ANAESTHESIOLOGICAL ASPECTS OF BIOMECHANICS OF LARYNGOSCOPY

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ANAESTHESIOLOGICAL ASPECTS OF BIOMECHANICS OF LARYNGOSCOPY

Anaesthesiologische aspecten van biomechanica van laryngoscopie

Proefschrift

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To Monique

For all those one feels it was a privilige to have worked with, and for those with whom ideas were exchanged.

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CHAPTER 1

INTRODUCTION

Laryngoscopy is a technique used to expose the laryngopharyngeal area, particularly the entrance of the trachea, in order to provide a diagnostic insight and, especially for anaesthesiologists, to facilitate the introduction of an endotracheal tube under direct view. The laryngoscope was developed almost one century ago: Alfred Kirstein (Germany), a laryngologist, invented the instrument in 1895, but used it only to serve the requirements of his own specialty. At first, anaesthesiologists neglected the instrument and continued to use 'blind methods' in the performance of endotracheal intubation. However, when in 1912 Elsberg (USA) reported use of the laryngoscope to facilitate endotracheal intubation under direct vision, the importance of this instrument to anaesthesiologists was recognized. Since that time, the laryngoscope has evolved to become one of the most important instruments in the armamentarium of modern anaesthesiology.
Many different types of laryngoscopes for routine use, or for special indications, have since been developed [1,2]. The most popular models in current routine use are about 50 years old; the Miller was introduced in 1941 [3] and the Macintosh in 1943 [4]. Since their introduction only minor modifications have been made and they have gradually gained their dominant position, which has not been seriously affected by the many new blades introduced thereafter. Although the use of modern laryngoscopes is satisfactory in the majority of patients, in some patients with no apparent anatomic peculiarities, visualisation of the tracheal entrance is not possible. This can lead to a potentially life-threatening situation and contributes to the current morbidity and mortality due to the anaesthetic procedure. In addition to the risks resulting from failure to bring the glottis into view, many side-effects of laryngoscopy have been reported [5]. These include damage to structures in the oro-pharyngeal area, especially the teeth; and cardiovascular changes, resulting from laryngoscopy and subsequent tracheal intubation, which can be detrimental in some patients. Therefore, although there is a long history behind the laryngoscopic procedure we perform today, there is certainly need for improvement.

In order to improve the laryngoscopic procedure, we first need a more thorough analysis of the procedure. Sensor and imaging techniques combined with clinical observations should supply essential information to enable the construction of biomechanical models which will more accurately describe the procedure. These models will then allow us to rationalise the design of new laryngoscopes and will optimise their handling. The following step will be to test these new designs: this should comprise comparisons with a 'gold standard', during which measurements of their performance are carried out. This information should subsequently be used to improve the biomechanical models, thereby closing the circle to a further development of the overall design.

In the past, and especially at the time that our currently most popular blades were described, the methods to analyse the problems encountered during laryngoscopy and subsequent endotracheal intubation were limited. The specialty of anaesthesiology, though rapidly developing, was still young and, in those days, 'art' was seen to be as important as 'science'. Therefore, it is not surprising that the design of laryngoscopes was a rather subjective matter, which is well illustrated by a statement of Macintosh in the 1940s, that: "the precise shape or curve of the blade does not seem to matter much provided the tip does not go beyond the epiglottis" [4,6].

In the last decade, our knowledge on some aspects of the laryngoscopic procedure has greatly improved, particularly anticipation of intubation problems and functional anatomy of the larynx. Various measurement techniques have been described to gain insight into what is actually happening during laryngoscopy [7,8,9] and, recently, a new theoretical method of analysing laryngoscope blade shapes was introduced [10], although the latter has its limitations [11]. However, even today, detailed evaluation and comparison of laryngoscopes are virtually non-existent [1] and knowledge on the biomechanics of this procedure remains limited. One should realize, however, that although it may seem that, potentially, much can be gained from more thorough knowledge about the procedure, it does not necessarily mean that changes will ultimately be made. Present-day laryngoscopes might, in fact, already be the optimal compromise of factors not yet well understood. This idea seems to be supported by the fact that only minor modifications of the currently most popular laryngoscopes have been implemented since their introduction about 50 years ago.

The aim of the work presented in this thesis was to gain insight into the biomechanical aspects of laryngoscopy and their relationship with anatomical structures and impact on physiological responses.

The goal of the first phase of the study was to develop a simple method to measure the most relevant forces applied during laryngoscopy, using the currently most popular laryngoscope blade: the Macintosh blade. For this purpose a sensor based on a strain gauge technique was developed and is described in ***chapter 2***.

The forces applied during laryngoscopy and their relationship with individual morphologic characteristics in patients were investigated, and are discussed in ***chapter 3***.

A particularly relevant problem in laryngoscopy and subsequent endotracheal intubation is how the effects on the cardiovascular system, which are detrimental in some patients, are triggered. Compared to the large amount of literature concerning the pharmacological blocking of these responses by agents acting directly on the cardiovascular system or increasing the 'depth of anaesthesia', studies on the origin of these responses are very limited. However, based on these few studies, it is thought that the forces applied onto the base of the tongue, needed to bring the glottis into view, represent the major stimulus. The relationship between the forces applied and the cardiovascular responses involved are evaluated in ***chapter 4***.

A special concern for anaesthesiologists is the relationship between malignant hyperthermia, suxamethonium, volatile anaesthetics and increased masseter muscle tone. Although a relationship between malignant hyperthermia and a greatly increased masseter muscle tone has been well established, the significance of smaller increases in tone is less obvious [12,13]. Certainly, the inability to quantify masseter muscle tone was an important reason for this lack of insight. However, a method to quantify masseter muscle tone was recently reported, and it was demonstrated that suxamethonium increases masseter muscle tone in the majority of children [14]. Whether or not this phenomenon depends on the presence of volatile anesthetics was not clarified. This question, as well as possible explanations for this phenomenon, are addressed in ***chapter 5***.

An increased insight into the complexity of the laryngoscopic procedure, as the result of an improved measurement technique, led to the conclusion that the biomechanical model used so far had to be redesigned. The first model was based on the assumption that the most prominent force was that applied by the blade of the laryngoscope onto the base of the tongue. However, a second force appeared to be present as well: namely, that exerted onto the maxillary incisor teeth. The redesigned model, as well as the methodology of measuring both forces, were investigated and are described in ***chapter 6***.

Experience is considered to be an important factor influencing the laryngoscopic procedure; favouring the success of the procedure and allowing the best possible view on the glottis. In addition, experience is said to reduce the frequency and severity of complications during the procedure. The most commonly encountered complication is dental damage, especially damage to the maxillary incisors, which results from contact (force) between the blade and the teeth. The influence of experience in laryngoscopy with respect to the forces exerted onto the maxillary incisors, is addressed in ***chapter 7***.

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CHAPTER 2

MEASUREMENT OF FORCES DURING LARYNGOSCOPY

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Summary

Laryngoscopy and tracheal intubation have large impact on cardiovascular parameters and intracranial pressure. It is seen as a pressure response. The forces transmitted by the laryngoscope blade onto the base of the tongue are assumed to be a major stimulus. This study investigates the various forces applied onto the laryngoscope during laryngoscopy. The forces acting along the axis of the handle are described, as well as the forces exerted by the anaesthesiologist to prevent the laryngoscope from turning. Based on a relatively simple technique, a modified laryngoscope has been designed to measure these forces. Four different laryngoscopic factors are determined: 1. the duration of laryngoscopy, 2. the maximally applied force, 3. the mean force, and 4. the integral of the force over the time (area under the curve). The force measurements of 49 anatomically normal patients undergoing uncomplicated intubation are included in the study. The duration of laryngoscopy was 16.3 s (11.8), mean (SD), the applied peak force was 35 N (12) and mean force necessary was 20 N (6) while the force-time integral was 324 Ns (194). The modified laryngoscope proved a reliable and simple technique to measure forces applied to the laryngoscope blade and subsequently to the tissues. It contributes to knowledge on the interaction between these forces and cardiovascular parameters and intracranial pressure, helps investigate laryngoscopic blades for clinical compatibility and can serve as a useful teaching device.

Introduction

Laryngoscopy and subsequent tracheal intubation are known to have profound influence on circulatory parameters and intracranial pressure [1-4]. Forces transmitted by the laryngoscope blade onto the base of the tongue are assumed to be a major stimulus [5-8]. Induction agents [9,10], opioids [11,12] and neuromuscular relaxants [13,14] also influence circulatory parameters, as do patient dependent variables such as age [15] and hypertension [16,17].

To investigate the relationship between laryngoscopy and intubation stimulus on the one hand and response on the other, the forces applied by the blade of the laryngoscope have to be quantified. Different devices to measure these forces have been described [18-21]. However, these devices were difficult to construct, measurements were difficult to interpret or were not described in humans.

In the development of a laryngoscope to measure these forces, the following basic criteria have to be fulfilled: 1) in use the handling of the laryngoscope should not differ from a conventional laryngoscope; 2) changing of the blade should be easy; and 3) view of the glottis should be unobstructed.

Methods

During proper use of the curved blade laryngoscope designed by Macintosh the forces applied to the laryngoscope should be directed parallel to the axis of the handle[22,23]. The forces applied by the laryngoscope are counteracted by the tissues in contact with the blade (Fig 1). According to the first law of Newton the tissues exert forces with the same magnitude but with opposite direction. The different mechanical characteristics of the tissues, the curved shape of the blade and the direction of the forces applied to the handle result in a non-homogeneous

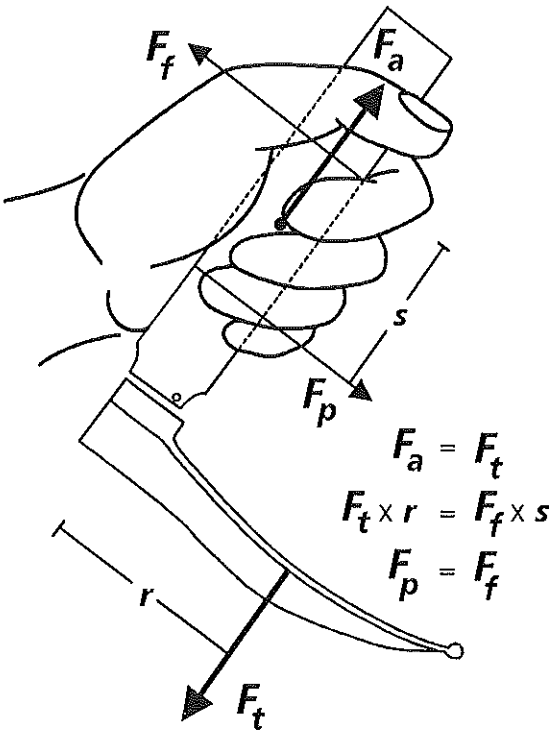

Figure 1. *Hand of the anaesthesiologist with laryngoscope. The force exerted by the tissues (F_t) with the corresponding moment ($F_t \times r$) is shown. The forces exerted by the hand in the axial direction (F_a) as well as the forces exerted by the fingers (F_f) and palm (F_p), to compensate the moments exerted by the tissues, are shown.*

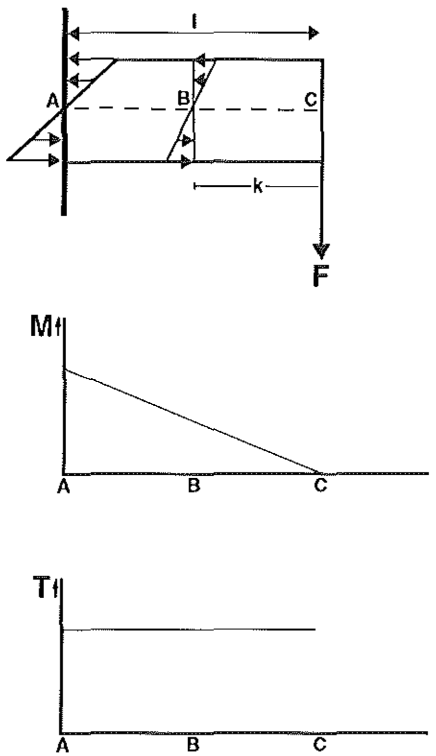

Figure 2. *Schematic representation of the connection between handle and blade with the downward directed force F exerted by the tissues. The moment (M) in A is the product of F and l. The shearing forces (T) in the beam are constant.*

distribution of the forces along the blade.

These forces can be summed by vector analysis. The resulting forces transmitted by the tissues onto the blade (F_t) are characterised by a varying point of application, magnitude and direction. Because of the eccentric application point these forces produce a certain moment onto the laryngoscope ($F_t \times r$). To prevent the laryngoscope from turning, this moment should be balanced by a counteracting moment exerted by the hand of the anaesthesiologist. Forces exerted by the palm of the hand (F_p) and the fingers (F_f) account for the overall moment ($F_f \times s$). However, during laryngoscopy one should avoid overcompensation which could result in using the front teeth as a fulcrum of leverage, with associated serious damage. The tendency to overcompensate is commonly seen in the inexperienced and during careless anaesthetic practice [22,23].

Obviously, this model is a simplification of what actually happens. Other forces, such as rotational forces in the plane perpendicular to the handle of the laryngoscope, will be present; moreover, the forces discussed may not be exerted precisely in the optimal direction. However, it is obvious that forces parallel to the axis of the handle are the most relevant.

Technical development

Construction of a laryngoscope with a force-sensing device positioned between the handle and the blade appeared a feasible option. However, at this position different forces are present [24,25] (Fig 2). There are tensile and compressive forces to counteract the moments resulting from forces exerted on the blade, and there are shearing forces, perpendicular to the axis of the blade. In contrast to the tensile and compressive forces, shearing forces are independent of the application point mentioned above [24]. Moreover, they are independent of the shape of the blade [26].

A strain gauge based sensor to measure shearing forces using strain gauges has been described by Gommers [25] (Fig 2). This device is sensitive in one direction only with minimal influence of other forces (deviation <2%) acting at the same location. A clinical application of this sensor has been described [6].

This sensor was built into a laryngoscope with a curved blade (Macintosh) enabling only measurement of the forces parallel to the axis of the handle. The device has excellent linearity (deviation <1%), reproducibility (deviation «1%) and fulfills the criteria stated earlier. The shape and weight of the handle and blade are similar to that of a conventional laryngoscope, except for the shearing force sensor, protruding backward to the anaesthesiologist but causing no inconvenience (Fig 3). The Newton (N) was used as a unit of force (1.0 N = 0.102 kgf). Due to the weight of the blade and the connection to the sensor, the position of the laryngoscope has an influence on the measurement. With the handle in the vertical position this influence is zero; with the handle at an angle of 45 degrees to the horizon it is −0.64 N and with the handle in a horizontal position the influence is −2.21 N.

