documenting cases where adverse anaesthetic outcomes occurred. Analysis of these records showed that between 1985 and 1990, respiratory events accounted for the majority of adverse outcomes (34%). Oesophageal intubation and endobronchial intubation accounted for 18% and 1% of these respiratory complications respectively. (37, 38). Eighty five percent of patients who suffered respiratory complications either died or developed permanent brain damage as a result, and it was estimated that 72% of these complications could have been avoided with better monitoring (37).

As this database includes only the cases in which anaesthetic mishaps resulted in severe complication that ultimately lead to claims being made against the relevant hospitals and/or staff involved; it probably underestimates the true incidence of inaccurate ETT placement in this setting. A further limitation in this study is that it was published in 1990, before the use of capnography and oxygen saturation monitoring in the intraoperative period became routine. With the routine use of these monitors in modern anaesthetic practice, it is hopeful that unrecognised ETT misplacement is detected earlier, and the devastating complications associated with it are becoming less frequent.

The Australian Incident Monitoring Study (AIMS) is an Australian database containing all reported anaesthetic related incidents since 1988, as reported by anaesthesiologists (68). Szekely et al. (39), in an analysis of the first 2000

reports from AIMS, found that problems with the ETT accounted for 9% of all incidents reported by anaesthetists. Of these, endobronchial intubation was the most commonly reported incident (42%) and oesophageal intubation accounted for a further 18% of cases. Of these ETT related incidents, 58% where first detected by capnography and arterial oxygen saturation monitoring, and only 25% by clinical examination.

McCoy et al. (69) analysed the first 3947 cases reported to AIMS between 1988-1994. Accidental endobronchial intubation was found to occur in 154 (3.7%) of all reported incidents. The majority of these endobronchial intubations where detected in theatre (93.5%) by unexplained oxygen desaturation alone (63.6%). Three of the reported cases of endobronchial intubation resulted in severe patient morbidity, and unplanned ICU admission was required in a further five of these patients. It was estimated that 90% of these incidents could have been prevented.

2.6. Ideal endotracheal tube placement

The ideal ETT position can be described by two important measurements. Firstly, the distance from the ETT tip to the carina, and secondly the distance that the ETT cuff should be placed past the vocal cords. Both these factors are important to ensure correct ETT placement, minimise complications and ensure patient safety.

The recommended ETT tip to carina distance for adults varies in the literature between 4 to 5 cm (2, 6, 13, 23-25). Conrardy et al. (24), showed that in adults, an ETT moves on average 1.9 cm towards and away from the carina with head flexion and extension respectively; and recommended that based on these observations, the ETT tip to carina distance should be 5±2 cm with the head in the neutral position. When placed at this depth, an ETT should have enough space to move within the trachea without causing inadvertent endobronchial intubation, extubation or laryngeal injury with a normal degree of head movement.

The recommended distance that an ETT cuff should be placed beyond the vocal cords varies between 2 to 3 cm (13, 44). An ETT placed in this position will have enough space to move upwards within the trachea without causing trauma to the vocal cords and larynx, or become dislodged with excessive neck extension (2, 3, 5, 24).

For the purposes of our study, ideal ETT placement was defined as an ETT tip to carina distance of 4 cm. ETTs positioned 25% above or below this position (ETT tip to carina distance of 3-5 cm) where considered to be accurately placed. Evron et al. (25), used a similar criteria to define ideal ETT placement in a study assessing appropriate ETT insertion depth guided by topographic landmark measurements. This ideal ETT position was chosen for safety purposes, to allow for at least 2 cm of ETT movement towards and away from the carina with head flexion and extension respectively, without causing endobronchial intubation, extubation or risking laryngeal injury.

As the distance from an ETTs tip to the proximal part of the cuff varies between different ETT brands and sizes of ETTs (27); the exact distance that an ETT cuff is placed beyond the vocal cords is difficult to predict. However, by ensuring that the ETT tip is as close to the carina as possible, the distance that the ETT cuff is placed beyond the vocal cords can be maximised. As the ETT tube type and size could not be standardised in this study, an ideal ETT tip to carina distance of 4 cm was chosen to allow for maximum distance of the ETT cuff beyond the cords, thereby minimising the risk of inadvertent extubation and laryngeal injury with neck extension.

2.7. Patient positioning and endotracheal tube movement

The operating theatre is a dynamic environment, with patients continuously being moved or repositioned for both surgical and anaesthetic related procedures. Using X-ray to measure ETT position, Conrardy et al. (24) showed that an ETT moves, on average, 1.9 cm towards and away from the carina with neck flexion and extension respectively, and 0.7 cm away from the

carina with lateral head rotation. The maximum ETT movements observed in this series were 3.1 cm towards the carina with head flexion, and 5.2 cm away from the carina with neck extension. Trendelenburg position, abdominal packing and exhalation where also noted to move the ETT away from the carina. In a similar study, Hartrey and Kestin (66) used a fiberoptic bronchoscope to determine the amount of ETT movement with head movement. ETTs where found to move on average, 1,5 cm towards the carina, and 0.85 cm away from the carina with neck flexion and extension respectively. Lateral head rotation was shown to move the ETT in either direction from the carina. Yap et al. (67) conducted a similar study, however, ETTs where found to move on average only 0.55 cm towards the carina and 0.63 cm away from the carina with neck flexion and extension respectively. Lateral head rotation and Trendelenburg position where not associated with any significant ETT movement in their study.

2.8. Factors effecting tracheal length and endotracheal tube placement

Patient gender, height and age are factors mentioned in the literature to effect tracheal length and subsequently ETT placement (18, 20, 21, 25-27).

In a large prospective study involving 271 emergency endotracheal intubation in the ICU setting, Schwartz et al. (26), found the incidence of ETT misplacement to significantly higher in females compared to males ($p<0.001$). Correct ETT placement was defined as an ETT tip to carina distance of between 2 to 6 cm, and ETT position was confirmed by chest X-ray. Of the 42 inaccurately placed ETTs, 61.9% occurred in females, compared to 38.1% in males. Of the ETTs placed too deep (≤2 cm from the carina), 72.7% occurred in females and 27.3% in males. Ten endobronchial intubations where identified, nine of which occurred in females. Of the ETTs placed to high in trachea (>6 cm from the carina) 22.2% occurred in females and 77.3% in males.

Several studies have mentioned patient height as a factor that could potentially effect ETT placement. Cherng et al. (18), Eagle (21), Techanivate et al. (19, 20) and Chong et al. (27) all found a significant correlation between patient height and airway length, although the strength of this correlation varied between the different studies.

In a study comparing the accuracy of ETT placement in topographic landmark methods and the 21/23 cm method, Evron et al. (25), found the occurrence of misplaced ETTs using the 21/23 cm method, to be significantly higher in patients older than 65 years (p=0.012) when compared to younger patients. Although no other studies could be found to support this association between patient age and ETT insertion depth, it is reasonable to assume that the human airway changes with advancing age. As people get older, cartilages calcify and the soft tissues become less elastic, which could potentially lead to changes in tracheal length, and an increased risk of ETT misplacement in this population.

2.9. Formulae for predicting endotracheal tube depth

Several standard formulae have been developed to determine the appropriate depth of ETT placement. Everett (16) recommends the following formulae:

$$ETT\ depth\ (cm) = \ ETT\ size\ (mm\ internal\ diameter) \times 3$$

Butterworth et al. (3) , recommend the following formulae:

$$ETT\ depth\ (cm) = \frac{Age}{2} + 14$$

Both of these formulae have, however, only been validated for use in children (3, 16, 17).

Several authors have tried developing formulae for determining optimal ETT depth in adults, based on patient height and other topographical measurements (18-21, 27, 70); however, these formulae have not been widely accepted.

Using a fiberoptic bronchoscope to measure airway length, Cherng et al. (18), found a significant correlation between body height and airway length ($r=0.7939$, $p<0.001$); and subsequently developed a formula based on patient height in order to estimate appropriate ETT insertion to a depth of 5 cm above the carina. An earlier study by Eagle (21), found comparable results and suggested a similar formula for predicating optimal ETT insertion depth based on patient height. Techanivate et al. (19) conducted a similar study, using a fiberoptic bronchoscope to measure airway lengths. Vocal cord to carina distance was found to be significantly correlated to patient height ($r=0.557$, $p<0.05$), although the correlation was weaker than that found by Cherng et al (18). The "Chula formula" was subsequently derived from this study, using patient height to approximate ETT insertion depth. Techanivate et al. (20) went on to validate this formula in a follow-up study, and found that it correctly predicted the depth of oral ETT placement in 99% of patients. Despite all these formulae being developed, none have been validated in the literature; and most are too complicated to be useful in clinical practice.

A commonly used clinical method for determining ETT depth in adults is the 21/23 cm method, which involves placing the ETT to 21 cm at the upper incisors in females and 23 cm in males (9). Owen and Cheney (9), conducted a large prospective study, involving 567 intubations in the ICU setting. ETT position was compared between a study group, where ETTs were positioned based on the 21/23 cm guideline, and a control group, where ETT's were positioned by other clinical methods. ETT position was verified by chest X-ray with the head in the neutral position using Goodman's criteria, where ideal ETT position is defined as an ETT tip to carina distance of 5±2 cm (23). The ETT tip was found to be located too close to the carina in 13% of patients in

the control group compared to <1% in the study group ($p<0.001$). Endobronchial intubations occurred in seven patients in the control group, while no patients in the study group experienced this complication. ETTs where found to be >7 cm above the carina in 27% of patients in the study group compared to 7% in the control group. All patient included in this study where in the “normal range” for height, which was arbitrarily defined as 168-184 cm for males, and 158-174 cm for females. There was no statistically significant difference found between the heights of participants in the study and control groups.

Other authors have, however, questioned the reliability of the 21/23 cm method. Ong et al. (71) conducted a similar study in an Asian population using the same criteria for ideal ETT placement. In this study, ETT’s where found to be placed too close to carina in 28.6% of patients, and too far from the carina in 4.8% of patients where the 21/23 cm method was used. The authors postulated that these differences where possibly due to the Asian population being generally shorter than the participants included in other studies.

Evron et al. (25), conducted a prospective study on 200 patients, comparing ETT insertion depth with the 21/23 cm method and a topographic landmark method. Ideal ETT position was defined as an ETT tip to carina distance of 4 cm, allowing for a 25% margin of error above or below this value (3 to 5 cm). Endotracheal tubes where found to be positioned too close to the carina significantly more frequently when the 21/23 cm method (58.5%) was used compared to the topographic method (24%) ($p<0.0001$). When using the 21/23 cm method, ETTs positioned less than 3 cm above the carina occurred significantly more frequently in women ($p=0.0001$) and in those older than 65 years ($p=0.012$).

Sitzwohl et al. (22) showed that 20% of women and 18% of men had their ETTs positioned too close to the carina (less than 2.5 cm) when the 21/23 cm

method was used in their study of 160 intubated patients. The authors commented that if the 21/23 cm method was modified, and ETTs where placed to 20 cm at the upper incisors in females and 22 cm in males; all of the observed intubations would have been at the correct depth. This modified 20/22 cm method has not, however, been validated in the literature.

A study by McKay et al. (72) comparing the accuracy of ETT placement using the 21/23 cm method with palpation of the ETT cuff in the suprasternal notch, found that the 21/23 cm method resulted in significantly fewer accurate ETT placements (61% vs. 77%, p=0.037). These authors defined accurate ETT placement as an ETT tip to carina distance of more than 2.5 cm with the ETT tip more than 3.5 cm below the vocal cords, and correct ETT placement was confirmed by means of a fiberoptic bronchoscope (72).

2.10. Methods for verifying correct endotracheal tube placement

There have been several methods described in the literature for verifying correct ETT placement. These can be divided into methods for identifying correct intratracheal ETT placement, and methods for determining correct depth of ETT placement (5).

Methods for confirming intratracheal ETT placement include visualisation of the ETT passing through the vocal cords, misting on the ETT, auscultation of the chest and abdomen, carbon dioxide detection in expired gas, visualising chest rise, palpation of the ETT cuff in the neck, pulse oximetry, oesophageal suction devices, visualisation with fiberoptic bronchoscopy and the use of ultrasound imaging (1, 5).

Methods for determining the correct depth of ETT placement include direct visualisation of the position of the ETT cuff as it passes through the cords, using the markings printed on the side of the ETT as a reference, auscultation on the chest for bilateral breath sounds, palpation of the ETT cuff in the

suprasternal notch, fiberoptic bronchoscopy, chest X-ray and ultrasound imaging (1, 5).

Despite the numerous methods available for checking ETT position, none used alone has been proven completely accurate (1, 5, 73).

2.10.1. Physical examination

Auscultation

Five-point auscultation is the traditional clinical method for confirming correct ETT placement. However, auscultation is a highly subjective test which depends largely on the experience of the clinician (22, 74), and a noisy operating environment can make it unreliable (1). Brunel et al. (15) found that 60% of patients who had radiologically confirmed right endobronchial intubations where reported as having equal breath sounds bilaterally on clinical examination.

Palpation

Palpation of the ETT cuff in the suprasternal notch has been described as a method for confirming correct ETT position (1, 72). However, anatomical variations between patients can make this test unreliable, and it cannot be recommended as an accurate test for confirming correct ETT position (1, 15).

Visualisation

Direct observation of the ETT passing through the vocal cords has been described as a failsafe method for confirming ETT placement (1). However, ideal views of the glottis and vocal cords are not achievable in all patients. Anatomical variations between different patients, oral pathology, blood, mucus and oral secretions can all impair the view of the airway during direct laryngoscopy (1).

Misting in the ETT, although described as a feature of intratracheal intubation, can also occur with oesophageal intubation, and therefore, cannot be used as a reliable sign of correct ETT placement (1).