The strain gauges (Measurements Group Inc, Raleigh, NC, USA) are placed in a full electronic bridge and connected to a bridge amplifier with zero calibration and gain adjustment (Peekel Instruments, Strainindicator CA 660, Rotterdam, The Netherlands). The amplifier is connected to a recorder (Hewlett Packard, 7132A, SanDiego, CA, USA) for continuous registration. The electrical force signal is integrated over time to determine the 'area under the curve' and the integral is simultaneously recorded. Calibration to zero is achieved by keeping the laryngoscope handle in the vertical position. No zero drift was observed within a 3 hour period. Calibration is performed by simply placing a weight of 2 kg (=19.6 N) onto the laryngoscope blade, as calibration with additional weights had shown full linearity of the measuring system. It is thus possible to determine four laryngoscopic factors: 1) the duration of laryngoscopy (t_l); 2) the maximally applied force (Fmax); 3) the mean force (Fmean); and 4) the force-time integral (F*t; area under the curve). In routine practice, the instrument worked effectively.

Patient material

Using the modified laryngoscope, the laryngoscopic factors were determined in 49 adult patients (ASA 1-2; 22 males, 27 females) scheduled for elective surgery. The study was approved by the Hospital Ethics Committee. Before each measurement

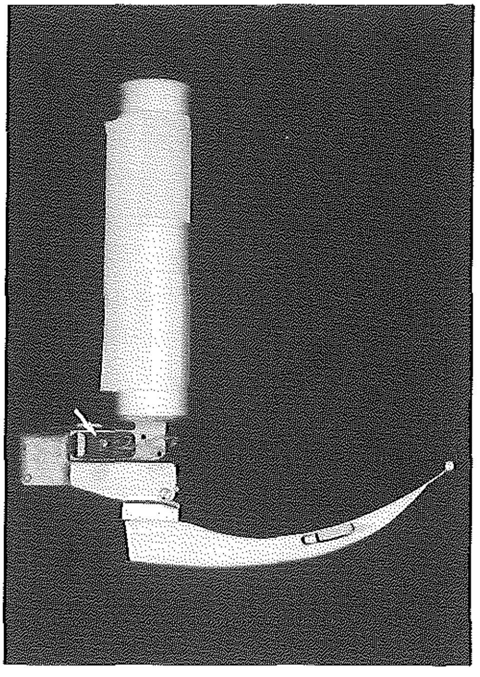

***Figure 3**. Laryngoscope enabling measurement of axial forces by strain gauges. The arrow indicates the position of the strain gauges.*

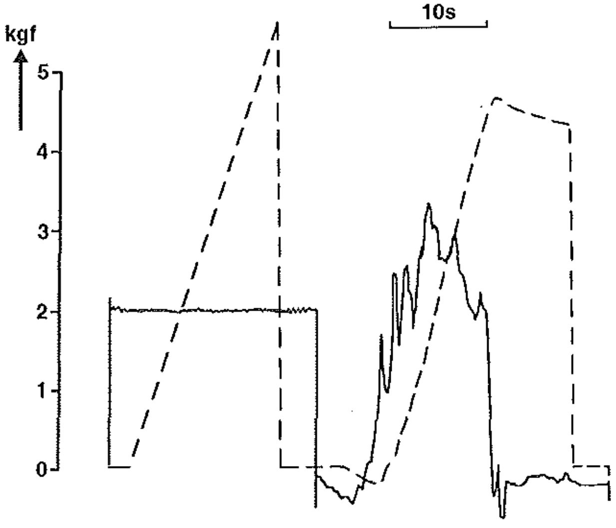

Figure 4. *Forces required in typical patients; the solid line shows the measured shearing force and the dotted line shows the force-time integral. The left part of the figure represents the calibration at 19.6 N (=2.0 kgf). The deflection just before laryngoscopy is caused by the position of the laryngoscope.*

the instrument was calibrated as described above. Only patients in whom routine uncomplicated laryngoscopy and subsequent intubation were anticipated were included in the study. Patients in whom intubation proved difficult or was not achieved at first attempt, were excluded. Premedication consisted of midazolam 2.5 mg i.m. and atropine 0.5 mg i.m. given 1 h before induction of anaesthesia. Anaesthesia was induced with thiopentone 4–5 $mg.kg^{-1}$, fentanyl 2 $\mu g.kg^{-1}$ and suxamethonium 1.0–1.5 $mg.kg^{-1}$. Patients' lungs were ventilated with 66% nitrous oxide in oxygen.

Results

The duration of laryngoscopy was 16.3 s (SD 11.8) (range 6.8–43.2 s); Fmax was 35 N (SD 12) (range 13–60 N), Fmean was 20 N (SD 6) (range 9–32 N) and F*t integral was 324 (SD 194) (range 66–981 Ns). In all patients the view on the glottis was classified as Cormack and Lehane grade I[27]. Data from an uncomplicated intubation is shown in Figure 4, and high and low force requirements in Figure 5A,B.

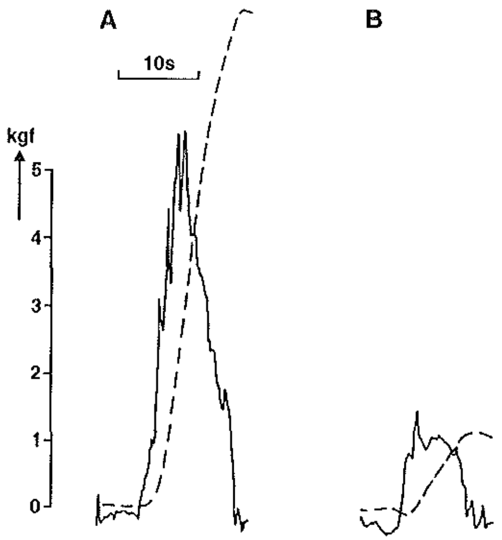

Figure 5. High (A) and low (B) force requirements. Calibrations are not shown.

Discussion

More complicated devices which measure several component forces have been described previously [18] but, to our knowledge, routine use in humans has not been reported. A technique to monitor laryngoscopic pressures on the tissues using a hydrostatic transmitter fixed to the distal part of the blade has also been reported [19,20]. However, it is difficult to relate these pressures to the forces applied by the blade.

The modified instrument described here has proved to be effective and reliable in measuring forces during routine laryngoscopy. The construction was simple; results are clear and easy to interpret, thus fulfilling the needs of anaesthesiologists. The device may be particularly useful to study the relationship between applied forces and changes in circulatory parameters, and to compare different blades with respect to the forces necessary to perform intubation. Moreover, the described device could be an important aid in the instruction of laryngoscopic techniques [18].

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CHAPTER 3

FORCES APPLIED DURING LARYNGOSCOPY AND THEIR RELATIONSHIP WITH PATIENT CHARACTERISTICS

Influence of height, weight, age, sex and presence of maxillary incisors

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Summary

The relationships between patients' height, weight, age, body mass index, gender and presence of maxillary incisors and a series of laryngoscopic factors have been studied. These include the duration of laryngoscopy, maximally applied force, mean applied force and the integral of force over time. There was a positive correlation between height and weight and laryngoscopic factors. Sex and age also showed a positive correlation but these could be explained by differences in height, weight and the presence of maxillary incisors. This latter factor was the dominant patient characteristic influencing the laryngoscopic factors. Use of these laryngoscopic factors as a measure of difficulty of laryngoscopy, in addition to the grading system of Cormack and Lehane, is discussed.

Introduction

In a previous publication a curved blade laryngoscope was described which permitted the measurement of forces applied to the patient during laryngoscopy [1]. By means of this instrument four laryngoscopic factors can be quantified: 1) the duration of laryngoscopy (t_l); 2) the maximally applied force (Fmax); 3) the mean force (Fmean); and 4) the integral of the forces over the time (F*t). Quantification of these factors could be important when studying the relationship between laryngoscopy and intubation stimuli, and the resulting stress response [2]. Moreover, these factors might also be measured in studies concerning the difficulty of laryngoscopy or the effect of neuromuscular blocking drugs on intubation [3,4]. In this context, the identification of patient characteristics which correlate with the laryngoscopic factors described above in 'routine' laryngoscopy and intubation is a logical first step. The purpose of this study was to investigate the relationship, if any, between these laryngoscopic factors and the patient's height, weight, body mass index, age, sex and the presence or absence of maxillary incisors.

Methods

Forty-nine patients, scheduled for elective surgery, participated in the study. Approval from the Hospital Ethics Committee and informed consent from each subject were obtained. All patients were ASA grade 1 or 2 adults, in whom no difficulty with intubation was anticipated. Patients in whom endotracheal intubation proved difficult, or was not achieved at first attempt, were excluded from the study. Before laryngoscopy the patient's head was placed in the 'sniffing' position. Laryngoscopy in all patients was performed by the same person using the technique for curved blade laryngoscopes. In all patients, height (cm), weight (kg), sex, age and body mass index ($kg.m^{-2}$) were registered, as was the presence or absence of maxillary incisors.

The following laryngoscopic factors were determined: 1) the duration of laryngoscopy, 2) the maximally applied force, 3) the mean force and 4) the integral of forces over the time. These were studied using a modified curved blade (Macintosh) laryngoscope as was described previously [1]. This instrument measures forces acting along the axis of the handle of the laryngoscope by means of a strain gauge based sensor positioned between the handle and the blade. The instrument was calibrated before each measurement by placing a weight of 2 kg (=19.6 N) on to the laryngoscope blade, keeping the handle in the vertical position. Each patient received intramuscular midazolam 2.5 mg and intramuscular atropine 0.5 mg 60 minutes before surgery. Anaesthesia was induced with thiopentone 4–5 $mg.kg^{-1}$, fentanyl 2 $\mu g.kg^{-1}$ and suxamethonium 1.0–1.5 $mg.kg^{-1}$. Before intubation, the patients' lungs were manually ventilated with 66% nitrous oxide in oxygen.

Statistical methods

To study the univariate relationships between the patient characteristics and the laryngoscopic factors, linear regression analysis or Student's *t*-test was used. The results of the different groups were compared by the two-way unpaired Student's *t*-test. F*t and t_l were logarithmically transformed to obtain approximate normal distributions. To study the joint relationship of several patient characteristics simultaneously with the laryngoscopic factors, stepwise forward multiple linear regression analysis was performed. For each laryngoscopy factor, the best single discriminatory variable was selected; then the best pair of variables, which included the first, was determined and so on, until the addition of a further variable was no more significant. A p value of ≤ 0.05 was considered significant.

Results

The demographic details and the laryngoscopic factors studied are presented in Tables 1 and 2. There was a significant relationship between patients' height and Fmax (Fmax = 0.5 × height – 50) ($p = 0.008$) ($r = 0.37$) and F*t (logF*t = 0.02 × height –1.63) ($p = 0.01$) ($r = 0.37$). Furthermore, there was a significant relationship between weight and Fmax (Fmax = 0.3 × weight + 13) ($p = 0.01$) ($r = 0.36$), Fmean (Fmean = 0.2 × weight + 6.7) ($p = 0.004$) ($r = 0.40$) (Fig 1.) and F*t (logF*t = 0.01 ×

Table 1. Demographic details; values are mean (SD) range or numbers of patients.

Height; cm	174		(9.0)	155 - 197
Weight; kg	74		(13.9)	50 - 113
Age; years	38		(17.0)	16 - 75
Body mass index; kg.m^{-1}	24.3		(3.8)	18.4 - 33.4
Male:Female	22	:	27	
With maxillary incisors: without maxillary incisors	40	:	9	

weight + 1.3) (p = 0.02) (r = 0.34). The body mass index was significantly related to Fmean only (Fmean = 0.5 × BMI + 8) (p = 0.03) (r = 0.30) and not to the other factors. A negative significant relationship was found between age and Fmax (Fmax = −0.2 × age + 45) (p = 0.02) (r = −0.34).

All mean laryngoscopic measurements were greater in men than in women, but multiple regression analysis indicated that sex did not correlate with the laryngoscopic factors when corrected for height, weight and the presence of maxillary incisors. The presence of maxillary incisors had a significant influence on all laryngoscopic measurements (Table 3).

Stepwise forward regression analysis showed the presence of maxillary incisors to be the only variable with a statistically significant influence on the duration of laryngoscopy (R^2 = 0.10). For Fmax the best single discriminatory variable was maxillary incisors (R^2 = 0.27); the best pair of variables was maxillary incisors and sex (R^2 = 0.36), the latter combining the effects of height and weight, thus making its predictive power greater than height or weight separately. Using the same method, for Fmean the best single variable was weight (R^2 = 0.16) (Fig 1), the best pair of

Table 2. Measured laryngoscopic factors; values are mean (SD) and range.

t_l; s	16.3	(11.8)	6.8 - 43.2
Fmax; N	35	(12)	13 - 60
Fmean; N	20	(6)	9 - 32
F*t; N.s	324	(194)	66 - 981

t_l, duration of laryngoscopy; Fmax, maximally applied force; Fmean, mean applied force; F*t, force-time integral.

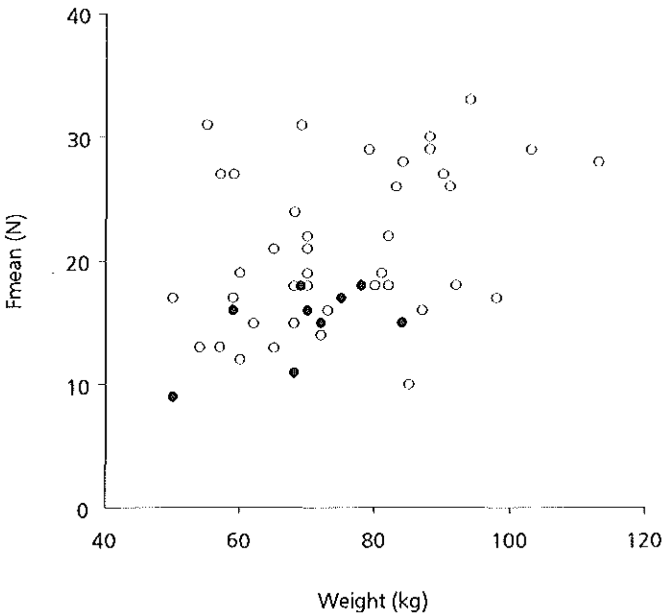

Figure 1. *Effect of weight (kg) on the mean applied force (N) during laryngoscopy. Patients with maxillary incisors (o) and without maxillary incisors (•) are indicated).*

variables weight and maxillary incisors ($R^2 = 0.27$). For F*t the best single variable was maxillary incisors ($R^2 = 0.21$) and the best pair of variables maxillary incisors and sex ($R^2 = 0.30$). The addition of a third variable did not significantly improve the correlations with laryngoscopic measurements. In all patients the view on the glottis was classed as grade I[5].

Discussion

Potentially there are many variables which might influence laryngoscopic measurements. These could be related to the patient, the person intubating (e.g. experience), and/or anaesthetic technique e.g. the degree of muscle relaxation and the type of blade used. The forces applied during laryngoscopy to bring the glottis into view are those which are necessary to open the mandible, sometimes even to subluxate[6,7], and to displace the tongue base/hyoid-complex forward.

Table 3. The effect of presence or absence of maxillary incisors on the measured laryngoscopic factors; values are mean (SD).