Sitzwohl et al. (22) conducted a study comparing various clinical methods of ETT position confirmation in experienced and inexperienced anaesthetists. In their study they showed that first year anaesthetic residents failed to detect endobronchial intubations in 55% of patients by using auscultation alone, and performed significantly worse than their more experienced colleges when using this test. In their study the authors showed that by using either the markings printed on the ETT as a guide to ETT insertion depth, or a combination of clinical methods (auscultation, ETT markings and visualisation of equal chest rise) were significantly more sensitive than auscultation alone in detecting endobronchial intubations (22). It was concluded from this study that inexperienced anaesthetists should use a combination of clinical techniques to confirm correct ETT placement, and that both the sensitivity and specificity for excluding endobronchial intubations were highest when using a combination of clinical methods (22). A similar study by Qi et al. (74) comparing the ability of experienced and inexperienced anesthetists at confirming correct ETT placement in the trachea compared to the oesophagus using either auscultation, end tidal carbon dioxide or trans-illumination techniques, showed comparable results. Experienced anaesthetists were found to be significantly better at identifying correct ETT placement using auscultation (95.0%) compared to non-experienced anaesthetists (78.3%) ($p=0.013$) (74).

2.10.2. Pulse oximetry

Pulse oximetry is a necessity for any safe anaesthetic practice (5). However, due to the delay between the onset of arterial hypoxaemia and desaturation detected by the pulse oximeter, this instrument cannot be reliably used to timeously confirm correct ETT placement (1). Pulse oximetry is also prone to other problems, including movement artifact and inaccuracies at low arterial

oxygen saturations (75). The levels of ambient light, degree of peripheral vasoconstriction and the presence of nail polish or other pigments on the skin can also influence pulse oximetry readings (75).

2.10.3. Carbon dioxide detection methods

Methods of carbon dioxide detection can be divided in qualitative (capnography) and quantitative (capnometry) testing (1). The qualitative methods rely on colorimetric assays to detect the presence or absence of carbon dioxide in expired gas (1). Previous studies have documented the sensitivity and specificity for capnography in confirming emergency ETT placement as being 93% and 97% respectively (73). Continuous waveform capnometry is a tool used predominantly in the theatre environment to continuously measure the level of carbon dioxide in expired gas and display this information in the form of a capnograph (1, 5). A study by Grmec (76) reported the sensitivity and specificity of continuous wave form capnometry to both be 100% in confirming correct ETT placement after emergency intubation in the pre-hospital setting. Qi et al. (74) found similar results in the intraoperative setting, where continuous wave form capnometry was found to have both 100% sensitivity and specificity at distinguishing between oesophageal and tracheal intubation.

Despite these impressive results, carbon dioxide detection is not without its limitations. Expectorated blood, mucus, pulmonary oedema or gastrointestinal secretions can contaminate the colometric membrane on capnography devices making the results inaccurate (1). Waveform capnometry relies on patent pulmonary blood flow to deliver carbon dioxide to the alveoli to be exhaled. Any condition that significantly impairs pulmonary bloody flow, such as cardiac arrest or a massive pulmonary embolus, will result in a false negative capnograph tracing (1, 5). The presence of intragastric carbon dioxide, from recent ingestion of carbonated beverages or prolonged bag mask ventilation, may also result in falsely positive capnography and capnometry results (1, 5).

2.10.4. Imaging

Chest X-Ray

The use of a portable chest X-ray for confirming correct ETT depth has its own limitations. A standard anterior-posterior chest X-ray cannot be used to reliably differentiate intratracheal from oesophageal intubation as the oesophagus lies directly posterior to the trachea (1). As the process of ordering, shooting, developing and then reading a chest X-ray often takes time, it is impractical and potentially dangerous to use it as a primary method for excluding oesophageal intubation, which is an imminently life threatening emergency (1, 5). For the same reasons, it is often impractical to use chest X-ray as a tool in theatre to confirm correct ETT placement. The primary use for chest X-ray in confirming correct ETT position is in the intensive care unit and emergency department setting, where it can be used to accurately determine correct ETT depth after emergency intubation (15, 26, 77).

Fiberoptic bronchoscopy

Fiberoptic bronchoscopy is potentially an excellent tool for confirming correct ETT placement in the theatre environment. It has been reported to be as consistent as chest X-ray in confirming correct ETT position, and potentially less costly (5). Direct visualisation of the ETT tip above the carina can correctly confirm both intratracheal ETT position and exact ETT depth (1). Potential limitations include the labour-intensive nature of the procedure, the experience needed to perform the procedure and the availability of a functional fiberoptic bronchoscope (1).

Ultrasonography

Ultrasonography is emerging as excellent tool for assessing and managing problems in both the upper and lower airways (78). It has the advantages of providing dynamic point of care imaging in real time, being safe, noninvasive, portable and reproducible (78, 79). All of which make it an ideal tool to use in the perioperative setting. Potential problems with ultrasonography include the

steep learning curve required to become proficient in its use, and the operator dependent nature of its results (78).

Some of the uses for ultrasound in airway management described in the literature include:

- visualisation of airway anatomy (from the oral cavity to the lungs and pleura);
- visualisation of airway pathology;
- prediciting potential difficult airway management scenarios;
- identification of the cricothyroid membrane and tracheal rings for surgical airway management;
- assessment of gastric contents and prediction of aspiration risk;
- performing airway related nerve blocks;
- estimating appropriate ETT or double lumen tube sizes;
- distinguishing between oesophageal and tracheal intubation;
- distinguishing between tracheal and endobronchial intubation;
- confirming lung isolation;
- determining appropriate nasogastric tube placement;
- diagnosing lung pathology such as pneumothorax, pleural effusions and lung consolidation (78, 79).

Ultrasonography can be used to assess ETT position by either direct or indirect methods (78). The direct method involves real time ultrasound examination of the anterior neck (just above the suprasternal notch) during the intubation process, and direct visualisation of the ETT as it passes through the trachea (78). This method can be used to distinguish between oesophageal intubation and tracheal intubation (1, 78, 80). In a pilot study of 33 electively intubated patients, Werner et al. (81) found both the sensitivity and specificity of real time ultrasonographic confirmation of ETT position in the neck during intubation to be 100%. A similar study by Hofmann et al (80) concluded that ultrasound examination of the neck had 100% accuracy in

distinguishing between endotracheal and oesophageal intubations in the emergency room setting.

The indirect method involves bilateral ultrasound examination of the lungs and diaphragm during ventilation (1, 78, 82). Bilaterally equal diaphragmatic movement and “lung sliding” corresponding with ventilation is suggestive of correct intratracheal ETT placement (1, 78). Unilateral diaphragmatic movement and “lung sliding” is associated with endobronchial intubation, while bilateral paradoxical diaphragmatic movement or no movement of the diaphragm with absent “lung sliding” and the presence of a “lung pulse” are suggestive of oesophageal intubation (1, 78).

Ultrasonographic confirmation of ETT position has advantages over other more traditional methods. It can be used in noisy environments (such as helicopter or ambulance transfers) where auscultation would be difficult (78), and has been shown to be significantly superior to auscultation in distinguishing between endobronchial and intratracheal ETT placement (83). It also has the advantage over capnography in that it does not required patent pulmonary blood flow, and can therefore be used to determine correct ETT position in low cardiac output states (such as pulmonary embolus or cardiac arrest) (78).

Although ultrasound can be used to distinguish between oesophageal, tracheal and endobronchial intubations (78) it cannot be used to directly measure the depth of ETT placement within the trachea. Due to the differences in the acoustic impedance to ultrasound between air and soft tissues, direct visualisation of the ETT tip within the trachea is difficult (78). A way to potentially overcome this problem however would be to fill the ETT cuff with saline, which would allow the ETT cuff to be visualised, and then to measure the depth of the ETT cuff placement below the cricoid cartilage.

2.10.5. Other methods

There are many other devices and techniques described in the literature which have been used, with varying success, to confirm correct ETT placement. Some of these include oesophageal suction devices, electronic oesophageal detection devices, transtracheal transillumination techniques, computerised breath sound analysis, computerised gas flow analysis and thoracic impedance analysis (1). Most of these techniques require sophisticated equipment, are highly operator dependent and are not practically useful in the everyday theatre environment, and will therefore not be described further.

Based on the shortcomings of all of the above-mentioned tools and techniques, one cannot completely rely on a single method to accurately confirm correct ETT placement (3). It is therefore generally recommended that several methods should be used in conjunction to confirm correct ETT placement (1, 3, 5, 73).

2.11. Summary

In this chapter the literature review was presented. The methodology of this study will be presented in Chapter 3.

CHAPTER 3. Methodology

3.1. Introduction

In this chapter the problem statement, aims and objectives, ethical considerations, research methodology and the validity and reliability of the study will be described.

3.2. Problem statement

Incorrect placement of ETTs can have disastrous or even fatal consequences for patients (2, 6-12). Anaesthetists working in the CHBAH Department of Anaesthesiology are currently using clinical methods to decide on how deep to place ETTs. It was not previously known how accurate these anaesthetists were at placing ETT's to the correct depth.

3.3. Aims and objective

3.3.1. Aims

The aims of this study were to describe the accuracy of anaesthetists at CHBAH in placing oral ETTs to the correct depth. Secondly, to describe how selected variables influenced the correct placement of ETTs. Lastly to describe the various methods used by these anaesthetists to confirm correct ETT placement.

3.3.2. Objectives

The objectives of this study were:

- to describe the accuracy of anaesthetists in placing oral ETTs to the correct depth in adults based on the distance from ETT tip to the carina, and to compare this between male and female patients;
- to describe the influence of patient height on the accuracy of ETT placement;

- to describe the various methods used by anaesthetists to confirm correct ETT depth on intubation;
- to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to either 20 cm or 21 cm at the front upper incisors in females;
- to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to either 22 cm or 23 cm at the front upper incisors in males;
- to correlate the depth of ETT placement based on the centimeter markings at the level of the front upper incisors with the ETT tip to carina distance in female and male patients.

3.4. Ethical considerations

Approval to conduct this study was obtained from the Human Research Ethics Committee (Medical) (Appendix B) and the Postgraduate Committee, Faculty of Health Sciences, Wits (Appendix C). Permission to conduct this study was also obtained from the Medical Advisory Committee at CHBAH (Appendix D). The theatre matrons working in the general theatre complex at CHBAH were informed of the study.

Both patients and anaesthetists were invited to take part in the study the day prior to surgery. Those who agreed were given an information letter and asked to sign informed consent (Appendix E and F).

All inaccurately placed ETTs found during the course the study were immediately reported to the primary anaesthetist to allow for the recommended ETT adjustment to be made.

The findings of this study will be reported back to the Department of Anaesthesiology at a relevant morbidity and mortality meeting in order to improve awareness of ETT misplacement and therefore patient safety.

This study was conducted in accordance with the Declaration of Helsinki (41) and the South African Good Clinical Practice Guidelines (42).

3.5. Research methodology

3.5.1. Research design

A prospective, contextual, descriptive research design was used in this study.

A prospective study design is one where the variables are measured during the time that the study takes place (84). The accuracy of the ETTs was assessed at the time of data collection.

A contextual study is one that separates certain components from the larger context (85). This study evaluated anaesthetists accuracy in placing oral ETTs at an academic hospital.

A descriptive study aims to describe a population or phenomenon in order to answer the research question that was posed. The researcher does not manipulate the variables during the course of the study. (84). This study described the accuracy of anaesthetists in oral ETT placement.

3.5.2. Study population

The study population included:

- Adult patients presenting for elective surgery at the CHBAH general theatre complex, requiring oral ETT insertion as part of their anaesthetic.
- The anaesthetists providing the anaesthetics and placing the ETTs for these patients.

3.5.3. Study samples

In this study both patients and anaesthetists made up the study samples. However, the patient sample determined the sample size and sampling method used.

3.5.4. Patient study sample

Sample size

The prevalence of inaccurately placed ETTs varies between 8 to 15.6% in the critical care setting (10, 26, 34-36). The exact prevalence of inaccurately placed ETTs in the intraoperative setting is unknown. Previous studies looking at inaccurate ETT placement in the critical care setting have had sample sizes ranging from 101 to 578 patients (9, 10, 26, 34-36, 45).

In consultation with a biostatistician, using Epi Info™ version 6, a sample size of 138 patients was found to be sufficient if it was estimated that 10% of ETTs would be inaccurately placed with a 95% confidence level. The power of this study would then be 80%.

Sample method

Due to the nature of this study, a non-probability, convenience sampling method was used for patient selection (84). As patients coming to theatre are generally only booked for surgery the day before their operation, the anaesthetic premed consultation can only be done on the day, or in some cases, the night before surgery. In many cases the type of anaesthetic and the decision to place an oral ETT tube is only made on the day of surgery. For these reasons it was impractical to randomly assign patients for this study, and a probability based sampling method was not feasible.

Inclusion and exclusion criteria

The inclusion criteria for this study were:

- adult patients, 18 to 65 years of age, presenting for elective surgery, requiring oral ETT insertion as part of their general anaesthetic;
- American Society of Anesthesiologists Physical Status Classification 1 and 2 (Appendix A).

The exclusion criteria for this study were:

- patients who did not consent to take part in this study;
- the primary anaesthetist declining participation of the patient;
- patients in whom oral intubation was expected to be difficult;
- patients with underlying pulmonary pathology.

3.5.5. Anaesthetist study sample

No predetermined sample size or sampling method for the selection of anaesthetists was used. The weekly allocation roster places anaesthetists in a specific theatre on a specific day. Therefore, an anaesthetist could be included in the study more than once, as different ETT placement verification methods may have been used under different circumstances. Patients of anaesthetists who decline to take part in the study were automatically excluded.

3.5.6. Data collection

Data collected

A data collection sheet (Appendix G) was used to collect the following data from all patients who participated in this study:

- patient age;
- patient gender;
- patient height;
- tube depth, based on cm markings at the front upper incisors;
- distance from ETT tip to carina;
- the presence of endobronchial intubation.

The methods used to confirm correct ETT placement were obtained from the primary anaesthetist.

Data collection process

The anaesthetists who were providing services at the general theatre complex at the CHBAH were contacted the day before, the nature of the study was explained to them, an information letter was given to them and they were asked to sign informed consent to participate in the study (Appendix F). Any of their patients whom they believed to meet the study criteria and, based on the nature of their operations, would most likely require an oral ETT as part of their general anaesthetic, were considered as candidates for the study. These patients were then approached by the researcher, and if eligible, counseled about the nature of the study and an information letter was provided to them (Appendix E). These patients were then invited to participate in the study and they were asked to sign informed consent if they agreed. On the day of surgery, the relevant anaesthetists were again contacted, and all patients who were still eligible to participate in the study, were included.

Patients were brought to theater and managed by the primary anaesthetist according to standard practice guidelines. After induction of anaesthesia, ETT placement and verification, and once the patient was deemed to be stable from a haemodynamic and ventilatory point of view, measurements were taken. All measurements were taken with the patients heads in the neutral position and before any patient positioning took place. A swivel adapter with a fiberoptic cap was used in the breathing circuit to allow for continued oxygenation and ventilation while fiberoptic measurements were being taken. Continuous oxygen saturation monitoring and capnography were continued throughout the measurement process. All data were recorded on a separate data collection sheet (Appendix G).

Patient height was measured using a standard measuring tape. Height was recorded in centimeters, as the distance from the crown of the head to the base of the heels in the supine patient with the head in the neutral position. Patient age and gender was recorded from the patients file.

Initial ETT depth was recorded as the centimeter marking on the ETT that corresponds with the front upper incisors, with the head in the neutral position. The primary anaesthetist was then asked how ETT position was confirmed.

A flexible paediatric bronchoscope was introduced through the fiberoptic port in the swivel adapter, and advanced to the carina. At this point the fiberoptic scope was marked, using a fine chalk line, at the point where it leaves the port. The scope was then retracted to the point where the tip of the ETT was seen, and was again marked in a similar fashion. The fiberoptic scope was then removed and the patient was ventilated and managed as required by the primary anaesthetist. The distance from the ETT tip to carina was measured, to the closest half centimeter, with a ruler as the distance between the two marked points. All endobronchial intubations were recorded. All ETTs found to be inaccurately placed were reported to the primary anaesthetist for appropriate repositioning.

All appropriate measures were taken to ensure infection control during the data collection process, and the fiberoptic scope was cleaned and sterilised between patients according to the recommended guidelines (43). (Appendix H).

The researcher was responsible for obtaining informed consent from all patients and anaesthetists involved, and for the measuring and recording of all data. All data was collected over an eleven-month period between April 2015 and February 2016.

3.5.7. Data analysis

All data were recorded in a Microsoft Excel® spreadsheet and analysed using descriptive and inferential statistical tests. Statistical analysis was done using the GraphPad InStat software program.

Continuous variables that were normally distributed included patient age, patient height and the distance of the ETT tip above the carina. The only continuous variable not normally distributed was the ETT position measured at the front upper incisors.

Continuous variables that were normally distributed were described using means and standard deviations, and those not normally distributed with medians and interquartile ranges. Frequencies and percentages were used to summarise categorical variables. Normally distributed variables were compared between male and female groups using student t-tests. The numbers of accurate, too deep and too shallow ETT placements were compared between the male and female groups using Fishers Exact tests. Accurate and inaccurate ETT placements in actual and predicted ETT placement groups were compared using Chi^2 tests. Analysis of variance (ANOVA) was used to compare patient heights in the accurate, too deep and too shallow ETT placement groups. A Turkey-Kramer test was done for post hoc analysis. A Kruskal-Wallis test was used to compare the number of methods used by anesthetists to confirm correct ETT placement, which was a non-normally distributed variable, in the accurate, too deep and too shallow ETT placement groups. Correlations between the ETT distances measured at the front upper incisors and ETT distances measured above the carinae were done using a Spearmans Rho calculation, due to the high number of outliers observed. P-values of ≤ 0.05 were considered statistically significant.

3.6. Validity and reliability of the study

Botma et al. (86), defines the validity and reliability of a study as follows: “validity indicates whether the conclusions of the study are justified based on

the design and interpretation" and "reliability represents the consistency of the measure achieved".

The validity and reliability of this study were ensured by the following:

- an appropriate research design was used;
- one researcher was responsible for collecting all data;
- the same technique for measuring ETT tip to carina distance was used in all patients;
- the same flexible fiberoptic paediatric bronchoscope was used in all patients;
- the measuring techniques used were standardised in all patients;
- a biostatistician was consulted to determine the appropriate sample size and methods for data analysis.

3.7. Summary

This chapter has provided an overview of the problem statement, aims and objectives, ethical considerations, research methodology and the validity and reliability of the study. The results of this study will be presented and discussed in Chapter 4.

CHAPTER 4. Results and discussion

4.1. Introduction

In this chapter the results of the study according to the study objectives and the discussion will be presented. The objectives of the study will therefore be repeated.

4.2. Objectives

The objectives of this study were:

- to describe the accuracy of anaesthetists in placing oral ETTs to the correct depth in adults based on the distance from ETT tip to the carina, and to compare this between male and female patients;
- to describe the influence of patient height on the accuracy of ETT placement;
- to describe the various methods used by anaesthetists to confirm correct ETT depth on intubation;
- to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to either 20 cm or 21 cm at the front upper incisors in females;
- to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to either 22 cm or 23 cm at the front upper incisors in males;
- to correlate the depth of ETT placement based on the centimeter markings at the level of the front upper incisors with the ETT tip to carina distance in female and male patients.

4.3. Sample realisation

A total of 138 patients were enrolled into the study between the period of April 2015 and February 2016. Patients from a variety of surgical disciplines were

included, representing the fields of gynaecology, general surgery, trauma, orthopaedics, urology, vascular surgery, plastics and neurosurgery.

A total of 40 anaesthetists agreed to participate in the study. Due to the nature of the study, no predetermined sample size or sampling method for the selection of anaesthetists was used. None of the anaethetists who were approached refused to participate in the study.

4.4. Results

The results presented were analysed using both descriptive and inferential statistical tests. P-values of ≤ 0.05 are considered statistically significant.

For the purposes of this study, an ETT tip to carina distance of 3 - 5 cm was defined as accurate ETT placement. All ETTs placed less than 3 cm or more than 5 cm above the carina were considered to be misplaced. Endotracheal tubes placed < 3 cm above the carina were defined as deep ETT placement, while those > 5 cm above the carina as shallow ETT placement.

4.4.1. Demographics

Of the 138 patients who agreed to participate in the study, 91 (65.9%) were female and 47 (34.1%) were males. Patient demographics are described in Table 4.1.

Table 4.1 Patient demographics

Variable	Measurement	Females (n=91)	Males (n=47)	Total (n=138)
Age (years)	Mean ± SD	45 ± 12	38 ± 12	42 ± 13
	Range	18 - 65	19 - 62	18 - 65
Height (cm)	Mean ± SD	160.4 ± 8.1	171.4 ± 6.6	164.2 ± 9.2
	Range	134.0 - 178.0	157.0 - 185.0	134.0 - 185.0

Patient age and height were compared in the male and female groups using unpaired t-tests. On average the male participants were significantly younger ($p=0.0025$) and taller ($p<0.0001$) than their female counterparts.

A comparison of the ETT distance measured above the carina in the male and female patient groups is depicted in Table 4.2. An unpaired t-test was used for this comparison.

Table 4.2 Endotracheal tube distance measured above the carina

Variable	Measurement	Females (n=91)	Males (n=47)	Total (n=138)	P value
ETT distance above the carina (cm)	Mean ± SD	3.4 ± 1.8	4.3 ± 1.6	3.7 ± 1.8	0.0034
	Range	Endo-bronchial – 11.2	0.8 – 7.5	Endo-bronchial – 11.2	

The median ETT position measured at the front upper incisors was 22 cm (IQR 22 -23 cm) in males and 21 cm (IQR 20 – 22 cm) in females. The median ETT position measured at the front upper incisors for the entire patient sample was 22 cm (IQR 20 – 22 cm).

4.4.2. Objective: to describe the accuracy of anaesthetists in placing oral ETTs to the correct depth in adults based on the distance from the ETT tip to the carina, and to compare this between male and female patients

The accuracy of anaesthetists at placing ETTs to correct depth is described in Table 4.3. Males and females were compared using a Fishers Exact tests. Only 45.7% (n=63) of ETTs were found to be accurately placed. Of the 54.3% (n=75) of misplaced ETTs, the majority (34.8%, n=48) were placed too deep. There was only 1 case (0.7%) of an unrecognised endobronchial intubation, which occurred in a female patient.

Table 4.3 Accuracy of ETT placement

ETT position	Females (n=91)	Males (n=47)	Total (n=138)	P values
Accurate	39 (42.8%)	24 (51.0%)	63 (45.7%)	0.3736
Deep	38 (41.8%)	10 (21.3%)	48 (34.8%)	0.0231
Shallow	14 (15.4%)	13 (27.7%)	27 (19.5%)	0.1126

The group of patients with ETTs placed too deep was subdivided into those placed < 1 cm, 1.0 - 1.9 cm and 2.0 - 2.9 cm above the carina. The group of patients with ETTs placed too shallow was similarly subdivided into those placed 5.1 - 6.9 cm, 7.0 - 8.9 cm and > 9 cm above the carina. The numbers and percentages of inaccurate ETT placements are shown in Table 4.4.

Table 4.4 Numbers and percentages of inaccurate ETT placements

ETT position	ETT distance above the carina (cm)	Females (n=91) n (%)	Males (n=47) n (%)	Total (n=138) n (%)
Deep	<1.0	2 (2.2)	1 (2.1)	3 (2.2)
	1.0 – 1.9	13 (14.3)	2 (4.3)	15 (10.9)
	2.0 – 2.9	23 (25.3)	7 (14.9)	30 (21.7)
	Subtotal	**38 (41.8)**	**10 (21.3)**	**48 (34.8)**
Shallow	5.1 – 6.9	11 (12.1)	10 (21.3)	21 (15.2)
	7.0 – 8.9	1 (1.1)	3 (6.4)	4 (2.9)
	≥ 9.0	2 (2.2)	0 (0.0)	2 (1.4)
	Subtotal	**14 (15.4)**	**13 (27.7)**	**27 (19.5)**
Total misplaced		**52 (57.2)**	**23 (49.0)**	**75 (54.3)**

4.4.3. Objective: to describe the influence of patient height on the accuracy of ETT placement

The accuracy of ETT placement according to patient height is described in Table 4.5.

Table 4.5 Patient height and accuracy of ETT placement

ETT position	Number	Height (cm) Mean ± SD	Height range (cm)
Accurate	63	164.7 ± 8.7	146.0 – 185.0
Deep	48	160.7 ± 9.7	134.0 – 178.0
Shallow	27	169.3 ± 6.9	157.0 – 183.0

Using an ANOVA test, a significant difference was found in the patient heights between the accurate, too deep and too shallow groups ($p=0.0003$). A pst-hoc Turkey-Kramer test showed that patients with deep ETT placement were significantly shorter (160.7 ± 9.7 cm) than those with accurate ETT placement (164.7 ± 8.7 cm) ($p<0.05$), however patients with shallow ETT placement were not found to be significantly taller (169.3 ± 6.9 cm) than those with accurate ETT placement (164.7 ± 8.7 cm) ($p>0.05$). Patients with shallow ETT placement (169.3 ± 6.9 cm) were found to be significantly taller than those with deep ETT placement (160.7 ± 9.7 cm) ($p<0.001$).

4.4.4. Objective: to describe the various methods used by anaesthetists to confirm correct ETT depth on intubation

The various methods used by anaesthetists to confirm correct ETT placement are described in Table 4.6. As the anaesthetists participating in the study could use multiple methods to confirm correct ETT placement, the numbers and percentages totaled to more than 100%.

Table 4.6 Methods used by anaesthetists to confirm correct ETT

Confirmation method	Number	Percentage of total (%)
Visualisation	112	81.2
Misting	44	31.9
Capnography	83	60.1
Auscultation	136	98.6
Position of ETT at front upper incisors	26	18.9
Lines on ETT in relation to vocal cords	3	2.2
Palpated ETT cuff	1	0.7
Airway pressures	1	0.7
Chest rise	15	10.9
Pulse oximetry	2	1.4
Compliance of bag	1	0.7

Many of the anaesthetists who participated in the study reported using multiple methods to confirm correct ETT placement. The number of methods used to confirm correct ETT placement are described in Table 4.7.

Table 4.7 Number of methods used by individual anaesthetists to confirm correct ETT placement

Number of methods used	Number (n=138)	Percentage (%)
1	13	9.4
2	28	20.3
3	44	31.9
4	42	30.4
5	11	8.0

In the accurate, too deep and too shallow ETT placement groups, the median numbers of methods used to confirm correct ETT placement were 3 (IQR 2 – 4), 3 (IQR 2 – 4) and 3 (IQR 3 – 4) respectively. Using a Kruskal-Wallis test, there was no significant difference found in the number of methods used by anaesthetists to confirm correct ETT placement between the accurate, too deep and too shallow groups (p=0.4014).

4.4.5. Objective: to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to either 20 cm or 21 cm at the front upper incisors in females

The accuracy of ETT placement, had the ETT depth been adjusted to either 20 cm or 21 cm at the front upper incisors, in female patients is described in Table 4.8. A Chi^2 test was used to compare the number of accurately and inaccurately (too deep and too shallow) placed ETTs in the actual position compared to the predicted position of ETT placements.