Laryngoscopic factors	Maxillary incisors Present		Maxillary incisors Absent		p
t_l; s	17.4	(8.9)	11.4	(2.9)	0.001
Fmax; N	39	(11)	23	(5)	<0.001
Fmean; N	21	(6)	15	(3)	<0.001
F*t; N.s	364	(201)	178	(70)	<0.001

t_l, duration of laryngoscopy; Fmax, maximally applied force;Fmean, mean applied force; F*t, force-time integral.

Different criteria to predict the difficulty of laryngoscopy and intubation have been described [6, 8-10] assuming that mouth opening was sufficient to allow the introduction of the blade. The amount of atlanto-occipital extension has been identified as an important predictor of difficult laryngoscopy. Also important is the size of the tongue relative to the mandibular space available [7-9]. In turn, the volume of the mandibular space is related to the mobility and possibility of (sub)luxation of the temporomandibular joint, the adequacy of mouth opening and the ratio of the length of the mandible and maxilla. The concept of the line of vision [5,6] explains the importance of the ratio of tongue size and mandibular space, bearing in mind that it is a construction in only two dimensions; the greater the part of the tongue behind the line of vision, the more forceful will be the effort needed to displace the tongue base/hyoid-complex forward to bring the glottis into view [7]. This implies, not surprisingly, that forces applied during laryngoscopy increase as the degree of difficulty increases, an association confirmed by several studies [11,12]. In addition, both calcification of the stylohyoid ligament, disabling the forward displacement of the hyoid, and inadequate traction on the laryngoscope were identified as causes of difficult laryngoscopy [13,14].

In this study the relationships between some easily identified patient characteristics and the laryngoscopic factors were investigated. The fact that many different variables influence these factors is evident from the large standard deviations and small correlation coefficients. As was expected, there was a positive correlation between the laryngoscopic factors and the height and weight of the patients, but body mass index had only a minor influence. Age and sex were univariately related with the laryngoscopic factors, but multivariate regression analysis proved these relationships could be explained by differences in height, weight and the presence of maxillary incisors. An independent effect of age on masticatory muscle weakening [15,16] could not be detected in this study, but the presence of maxillary incisors had a strong influence on the laryngoscopic factors. A possible explanation for this might be that in the absence of maxillary incisors the part of the tongue behind the line of vision is smaller, reducing the effort needed to displace the tongue forward. In addition, resorption of the maxillary alveolus after loss of maxillary incisors is a contributing factor, although this phenomenon is more prominent in the mandible. Moreover, the loss of maxillary incisors results in a decline in masticatory performance [15,17] The duration of laryngoscopy was correlated only with the presence of maxillary incisors and this can be explained by the additional care required to prevent damage to the teeth.

In conclusion, the laryngoscopic factors studied here are related to some easily identified patient characteristics, the presence of maxillary incisors being the most important. These factors may be a useful guide to possible difficult laryngoscopy, and can supplement the grading system introduced by Cormack and Lehane [5,14].

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CHAPTER 4

CARDIOVASCULAR EFFECTS OF FORCES APPLIED DURING LARYNGOSCOPY

The importance of tracheal intubation

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Summary

The relationship between the forces applied during laryngoscopy and cardiovascular changes were studied in patients undergoing laryngoscopy with or without intubation. This enabled us to differentiate between the cardiovascular effects of laryngoscopy and the effects of tracheal intubation. The forces applied during laryngoscopy were only weakly related to the cardiovascular changes, whereas tracheal intubation had a major influence. The many difficulties encountered in interpreting results from these studies are discussed. It is concluded that tracheal intubation causes more cardiovascular changes than laryngsocopy in routine uncomplicated procedures.

Introduction

Laryngoscopy and subsequent tracheal intubation cause cardiovascular changes which can lead to myocardial ischaemia and arrythmias [1]. A number of factors influence the magnitude of these changes, notably induction agents [2,3], opioids [4,5], neuromuscular blockers [6,7], as well as patient dependent variables such as age [8] and hypertension [9,10]. Moreover, the type of blade used has been reported to affect cardiovascular changes [11].

Previously, attempts were made to differentiate between the cardiovascular effects of laryngoscopy and those of tracheal intubation. A much better understanding of the aetiology of these changes is needed in order to find ways of reducing them and to develop methods for prevention instead of, or in addition to, methods to block them pharmacologically.

A variety of studies suggest that the forces transmitted by the laryngoscope blade on to the base of the tongue are a major stimulus [12-15]. However, the results of these studies are often difficult to interpret and in some the laryngoscopic technique seemed far removed from common clinical practice.

Recently a curved blade laryngoscope has been developed with which the forces applied during laryngoscopy can be measured [16]. Quantification of these forces permits their comparison with the cardiovascular responses to laryngoscopy [17], and introduces the possibility of distinguishing the cardiovascular effects of laryngoscopy from those of tracheal intubation.

The initial aim of this study at first was to investigate the effects of the applied forces on the cardiovascular responses during routine laryngoscopy and tracheal intubation (group 1 patients). On the basis of the results of the first part of the study a second study was performed concentrating on cardiovascular responses to tracheal intubation as a stimulus itself (group 2 patients).

Table 1. Physical characteristics of the patients. Values are mean (SD) and range, or ratios.

	Group 1			Group 2			p
Height (cm)	174	(9.0)	155 – 197	169	(10.7)	149 – 190	0.06
Weight (kg)	74	(13.9)	50 – 113	65.7	(10.5)	49 – 90	0.007
Age (yr)	38	(17.0)	16 – 75	36.1	(14.6)	15 – 78	0.55
Male : Female	22	:	27	9	:	15	0.55
with incisors : without incisors	40	:	9	19	:	5	0.80

Patients and Methods

Seventy-three patients, 49 in group 1 and 24 in group 2, scheduled for elective surgery, participated in the study. Approval from the Hospital Ethics Committee and informed consent from each subject were obtained. All patients were adults, in ASA grade 1 or 2, in whom no difficulty with intubation was anticipated. Patients in whom endotracheal intubation proved difficult, or was not achieved at the first attempt, were excluded from the study.

Before laryngoscopy the patient's head was placed in the 'sniffing'. position. Laryngoscopy in all patients was performed by the same person using the technique for curved blade laryngoscopes. In all patients, height (cm), weight (kg), sex, age and body mass index ($kg.m^{-2}$) were recorded, as was the presence or absence of maxillary incisors.

Table 2. Measured laryngoscopic values in the patient groups. Values are mean (SD).

	Group 1	p value difference 1 v 2(a)	Group 2(a)	p value difference 2(a) v 2(b)	Group 2(b)	p value difference 2(b) v 1
t_l (s)	16.3 (8.5)	0.01	12.5 (3.9)	0.26	13.5 (3.8)	0.66
Fmax (N)	35 (12.0)	0.82	37 (11.0)	0.42	35 (12.0)	0.77
Fmean (N)	20 (6.0)	0.17	22 (7.0)	0.45	21 (6.0)	0.54
F*t (Ns)	324 (194)	0.31	285 (161)	0.90	279 (124)	0.20

t_l, duration of laryngoscopy; Fmax, maximally applied force; Fmean, mean applied force; F*t, force-time integral; group 1, laryngoscopy and intubation; group 2(a), laryngoscopy only; group 2(b), laryngoscopy and intubation.

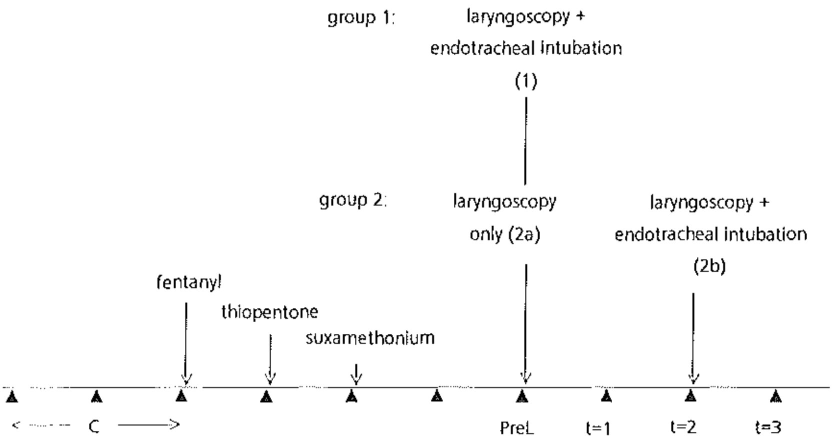

Figure 1. *Flow diagram of the investigational protocol. All cardiovascular measurements (▲) were carried out at 1 min intervals. The first three measurements were averaged to represent control readings (C). PreL, readings preceding first laryngoscopy; t = 1, 2, 3, measurements 1, 2 and 3 min after start of first laryngoscopy.*

The following laryngoscopic factors were measured using a modified curved blade laryngoscope [16]: 1) the duration of laryngoscopy (t_l), 2) the maximally applied force (Fmax), 3) the mean force (Fmean) and 4) the integral of the forces over the time (F*t). The forces acting along the axis of the laryngoscope handle are measured by a strain gauge based sensor positioned between the handle and the blade. The instrument was calibrated before each measurement by placing a weight of 2 kg (=19.6 N) on the laryngoscope blade, whilst keeping the handle in the vertical position.

Each patient received midazolam (2.5 mg) and atropine (0.5 mg) intramuscularly 60 minutes before surgery. The systolic and diastolic blood pressures (SBP, DBP) and heart rate (HR) were recorded at 1 min intervals by a Dinamap 1846 SX automatic oscillometric blood pressure monitor with attached printer.

The timing of the cardiovascular measurements, pharmacological interventions and laryngoscopic procedures are shown in the flow diagram (Fig 1). All cardiovascular measurements were carried out at 1 min intervals. The first three measurements were averaged to represent control readings. Directly after the last control measurement, fentanyl (2 $\mu g.kg^{-1}$) was administered. After the two subsequent cardiovascular measurements thiopentone (4–5 mg.kg^{-1}) and suxamethonium (1.0–1.5 mg.kg^{-1}) were given. Ventilation was manually assisted using a face mask and reservoir bag with 66% nitrous oxide in oxygen. Two minutes after the start of suxamethonium administration, directly following measurement PreL, the first laryngoscopic procedure was started, cardiovascular measurements continuing for 3 min (t = 1, t = 2, t = 3). In patients in group 1, laryngoscopy was directly followed by tracheal intubation. In group 2 patients, laryngoscopy was performed but the tip of the tube was positioned just above the laryngeal inlet avoiding direct contact (group 2 a). The tip was kept in this position for three seconds after which it was removed and ventilation was re-instituted with the face mask. Directly after the second cardiovascular measurement following the first laryngoscopy (t = 2), a second laryngoscopy was performed in group 2 patients and on this occasion was immediately followed by tracheal intubation (group 2 b).

Statistical methods

Linear regression analysis or Student's two sample *t*-test were used to study the univariate relationships between the patient characteristics and the laryngoscopic measurements. The differences between the groups were compared by Student's two-sample *t*-test. In order to obtain approximate normal distributions t_l and F*t were logarithmically transformed. To determine whether the variability in a variable Y increased or decreased when X increased, the ordinary regression line of Y and X was determined initially. Subsequently, the absolute deviations of the Y values from the regression line were correlated with X. The level of significance was set at 5%.

Results

The demographic details, laryngoscopic factors and measurements, and cardiovascular values are shown in Tables 1, 2 and 3. Compared with group 2, patients in group 1 were heavier (p = 0.007), had longer duration of laryngoscopy than patients of group 2(a) (p = 0.01), and had a higher systolic blood pressure (p = 0.003).

The relationships between demographic details and the cardiovascular values were studied in group 1 patients. Age was not related to control heart rate or to changes in heart rate at 1 (Fig 2), 2 or 3 minutes after laryngoscopy and intubation compared to control readings. However, age was significantly negatively related to variability of control heart rate (r =–0.46/p = 0.0008) and changes in HR at 1 (r = –0.42/

p = 003), 2 (r = –0.33/ p=0.02) and 3 min (r = –0.43/p = 0.002) after laryngoscopy. Control heart rates exceeding 90 beats/min were only seen in patients aged under 55 years.

There was a significant relationship between age and control systolic (r = 0.41/p < 0.005) and diastolic (r = 0.29/p < 0.01) blood pressures (r = 0.29/p < 0.01) but age was not related to pressure changes at 1, 2 and 3 minutes compared to control readings.

Height, weight, sex, body mass index and presence of maxillary incissors were not related to the cardiovascular values. Compared to control readings, there was no significant relationship between t_I and changes in HR at 1 and 2 minutes after laryngoscopy, but t_I was significantly related to changes in SBP at 2 minutes (r = 0.27/p = 0.05) and DBP at 1 and 2 min (r = 0.34/p = 0.02 and r = 0.39/p = 0.006 respectively).

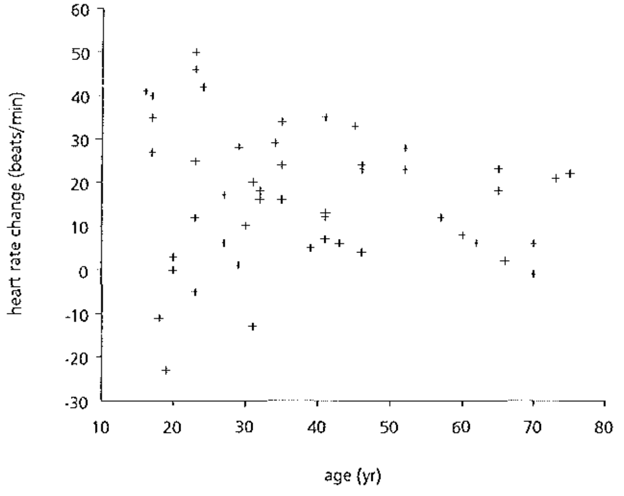

Figure 2. *Group 1: The effect of age on changes in heart rate measured 1 min after the start of laryngoscopy with subsequent tracheal intubation compared to control values.*

Table 3. Cardiovascular data in groups 1 and 2. Values are mean (SD).

	Group	C		PreL		t = 1		t = 2		t = 3	
Heart rate	1	80	(18)	84	(11)	97	(15)†	92	(14)	86	(14)
(beat.min^{-1})	2	80	(14)	85	(12)	81	(9)‡	80	(12)	96	(15)§
Systolic BP	1	130	(17)	120	(20)	145	(22)†	138	(26)	126	(24)
(mmHg)	2	118	(13)	114	(20)	118	(21)‡	112	(19)	128	(24)§
Diastolic BP	1	75	(8)	70	(11)	90	(14)†	79	(14)	72	(12)
(mmHg)	2	71	(9)	70	(12)	73	(14)‡	68	(13)	84	(19)§

BP, blood pressure; *, significantly different compared to group 2; †, significantly different compared to values PreL; ‡, significantly different compared to group 1; §, significantly different compared to values t = 2; C, control readings; PreL, readings preceding first laryngoscopy; t =1,2,3; measurements 1,2 and 3 min after start of first laryngoscopy (see Fig 1).

There was no significant relationship between the forces applied during laryngoscopy and the cardiovascular results. There was only a trend for Fmax to be related to changes in SBP at 2 minutes after laryngoscopy ($r = 0.25/p = 0.09$).