Table 4.8 Predicted accuracy of ETT placement in actual position compared to corrected position at 20 cm or 21 cm at front upper incisors in females

ETT position	Accurate n (%)	Deep n (%)	Shallow n (%)	P value
Actual	39 (42.8%)	38 (41.8%)	14 (15.4%)	
Corrected to 20 cm	47 (51.6%)	13 (14.3%)	31 (34.1%)	0.2349
Corrected to 21 cm	46 (50.5%)	31 (34.1%)	14 (15.4%)	0.2983

The way the ETT placements would be expected to change between the accurate, too deep and too shallow groups for corrected ETT placement to 20 cm in female patients is depicted in Figure 4.1. Regarding Figures 4.1 – 4.4,

the numbers in blue represent the number of ETT placements that remained unchanged within a group. The numbers in the red boxes represent the number of ETT placements that changed between groups.

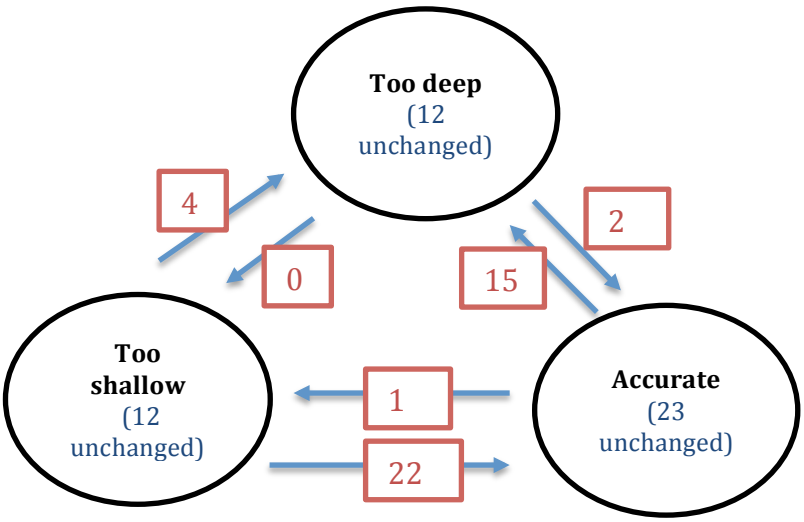

Figure 4.1 Predicted ETT placements in females if ETT position was adjusted to 20 cm at the front upper incisors

The way the ETT placements would be expected to change between the accurate, too deep and too shallow groups for corrected ETT placement to 21 cm in female patients is depicted in Figure 4.2.

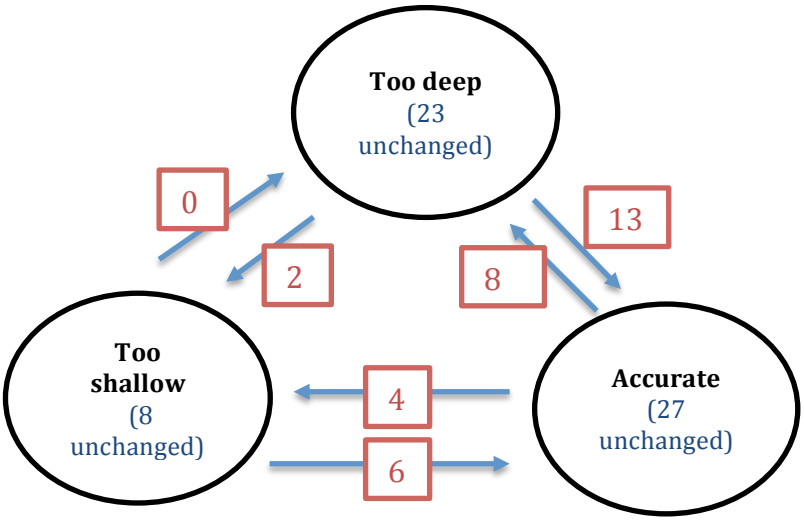

Figure 4.2 Predicted ETT placement in females if ETT position was adjusted to 21 cm at the front upper incisors

4.4.6. Objective: to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to 22 cm or 23 cm at the front upper incisors in males

The accuracy of ETT placement, had the ETT depth been adjusted to either 22 cm or 23 cm at the front upper incisors, in male patients is described in Table 4.9. A Chi^2 test was used to compare the number of accurately and inaccurately (too deep and too shallow) placed ETTs in the actual position compared to the predicted position of ETT placements.

Table 4.9 Predicted accuracy of ETT placement in actual position compared to corrected position at 22 cm or 23 cm in males

ETT position	Accurate n (%)	Deep n (%)	Shallow n (%)	P value
Actual	24 (51.1%)	10 (21.3%)	13 (27.6%)	
Corrected to 22 cm	22 (46.8%)	8 (17.0%)	17 (36.2%)	0.6799
Corrected to 23 cm	24 (51.1%)	14 (29.8%)	9 (19.1%)	1

The way the ETT placements would be expected to change between the accurate, too deep and too shallow groups for corrected ETT placement to 22 cm in male patients is depicted in Figure 4.3.

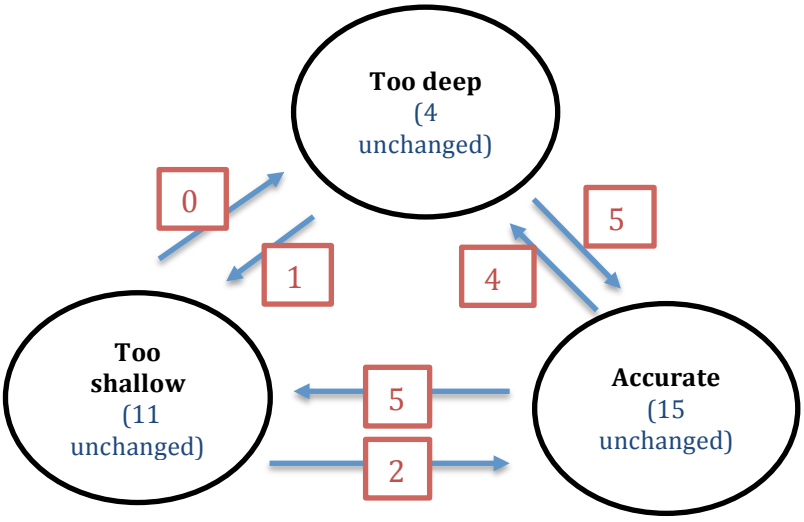

Figure 4.3 Predicted ETT placement in males if ETT position was adjusted to 22 cm at the front upper incisors

The way the ETT placements would be expected to change between the accurate, too deep and too shallow groups for corrected ETT placement to 23 cm in male patients is depicted in Figure 4.4.

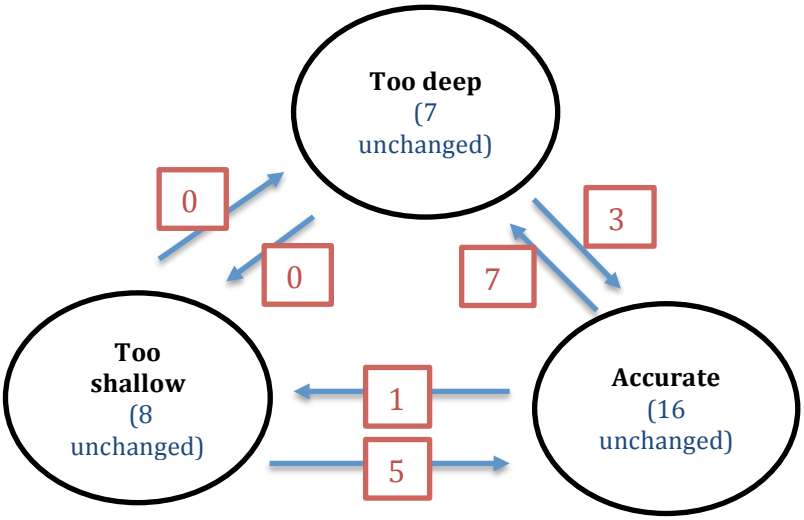

Figure 4.4 Predicted ETT placement in males if ETT position was adjusted to 23 cm at the front upper incisors

4.4.7. Objective: to correlate the depth of ETT placement based on the centimeter markings at the level of the front upper incisors with the ETT tip to carina distance in female and male patients

The relationship between ETT position at the front upper incisors and ETT distance measured above the carina in female patients is described in Figure 4.5.

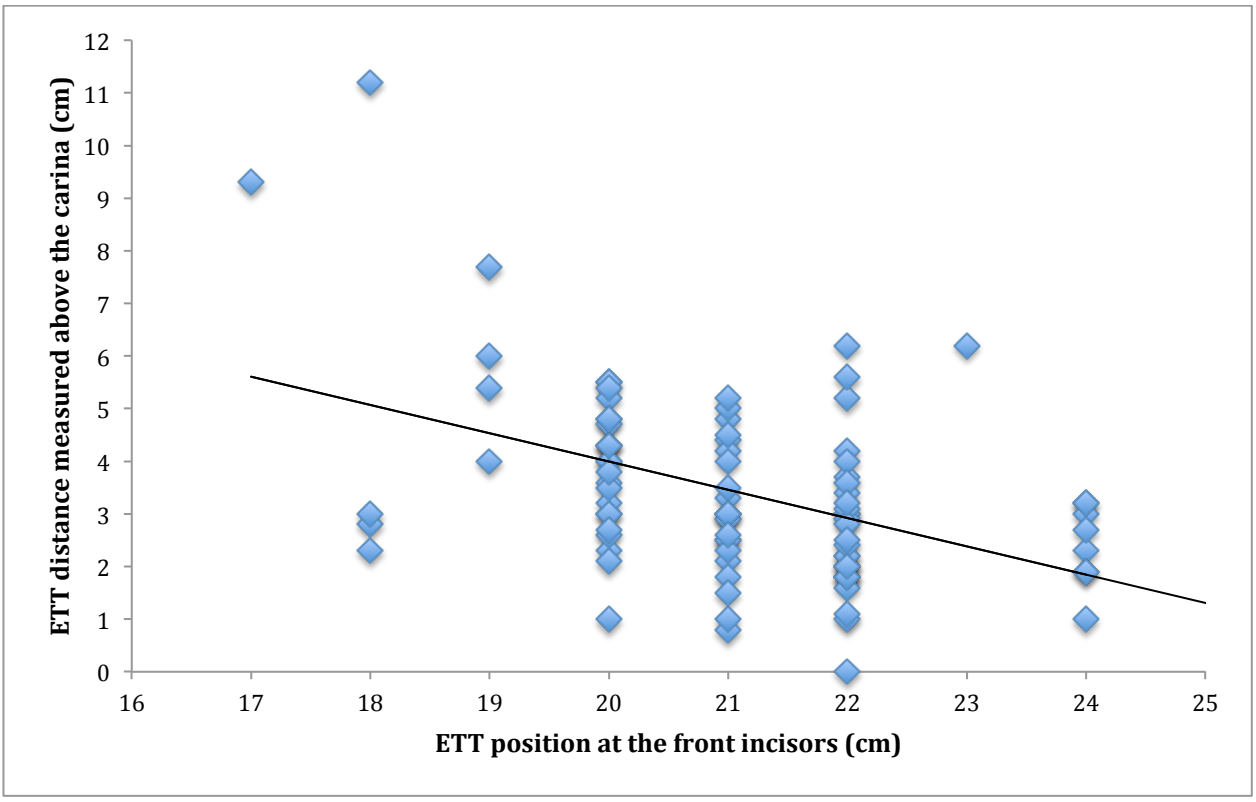

Figure 4.5 Correlation between ETT position at the front upper incisors and ETT distance measured above the carina in females

Using a Spearmans Rho calculation, a significant negative correlation was found between the ETT position at the front upper incisors and the ETT distance measured above the carina in female patients (r=-0.39057, p=0.00013). This correlation was however weak.

The relationship between ETT position at the front upper incisors and ETT distance measured above the carina in male patients is described in Figure 4.6.

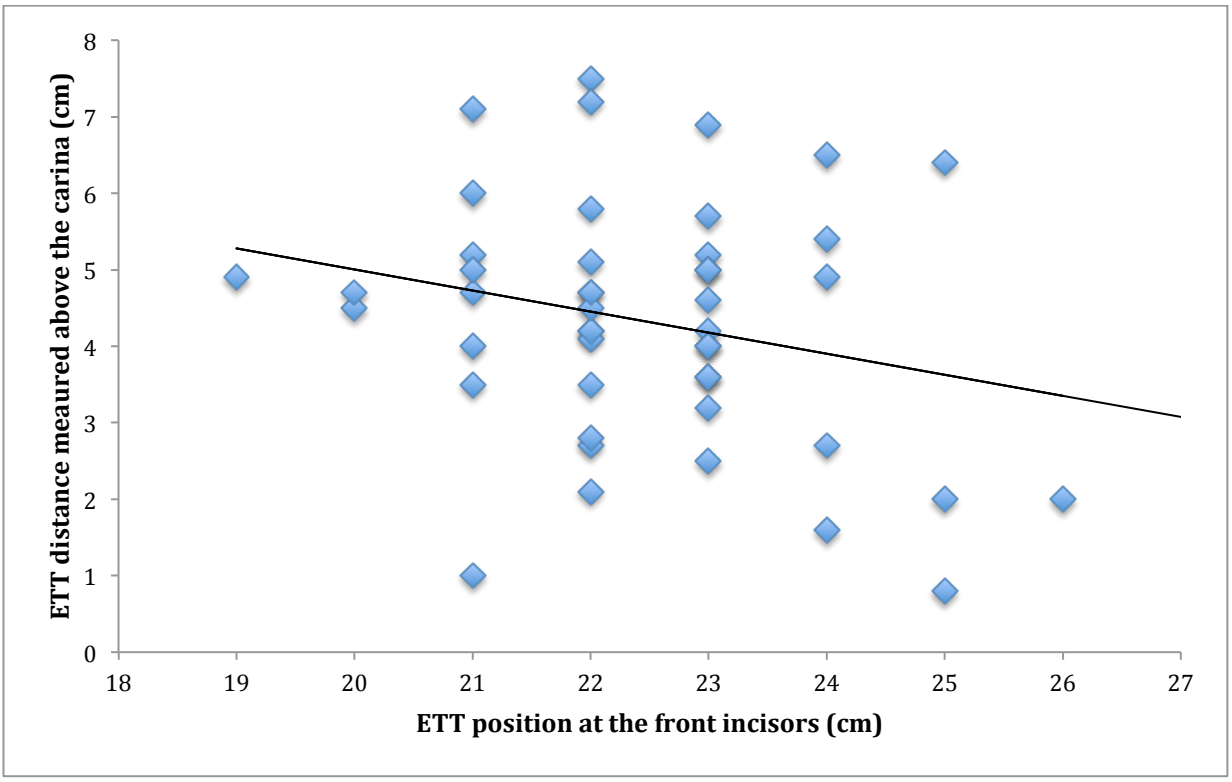

Figure 4.6 Correlation between ETT position at the front upper incisors and ETT distance measured above the carina in males

Using a Spearmans Rho calculation, no significant correlation was found between the ETT position at the front upper incisors and the ETT distance measured above the carina in male patients (r=-0,18321, p=0,2177).

4.5. Discussion

Of the 138 patients who agreed to participate in the study, the majority (66%, n=91)) were females. As a large percentage of eligible participants came for the gynaecology department, this could possibly account for the relatively large percentage of females enrolled.

Accurate ETT placement for this study was defined as an ETT tip to carina distance of 3 to 5 cm, a similar criteria to that used by Evron et al. (25). This range of ETT position was chosen for safety purposes. Conrardy et al. (24), showed that in adults, an ETT moves on average 1.9 cm towards and away from the carina with head flexion and extension respectively. Therefore, by

allowing for at least 2 cm of ETT movement towards and away from the carina, the risk of endobronchial intubation, inadvertent extubation and laryngeal injury can be reduced.

The actual incidence of inaccurate ETT placement in the intraoperative period is unknown. However, data from the ASA Closed Claims database and AIMS showed that inaccurate ETT placement is a common problem in the intraoperative period and is associated with significant patient morbidity (37-39, 69). Our study showed that only 45.7% (n=63) of ETTs were accurately placed in the intraoperative period. Of the inaccurately placed ETTs, the majority were placed too deep (34.8%, n=48). The reason for the high proportion of deep ETT misplacements is possibly two fold. Firstly, when placing an ETT, the anesthetist will usually push the ETT until they are sure that the cuff is at least past the vocal cords (this tendency to ensure that ETTs are not placed too shallow could potentially result in more ETTs being placed too deeply). Secondly, there were more female than male participants enrolled in this study, and the females were found to be significantly shorter than males. These shorter females could reasonably be expected to have shorter airways than their male counterparts, which could potentially explain the higher prevalence of deep ETT misplacements.

This is supported by our findings that deep ETT placement occurred significantly more commonly in females (41.8%, n=38) compared to males (21.3%, n=10) ($p=0.0231$), and of the three cases of ETT placement less than 1 cm above the carina, two occurred in female patients. These finding are in accordance with those of Schwartz et al. (26), were the incidence of ETT misplacement was found to be significantly higher in females compared to males ($p<0.001$). These authors similarly reported that of all the deep ETT misplacements found in their study, the majority occurred in females (72.7%). There was only one case of an unrecognised endobronchial intubation found in our study, and that occurred in a female patient. This is again in accordance with the findings of Schwartz et al. (26), where of the 10

endobronchial intubations identified, 9 occurred in female patients. Although patient height was not reported in their study, it was possibly also a contributing factor in ETT misplacements.

In our study, the majority of deep ETTs were placed between 2.0 and 2.9 cm above the carina (21.7%, n=30), which according to Conrardy et al. (24), should still remain safely above the carina with any head extension. However, 13.1% (n=18) of ETT placements were less than 2 cm above the carina, potentially putting these patients at risk of inadvertent endobronchial intubation with neck extension (24). Three cases (2.2%) of ETT placement less that 1 cm above the carina were found; including 1 case (0.7%) of an unrecognised endobronchial intubation.

Although our study showed that ETT misplacement is a common phenomenon (54.3%, n=75) in the intraoperative period, the overall incidence of endobronchial intubation was found to be low (0.7%, n=1). Studies in the ICU setting have shown the prevalence of inadvertent endobronchial intubation to be between 9 to 9.6% (10, 36), while the prevalence of endobronchial intubation in the pre-hospital setting has been estimated to be between 2 to 10.7% (8, 30, 33). These observed differences are possibly due to several factors. Firstly, the settings in which the intubations occur are different. Intubation in the theatre environment often occurs in a relatively calm and controlled fashion, with the aid of multimodal monitoring techniques and the use of multiple clinical methods to confirm correct ETT position. Intubation in the ICU or pre-hospital setting often occurs in a less controlled, emergent setting, where a noisy environment and limited access to appropriate airway and monitoring equipment could potentially make placing an ETT more difficult. Secondly patients in the ICU or pre-hospital settings are often moved after being intubated, and as excessive patient movement (especially involving neck flexion, extension or rotation) has been be associated with ETT migration (2, 3, 5, 24), this could potentially contribute to

the relatively high prevalence of endobronchial intubations reported in these settings.

Conrardy et al. (24), recommended that the maximum ETT tip to carina distance should be 7 cm with the head in the neutral position in order to prevent inadvertent extubation with neck flexion. Of the ETTs placed too shallow in our study, the majority (15.2%, n=21) were placed 5.1 to 6.9 cm above the carina. However, 4.3% (n=6) of ETTs were placed more than 7 cm above the carina, placing these patients at increased risk of inadvertent extubation, or laryngeal injury with neck flexion (24).

In our study, the male and female patient groups differed significantly in terms of mean age, height and ETT distance measured above the carina. Male patients were significantly younger (38 years vs. 45 years, $p=0.0025$) and taller (171.4 cm vs. 160.4 cm, $p<0.0001$) than their female counterparts. The mean ETT distance measured above the carina was also significantly greater in male compared to female patients (4.3 cm vs. 3.4 cm, $p=0.0034$). This is possibly due to the fact that the male participants were, on average, taller and could potentially have longer tracheas compared to females.

In our study, accurate ETT placement tended to occur more commonly in males (51.0%, n=24), compared to females (42.8%, n=39), however this difference was not found to be significant ($p=0.3736$). Considering all inaccurate ETT placements, deep ETT placement (41.8%, n=38) tended to occur more commonly than shallow ETT placement (15.4%, n=14) in females patients. The opposite was found in male patients, where shallow ETT placement (27.7%, n=13) was found to occur more commonly than deep ETT placement (21.3%, n=10). This tendency is again possibly explained by the relative height differences and expected differences in airway length between the male and female patients. This is further supported by our finding that inaccurate ETT placement tended to occur in patients who were either above or below the mean height of the patient sample. Patients with deep ETT

placement tended to be shorter (160.7 ± 9.7 cm), while patients with shallow ETT placement tended to be taller (169.3 ± 6.9 cm). Patients with deep ETT placement were significantly shorter (160.7 ± 9.7 cm) than those with accurate ETT placement (164.7 ± 8.7 cm) ($p<0.05$), and patients with shallow ETT placement (169.3 ± 6.9 cm) were found to be significantly taller than those with deep ETT placement (160.7 ± 9.7 cm) ($p<0.001$). Although several studies have examined the relationship between patient height and airway length (18, 19, 21, 27), no studies could be found which looked specifically at the effect of patient height on the accuracy of ETT placement. As anaesthetists are trained to place ETTs so that the cuff is at least past the vocal cords, it can be expected that shorter patients with shorter airways would be at higher risk of deep ETT placement, while taller patients with longer airways would be at higher risk of shallow ETT placement.

Previous studies have shown patient height to be significantly correlated to airway length (18, 19, 21, 27); however, the strength of this relationship is still debated. Fiberoptic bronchoscopy studies by Cherng et al. (18) and Eagle (21) have both found significant, and relatively strong correlations between airway length and patient height. However, similar studies by Techanivate et al. (19) and Chong et al. (27), found patient height to be only weakly correlated to airway length.

The most common methods used by anaesthetists to confirm accurate ETT placement in our study were auscultation of the chest and abdomen (98.6%, n=136), followed by visualisation of the ETT passing through the vocal cords (81.2%, n=112) and capnography (60.1%, n=83). All of these methods have however been shown to have their own limitations and none used alone has been proven completely accurate (1, 5, 73). Auscultation is a highly subjective test, the reliability of which is effected by both a noisy environment (1) and the experience of the clinician preforming the examination (22, 74). Brunel et al. (15) found that 60% of patients who had radiologically confirmed right endobronchial intubations where reported as having equal breath sounds

bilaterally on clinical examination. Of the 13 cases in our study, where only a single method was used to confirm correct ETT placement, auscultation was the method used in all cases. During the only case of an unrecognised endobronchial intubation in our study, the anaesthetist involved reported using four methods, including auscultation, to confirm correct ETT placement, confirming the subjective nature of this test. Direct observation of the ETT passing through the vocal cords relies on ideal views being achieved during laryngoscopy, which are not achievable in all patients. Anatomical variations between different patients, oral pathology, blood, mucus and oral secretions can all impair the view of the airway during direct laryngoscopy making visualisation of the ETT as it passes through the cords difficult (1). Continuous waveform capnometry relies on patent pulmonary blood flow to deliver carbon dioxide to the alveoli to be exhaled. Any condition that significantly impairs pulmonary bloody flow, such as cardiac arrest or a massive pulmonary embolus, will result in a falsely negative waveform capnograph (1, 5). The presence of intragastric carbon dioxide from recent ingestion of carbonated beverages or prolonged bag mask ventilation, may also result in falsely positive capnometry results (1, 5).

In our study, the majority of anaesthetists reported using multiple methods to confirm correct ETT placement, with 31.9% (n=44) using three methods and 30.4% (n=42) using four methods. Only 9.4% (n=13) of anaesthetists reported using one method only to confirm correct ETT placement. The use of any one single method to definitively confirm correct ETT placement cannot however be recommended, as all available methods for confirming correct ETT placement have their own limitations (3). It is therefore advised that several methods should be used in conjunction to confirm correct ETT placement (1, 3, 5, 22, 73).

When the number of methods used to confirm correct ETT placement was compared to accuracy of ETT placement, there was no significant difference found between the accurate, too deep and too shallow groups. This is

possibly due to the fact that most of the methods used in daily clinical practice for checking correct ETT placement are only useful for confirming whether the ETT is within the trachea (as apposed to in the oesophagus or bronchus), and cannot reliably predict the actual depth that the ETT is placed above the carina. The only way to accurately tell how deep the ETT is placed above the carina is by directly visualising the tip of the ETT using imaging techniques such as fiberoptic bronchoscopy or chest X-ray (1, 5, 15, 26).

Both the 21/23 cm and 20/22 cm methods have been described as clinical methods which could be used to estimate the correct depth of ETT placement after intubation in adult patients (9, 22). The evidence to support these methods is however controversial. The results of our study did not show any significant increase in the number of accurately placed ETTs if all ETTs had been adjusted using either the 21/23 cm or 20/22 cm method, and do not support the finding of Owen and Cheney (9) or Sitzwohl et al. (22).

In our study, the only possible benefit of using this method was seen in female patients by adjusting all ETT placements to 20 cm at the front upper incisors. This placement would have resulted in an overall increase in the number of accurately placed ETTs to 51.6% (n=47), with no expected endobronchial intubations. However this apparent increase in accuracy was not statistically significant (p=0.2349), and would have resulted in an increase in the total number of shallow ETT placements (34.1%, n=31) with two cases of ETT placements more than 9 cm above the vocal cords. For all other predicted placements there seemed to be no advantage. Adjustment of all ETT placements to 21 cm at the front upper incisors in females increased the total number of accurate ETT placements to 50.5% (n=46), however this increased accuracy was again not statistically significant (p=0.6799) and would have increased the total number of endobronchial intubations to four. The total number of shallow intubations would have stayed the same at 15.4% (n=14), with no cases of ETT placement more than 9 cm above the carina expected.

For male patients, adjustment of all ETT placements to 22 cm at the front upper incisors decreased the overall number of accurate ETT placements to 46.8% (n=22), and would have resulted in one endobronchial intubation. This decrease in accuracy was however not statistically significant (p=0.6799). The total number of shallow ETT placements would have increased to 36.2% (n=17) with one expected ETT placement more than 9 cm above the vocal cords. Adjustment of all ETT placements to 23 cm at the front upper incisors in male patients did not change the total number of accurate ETT placements (51.1%, n=46), but would have resulted in one endobronchial intubation. The total number of shallow ETT placements would have decreased to 19.1% (n=9), with no cases of ETT placement more than 9 cm above the carina expected.

Based on the above findings, it seems that one cannot rely on a fixed, one size fits all approach to ETT placement in adult patients. Different patients have different heights and different airway lengths, and ETT placement should therefore be individualised taking all these different variables into consideration.

In our study, a significant, but weak, negative correlation (r=-0.39057, p=0.00013) was found between the ETT position measured at the front upper incisors and the ETT distance measured above the carina in female patients. One would anticipate a negative correlation between these two variables, as one can expect that as an ETT is placed deeper at the level of the front upper incisors, the distance measure from the tube tip to the carina should decrease. The weak correlation observed between these two variables could possibly be explained by variability in airway length in female patients.

Interestingly, there was no such significant correlation found between the ETT position at the front upper incisors and the ETT distance measured above the carina in male patients, although a very weak negative trend was observed (r=-0.18321, p=0.2177). This is possibly due to two factors. Firstly, there were

a larger number of outliers in the male group, which could have obscured the relationship between these two variables. Secondly, there were fewer male participants compared to females, and with a larger sample size a significant relationship might have been found.