No significant relationship could be detected between F*t and changes in HR after laryngoscopy but F*t was significantly related to SBP at 2 minutes ($r = 0.30/p = 0.04$) and DBP at 1 ($r = 0.37/p = 0.01$) and 2 minutes ($r = 0.36/p = 0.01$) compared with control readings.

In group 1 patients, mean HR, SBP and DBP increased significantly after laryngoscopy and intubation ($p < 0.001$, $p < 0.001$ and $p < 0.001$, respectively) (Fig 3). In contrast, in group 2 patients there were no significant changes when laryngoscopy alone was performed, but when laryngoscopy and intubation were performed simultaneously, HR, SBP and DBP increased significantly at t = 3 (Fig 1) ($p < 0.001$, $p = 0.01$ and $p < 0.001$, respectively). Moreover these changes were not significantly different from the changes after laryngoscopy and intubation in group 1.

Discussion

The cardiovascular responses to laryngoscopy and subsequent intubation are influenced by many factors, one of which is age. In contrast to a previous study in 27 patients[8], we could not detect a significant relationship between age and increased heart rate. However, the variability of HR changes decreased with increasing age, youger patients showing more extreme changes.

The results of the first part of this study suggest that the most important laryngoscopic factor influencing the cardiovascular response was duration of laryngoscopy, the forces applied having only minor effects. The latter was confirmed by the absence of a relationship between the presence of maxillary incisors and cardiovascular changes. The presence of maxillary incisors has been shown to have a dominant effect on the forces needed [18]. We are unaware of studies that describe the influence of duration of routine laryngoscopy on heart rate and arterial blood pressure. The results of the second part of the study confirm that routine laryngoscopy as normally performed in clinical practice has only a minor influence on

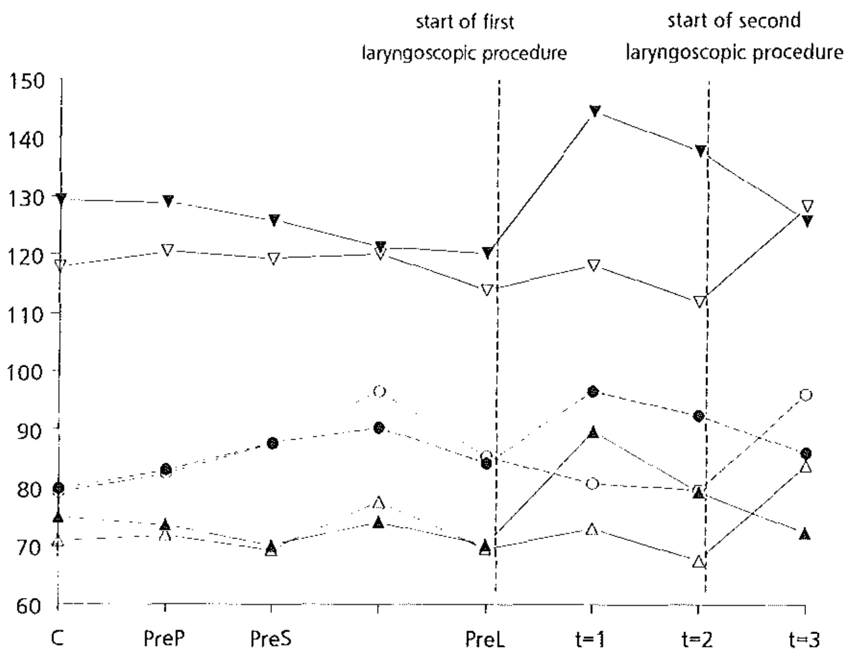

Figure 3. *Heart rate (●,○), systolic blood pressure (▼,▽), and diastolic blood pressure (▲,△) (groups 1 and 2, respectively) all measured at 1 min intervals. Control readings (C) were averaged over three measurements, readings at PreL were taken directly before start of first laryngoscopy; t = 1, t = 2 and t = 3: readings taken at 1, 2 and 3 min after the start of the first laryngoscopic procedure. The start of the first (groups 1 and 2) and second (group 2) laryngoscopy is indicated. For the exact sequence of events see Fig 1.*

cardiovascular function. However, there are unexplained differences between groups 1 and 2, notably in weight and duration of laryngoscopy. Both of these parameters had minimal effects on cardiovascular values with respect to laryngoscopy alone, and we feel that they have no substantial influence on the main conclusions of this study. A study relating forces applied during laryngoscopy to cardiovascular changes was published recently [19]. In this study 'impulse', the equivalent of F*t, was found to be highly significantly related to the cardiovascular change, tracheal intubation having additional effects. However, the mechanical characteristics of the instrument used have not been validated, the values for 'impulse' being extremely low compared to our values and those of other investigators [20]. Moreover, laryngoscopy was performed using a non standard technique.

Studies concerning the relative contribution of laryngoscopy and intubation to the cardiovascular changes are beset by problems. Firstly, laryngoscopy can be carried out easily without intubation, but it is more difficult to perform intubation in a comparable situation without laryngoscopy. Secondly, two stimuli administered within a short time interval in general do not result in a doubling of the response. More often there is a non linear, usually logarithmic, relationship between stimulus and response [21]. If laryngoscopy and tracheal intubation were stimuli of the same magnitude, intubation after laryngoscopy would lead to a relatively small additional increase in cardiovascular (or hormonal) response compared to the initial response to laryngoscopy alone. In this situation it might be erroneously concluded that laryngoscopy is a greater stimulus than intubation. Unfortunately, we are unaware of investigations specifically addressing this problem. Thirdly, a difficulty arises when two very powerful stimuli are involved, which can both lead to a (sub)maximal response. Again, in the situation described above the same erroneous conclusion might be drawn. A further problem concerns the effect the anaesthetic technique might have on the separate responses to laryngoscopy and intubation. Both the drugs and technique used must be standardised — but is there a fixed time allowed for laryngoscopy and/or a predetermined force applied, or is laryngoscopy to be performed normally with just enough force to bring the glottis into view, allowing the introduction of the tube? As duration of laryngoscopy is normally less than 30 s [20] the results of studies in which it takes longer than this have less clinical relevance. The final point concerns studies in which local anaesthetics have been applied. There is much controversy about the effectiveness of these agents in preventing cardiovascular changes [22]; some receptors are submucosal and are not blocked topically [23].

In this study, the laryngoscopic measurements are related to the cardiovascular changes induced by laryngoscopy, assuming that they are a measure of laryngoscopic stimulus strength. However, the forces applied by the laryngoscope are not homogeneously distributed along the blade. Forces exerted by the tip of the blade might be more stimulating than the others. This could lead to confusion in the interpretation of the relationship between laryngoscopic measurements and the extent to which laryngoscopic stimulation affects the cardiovascular system. The results of this study suggest that in order to reduce cardiovascular changes, in addition to the methods already developed, attention should be focused on methods to reduce the stress of tracheal intubation; more effective local anaesthesia of the larynx and trachea and even more careful introduction of the tracheal tube. Moreover, the duration of laryngoscopy should be as short as possible, preferably less than 25 s. Obviously, our results do not rule out the possibility that cardiovascular changes can be caused by laryngoscopy alone.

In conclusion, however, tracheal intubation, more than laryngoscopy, causes cardiovascular changes in routine uncomplicated laryngoscopy and subsequent tracheal intubation in this group of patients undergoing this type of induction technique.

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CHAPTER 5

FORCES APPLIED DURING LARYNGOSCOPY IN CHILDREN

Are volatile anaesthetics essential for suxamethonium induced muscle rigidity ?

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Summary

Increased masticatory muscle tone after administration of suxamethonium has been demonstrated in children when combined with volatile anaesthetics. Whether volatiles are a prerequisite for this phenomenon is not known. In this study upper airway muscle tone, including the tone of the masticatory muscles, was determined in 54 children (age range 2-15 years), anaesthetized with propofol, fentanyl and nitrous oxide and avoiding any use of volatiles. The children were either relaxed with suxamethonium (n = 26) or vecuronium (n = 28). The forces applied during laryngoscopy were used to quantify upper airway muscle tone and were significantly greater in the suxamethonium group than in the vecuronium group: maximally applied force was 25 N versus 21 N (p = 0.008), and mean applied force was 16 N versus 13 N (p = 0.006), respectively. The results of this study indicate that upper airway muscle tone increases after administration of suxamethonium in children independent of the presence of volatile anaesthetics. Moreover, increased muscle tone had no effect on the difficulty of laryngoscopy or the intubation conditions. Increased masseter muscle rigidity after suxamethonium could be due to the very unique characteristics of this muscle.

Introduction

An increase in masticatory muscle tone after administration of suxamethonium has been demonstrated by various investigators [1-4]. This phenomenon persists even when after fasciculations limb muscles are clinically flaccid and there is complete twitch depression [2,5]. The increase in muscle tone induced by suxamethonium stands in contrast to the opposite effects of non-depolarizing relaxants with a significant decrease in muscle tone. In all these studies, volatile anaesthetics were used and the increase in tone occurred independent of which volatile anaesthetic was given. Whether this finding is the result of the combination of suxamethonium with volatile anaesthetics rather than an effect solely of the depolarizing relaxant itself is unknown.

Muscle rigidity might have a significant effect when laryngoscopy and intubation are involved. The degree of relaxation of the jaw muscles has been identified as an important factor influencing the intubation conditions [6]. Until now, studies on increased muscle rigidity after suxamethonium focused on the masticatory muscles. However, intubating conditions do not only depend on jaw muscle relaxation, but also on the state of a large number of other upper airway and respiratory muscles [7]. Increased rigidity of the stylohyoid, styloglossus, mylohyoid and many other muscles might have a significant influence, as these muscles are stretched to allow forward displacement of the hyoid bone. In addition, increased rigidity of the tongue might have an influence as additional force will be needed to deform it.

During laryngoscopy forces are applied to induce spatial changes of the upper airway in order to enable a view on the glottis and are, therefore, closely related to upper airway rigidity, which includes masticatory muscle rigidity. Once the mouth is opened sufficiently to allow the introduction of the blade, the whole upper airway rigidity will define the ease of intubation rather than masticatory muscle rigidity.

The objective of this prospective study was to determine the forces applied during laryngoscopy in children, using a recently introduced modified laryngoscope [8], and to answer the so far unsolved question as to whether the phenomenon of increased muscle rigidity after application of suxamethonium in children, as compared to vecuronium, depends on the presence of volatile anaesthetics. Moreover, we wanted to verify whether the ease of intubation is related to the forces applied during laryngoscopy.

Patients and methods

Fifty-eight ASA physical status 1 or 2 patients (age range 2–15 years), undergoing elective surgery, in whom no difficulty with endotracheal intubation was anticipated, were selected for this study. Parental informed consent and approval from the Hospital Ethics Committee were obtained.

Premedication was administered 60 min before surgery; all patients received atropine 0.03 $mg.kg^{-1}$ orally with a maximum of 0.5 mg. In addition, all patients received a local anaesthetic cream to alleviate pain during venous cannulation. The investigational protocol is shown in Figure 1. On arrival at the induction room an i.v. cannula was inserted and anaesthesia was induced with propofol [9] 2.5 $mg.kg^{-1}$and fentanyl 2 $\mu g.kg^{-1}$. To reduce pain on injection of propofol, 2 ml of a 1% lidocaine solution was added to 20 ml propofol (10 $mg.ml^{-1}$) [10]. The induction was directly followed by a continuous infusion of propofol 6 $mg.kg^{-1}.h^{-1}$ continued throughout the study period. Before operation patients were randomly assigned to one of two groups; patients receiving suxamethonium and those receiving vecuronium. Patients in the suxamethonium group received 1.5 $mg.kg^{-1}$ suxamethonium 75 s after the administration of fentanyl and 75 s later laryngoscopy was started. Patients of the vecuronium group received vecuronium 0.1 $mg.kg^{-1}$ directly after the administration of fentanyl, 150 s later laryngoscopy was started. The patient's lungs were ventilated

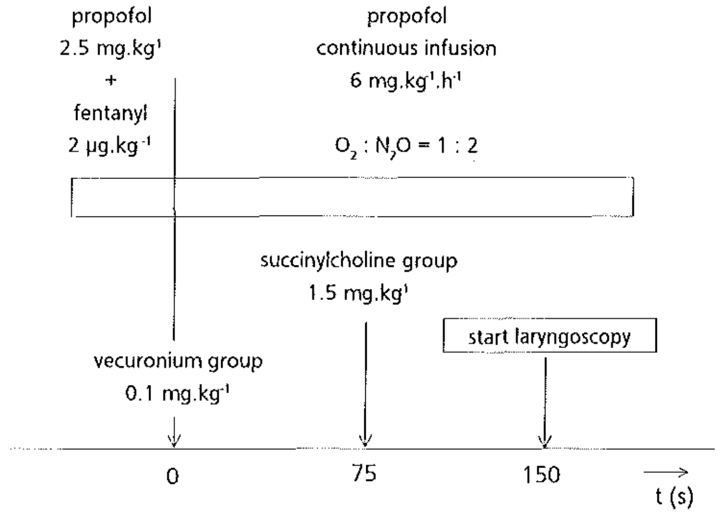

Figure 1. *Flow diagram of the investigational protocol. Patients of both groups received a propofol induction dose and fentanyl followed by a propofol continuous infusion. The timing of administration of suxamethonium and vecuronium is shown. (See text for additional information).*

manually with 66% nitrous oxide in oxygen. Heart rate and blood pressures were recorded using an automatic device (Dinamap). Monitoring of ECG, oxygen saturation and temperature was performed. Laryngoscopy in all patients was performed by the same person using the technique for a curved blade laryngoscope. For all patients, height (cm), weight (kg), age and gender were registered, as was the presence or absence of maxillary incisors. Before starting laryngoscopy the patient's head was placed in the sniffing position [11].

To grade the difficulty of laryngoscopy the system of Cormack and Lehane [12] was used; grade 1, most of the cords visible, grade 2, less than half of the cords visible, grade 3, only the epiglottis visible, grade 4, not even the epiglottis visible. The first view without cricoid compression was recorded. However, for optimal view in all patients cricoid compression was performed. The latter view was also recorded. Intubation conditions were scored according to known criteria [13,14] (Table 4). The following laryngoscopic parameters were determined: 1) the duration of laryngoscopy, 2) the maximally applied force, 3) the mean force and 4) the integral of the forces over the time. A previously described modified curved blade

(Macintosh) laryngoscope was used to determine these parameters[8]. This instrument enables the measurement of forces acting along the axis of the handle of the laryngoscope. These forces are measured by a strain gauge based sensor positioned between the handle and the blade. The instrument was calibrated before each measurement by placing a weight of 2 kg (= 19.6 N) onto the laryngoscope blade, keeping the handle in the vertical position. During laryngoscopy no person could see the force recordings.

Statistical methods

To study the univariate relationships between the patient characteristics and the laryngoscopic parameters, linear regression analysis or Student's two sample *t*-test were used. The results of the different groups were compared by the two-way unpaired Student's *t*-test or Fisher's exact test when appropriate. To study the joint relationship of several patient characteristics simultaneously with the laryngoscopic parameters, stepwise forward multiple linear regression analysis was performed. For each laryngoscopic parameter, the best single discriminatory variable was selected: the variable most strongly related to the laryngoscopic parameter concerned; then the best pair of variables, that included the first, was determined and so on, until the addition of a further variable was not anymore significant. For testing the difference in an ordinal variable between groups the Chi square test for linear association was used. The level of significance was set at 0.05.

Table 1. Demographic data of patients receiving suxamethonium or vecuronium.

	Suxamethonium	Vecuronium
Height (cm)	128 (28.2) 89 – 172	127 (22.3) 90 – 165
Weight (kg)	30.3 (17.0) 12.5– 63	27.5 (12.3) 13 – 60
Age (yr)	7.8 (4.4) 2 – 15	7.4 (4.0) 2 – 15
Male : Female	16 : 10	16 – 12

Values are mean (SD) and range, or numbers of patients. There were no statistically significant differences between the two groups for these variables.

Table 2. Laryngoscopic factors in patients receiving suxamethonium or vecuronium

	Suxamethonium			Vecuronium			p value
tl (s)	10.5	(2.5)	6.8– 17.7	10.3	(2.7)	6.7– 14.4	NS
Fmax (N)	25	(5.7)	16 – 36	21	(3.9)	13 - 30	0.008
Fmean (N)	16	(3.2)	10 – 22	13	(2.4)	6.0– 18	0.006
F*t (Ns)	166	(62)	72 – 309	137	(39)	43 – 223	0.04

Values are mean (SD) and range. tl, duration of laryngoscopy

Results

Four patients were excluded from the study. In one patient endotracheal intubation was not achieved at first attempt, in another the recording of the forces was done incorrectly. In the other two patients the preselected endotracheal tube proved to be too large to fit the airway properly.

There were no substantial differences in demographic variables between the two treatment groups (Table 1). In Table 2 the values for the laryngoscopic factors are presented. There were no significant differences between the two treatment groups with respect to the duration of laryngoscopy. However, there was a significant difference between patients in the two groups with regard to Fmax, Fmean and F*t, with higher values in the suxamethonium group (Table 2). Analysis of covariance showed these differences could not be ascribed to differences in height, weight, age and gender between the groups. The difference between both groups in the difficulty of laryngoscopy before cricoid compression was applied (Table 3) revealed borderline significance (Chi square test for linear association, $p = 0.05$); laryngoscopy in patients of the vecuronium group might be a little more difficult. However, there was no significant difference when cricoid compression was applied, which occurred in all patients. The intubation conditions in the suxamethonium group were not significantly different from the vecuronium group (Fisher's exact test) (Table 4). Analysis of variance indicated that there was no significant relationship between the laryngoscopic parameters and the difficulty of laryngoscopy, whether or not cricoid compression was applied.

There was a significant relationship between patients' height and the duration of laryngoscopy ($t_l = 0.03 \times \text{height} + 7$ s) ($p = 0.05$) ($r = 0.27$), Fmax (Fmax =

0.09 × height + 12N) (p = 0.008) (r = 0.44), Fmean (Fmean = 0.04 × height + 10 N) (p = 0.03) (r = 0.30) and F*t (F*t = 0.7 × height + 56 Ns) (p = 0.008) (r = 0.36).
Stepwise forward regression analysis showed t_l to be best predicted by the combination of height and weight, Fmax by height, group and age, and Fmean as well as F*t by group and height.
There were no signs of malignant hyperthermia, cardiovascular complications or pulmonary complications in any of the study population.

Discussion

In this study, the forces applied during laryngoscopy in patients of the suxamethonium group were 19% greater for Fmax and 23% greater for Fmean than in patients of the vecuronium group. Our results are in accordance with studies demonstrating an increased masticatory muscle rigidity after suxamethonium [1-5].
Since forces during laryngoscopy are exerted on muscles as well as on other tissues and since suxamethonium is not supposed to have any effect on the mechanical characteristics of the tissues other than muscle, we conclude that the greater forces exerted during laryngoscopy are the result of an increased muscle tone after suxamethonium. Moreover, as in this study no volatile anaesthetics were used, it can be concluded that increased muscle tone after application of suxamethonium does not depend on the presence of these agents.
Many speculations have been made about the nature of the muscle rigidity after suxamethonium administration. Some investigators regard it as being the result of incomplete relaxation [15] which might be the result of inadequate dosage [16], or insufficient time allowed for the drug to act [16], or a hypothesised decreased sensitivity of the masseter to suxamethonium [7]. However, the dosage of 1.5 $mg.kg^{-1}$ used in this study is expected to induce complete neuromuscular blockade [17] and it has been shown that the masseter has a higher sensitivity to suxamethonium than the adductor pollicis [7]. Another explanation could be that the (initial) increased rigidity is the result of the 'normal' agonist effect, maximal at the time of muscle fasciculations [15,16]. However, we started laryngoscopy 75 s after administration of suxamethonium, at which time complete neuromuscular blockade can be expected [18]. Thus, the greater forces used in the suxamethonium group can not be explained by this 'normal' agonistic effect. Other explanations for the muscle rigidity after suxamethonium might be found in the unique characteristics of the masseter

muscle, very different from the limb and trunk muscles, which might be related to the special function of the human mandibular locomotor system [19,20].

The human masseter has a unique fibre type composition, with marked differences between the type I (slow) and type II (fast) fibre diameters. In addition, ATPase-intermediate fibres are frequent, which are rarely seen in muscles other than the masticatory muscles [21,22]. Increased rigidity could be the result of agonist effects on different muscle fibre types, resembling the situation in human and mammalian extraocular and other muscles [1,2,22]. With regard to this fibre type composition, the pig [20] might be a more suitable animal model for experimental studies of the masseter than the cat [5,21].

In addition, muscle spindles within the masseter differ from muscle spindles in limb and trunk muscles, suggesting unique properties of this muscle [19]. However, it has been shown that a presynaptic mechanism for suxamethonium to induce masseter rigidity is unlikely [3].

Extrajunctional acetylcholine receptors constitute another mechanism. Although these receptors are typical for developing muscles and certain pathologic conditions, these receptors have also been demonstrated in some adult muscles in non-pathologic circumstances, responding to the in vitro application of a cholinergic agonist by the development of sustained contracture [23]. Certainly the masseter muscle has been shown to persist in the expression of neonatal and embryonic myosine chains, which is in contrast to the other muscles [24].

Train-of-four monitoring was not performed in this study as the adductor pollicis has been shown to be a poor index of tracheal intubating conditions [25,26]. Moreover, as outlined before, all patients of the suxamethonium group were expected to have complete neuromuscular blockade during laryngoscopy. In patients of the vecuronium group the great majority are expected to have complete neuromuscular blockade after 150 s [17]. When vecuronium (in a very limited number of patients) would have resulted in incomplete blockade, this would have caused greater forces, which is in contrast to the results obtained.

The degree of muscle relaxation has been pointed out as an important factor influencing the intubation conditions [6] and the difficulty of laryngoscopy [27]. However, for the condition that mouth opening was sufficient to allow the introduction of the blade, in previous studies [1,2,3] as well as in the present, increased muscle tone had no effect on the intubation conditions and difficulty of laryngoscopy. In addition, many studies have shown that laryngoscopy and intubation can be performed under good to adequate conditions without the use of neuromuscular blocking agents, which obviously was common practice before their introduction.

This brings us to the conclusion that, within certain limits, prevention of active muscle contraction during laryngoscopy and intubation might be more important than the amount of resting muscle tone. Moreover, as airway obstruction has been attributed to decreased muscle tone [25,28,29] and decreased muscle tone might lead in some patients to increased difficulty of laryngoscopy [30], preservation of a certain amount of resting tone might be more favourable than complete loss of muscle tone.

In conclusion, the results of this study indicate that increased upper airway muscle rigidity after administration of suxamethonium in children does not depend on the presence of volatile anaesthetics. Moreover, it affirms that muscle relaxation and muscular relaxants are terms which might lead to confusion [15]: namely, do they refer to effects on the neuromuscular junction or do they refer to effects on resting tone of muscles? Studies on masticatory muscle rigidity, as well as the present study, make us increasingly aware of this difference. Moreover, they underline the unique characteristics of the human masseter muscle.

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CHAPTER 6

FORCES ACTING ON MAXILLARY INCISOR TEETH DURING LARYNGOSCOPY USING THE MACINTOSH LARYNGOSCOPE

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Summary

We determined the forces on the maxillary incisors during routine laryngoscopy in 65 adult patients. The forces were measured by a strain gauge based sensor positioned between the handle and the blade of the laryngoscope. The mean maximal force acting on the maxillary incisors was 49 N. In patients without maxillary incisors, the force acting on the gums was significantly lower at 21 N ($p < 0.001$). These results suggest that, despite traditional advice to the contrary, a levering movement of the laryngoscope, using the maxillary incisors (or gums) as a fulcrum is common practice. Biomechanical analysis revealed that, although levering is not the preferred movement, it is an efficient way of bringing the glottis into view. These results may have implications for future laryngoscope design.

Introduction

The Macintosh laryngoscope has proved itself over half a century and is still one of the most popular laryngoscopes[1]. Even in experienced hands, however, complications can occur, notably damage to the maxillary incisors[2,3]; damage to teeth is reported to be the most common single reason for complaints against anaesthesiologists[4]. Because such damage is the result of contact between the laryngoscope blade and the teeth, the design and manipulation of the blade has a major influence on the risk of this type of morbidity[5]. Until now, this aspect of laryngoscopy has been based on subjective and empirical criteria; detailed practical evaluation of performance has been virtually non-existent[6]. To assist the rational development and use of laryngoscopes, an understanding of the forces involved is essential. This, in turn, is only possible through study of a biomechanical model followed by objective measurements. Although we realise that our knowledge on the biomechanics of laryngoscopy is limited, the current methods are inadequate for quantifying the forces generated during laryngoscopy in clinical practice.

In recent years, various sensors have been described for the measurement of forces applied to the tongue[7-9]. Clearly, accurate quantification of other forces present offers the possibility of better laryngoscope design, technique and testing. At present the contact between the laryngoscope blade and the teeth can only be assessed by observing the presence of it, or the sequelae which may result from this contact. It is said that, to minimise the pressure on the teeth, the blade of the laryngoscope should be lifted upward and forward along the axis of the handle and rotation should be avoided[3,10]. However, the biomechanical basis of these recommendations is poor. Measurement of the forces acting on the teeth is essential to identify the cause and to prevent damage.

In this paper we present a new technique for the measurement of forces on the maxillary incisors during laryngoscopy. This is based on a modification of a strain gauge sensor described previously[8]. The aim of this study was to quantify these forces and, if possible, improve our understanding of the mechanics of laryngoscopy.

Methods

Measurement of the forces on the maxillary incisors

To understand the forces on the maxillary incisors during routine laryngoscopy, some conditions have to be satisfied. Firstly, an accurate method of measuring these forces must be developed which is not apparent in use, since it is essential that the laryngoscopist is totally unaware of the fact that any measurements are taking place. Until recently this did not seem feasible.

In theory, there are several techniques for quantifying the forces. Methods using modifications of the blade to incorporate a force sensor at the contact point with the teeth, have major disadvantages. Apart from technical difficulties, they are obvious to the laryngoscopist and hence might influence the way laryngoscopy is performed. A method using a sensor positioned between the handle and the blade does not have this drawback and seems to be the best option.

Recently, a laryngoscope with a curved blade (Macintosh) was described which permits the measurement of forces parallel to the axis of the handle[8]; these forces are considered to be the most relevant during laryngoscopy. A strain gauge based shear force sensor was built into this laryngoscope between the handle and the blade which enables to measure forces independent of their point of application on the blade.

During laryngoscopy, the direction of forces on the maxillary incisors (Fm) will be opposite to the forces on the tongue (Ft). Furthermore, the point of contact of the former will be closer to the handle than the latter (Fig 1). When two opposing forces act along the axis of the handle, this sensor will take the sum of the forces. If there is no force on the maxillary incisors during laryngoscopy, the sensor will measure the forces on the tongue. However, when there are also forces on the maxillary incisors the sensor will give lower readings. When the forces onto the teeth exceed the forces onto the tongue, the reading will become negative.

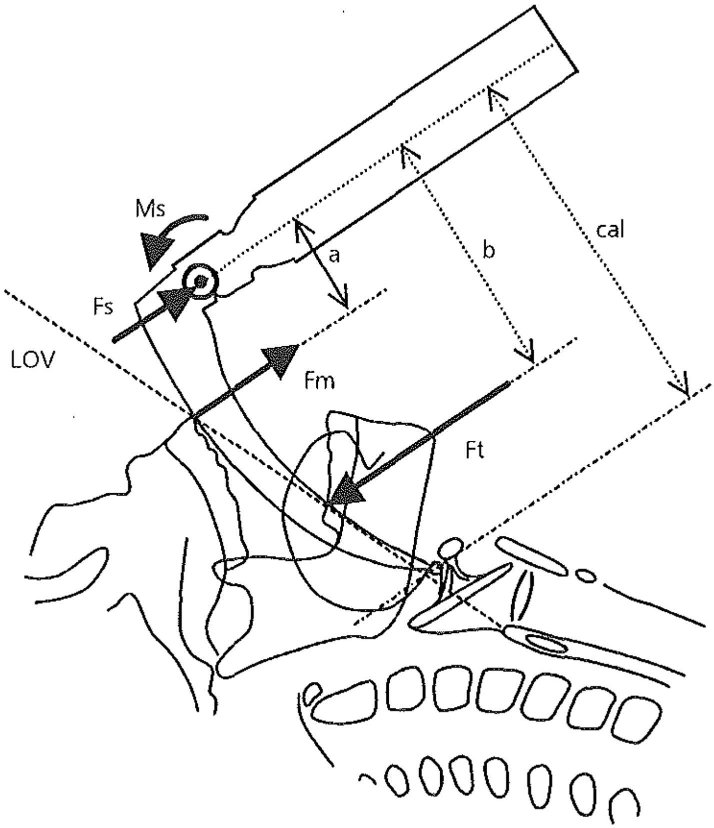

Figure 1. *Biomechanical model of the forces applied during laryngoscopy: moment (Ms) and force (Fs) are exerted by the sensor on the blade. Force is applied by the maxillary incisor teeth (Fm) and the tongue (Ft) on the blade. cal: calibration length. LOV: line of vision. a and b: distance from the heart of the sensor to the application point of Fm and Ft.*

The laryngoscope was further modified by the addition of another sensor which permitted the measurement of moments produced by forces exerted on the blade. Basically, a moment sensor is a simple device, the principles of which can be illustrated by considering a horizontally placed weightless beam which is fixed at one end to a vertical wall[8]. At the other end of this beam a downward directed force, F, is applied which exerts a moment at the fixation point. As the beam does not turn, a counteracting moment must be present, resulting from horizontally oriented forces in the beam which are tensile at the top side and compressive at the underside. The magnitude of these forces is linearly related to the distance from the application point of F[11]. These forces induce minute spatial changes in the beam which can be detected by strain gauges positioned above and below the fixation point. By inserting these into an electronic bridge, a moment sensor is created. The combination of these two sensors, one to measure shear forces and another to measure moments, will provide a more accurate picture of the forces acting during laryngoscopy.