Based on the weak correlation observed in females and the lack of a significant correlation in males, one cannot recommend using the ETT position measured at the level of the front upper incisors as a surrogate marker of the depth of ETT insertion. Variability in patient airway length makes this method unreliable, and this further supports the finding of Ong et al. (71), Evron et al. (25) and McKay et al. (72) in that a fixed ETT placement at a specific level at the teeth does not improve accuracy of ETT placement.

4.6. Summary

In this chapter the results of the study were presented and discussed based on the objectives of the study. The study summary, limitations, recommendations and conclusion will be presented in the final chapter.

CHAPTER 5. Study summary, limitations, recommendations and conclusion

5.1. Introduction

In this final chapter a summary of the study will be presented, including the aims and objectives, methodology and main findings. The limitations of the study will be presented, recommendations made on how the study can potentially change clinical practice and other areas that require further research will be discussed. A conclusion to the study will also be presented.

5.2. Study summary

5.2.1. Aims

The aims of this study were to describe the accuracy of anaesthetists at CHBAH in placing oral ETTs to the correct depth. Secondly, to describe how selected variables influenced the correct placement of ETTs. Lastly to describe the various methods used by these anaesthetists to confirm correct ETT placement.

5.2.2. Objectives

The objectives of this study were:

- to describe the accuracy of anaesthetists in placing oral ETTs to the correct depth in adults based on the distance from ETT tip to the carina, and to compare this between male and female patients;
- to describe the influence of patient height on the accuracy of ETT placement;
- to describe the various methods used by anaesthetists to confirm correct ETT depth on intubation;
- to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to either 20 cm or 21 cm at the front upper incisors in females;

- to assess the predicted accuracy of ETT placement had the ETT depth been adjusted to either 22 cm or 23 cm at the front upper incisors in males;
- to correlate the depth of ETT placement based on the centimeter markings at the level of the front upper incisors with the ETT tip to carina distance in female and male patients.

5.2.3. Summary of methodology

A prospective, contextual, descriptive research design was used in this study. The study population included adult patients presenting for elective surgery at the CHBAH general theatre complex who required oral ETT insertion as part of their anesthetic, as well as the anaesthetist providing the anaesthetic and placing the ETT for these patients.

A non-probability, convenience based sampling method was used for patient selection (84). No predetermined sample size or sampling method for the selection of anaesthetists was used.

Both anaesthetists and patients were informed about the study, given an information letter, invited to participate in the study and asked to sign informed consent the day prior to their scheduled operation (Appendices E and F). After induction of anaesthesia, ETT placement and verification, and once patients were deemed to be stable, all relevant measurements were taken. All measurements were taken with the patients head held in the neutral position and before any patient positioning took place. All data was recorded on a separate data collection sheet (Appendix G). Recorded variables included patient height, age, gender, ETT position at the front upper incisors, methods used to confirm correct ETT placement and ETT tip to carina distance. The ETT tip to carina distance was measured using a flexible paediatric fiberoptic bronchoscope advanced through the fiberoptic port in a swivel adapter. Patients were continuously ventilated, and oxygen saturation and capnography monitoring continued throughout the measurement process.

5.2.4. Summary of results

Of the 138 patients who agreed to participate in the study, the majority (66%, n=91) were females. Only 45.7% (n=63) of ETTs were found to be accurately placed. Of the inaccurately placed ETTs, the majority were placed too deep (34.8%, n=48). One case (0.7%) of an unrecognised endobronchial intubation was found. Although there was no significant difference found in the number of accurately placed ETTs between the male and female groups, the number of deep ETT misplacements was significantly higher in the female group ($p=0.0231$), and the only case of an unrecognised endobronchial intubation occurred in a female patient.

Considering all inaccurate ETT placements, deep ETT placement (41.8%, n=38) tended to occur more commonly than shallow ETT placement (15.4%, n=14) in females patients. The opposite was found in male patients, where shallow ETT placement (27.7%, n=13) was found to occur more commonly than deep ETT placement (21.3%, n=10).

There was a general trend observed with patient height and ETT placement. Patients with deep ETT placement tended to be shorter (160.7 ± 9.7 cm), while patients with shallow ETT placement tended to be taller (169.3 ± 6.9 cm). Patients with deep ETT placement were found to be significantly shorter (160.7 ± 9.7 cm) than those with accurate ETT placement (164.7 ± 8.7 cm) ($p<0.05$), and patients with shallow ETT placement (169.3 ± 6.9 cm) were found to be significantly taller than those with deep ETT placement (160.7 ± 9.7 cm) ($p<0.001$).

The male and female patient groups differed significantly, both in terms of mean patient height and ETT distance measured above the carina. Male patients were significantly taller ($p<0.0001$) and the mean ETT distance measured above the carina was also significantly greater ($p=0.0034$) in male patients compared to female patients. Endotracheal tubes also tended to be placed deeper at the level of the front incisors in males compared to females.

The most common method used by anaesthetists to confirm accurate ETT placement was auscultation of the chest and abdomen (98.6%, n=136). The majority of anaesthetists reported using multiple methods to confirm correct ETT placement. When the number of methods used to confirm correct ETT placement was compared to accuracy of ETT placement, there was no significant difference found between the accurate, too deep and too shallow groups (p=0.4014).

Our study showed no significant increase in the number of accurately placed ETTs if all ETTs had have been adjusted using either the 21/23 cm or 20/22 cm method.

A significant negative correlation was found between the ETT distance measured at the front upper incisors and the ETT distance measured above the carina in female patients (p=0.00013), however this correlation was found to be weak. There was no such significant correlation found in male patients (p=0,2177) although a very weak negative trend was observed.

5.3. Limitations

The following limitations were identified in this study:

- A non-probability, convenience based sampling method was used for this study. This did however introduce an element of bias into the study. This sampling method does not contribute to generalisation and the degree of sampling error could not be estimated (84).
- Due to the limited number of anaesthetists working at CHBAH, the same primary anaesthetist could potentially be included more than once during the course of the study. The Hawthorne effect occurs when the study participants are aware they are being observed, and may change their behavior accordingly (84). As the anaesthetists working at the CHBAH became aware of the study as time progressed, their intubation and ETT verification practices could have changed.

- This was a contextual study, and as it was done at only one hospital, the results may not be generalisable to other anaesthetic settings.

5.4. Recommendations

5.4.1. Clinical practice

This study has served to document the prevalence of ETT misplacement occurring in the intraoperative period at the CHBAH, and investigated some of the factors potentially contributing to inaccurate ETT placement in this setting. The following recommendations are proposed for the application of the results in clinical practice:

- anaesthetists should be more aware that ETT misplacement in the intraoperative period is a common event, and is associated with significant patient morbidity;
- anaesthetists should be aware that potential risk factors identified for ETT misplacement include extremes of patient height and female gender;
- anaesthetists should be aware that the commonly used clinical methods for determining correct ETT position are not completely reliable for confirming accurate ETT placement within the trachea;
- in cases where accurate ETT placement cannot be confirmed by other clinical methods (such as obese patients or patients with underlying lung pathology), direct visualisation of the ETT tip with a fiberoptic bronchoscope or confirmation of ETT placement with ultrasound should be considered;
- anaesthetists cannot rely on placing an ETT to a specific predetermined distance at the front upper incisors to ensure correct depth of ETT placement, including the so-called 21/23 cm or 20/22 cm method. The depth of ETT insertion should rather be individualised based on clinical acumen, taking into consideration that patient gender and patient height will both affect airway length.

5.4.2. Further research

The following topics are proposed as areas where future research could be done:

- the usefulness of clinical methods for assessing the accuracy of ETT placement in patients where ETT confirmation could be potentially difficult, such as obese patients or patients with underlying lung pathology;
- the use of ultrasound as a tool to assess accuracy of ETT placement in the intraoperative environment as compared to other clinical methods.

5.5. Conclusion:

This study has shown that inaccurate ETT placement is a common occurrence in the intraoperative period in patients presenting to the CHBAH general theatre complex. The majority of these ETT misplacements were found to be deep, with the tip of the ETT less than 3 cm above the carina; however, the prevalence of unrecognised endobronchial intubation was low. The potential risk factors identified for ETT misplacement included female gender and extremes of height.

Anaesthetists working at the CHBAH tend to use multiple methods to confirm correct ETT placement; however, despite this being in line with the general recommendations (1, 3, 5, 22, 73), it was not found to impact on the accuracy of ETT placement.

The depth of ETT placement measured at the front upper incisors was found to be an unreliable measure of the ETT tip to carina distance. The accuracy of ETT placement would not have been improved by placing all ETTs to a predetermined depth at the front upper incisors using either the 21/23 cm or 20/22 cm rules. Endotracheal tube placement should instead be individualised based on patient gender, height and a complete clinical examination.

Airway ultrasonography is an evolving field, which has the advantages of providing dynamic point of care imaging in real time, being safe, noninvasive, portable and reproducible (78, 79). All of the above make it an attractive alternative to fiberoptic bronchoscopy for confirming correct ETT placement in scenarios where clinical examination is unreliable, however further research needs to be done to confirm its application in this setting.

References

1. Rudraraju P, Eisen LA. Analytic Review: Confirmation of Endotracheal Tube Position: A Narrative Review. Journal of Intensive Care Medicine. 2009 Sep;24(5):283-92.
2. Stauffer JL. Complications of Translaryngeal Intubation. In: Tobin MJ, editor. Principles and Practice of Mechanical Ventilation. 3 ed. New York: McGraw-Hill; 2013.
3. Butterworth JF, Mackey DC, Wasnick JD. Airway Management. In: Butterworth JF, Mackey DC, Wasnick JD, editors. Morgan & Mikhail's Clinical Anesthesiology. 5 ed. New York: McGraw-Hill; 2013.
4. Domino KB, Posner KL, Caplan RA, Cheney FW. Airway injury during anesthesia: a closed claims analysis. Anesthesiology. 1999 Dec;91(6):1703-11. PubMed PMID: 10598613. Epub 1999/12/22. eng.
5. Tobin MJ. Artificial Airway Problems. In: Tobin MJ, editor. Principles and Practice of Mechanical Ventilation. 3 ed. New York: McGraw-Hill ; 2013.
6. Joffe AM, Deem S. Airway Management. In: Tobin MJ, editor. Principles and Practice of Mechanical Ventilation. 3 ed. New York: McGraw-Hill; 2013.
7. Geisser W, Maybauer DM, Wolff H, Pfenninger E, Maybauer MO. Radiological validation of tracheal tube insertion depth in out-of-hospital and in-hospital emergency patients. Anaesthesia. 2009 Sep;64(9):973-7. PubMed PMID: 19686482. Epub 2009/08/19. eng.
8. Timmermann A, Russo SG, Eich C, Roessler M, Braun U, Rosenblatt WH, et al. The Out-of-Hospital Esophageal and Endobronchial Intubations Performed by Emergency Physicians. Anesthesia & Analgesia. 2007 March;104(3):619-23.
9. Owen RL, Cheney FW. Endobronchial intubation: a preventable complication. Anesthesiology. 1987 Aug;67(2):255-7. PubMed PMID: 3605754. Epub 1987/08/01. eng.

10. Zwillich CW, Pierson DJ, Creagh CE, Sutton FD, Schatz E, Petty TL. Complications of assisted ventilation: A prospective study of 354 consecutive episodes. The American Journal of Medicine. 1974 Aug;57(2):161-70.
11. Lee BJ, Yi JW, Chung JY, Kim DO, Kang JM. Bedside prediction of airway length in adults and children. Anesthesiology. 2009 Sep;111(3):556-60. PubMed PMID: 19672184. Epub 2009/08/13. eng.
12. Werman HA, Falcone RE. Glottic positioning of the endotracheal tube tip: a diagnostic dilemma. Annals of Emergency Medicine. 1998 May;31(5):643-6. PubMed PMID: 9581151. Epub 1998/05/15. eng.
13. Salem MR. Verification of endotracheal tube position. Anesthesiology Clinics of North America. 2001 Dec;19(4):813-39. PubMed PMID: 11778382. Epub 2002/01/10. eng.
14. Andersen KH. [Methods for ensuring correct tracheal intubation. A review]. Ugeskrift for laeger. 1991 Jan 21;153(4):267-9. PubMed PMID: 1899954. Epub 1991/01/21. Metoder til sikring af korrekt trakeal intubation. En oversigt. dan.
15. Brunel W, Coleman DL, Schwartz DE, Peper E, Cohen NH. Assessment of routine chest roentgenograms and the physical examination to confirm endotracheal tube position. Chest. 1989;96(5):1043-5.
16. Everett LL. Anesthesia for Children. In: Longnecker DE, Newman MF, Brown DL, Zapol WM, editors. Anesthesiology. 2 ed. New York: McGraw-Hill; 2012.
17. Eskuri SA. Complications of Endotracheal Intubation. In: Faust RJ, editor. Anaesthesiology Review. 2 ed. New York: Churchill Livingstone; 1994. p. 547-8.
18. Cherng C-H, Wong C-S, Hsu C-H, Ho S-T. Airway length in adults: estimation of the optimal endotracheal tube length for orotracheal intubation. Journal of Clinical Anesthesia. 2002 June;14(4):271-4.
19. Techanivate A, Rodanant O, Charoenraj P, Kumwilaisak K. Depth of endotracheal tubes in Thai adult patients. Journal of the Medical

Association of Thailand = Chotmaihet thangphaet. 2005 Jun;88(6):775-81. PubMed PMID: 16083218. Epub 2005/08/09. eng.