For the equilibrium of a body in space, the equations of statics require the sum of all force-vectors acting on that body to be zero. Moreover, the sum of the moments of all forces around any axis must also be zero[11]. When applied to laryngoscopy (Fig 1), the following equations hold:

$$Fs + Fm - Ft = 0 \qquad (1) \text{ and}$$

$$Ms + Fm \times a - Ft \times b = 0 \qquad (2)$$

where Fs and Ms are the respective force and moment exerted (and measured) by the sensor on the blade, Fm is the force of the maxillary incisors on the blade, Ft is the force of the tongue on the blade, and (Fm × a) and (Ft × b) are the moments exerted by the forces of the maxillary incisors and the tongue on the sensor. Equation 1 can be rewritten as follows:

$$Fm = -Fs + Ft \qquad (3) \text{ and}$$

$$Ft = Fs + Fm \qquad (4)$$

When Fm and Ft in equation (2) are substituted in equations (3) and (4), the following formulae for Fm and Ft are obtained:

$$Fm = \frac{(Fs \times b) - Ms}{a - b}$$

$$Ft = \frac{(Fs \times a) - Ms}{a - b}$$

As a consequence, when a and b and their 95% coverage are known, Fm and Ft and their 95% coverage can be calculated. Moreover, b can be measured when there are no forces on the maxillary incisors. Unfortunately, this technique does not allow the measurement or calculation of these four factors in the same patient at the same time.

Using this technique, Ft and Fm can be measured in a group of patients when the distances, a and b, for this group of patients are known. These can be ascertained by determining a and b in a reference group which reflects the physical characteristics of the patients in whom Fm and Ft will be determined (measurement group). By placing a scale onto the blade of the laryngoscope, the position where the maxillary incisors (or gums) contact the blade during laryngoscopy can be determined allowing measurement of distance a. In addition, by taking great care not to touch the maxillary incisors, distance b can also be measured.

In a pilot study of 20 patients, mean values for distances a and b were determined during laryngoscopy; these values were found to be remarkably constant in each patient (95% C.I. for a and b were < 10 mm and < 15 mm, respectively). However, in some patients it proved to be very difficult to completely avoid touching the maxillary incisors or (in edentulous patients) the maxillary gums, even though laryngoscopy was easy to perform. In most of these patients the maxillary incisors were present. In the majority of patients, to prevent contact with the maxillary incisors, laryngoscopy was performed using a non-standard method which usually resulted in high forces being applied to other structures and increased duration of laryngoscopy. Consequently, the values of a and b were considered not to be representative for laryngoscopy as it is normally performed.
To obtain representative values of a and b, it was decided to measure these just before the introduction of the tracheal tube when the glottis was in full view. This proved to be a practical method and, subsequently, distances a and b were determined in a reference group comprising 75 patients. Later on, these values were correlated with other physical characteristics of patients in the reference group, such as age, weight, height, gender and presence of maxillary incisors.
The simple algorithms describing these relationships were incorporated into the formulae describing Ft and Fm. It became possible to estimate Ft and Fm in patients of the measurement group with reasonable accuracy.

Processing of signals/calibration

The strain gauges (Measurements Group Inc, Raleigh, NC, USA) of both sensors were placed in two electronic bridges. To obtain optimal amplification of the signals, a preamplifier was positioned into the handle of the laryngoscope. During measurement, the analog signal of both sensors was digitized with a sampling

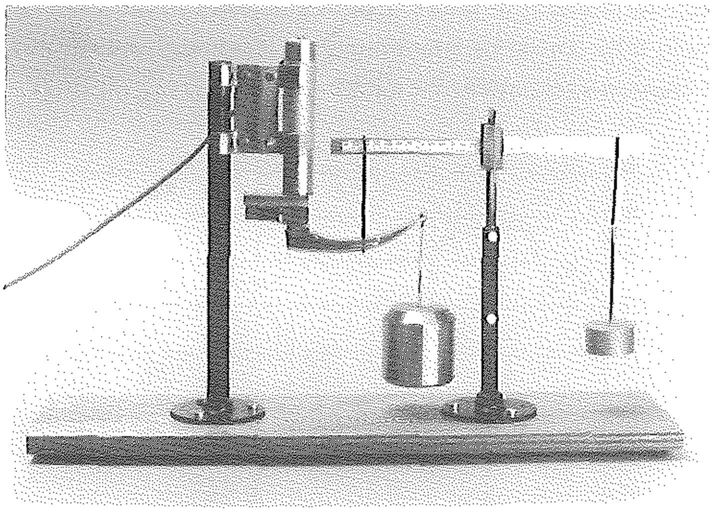

Figure 2. *Test frame allowing the application of two forces at two different positions in opposite directions on the blade. In this example, at the tip of the blade a downward directed force of 19.6 N is applied. At 4 cm from the tip, an upward directed force of 5.0 N is applied, resulting from a suspended weight fixed to the right of the horizontal beam.*

frequency of 15 Hz and stored on a memory card (LSI Card) with a capacity of 32 Kb, sufficient for multiple recordings with a total measurement duration of 35 minutes.

To test the validity of the instrument a special frame was constructed (Fig 2) which allowed the application of two opposing forces at two different positions on the blade, mimiking the clinical situation. The results of this showed the instrument to be highly accurate. Zero calibration was performed with the laryngoscope handle in the vertical position. By attaching a mass of 2 kg (=19.6 N) to the tip of the blade, the instrument was calibrated to this level. After each calibration procedure a standardized measurement was performed with the laryngoscope handle in the vertical position and a mass of 2 kg applied at the tip of the blade. This standardized measurement was used to verify the calibration procedure.

After a series of measurements the data on the memory card could be transferred to the hard disk of an IBM compatible personal computer. A computer program enabled the calculation and graphical representation against time of the various laryngoscopic factors such as duration of laryngoscopy, Fs, Ft and Fm, with the accompanying 95% confidence intervals (Fig 3). In addition, it calculated maximal and mean values and areas under the curves.

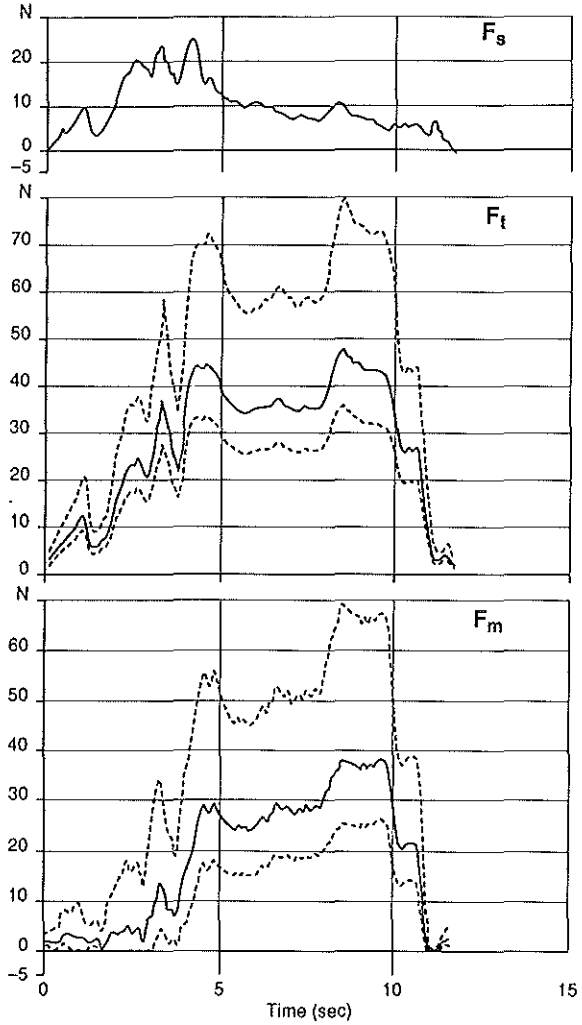

***Figure 3**. Typical recording of the forces applied during laryngoscopy. Fs, force of sensor on blade; Ft, force of tongue on blade; Fm, force of maxillary incisor teeth on blade. The respective forces are drawn in Fig 1. The 95% confidence intervals of Ft and Fm are shown (dotted lines).*

Subjects

After approval by the Hospital Ethics Committee and written informed consent 75 patients in the reference group and 65 patients in the measurement group were studied. All patients were ASA grades 1–3 adults, scheduled for elective surgery, in whom no difficulty with laryngoscopy and subsequent intubation was expected. Patients in whom tracheal intubation proved difficult or was not achieved at first attempt, were excluded from the study. Before laryngoscopy the patient's head was placed in the 'sniffing' position. A Macintosh blade 3 (Penlon Ltd) was used in all patients.

In order to minimise bias, the anaesthesiologists were not informed about the purpose of this study and there were no references to the way laryngoscopy was performed. For the same reason, the investigator stood some distance behind the anaesthesiologist during laryngoscopy, asked no questions about levering on the maxillary incisors of maxillary gums, and did not inspect the teeth. In addition, because of the way data were recorded, nobody (including the investigator) was aware of the results at the time of measurement.

Apart from recording the various laryngoscopic factors, the patient's age, weight, height, gender and the presence or absence of maxillary and mandibular incisors were noted.

Laryngoscopy was performed, in the measurement group, by 12 staff anaesthesiologists each of whom carried out a minimum of 4 and a maximum of 6 laryngoscopies. In patients of the reference group, laryngoscopy was performed by the investigators (MB, RvG, CR).

Laryngoscopy was graded using the system of Cormack and Lehane [12]: grade 1, most of the vocal cords visible; grade 2, less than half of the cords visible; grade 3, only the epiglottis visible; grade 4, not even the epiglottis visible.

The intubation conditions were scored as follows: 3 = excellent (jaw relaxed, cords abducted, no movement), 2 = good (same as 3, except slight cough or movement), 1 = poor (jaw poorly relaxed, cords moving, bucking), 0 = unable to intubate [13,14].

Neither premedication nor the anaesthetic induction technique were standardized except that the use of non-depolarizing neuromuscular blockers was mandatory, since their omission, or the use of depolarising agents, might have influenced the results [15].

Table 1. Physical characteristics of patients in the measurement and reference groups. Values are mean (SD), or numbers of patients.

	Measurement		Reference	
n	65		75	
Age (yr)	49	(16.0)	47	(18.1)
Weight (kg)	71	(15.2)	71	(13.4)
Height (cm)	169	(10.1)	170	(10.2)
Men/Women	28 / 37		31 / 44	
MI present/absent	34 / 31		51 / 24	

MI, maxillary incisors

Statistical methods

The differences between the groups were compared by Student's two-sample *t*-test or the Chi-squared test. To study the relationship between patient characteristics and the application points of the forces, Student's two-sample *t*-test, univariate regression analysis or stepwise multiple linear regression analysis was performed. In addition, univariate regression analysis was performed to study the relationship between the readings of the shear force sensor, the forces on the tongue and the forces on the maxillary incisors. The data were subjected to logarithmic transformation to obtain approximate normal distribution when appropriate.

Results

Two patients in the reference group were excluded from the study; in one patient laryngoscopy proved difficult and in the other it could not be performed without applying some force to the maxillary incisors. In the measurement group three patients were excluded as endotracheal intubation could not be achieved at the first attempt. Thus, 75 patients were studied in the reference group and 65 patients in the measurement group. The physical characteristics of patients in both groups are presented in Table 1; there were no significant differences between patients of either group.

In patients of the reference group the application points of the forces on the maxillary incisors, a and the tongue, b were determined (Fig 1). The positions of these points were calculated as their distance from the mid-point of the sensor. The mean (SD) values for a were 4.9 (0.8) cm (range 3.0–7.0); The corresponding values for b were 10.9 (0.9) cm (range 8.0–13.0). As the distance from tip to the midpoint of the sensor (calibration length) was 14.8 cm in all patients, the mean application point of the forces on the maxillary incisors measured from the tip of the blade was 9.9 cm (range 8.0–12.0). For the point of application of the forces on the tongue, these values were 3.9 and 2.0–6.0 cm, respectively.

When the values of a and b were related to patient characteristics, distance a was found to be significantly related to height ($a = 11.9 - 0.04 \times \text{height}$) ($p < 0.0001$) ($r = -0.49$) (SD = 0.74 cm) and gender (mean (SD) a in men was 4.5 (0.85) cm and in women 5.3 (0.70) cm, $p < 0.0001$). Distance b was significantly related to height ($b = 16.4 - 0.03 \times \text{height}$) ($p = 0.002$) ($r = -0.35$), gender (mean (SD) b in men was 10.5 (1.0) cm and in women 11.2 (0.76) cm, $p = 0.001$) and presence of maxillary incisors (when these were present mean b was 10.7 cm, when absent 11.2 cm, $p = 0.01$). There was no significant relationship between these application points and age and weight.

Stepwise regression analysis showed that the addition of gender did not improve the predictive power of the relationship between a and height. For b, however, the

Table 2. Mean, (SEM) and range of laryngoscopic forces and duration of laryngoscopy in patients in the measurement group (n = 65).

t_l (s)	13.9	(1.0)	5.6– 53.9
Fsmax (N)	19.2	(1.5)	0.5– 57.0
Fsmean (N)	7.8	(0.9)	−6.3– 31.7
Ftmax (N)	45.7	(2.7)	16.6– 138.3
Ftmean (N)	27.6	(1.5)	12.9– 83.6
Fmmax (N)	35.7	(2.9)	2.4– 138.8
Fmmean (N)	19.9	(1.7)	0.3– 85.5

t_l, duration of laryngoscopy; Fs readings of the shear force sensor; Ft, estimated forces on the tongue; Fm, estimated forces on the maxillary incisor teeth; max, maximum value

Table 3. Effect of presence or absence of maxillary incisors on the mean (SEM) laryngoscopic forces in the measurement group.

	MI present (n = 34)	MI absent (n = 31)	p value
t_l, (s)	16.2 (1.8)	11.5 (0.9)	0.02
Ftmax (N)	56.8 (4.1)	33.5 (1.6)	<0.001
Ftmean (N)	34.1 (2.3)	20.4 (0.9)	<0.001
Fmmax (N)	49.1 (4.4)	21.0 (1.6)	<0.001
Fmmean (N)	27.8 (2.5)	11.2 (1.0)	<0.001

MI, maxillary incisor teeth; t_l, duration of laryngoscopy; Fs, readings of the shear force sensor; Ft, estimated forces on the tongue; Fm, estimated forces on the maxillary incisors; max, maximum value.

best discriminatory variables were the combination of maxillary incisors and height ($b = 17.8 - 0.04 \times height - 0.68 \times MI$; MI present = 1, MI absent = 0) ($R^2 = 0.49$) (SD = 0.82 cm).

Table 2 shows the laryngoscopic factors of patients in the measurement group. During laryngoscopy, 11 patients produced negative values on the shear force sensor (Fs) and in seven patients this was consistent enough to give negative Fsmean results.

Concerning the forces on the maxillary incisors, with a probablility of 95%, mean Fmmax was between 29.9 and 41.5 N (mean ± 2 × SEM) and mean Fmmean was between 16.5 and 23.3 N. The effect of the presence or absence of maxillary incisor teeth on the laryngoscopic factors is shown in Table 3. In patients with maxillary incisors greater forces were applied, both on the tongue and on the teeth themselves, than in patients without maxillary incisors. In patients with maxillary incisors the 95% confidence interval of mean Fmmax was 40.3 – 57.9 (mean ± 2 × SEM) and of mean Ftmax 48.6 – 65.0. In contrast, in patients without maxillary incisors these values were 17.8 – 24.2 and 30.3 – 36.7, respectively.

In all 34 patients with maxillary incisors the estimated mean maximal forces applied on these teeth was more than 20 N; in 26 (76%) more than 30 N; in 18 (53%) more than 40 N; in 11 (32%) more than 50 N; and in 7 (21%) even more than 60 N.

When studying the association between the readings of the shear force sensor, the forces on the tongue and the forces on the maxillary incisors, the following results were obtained. There was a significant relationship between Fsmax and Ftmax ($Fsmax = 0.22 \times Ftmax + 9.1$) ($p = 0.001$) ($r = 0.39$). In contrast, a significant relationship between Fsmean and Ftmean, Fsmax and Fmmax, and Fsmean and Fmmean could not be established. However, there was a significant relationship between Ftmax and Fmmax ($Ftmax = 0.80 \times Fmmax + 17.2$) ($p < 0.0001$) ($r = 0.87$) and between Ftmean and Fmmean ($Ftmean = 0.77 \times Fmmean + 12.3$) ($p<0.0001$) ($r = 0.87$).

The difficulty of laryngoscopy was scored as grade 2 in 4 patients, the other 61 patients were scored as grade 1. The intubation conditions were excellent in 56 patients, good in 8 patients and poor in one patient. In the latter patient, who was edentulous, Ftmax was 35.6 N, Ftmean 19.4 N, Fmmax 29.9 N and Fmmean 14.2 N. A significant relationship between the intubation conditions and the laryngoscopic factors could not be established.

Discussion

The results of this study clearly indicate that during routine laryngoscopy, as performed by experienced intubators, great forces are exerted on the maxillary incisor teeth. In one instance a force of 138.8 N was recorded which is roughly equivalent to the force exerted on the ground by a large bucket filled with water (25 pints). The majority of anaesthesiologists used the maxillary incisors as a fulcrum of leverage and few attempted to avoid doing so. The presence and magnitude of these forces is somewhat surprising since contact with the maxillary teeth should be minimal when using the orthodox laryngoscopy technique. In practice, during difficult intubations, it is accepted that some levering on the maxillary incisors is inevitable [1].

Although the anaesthesiologists were aware that laryngoscopy was being monitored they were not informed about its precise nature. It is likely that these circumstances would have encouraged a high standard of laryngoscopy technique. Precautions were taken to conceal the true nature of the study in order to prevent bias, but we realise that this may be more difficult in future.

There are some limitations in this study. As is inherent in almost every model, the idealised representation of the forces shown in Figure 1 is a simplification of the

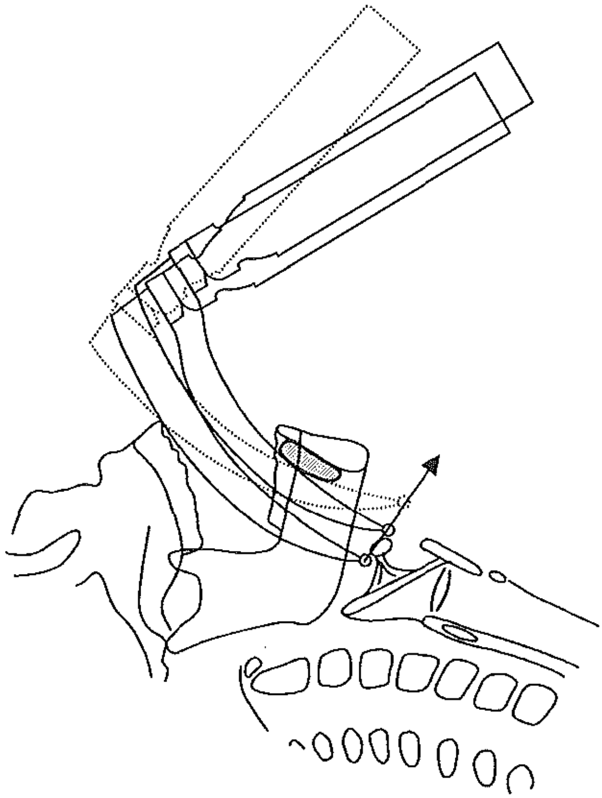

Figure 4. *Diagram showing the effect of a levering movement of the laryngoscope (dotted lines): the tip will reach further upward as compared to the movement parallel to the axis of the handle. In both instances, the upward movement is restricted by the soft tissues (cross-hatched) compressed between the blade and the inner boundaries of the lower jaw.*

actual situation. The forces described are assumed to be exactly parallel to the axis of the handle when, in fact, this will not be strictly the case. Moreover, other forces will be present due to torque in other planes. It is clear, however, that forces parallel to the axis of the handle are the most relevant [8].

Another limitation of this study is the fact that the forces on the maxillary incisors are not actually measured but estimated. The accuracy of the estimates is based on the accuracy of the determination of the position of the application points of the forces on the blade as measured in the reference group. Since these patients were physically similar to patients of the measurement group, it is likely that their application points were also similar.

Having shown that, on occasions, anaesthesiologists apply considerable force with the laryngoscope blade on the maxillary incisors it is pertinent to consider how this assists in the visualisation of the larynx.

In order to address this it is helpful to consider movements of the laryngoscope blade at the mouth and at the epiglottis.

By definition, the line of vision will run through the tips of the maxillary incisors (Fig 1). When this lies in a more upward direction, as it does in a patient with prominent maxillary incisors, it will make visualisation of the vocal cords more difficult[12]. Displacement of the blade at the entrance of the mouth in an upward direction, although enlarging the free space in the mouth to work in, will not improve the view on the glottis. In addition, the web of the Macintosh blade[1] guarantees an unobstructed, deep view of the oral cavity and whether or not the maxillary incisors are touched by the blade has little bearing. Unnecessary displacement of the tongue might even block a view of the glottis, especially when there is limited space in the oral cavity[16].

At the tip of the blade, in the region of the epiglottis, upward movement is necessary in order to displace the hyoid bone upwards, raise the epiglottis, and expose the glottis. Unfortunately, it is not known how far the hyoid should be moved to get a proper view on the glottis.

To further improve our understanding of the movements of the laryngoscope, we focus on the structures limiting the upward movement of the laryngoscope, assuming that the upward movement of the hyoid is sufficient to bring the glottis into view. The most important structure limiting the upward movement is the lower jaw. Obviously, the blade can not be moved beyond the inner boundary of the jaw (Fig 4), and as there will be always soft tissues compressed between the blade and this inner boundary, the extreme upward point of movement is positioned slightly downwards from this boundary (Fig 4). The distance from this point perpendicular to the line of vision can be regarded as a measure of maximal upward movement of the blade at the lower jaw. Of course, the exact position of this point can not be readily determined; however, for this geometric analysis this is not necessary.

When the laryngoscope is moved parallel to the axis of the handle, the tip of the blade can only move as far as the lower jaw permits. In contrast, when a levering

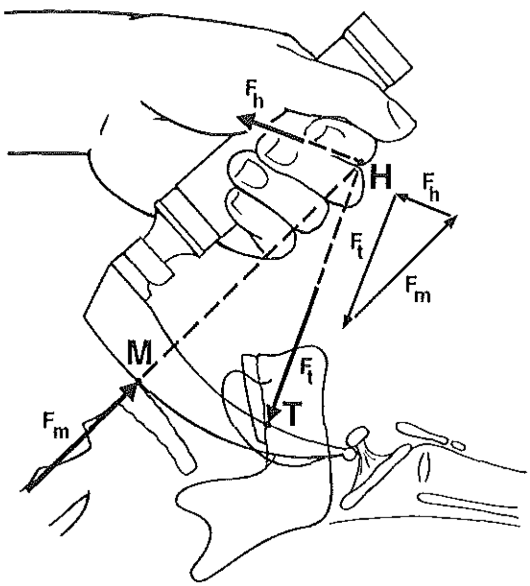

Figure 5. *Diagram showing the forces applied by the anaesthesiologist when no moment is exerted at the wrist; the forces exerted by the hand are magnified and passed on to the teeth (see text).*

movement is used, the maximal movement of the tip of the blade will be increased beyond the limits posed by the lower jaw (Fig 4).

Having described the movements of the blade to bring the glottis into view as well as the limiting factor of these movements, we conclude that the concept of the 'line of vision' implies that a levering movement, using the maxillary incisors as the fulcrum of leverage, is the movement which yields the best view onto the glottis.

Of course, this does not mean that this is always the preferred technique. In many patients the anatomy is such that levering is not necessary to bring the glottis into view and, if used routinely, this would lead to an unacceptably high risk of damage to the teeth.

There is ample evidence, however, that the levering method is widely employed in clinical practice. Damage to the teeth is one of the most frequent complications of laryngoscopy, its frequency increasing with the degree of difficulty [1-3]. Drawings or X-rays of laryngoscopes at the moment when the glottis is seen are generally anatomically crude and, in the majority of drawings, the flange of the laryngoscope is in contact with the teeth [16-18]. It has been said that "Beginners have a natural tendency to exert a levering movement..." [5,10]. There is a need for a laryngoscope which can provide additional lift at the tip of the blade and new designs have been reported [19,20].

This investigation shows that many anaesthesiologists have a poor awareness of the large forces which they sometimes apply to the maxillary incisors. The reason may be related to the fact that the human hand is not designed to exert large moments to the handle of the laryngoscope, especially if there is an angle between the hand and the lower arm [21]. However, when the maxillary incisors are not used as a fulcrum, a large moment must be exerted [8]. In the extreme situation that the 'ideal' levering movement on the maxillary incisors is performed without exerting a moment at the wrist (Fig 5), the forces exerted by the hand (Fh) will be magnified as shown, and can be represented by the triangle HTM. This triangle of forces shows the mutual proportion of Fh and Fm, which in this example reflects a magnification of more than two-fold. In this situation, the forces on the teeth will even exceed the force on the tongue! Although this is an extreme example, the majority of anaesthesiologists are probably unaware of the manner in which the forces become magnified.
Do experienced anaesthesiologists differ from novices with respect to the forces they apply to the maxillary incisors? Recently, it was reported that these were similar and not related to experience [22]. However, the instrument used in that study was not a force sensor but a moment sensor; its readings were therefore the result of the magnitude of the forces and their application points. In addition these workers did not include laryngoscopies during which force was applied to the maxillary incisors and the number of laryngoscopies studied was rather small.

In conclusion, the results of this study indicate that, in the majority of routine laryngoscopies, considerable forces are applied to the maxillary incisor teeth. This can be explained by the fact that a levering movement, using the maxillary incisors as a fulcrum, although not the orthodox technique, is the most efficient way to bring the glottis into view. These results may have implications for future laryngoscope design.

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CHAPTER 7

DOES EXPERIENCE INFLUENCE THE FORCES EXERTED ON MAXILLARY INCISORS DURING LARYNGOSCOPY?

A manikin study using the Macintosh laryngoscope

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Summary

The influence of level of experience of the laryngoscopist on the duration of laryngoscopy, the forces exerted on the tongue and on the maxillary incisors during laryngoscopy, were investigated. Five groups, (anaesthetists, residents in anaesthesia, nurse anaesthetists, surgeons and medical students) each consisting of 15 individuals participated in the study. An intubation manikin was used with a laryngoscope modified so that the forces applied during laryngoscopy could be measured. The mean duration of laryngoscopy in these groups was 23.4 s, 17.6 s, 27.1 s, 26.8 s and 42.7 s, respectively. The maximally applied forces on the tongue were 71.7 N, 60.5 N, 65.9 N, 74.2 N and 69,7 N, respectively. The maximally applied forces on the maxillary incisors were 49.9 N, 36.3 N, 41.1 N, 58.3 N and 53.9 N, respectively. These results indicate that level of experience has a significant influence on the duration of laryngoscopy but seems to have little influence on the forces applied to the tongue and the maxillary incisors. Attention is drawn to the relevance of this kind of research for manufacturers of intubation manikins.

Introduction

According to current opinion [1,2], force should not be exerted on the maxillary incisors during laryngoscopy using the Macintosh laryngoscope, particularly in patients in whom it is considered that the trachea is 'easy to intubate'. With more difficult cases the application of force to the teeth is sometimes inevitable and, therefore, justified [3]. However, the application of force on the maxillary incisors during routine tracheal intubation is very common, and the magnitude of this force is often high [4].

As the routine application of force on the teeth is considered to be in contradiction to accepted professional standards, and is sometimes even referred to as 'typical for the careless and unskillful' [1], the question arises whether experienced intubators differ from the inexperienced.

The purpose of this study was to investigate the influence of the level of experience on the forces applied during laryngoscopy, on the duration of laryngoscopy, the best view obtained and the success of intubation. In addition, the effect of re-laryngoscopy on these variables was investigated. Because many patient-related factors influence the forces applied during laryngoscopy [5,6], an intubation manikin was used to represent a 'standard patient', allowing straightforward comparisons between groups and avoiding ethical problems.

Methods

During a three-day period,150 laryngoscopies performed in an intubation manikin were studied. The procedures were performed by 75 study participants who were divided into five groups (15 per group) of different levels of experience. Group 1 were staff anaesthetists; group 2 were residents in anaesthesia (>two years experience or >300 tracheal intubations); group 3 nurse anaesthetists; group 4 consultants or senior residents in surgical fields with previous successful intubation experience in patients (referred to hereafter as surgeons), and group 5 were medical students. Each participant performed two laryngoscopies; for each procedure a maximum of 60 sec was allowed. The second procedure was defined as re-laryngoscopy. All participants performed intubation with the same manikin (Adult Intubation Model, Laerdal, Stavanger, Norway) with a Portex 8.5 mm endotracheal tube. The head of the manikin was put in a sniffing position. As we only wanted to study the effect of experience on handling of the laryngoscope (and not on head positioning), the head was fixed in this position by screws.

The forces applied during laryngoscopy were measured by means of a recent modification[4] to a previously described curved blade laryngoscope[7]. A combined moment and shear force sensor, based on the strain gauge technique, was built into this laryngoscope and positioned between the handle and the blade. This configuration of sensors allowed estimation of the forces applied on the tongue (Ft) and on the maxillary incisors (Fm), provided that the application points of these forces on the blade were known. The application points in the intubation manikin were determined by four investigators (MB, RvG, JW, CR) each performing seven laryngoscopies.

In addition to determining these forces, the mean and maximum values of the forces as well as their accompanying 95% confidence intervals can be determined. A detailed description of the principles of this measuring laryngoscope has been published recently[4]. An important feature of this laryngoscope is that it gives no indication to the intubator of the measurement. Before each measurement the instrument was calibrated. In all measurements the same No 3 Macintosh laryngoscope blade (Penlon Ltd) was used.