20. Techanivate A, Kumwilaisak K, Samranrean S. Estimation of the proper length of orotracheal intubation by Chula formula. Journal of the Medical Association of Thailand = Chotmaihet thangphaet. 2005 Dec;88(12):1838-46. PubMed PMID: 16518983. Epub 2006/03/08. eng.
21. Eagle CC. The relationship between a person's height and appropriate endotracheal tube length. Anaesthesia and Intensive Care. 1992 May;20(2):156-60. PubMed PMID: 1595848. Epub 1992/05/01. eng.
22. Sitzwohl C, Langheinrich A, Schober A, Krafft P, Sessler DI, Herkner H, et al. Endobronchial intubation detected by insertion depth of endotracheal tube, bilateral auscultation, or observation of chest movements: randomised trial. British Medical Journal. 2010 Nov;341.
23. Goodman LR, Conrardy PA, Laing F, Singer MM. Radiographic evaluation of endotracheal tube position. American Journal of Roentgenology. 1976 Sep;127(3):433-4. PubMed PMID: 183529. Epub 1976/09/01. eng.
24. Conrardy PA, Goodman LR, Lainge F, Singer MM. Alteration of endotracheal tube position. Flexion and extension of the neck. Critical Care Medicine. 1976 Jan-Feb;4(1):7-12. PubMed PMID: 1253616. Epub 1976/01/01. eng.
25. Evron S, Weisenberg M, Harow E, Khazin V, Szmuk P, Gavish D, et al. Proper insertion depth of endotracheal tubes in adults by topographic landmarks measurements. Journal of Clinical Anesthesia. 2007 Feb;19(1):15-9. PubMed PMID: 17321921. Epub 2007/02/27. eng.
26. Schwartz DE, Lieberman JA, Cohen NH. Women are at greater risk than men for malpositioning of the endotracheal tube after emergent intubation. Critical Care Medicine. 1994 Jul;22(7):1127-31. PubMed PMID: 8026201. Epub 1994/07/01. eng.
27. Chong DYC, Greenland KB, Tan ST, Irwin MG, Hung CT. The clinical implication of the vocal cords–carina distance in anaesthetized

Chinese adults during orotracheal intubation. British Journal of Anaesthesia. 2006 October 1, 2006;97(4):489-95.

28. Wirtz DD, Ortiz C, Newman DH, Zhitomirsky I. Unrecognized misplacement of endotracheal tubes by ground prehospital providers. Prehospital Emergency Care. 2007;11(2):213-8. PubMed PMID: 2009559566. Language: English. Entry Date: 20080208. Revision Date: 20091218.
29. Katz SH, Falk JL. Misplaced endotracheal tubes by paramedics in an urban emergency medical services system. Annals of Emergency Medicine. 2001 Jan;37(1):32-7. PubMed PMID: 11145768. Epub 2001/01/06. eng.
30. Jemmett ME, Kendal KM, Fourre MW, Burton JH. Unrecognized misplacement of endotracheal tubes in a mixed urban to rural emergency medical services setting. Academic Emergency Medicine : official journal of the Society for Academic Emergency Medicine. 2003 Sep;10(9):961-5. PubMed PMID: 12957980. Epub 2003/09/06. eng.
31. Jones JH, Murphy MP, Dickson RL, Somerville GG, Brizendine EJ. Emergency physician-verified out-of-hospital intubation: miss rates by paramedics. Academic Emergency Medicine : official journal of the Society for Academic Emergency Medicine. 2004 Jun;11(6):707-9. PubMed PMID: 15175215. Epub 2004/06/04. eng.
32. Denver Metro Airway Study group. A Prospective Multicenter Evaluation of Prehospital Airway Management Performance in a Large Metropolitan Region. Prehospital Emergency Care. 2009;13(3):304-10.
33. Bissinger U, Lenz G, Kuhn W. Unrecognized endobronchial intubation of emergency patients. Annals of Emergency Medicine. 1989 Aug;18(8):853-5. PubMed PMID: 2757282. Epub 1989/08/01. eng.
34. Schwartz DE, Matthay MA, Cohen NH. Death and other complications of emergency airway management in critically ill adults. A prospective investigation of 297 tracheal intubations. Anesthesiology. 1995 Feb;82(2):367-76. PubMed PMID: 7856895. Epub 1995/02/01. eng.

35. Benedetto WJ, Hess DR, Gettings E, Bigatello LM, Toon H, Hurford WE, et al. Urgent tracheal intubation in general hospital units: an observational study. Journal of Clinical Anesthesia. 2007 Feb;19(1):20-4. PubMed PMID: 17321922. Epub 2007/02/27. eng.
36. Stauffer JL, Olson DE, Petty TL. Complications and consequences of endotracheal intubation and tracheotomy. A prospective study of 150 critically ill adult patients. American Journal of Medicine. 1981 Jan;70(1):65-76. PubMed PMID: 7457492. Epub 1981/01/01. eng.
37. Caplan RA, Posner KL, Ward RJ, Cheney FW. Adverse respiratory events in anesthesia: a closed claims analysis. Anesthesiology. 1990 May;72(5):828-33. PubMed PMID: 2339799. Epub 1990/05/01. eng.
38. Morray JP, Geiduschek JM, Caplan RA, Posner KL, Gild WM, Cheney FW. A comparison of pediatric and adult anesthesia closed malpractice claims. Anesthesiology. 1993 Mar;78(3):461-7. PubMed PMID: 8384428. Epub 1993/03/01. eng.
39. Szekely SM, Webb RK, Williamson JA, Russell WJ. The Australian Incident Monitoring Study. Problems related to the endotracheal tube: an analysis of 2000 incident reports. Anaesthesia and Intensive Care. 1993 Oct;21(5):611-6. PubMed PMID: 8273884. Epub 1993/10/01. eng.
40. Chris Hani Baragwanath [cited 2013 27 June]. Available from: http://www.chrishanibaragwanathhospital.co.za/.
41. World Medical Association. World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects, Seoul; 2008.
42. Department of Health. Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa. In: Department of Health, editor. 2 ed. Pretoria, South Africa; 2006.
43. Jones PH, Malik T. Guidelines for Cleaning Fibreoptic Laryngoscopes. Chris Hani Baragwanath Hospital protocol; 2005.
44. Godoy MC, Leitman BS, de Groot PM, Vlahos I, Naidich DP. Chest radiography in the ICU: Part 1, Evaluation of airway, enteric, and

pleural tubes. American Journal of Roentgenology. 2012 Mar;198(3):563-71. PubMed PMID: 22357994. Epub 2012/02/24. eng.

45. Lotano R, Gerber D, Aseron C, Santarelli R, Pratter M. Utility of postintubation chest radiographs in the intensive care unit. Critical Care (London, England). 2000;4(1):50-3. PubMed PMID: 11056745. Pubmed Central PMCID: PMC29036. Epub 2000/11/01. eng.
46. Trimble C, Smith DE, Rosenthal MH, Fosburg RG. Pathophysiologic role of hypocarbia in post-traumatic pulmonary insufficiency. American Journal of Surgery. 1971 Nov;122(5):633-8. PubMed PMID: 5112069. Epub 1971/11/01. eng.
47. Breivik H, Grenvik A, Millen E, Safar P. Normalizing low arterial CO2 tension during mechanical ventilation. Chest. 1973 Apr;63(4):525-31. PubMed PMID: 4571976. Epub 1973/04/01. eng.
48. Szmuk P, Ezri T, Evron S, Roth Y, Katz J. A brief history of tracheostomy and tracheal intubation, from the Bronze Age to the Space Age. Intensive Care Medicine. 2008 Feb;34(2):222-8. PubMed PMID: 17999050. Epub 2007/11/14. eng.
49. Westhorpe RN, Ball C. The history of emergency airway management. Anaesthesia and Intensive Care. 2010;38(1):3-. PubMed PMID: 224824647; 20191768. English.
50. Klock AP, Hernandez M, Seraphin S. Airway Management. In: Longnecker DE, Newman MF, Brown DL, Zapol WM, editors. Anesthesiology. 2 ed. New York: McGraw-Hill; 2012.
51. Burdett E, Mitchell V. Anatomy of the larynx, trachea and bronchi. Anaesthesia & Intensive Care Medicine. 2011 Aug;12(8):335-9.
52. Lee C, Doyle E. Developmental anatomy of the airway. Anaesthesia & Intensive Care Medicine. 2012 May;13(5):217-9.
53. Fonseca R, Barber HD, Powers M, Frost DE. Emergency airway management in the traumatized patient. Oral and maxillofacial trauma. 4th ed. St. Louis: Elsevier Saunders; 2013.

54. Hagberg CA. Functional anatomy of the airway. Benumof and Hagberg's Airway management. 3 ed. Philadelphia: Elsevier Saunders; 2013.
55. Brown DL. Airway block anatomy. In: Saunders E, editor. Atlas of regional anaesthesia 2010.
56. Standring S, Ellis HF, Healy JC, Johnson D, Williams A, Collins P, et al. Gray's Anatomy: The Anatomical Basic of Clinical Practice. 39 ed. Standring S, editor. Edinburgh: Churchill Livingstone; 2005.
57. Minnich DJ, Mathisen DJ. Anatomy of the trachea, carina, and bronchi. Thoracic Surgery Clinics. 2007 Nov;17(4):571-85. PubMed PMID: 18271170. Epub 2008/02/15. eng.
58. Silvestri S, Ralls GA, Krauss B, Thundiyil J, Rothrock SG, Senn A, et al. The effectiveness of out-of-hospital use of continuous end-tidal carbon dioxide monitoring on the rate of unrecognized misplaced intubation within a regional emergency medical services system. Annals of Emergency Medicine. 2005 May;45(5):497-503. PubMed PMID: 15855946. Epub 2005/04/28. eng.
59. Listello D, Sessler CN. Unplanned extubation. Clinical predictors for reintubation. Chest. 1994 May;105(5):1496-503. PubMed PMID: 8181343. Epub 1994/05/01. eng.
60. Coppolo DP, May JJ. Self-extubations. A 12-month experience. Chest. 1990 Jul;98(1):165-9. PubMed PMID: 2361385. Epub 1990/07/01. eng.
61. Chevron V, Menard JF, Richard JC, Girault C, Leroy J, Bonmarchand G. Unplanned extubation: risk factors of development and predictive criteria for reintubation. Critical Care Medicine. 1998 Jun;26(6):1049-53. PubMed PMID: 9635654. Epub 1998/07/11. eng.
62. Thomas R, Kumar EV, Kameswaran M, Shamim A, al Ghamdi S, Mummigatty AP, et al. Post intubation laryngeal sequelae in an intensive care unit. The Journal of Laryngology and Otology. 1995 Apr;109(4):313-6. PubMed PMID: 7782687. Epub 1995/04/01. eng.
63. Tadie JM, Behm E, Lecuyer L, Benhmamed R, Hans S, Brasnu D, et al. Post-intubation laryngeal injuries and extubation failure: a fiberoptic

endoscopic study. Intensive Care Medicine. 2010 Jun;36(6):991-8. PubMed PMID: 20237758. Epub 2010/03/20. eng.

64. Colice GL, Stukel TA, Dain B. Laryngeal complications of prolonged intubation. Chest. 1989 Oct;96(4):877-84. PubMed PMID: 2791687. Epub 1989/10/01. eng.

65. Brzenski AB, Benumof JL. Left mainstem bronchial intubation at an extremely short incisor-to-carina distance in a patient with severe ascites. Anesthesia and Analgesia. 2011 Feb;112(2):445-7. PubMed PMID: 21156976. Epub 2010/12/16. eng.

66. Hartrey R, Kestin IG. Movement of oral and nasal tracheal tubes as a result of changes in head and neck position. Anaesthesia. 1995 Aug;50(8):682-7. PubMed PMID: 7645696. Epub 1995/08/01. eng.

67. Yap SJ, Morris RW, Pybus DA. Alterations in endotracheal tube position during general anaesthesia. Anaesthesia and Intensive Care. 1994 Oct;22(5):586-8. PubMed PMID: 7818064. Epub 1994/10/01. eng.

68. Foundation APS. History & Objectives [cited 2013 8 July]. Available from: http://www.apsf.net.au/history.php.

69. McCoy EP, Russell WJ, Webb RK. Accidental bronchial intubation. An analysis of AIMS incident reports from 1988 to 1994 inclusive. Anaesthesia. 1997 Jan;52(1):24-31. PubMed PMID: 9014541. Epub 1997/01/01. eng.

70. Li Y, Xie Y, Hu B, Wang J, Song H, Wei X. Sensitivity and Specificity of a Novel Approach to Confirm the Depth of the Endotracheal Tube: A Pilot Study. Medicine. 2015 Aug;94(34):e1460. PubMed PMID: 26313810. Pubmed Central PMCID: PMC4602919. Epub 2015/08/28. eng.

71. Ong KC, A'Court GD, Eng P, Ong YY. Ideal endotracheal tube placement by referencing measurements on the tube. Annals of the Academy of Medicine, Singapore. 1996 Jul;25(4):550-2. PubMed PMID: 8893928. Epub 1996/07/01. eng.

72. McKay WP, Klonarakis J, Pelivanov V, O'Brien JM, Plewes C. Tracheal palpation to assess endotracheal tube depth: an exploratory study. Canadian Journal of Anaesthesia = Journal canadien d'anesthesie. 2014 Mar;61(3):229-34. PubMed PMID: 24259250. Epub 2013/11/22. eng.
73. Li J. Capnography alone is imperfect for endotracheal tube placement confirmation during emergency intubation. The Journal of Emergency Medicine. 2001 Apr;20(3):223-9. PubMed PMID: 11267809. Epub 2001/03/27. eng.
74. Qi L, Liu R, Tang E, Li S, Jin J, He X, et al. [A comparison of degree of precision of auscultation, partial pressure of carbon dioxide in end-expiration, and transillumination technique in verifying accurate position of endotracheal tube]. Zhonghua wei zhong bing ji jiu yi xue. 2015 Oct;27(10):826-30. PubMed PMID: 27132446. Epub 2016/05/03. chi.
75. Davids PK, G. Basic Physics and Measurement in Anaesthesia. 5th ed: Butterworth Heinemann; 2003.
76. Grmec S. Comparison of three different methods to confirm tracheal tube placement in emergency intubation. Intensive Care Medicine. 2002 Jun;28(6):701-4. PubMed PMID: 12107674. Epub 2002/07/11. eng.
77. Hossein-Nejad H, Payandemehr P, Bashiri SA, Nedai HH. Chest radiography after endotracheal tube placement: is it necessary or not? The American Journal of Emergency Medicine. 2013 Aug;31(8):1181-2. PubMed PMID: 23810228. Epub 2013/07/03. eng.
78. Kristensen MS, Teoh WH, Graumann O, Laursen CB. Ultrasonography for clinical decision-making and intervention in airway management: from the mouth to the lungs and pleurae. Insights Into Imaging. 2014 Apr;5(2):253-79. PubMed PMID: 24519789. Pubmed Central PMCID: PMC3999368. Epub 2014/02/13. eng.
79. Teoh WHL. Ultrasound in airway management http://www.airwayelearning.com/2014 [cited 2016 17 August]. Available

from: http://www.airwayelearning.com/awel/articles/articles-1.aspx?Action=1&NewsId=2128&M=NewsV2&PID=71655.

80. Hoffmann B, Gullett JP, Hill HF, Fuller D, Westergaard MC, Hosek WT, et al. Bedside ultrasound of the neck confirms endotracheal tube position in emergency intubations. Ultraschall in der Medizin (Stuttgart, Germany : 1980). 2014 Oct;35(5):451-8. PubMed PMID: 25014479. Epub 2014/07/12. eng.
81. Werner SL, Smith CE, Goldstein JR, Jones RA, Cydulka RK. Pilot study to evaluate the accuracy of ultrasonography in confirming endotracheal tube placement. Annals of Emergency Medicine. 2007 Jan;49(1):75-80. PubMed PMID: 17014927. Epub 2006/10/04. eng.
82. Sim SS, Lien WC, Chou HC, Chong KM, Liu SH, Wang CH, et al. Ultrasonographic lung sliding sign in confirming proper endotracheal intubation during emergency intubation. Resuscitation. 2012 Mar;83(3):307-12. PubMed PMID: 22138058. Epub 2011/12/06. eng.
83. Ramsingh D, Frank E, Haughton R, Schilling J, Gimenez KM, Banh E, et al. Auscultation versus Point-of-care Ultrasound to Determine Endotracheal versus Bronchial Intubation: A Diagnostic Accuracy Study. Anesthesiology. 2016 May;124(5):1012-20. PubMed PMID: 26950708. Epub 2016/03/08. eng.
84. Brink HI. Fundimentals of Research Methodology for Health Care Professionals. 6 ed. South Africa: Juta & Co; 2003.
85. Strydom H, Fouche CB, Poggenpoel M, Schurink E, Schurink W. Research at grass roots: A primer for the caring professions. 2 ed. Pretoria: Van Schaik; 2000.
86. Botma Y, Greeff M, Mulaudzi FM, Wright SCD. Research in Health Sciences. 1 ed. Cape Town: Heinerman; 2010.
87. Longnecker DEN, M.F. Brown, D.L. Zapol, W.M. . The Anaethetic Plan for Healthy Patients. Anaesthesiology. 2 ed. New York: McGraw Hill; 2012.

APPENDICES

Appendix A: ASA Physical Status Classification System (87)

Table 7-1 American Society of Anesthesiologists Physical Status Classification

Class	Description	Examples
I	No organic, physiologic, biochemical, or psychiatric disturbances	Otherwise healthy patient
II	Mild to moderate systemic disturbance(s)	Hypertension, well-controlled diabetes, mild obesity, age <1 y or >70 y, malignancy without evidence or significant spread or physiologic disturbance
III	Severe systemic disturbance that may or may not be related to the reason for surgery	Angina, poorly controlled diabetes, massive obesity, controlled thyroid dysfunction
IV	Severe systemic disturbance that is life threatening	"Unstable" angina, congestive heart failure, debilitating respiratory disease, hepatorenal failure
V	Moribund patient who has little chance of survival	Septic patient with multiorgan failure, patient in cardiac arrest from major trauma
VI	Brain-dead patient for organ harvesting	
E	Any patient in whom an emergency operation is required	

Appendix B: Letter of approval from Human Research Ethics Committee (Medical) WITS

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M130705

NAME: (Principal Investigator)	Dr Ryan Campbell/Prof A Milner
DEPARTMENT:	Anaesthesiology Charlotte Maxeke Johannesburg Academic
PROJECT TITLE:	The Accuracy of Anaesthetists in Oral Endotracheal Tube Placement in an Academic Hospital
DATE CONSIDERED:	26/07/2013
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr E Mostert
APPROVED BY:	Professor PE Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 28/10/2013

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

Principal Investigator Signature M130705Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix C: Letter of approval from Postgraduate committee, Faculty of Health Sciences WITS

Faculty of Health Sciences
Private Bag 3 Wits, 2050
Fax: 027117172119
Tel: 02711 7172040

Reference: Ms Thokozile Nhlapo
E-mail: thokozile.nhlapo@wits.ac.za

07 January 2014
Person No: 0108709W
PAG

Dr RJ Campbell
P O Box 1295
Rivonia
2128
South Africa

Dear Dr Campbell

Master of Medicine: Approval of Title

We have pleasure in advising that your proposal entitled *The accuracy of anaesthetics in oral endotracheal tube placement in an academic hospital* has been approved. Please note that any amendments to this title have to be endorsed by the Faculty's higher degrees committee and formally approved.

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

Appendix D: Letter of approval from Medical Advisory Committee and CEO CHBAH

GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

MEDICAL ADVISORY COMMITTEE
CHRIS HANI BARAGWANATH ACADEMIC HOSPITAL

PERMISSION TO CONDUCT RESEARCH

Date: 07 January 2015

TITLE OF PROJECT: The accuracy of anaesthetists in oral endotracheal tube placement in an academic hospital

UNIVERSITY: Witwatersrand

Principal Investigator: R Campbell

Department: Aneasthesiology

Supervisor (If relevant): E Mostert, A Milner

Permission Head Department (where research conducted): Yes

Date of start of proposed study: January 2015
Date of completion of data collection: Dec 2016

The Medical Advisory Committee recommends that the said research be conducted at Chris Hani Baragwanath Hospital. The CEO /management of Chris Hani Baragwanath Hospital is accordingly informed and the study is subject to:-

- Permission having been granted by the Committee for Research on Human Subjects of the University of the Witwatersrand.
- the Hospital will not incur extra costs as a result of the research being conducted on its patients within the hospital
- the MAC will be informed of any serious adverse events as soon as they occur
- permission is granted for the duration of the Ethics Committee approval.

.....
Recommended
(On behalf of the MAC)
Date: 07 January 2015

.....
Approved/Not Approved
Hospital Management
Date: 12/01/15

Appendix E: Patient information and consent form

CONSENT TO PARTICIPATE IN RESEARCH

The accuracy of anaesthetists in the depth of oral endotracheal tube placement in an academic hospital

Hello, my name is Ryan Campbell. I am a qualified doctor who is studying further at the University of the Witwatersrand to become an anaesthetist. An anaesthetist is a doctor who gives patients special medicine to put them to sleep, or take away the pain during an operation. As a part of my studies I am doing a research study and I would like to invite you to take part.

During your operation, your anaesthetist doctor will put a special pipe inside your throat to help you breath. I am trying to see how good other anaesthetist doctors are at putting this pipe inside your throat, and if they are putting it into the right place.

If you agree to take part in my study, this is what will happen. You will come into the operating theatre and your anaesthetist doctor will put a mask on your face and give you a special injection to put you to sleep. When you are asleep, your anaesthetist doctor will put a pipe inside your throat to help you to breath during the operation. I will then write down how far your anaesthetist doctor has put the pipe into your throat and then, put a special camera down the inside of the pipe to see if it is in the right place. After this I will take the camera out again and the operation will carry on like normal. While you are asleep I will also measure your height and record your age and gender. I will not record your name or any other information that can be used to identify you.

The Human Research Ethics Committee (number) and the Postgraduate Committee of the University of the Witwatersrand have approved my study.

I do not believe that you will be hurt in any way by being in this study. If you decide to take part in my study and you feel that you have been hurt or upset in any way, you can stop being in the study.

Only my supervisors and myself will look at your results, and I will not write down your name or use any other information that can be used to identify you.

If you don't want to be in this study you don't have to. If you decide that you would like to be in this study and then change your mind, you can stop being in the study at any time. Your doctors will still give you the best treatment even if you decide not to be in the study.

For more information you can phone me at 072 383 1312, or professor Peter Cleaton-Jones, chair of the Human Research Ethics Committee, on (011) 717 1234.

Signing the consent form attached means that you agree to take part in this study. You will be given a copy of this form to keep.

Thanks for your time.

Regards
Dr Ryan Campbell

Consent Form

I, …… agree to participate in the study of the accuracy of anaesthetists **in the depth of** oral endotracheal tube placement in an academic hospital.

I have read and understood the information letter provided to me by Dr Ryan Campbell. I understand that I may withdraw from the study at any point if I do not wish to participate.

I have had the opportunity to ask questions about the study and my participation in it.

…….
Participant name

…….. ……..
Participant signature Date

Appendix F: Anaesthetist information and consent form

CONSENT TO PARTICIPATE IN RESEARCH

The accuracy of anaesthetists in the depth of oral endotracheal tube placement in an academic hospital

Hello, my name is Ryan Campbell. I am an anaesthetic registrar doing a research study in order to complete my MMed degree. My research study is on the accuracy of anaesthetists at placing an oral endotracheal tube, and I would like to invite you to take part.

My study will entail the following. After you have induced and intubated your patient and they are stable from a haemodynamic and ventilatory point of view, I will record their height, age, gender and endotracheal tube position. I will then pass a fiberoptic nasopharyngeal scope through the endotracheal tube and measure the tube tip to carina distance. The scope will be passed through a swivel adapter with a fiberoptic port so the patient can be continually ventilated during the measurement process. I will also ask you which methods you used to verify your endotracheal tube placement.

The Human Research Ethics Committee (number) and the Postgraduate Committee of the University of the Witwatersrand have approved my study.

I do not believe that this will endanger or harm your patient in any way. I will not record your name or any other information that can be used to identify you in any way. Only my supervisors and myself will see the results.

Misplaced endotracheal tubes can have potentially disastrous consequences for our patients. A better understanding of the prevalence of endotracheal tube misplacement in our own institute, and the factors associated with it, will help us to provide better and safer care to all our patients.

You are in no way obliged to take part in this study and if you feel that you don't want to take part in this study for whatever reason, there will be no repercussions.

For more information you can contact me on 072 383 1312, or professor Peter Cleaton-Jones, chair of the Human Research Ethics Committee, on (011) 717 1234.

Signing the consent form attached means that you agree to take part in this study. You will be given a copy of this form to keep.

Thanks for your time.

Regards
Dr Ryan Campbell

Consent Form

I, …… agree to participate in the study of the accuracy of anaesthetists in the depth of oral endotracheal tube placement in an academic hospital.

I have read and understood the information letter provided to me by Dr Ryan Campbell. I understand that I may withdraw from the study at any point if I do not wish to participate.

I have had the opportunity to ask questions about the study and my participation in it.

…….
Participant name

…….. ……..
Participant signature Date

Appendix G: Data collection form

Date:

Patient number:

Consent obtained:

YES	NO

1. Demographics:

Patient Age	……years	
Gender	M	F
Height	……cm	

2. ETT position:

ETT position at front upper incisors	……..cm	
ETT tip to carina distance	……..cm	
Endobronchial intubation	YES	NO

3. Anaesthetist:

Methods used to confirm correct ETT placement:

I. ……

II. ……....

III. ……....

IV. ……....

Appendix H: Fiberoptic nasopharyngeal scope cleaning and sterilisation procedure

Cleaning Guidelines for the Fibreoptic Bronchoscope:

- After using the FOB remove the portable light source
- Take the scope to the sink and wash the exterior with a sponge and chlorhexidine soap in warm water.
- Wrap the sponge around the shaft of the scope pull distally taking care not to bend or pull the glass fibres.
- Use the sponge to clean the distal aperture
- Rinse the exterior of the scope with warm water and flush the working channel and the suction port with a 20ml syringe full of warm water.
- Use the same 20 ml syringe to flush air down the channels.
- Take 20 mls of endozyme (located between theatre 8 & 9) and flush the working channel and suction port. Use the residual endozyme to clean the exterior surface of the scope.
- Repeat the warm water rinse and air flush of channels
- Take the scope to the cidex box between theatre 8 & 9 and immerse it in cidex (keeping the eyepiece and handle clear of the cidex) with a new 20 ml syringe flush the suction port and working channel till there are no more air bubbles visible)
- Leave in cidex for 5 mins.
- Remove and repeat the rinse and air flush described above so that the scope has no cidex left internally or externally.
- Take an oxygen cable and connect it to an external source and flush the scope with 15 l/min oxygen for 3mins.
- Dry the external surface of the scope with gauze.

- Take the silicone spray and cover the external surface of the scope with silicone (spray over the bin so that you don't spend the rest of the day falling on the floor)
- Place the distal shaft of the scope inside a 7.5 mm reinforced ett to keep it safe within its own box.
- Clean any junk out of the scope box
- Use the light source to confirm no new black dots and use the pressure kit supplied to test the freshly cleaned scope for leaks.
- (the scope should hold a pressure of 140 mmHg for an indefinite time)

(Adapted from the CHBAH guidelines on cleaning fiberoptic scopes)