To avoid any influence on the way laryngoscopy was carried out, the participants were not informed of the purpose of this study, nor were any comments made about the way laryngoscopy was performed. During laryngoscopy, no person other than the investigator and the study participant were present. During measurement

Table 1. Laryngoscopic factors at first laryngoscopy.

	Anaesthetists	Residents	Nurses	Surgeons	Students
t_l (s)					
M	23.4	17.6	27.1	26.8	42.7*
SD	14.8	6.2	16.2	16.7	18.1
range	8 - 60	10 - 30	8 - 57	10 - 65	17 -66
Ftmax (N)					
M	71.7	60.5	65.9	74.2	69.7
SD	25.1	20.6	25.6	30.1	26.3
range	38 -115	40 -114	25 -122	26 -153	24 -114
Ftmean (N)					
M	31.7	30.3	29.8	31.1	27.4
SD	13.2	15.5	11.7	12.5	12.1
range	18 - 64	11 - 78	13 - 46	14 - 61	10 - 49
Fmmax (N)					
M	49.9	36.3	41.1	58.3	53.9
SD	25.2	29.2	27.4	36.1	35.6
range	10 -100	8 -123	9 - 92	7 -127	3 -109
Fmmean (N)					
M	19.6	15.0	13.8	18.9	14.6
SD	17.0	21.7	13.5	12.7	13.2
range	2 - 67	1 - 88	1 - 42	1 - 37	0 - 43

t_l, duration of laryngoscopy; Ft, forces on the tongue; Fm, forces on the maxillary incisors; max, maximum value; mean, mean value; M, mean value; SD, standard deviation; *results from students significantly different from results of all other groups.

the data were stored onto a memory card for later analysis, so that no-one was aware of the results.

The best view obtained during laryngoscopy was determined by the investigator by asking the intubator which (and how much of the) structures in the larynx-pharynx area of the manikin were identified. Subsequently, this view was graded according to Cormack and Lehane[8]; grade 1, most of the cords visible; grade 2, less than half of the cords visible; grade 3, only the epiglottis visible; and grade 4, not even the epiglottis visible. After each intubation (attempt) the investigator determined the position of the tube by looking at the transparant trachea at the back of the manikin

Table 2. Laryngoscopic factors at second laryngoscopy.

	Anaesthetists	Residents	Nurses	Surgeons	Students
t_l (s)					
M	14.0	15.6	22.5	16.1	31.5*
SD	5.6	7.5	13.7	15.6	18.2
range	8 - 26	7 - 33	9 - 62	7 - 70	13 - 63
Ftmax (N)					
M	58.7	54.4	61.4	67.7	55.9
SD	28.3	15.9	25.4	20.0	20.1
range	26 -130	31 - 92	18 -114	39 -108	41 -117
Ftmean (N)					
M	30.7	26.6	27.7	33.4	23.7
SD	14.2	11.6	13.0	12.4	7.9
range	15 - 62	13 - 51	10 - 55	22 - 70	18 - 43
Fmmax (N)					
M	39.5	29.1	42.1	47.7	35.4
SD	29.5	16.0	31.8	25.8	26.9
range	6 -108	7 - 59	8 -103	13 - 83	5 -120
Fmmean (N)					
M	18.8	10.3	15.0	20.7	10.7
SD	17.3	7.5	16.0	15.5	11.4
range	1 - 66	1 - 21	1 - 45	1 - 51	1 - 43

t_l, duration of laryngoscopy; Ft, forces on the tongue; Fm, forces on the maxillary incisors; max, maximum value; mean, mean value; M, mean value; SD, standard deviation; *results from students significantly different from results of all other groups.

which was not visible to the intubator. The tip of the tube in the trachea represented successful intubation.

Statistical analysis

To test for differences between groups in ordinalvariables, the Kruskal and Wallis test was used. If this test proved significant, pairwise comparisons of groups were done with the Mann-Whitney-Wilcoxon test. The influence of re-laryngoscopy on the laryngoscopic factors was studied using the paired *t*-test. The influence of re-laryngoscopy on the best view obtained and the success of intubation were analysed using the Wilcoxon signed-rank test and McNemar's test, respectively. Logarithmic transformation to obtain approximate normal distribution was performed when appropriate. A P value <0.05 was considered statistically significant.

Results

The mean application point of the forces acting on the maxillary incisors was 8.3 cm (SD 0.28; range 7.7-9.1) and on the tongue 2.1 cm (SD 0.62; range 1.4-3.3); from the tip of the blade.

Tables 1 and 2 show the duration of laryngoscopy and the forces applied on the tongue and the maxillary incisors, recorded at the first and the second laryngoscopy attempts, respectively.

At first laryngoscopy, the global test indicated differences in the duration of laryngoscopy (tl_1). In medical students the duration of laryngoscopy was longer than in the four other groups (P=0.0005), but differences between the other groups could not be demonstrated. In addition, there were no differences among groups concerning the forces on the tongue and on the maxillary incisors. When first laryngoscopies of all groups were considered, the maximal force exerted on the maxillary incisors was >20 N in 55 (73%) cases, >40 N in 40 (53%), >60 N in 28 (37%) and >80 N in 10 (13%) cases. For anaesthetists and residents in anaesthesia these values were 24 (80%), 14 (47%), 9 (30%) and 2 cases (7%), respectively.

At second laryngoscopy, there was a decrease in duration of laryngoscopy (tl_2) (P<0.001), as well as on the forces applied on the tongue and the teeth. When only those intubators who were successful both times were included, these results were similar except for duration of laryngoscopy.

There were differences between groups in best view obtained at first laryngoscopy (P=0.0004) (Table 3). The best view obtained by medical students was worse than the other four groups; the differences between the other groups were not significant. The best view obtained improved at second laryngoscopy compared with the first, although this reached only borderline significance (P=0.05).

The number of failed intubations at the first laryngoscopy was 15; two in the anaesthetists, 0 in the residents, three in the nurses, three in the surgeons and seven in the students. For the second laryngoscopy the number of failed intubations was 12; 1, 0, 4, 1 and 6, respectively. There were differences between groups in intubation success at first laryngoscopy (P<0.01) but there was no difference between the number of intubation failures at first and second laryngoscopy. When the first intubation was successful, the chance of success in the second was 92%.

Table 3. Best view obtained at first laryngoscopy.

	Best view obtained*			
	1	2	3	4
Anaesthetists	10	5	–	–
Residents	11	4	–	–
Nurses	6	7	2	–
Surgeons	7	6	1	1
Students	2	5	3	5

*Best view was assessed according to the grading system of Cormack and Lehane [8]; 1, most of the cords visible; 2, less than half of the cords visible; 3, only the epiglottis visible; 4, not even the epiglottis visible. Values are number of participants per group.

However, when the first was not successful, the chance of success in the second was 53% (P=0.001). There was a relationship between intubation success and best view obtained (P<0.0001).

Discussion

The results of this manikin study demonstrate that, in the majority of laryngoscopies, use of the Macintosh laryngoscope is associated with the application of considerable force to the maxillary incisors. This confirms the results of a previous study performed in patients in whom the tracheas were considered easy to intubate [4]. Both the incidence and the magnitude of the forces are remarkable, as both are in contrast to accepted views regarding the way laryngoscopy should be performed. Experience proved to have a substantial influence in reducing the duration of laryngoscopy, which is in agreement with previous reports [5]. In addition, increased experience facilitated attainment of the best view on the glottis and the intubation success, both of which proved to be closely related. In contrast, level of experience had no influence on the forces applied to the tongue and to the maxillary incisors.

The influence of experience on the forces applied during laryngoscopy has been addressed in a recent study in which it was concluded that experience had no clear influence [5]. However, the instrument used in that study did not allow the measurement of forces both on the tongue and on the teeth; laryngoscopies during which force was exerted on the teeth were excluded from the study; and the number of laryngoscopies studied was rather small. In addition, the instrument used to measure these forces was a moment sensor and not a force sensor.

Should we now conclude that, as far as forces on the teeth are concerned, the experience of the intubator does not matter and, consequently, will have no influence on the (possible) resulting dental damage? We think not, and this opinion is based on the following reasons. The first reason is that, although the data indicate that level of experience has little influence, it does not exclude that such an influence exists. The large standard deviations within all groups preclude making precise statements about the differences between the groups; however, at the same time, they suggest that other factors, including the precision of the method of measurement, play a more important role. The second reason is that, although we are unaware of any prospective studies addressing the question as to whether experience will influence dental damage (which undoubtedly will involve ethical concerns), common sense leads us to assume that such a relationship exists. In this respect it is interesting that, as far as differences between anaesthetists and residents are concerned, the results of this study indicate that the laryngoscopic factors are not influenced by the total number of laryngoscopies performed throughout a career. A third reason might be related to the complexity of the mechanisms leading to dental damage and technical limitations of the sensor. Although teeth are able to withstand great forces in an axial direction, relatively small lateral forces can do great harm. Unfortunately, the measurement laryngoscope used enabled to measure only the axial forces, which are not influenced by level of experience. However, experience might have an effect on the lateral forces. Therefore, to quantify all essential force-related variables of laryngoscopy, a more sophisticated measuring laryngoscope is needed than the one used in the present study.

The results of this study do not support the contention that difficulty with laryngoscopy is associated with greater forces applied, nor that intubation failure is the result of applying too little force[9]; however, this study was not designed to address these points. (Heterogeneity of the participating groups in this study might account for these results).

Table 4. Laryngoscopic factors in the manikin compared to patients in two clinical studies

	Manikin	Patients		
	present study*	Bishop et al [5]	Bucx et al [4]	
			MI present	*MI absent*
n	28	17	34	31
t_l (s)	18.7	19	16.2	11.5
Ftmax (N)	64.3	43.2	56.8	33.5
Ftmean (N)	29.1	22.3	34.1	20.4
Fmmax (N)	40.4	–	49.1	21.0
Fmmean (N)	15.3	–	27.8	11.2

*Only the results of successful intubations by experienced intubators (i.e. anaesthesiologists and residents) are shown.
The presence or absence of teeth was not stated in Bishop's study, measurements during which force was exerted onto the teeth were excluded, only the results of experienced intubators are shown. MI, maxillary incisors; t_l, duration of laryngoscopy; Ft, forces on the tongue; Fm, forces on the maxillary incisors;

As expected, the results of this study demonstrate the favorable effect of re-laryngoscopy on the variables studied; the duration of laryngoscopy was decreased, as were the forces exerted on the tongue and the maxillary incisors. In addition, there was an improvement in the best view obtained and the number of successful intubations.

An important aspect of this study concerns the extent to which the intubation manikin used realistically mimics the clinical situation. Obviously, this question should only apply to the laryngoscopic factors measured in this study, as other characteristics of the manikin were not investigated. However, the measurements obtained with the manikin by experienced intubators in this study (i.e. anaesthetists and residents) proved to be comparable with measurements obtained by experienced intubators in patients[4,5] (Table 4). Therefore, it can be concluded that, within the limitations mentioned, this manikin is a reasonable representation of the situation in dentate patients. However, when no force is exerted on the maxillary incisors, the effort needed to perform laryngoscopy not only depends on the duration and the amount of force needed to lift the base of the tongue, but also on the magnitude of the moment to be exerted. In turn, the magnitude of this moment depends not only on the magnitude of the force to be exerted, but also on its application point on the blade. In the manikin used in this study, this application point was 2.1 cm, whereas in patients it is 3.9 cm from the tip of the blade[4]. As the distance from the central axis of the handle to the tip of the blade is 12.0 cm, the magnitude of the moment to be exerted in the manikin used in this study is approximately 22% greater than would be needed in dentate patients. Manufacturers of manikins should be aware of these facts.

In conclusion, this manikin study demonstrates that, in the majority of laryngoscopies using the Macintosh laryngoscope, great forces are exerted on the maxillary incisors. This is comparable to the situation in patients. The experience of the intubator did not seem to influence the incidence and magnitude of these forces. Re-laryngoscopy reduced the duration of laryngoscopy and the forces applied. The results of this study pose challenging questions concerning the validity of currently generally accepted basic knowledge on laryngoscopy, and stress the need for more rational methods in laryngoscope design and development.

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CHAPTER 8

SUMMARY AND CONCLUSIONS

The laryngoscope was invented almost a century ago and although many changes were made to its design in the first 50 years of its existence, in the last 50 years it has remained essentially unchanged. In the majority of patients, the use of modern laryngoscopes seems to be satisfactory. However, in some patients without anatomic peculiarities suggesting difficulty with intubation, getting the glottis into view is not possible. This can lead to a potentially dangerous situation because a free airway can not be guaranteed and difficulties may arise to ventilate the patient. In addition, in the majority of these 'unexpected' situations, a neuromuscular blocking agent has already been administered, leading to a paralysed patient, who is unable to maintain a free airway and adequate ventilation of the lungs without assistance. A more frequent but less serious complication of laryngoscopy is damage to the teeth, particularly the maxillary incisors.

Because of these and other problems, this study was initiated with the objective to gain a more fundamental insight into the laryngoscopic procedure which is, in essence, a matter of biomechanics.

A method to measure forces applied in the oropharyngeal area was developed by our group. Initially, based on current opinion as to how laryngoscopy is performed, a simple model was assumed, taking the forces applied onto the tongue as the dimension to be measured. However, gradually the idea evolved that forces applied onto the maxillary incisors could not be neglected; the biomechanical model was adjusted and the number of factors to be measured was increased.

In these studies, it was considered important to adhere to common clinical practise as much as possible. Therefore, the majority of investigational measurements was performed in patients, using methods which are currently in most frequent use. Only one study was performed in an intubation manikin. In addition, it was considered important that the anaesthesiologists, residents, nurse anaesthetists, surgeons and students participating in the studies, were unaware of the factors being measured.

The most striking finding of these studies was that during routine laryngoscopy of patients considered easy to intubate, great forces (with magnitudes up to 100 N) were exerted onto the teeth in the majority of patients. This is in contrast to how, according to current opinion, laryngoscopy should be performed.

During the various investigations, the biomechanics of laryngoscopy are related to clinical aspects important to the anaesthesiologist, such as anatomical characteristics, cardiovascular reactions, upper airway muscle tone and level of experience of the person performing the procedure. The results of these studies are published and are summarized below. The successive articles not only reflect the various aspects of this work, but also illustrate the gradually increasing insight into the topics addressed. For example, in chapters 6 and 7 some of the conclusions based on results from earlier studies have already lost some of their original impact.

Chapter 1 is the introduction to the subject area of this thesis and presents the overall aims of the work.

In ***chapter 2***, a shear force sensor based on a strain gauge technique is described. This sensor enables measurement of the forces exerted along the axis of the handle of the laryngoscope. According to current concepts as to how laryngoscopy should be performed, these forces are considered to be the most relevant ones exerted during laryngoscopy. The measurement of these forces enabled us to quantify some aspects of laryngoscopy. Four so-called laryngoscopic factors could be derived: 1) the duration of laryngoscopy; 2) the maximally applied force; 3) the mean applied force; and 4) the integral of force over time (area under the curve). In 49 patients undergoing routine uncomplicated intubation the duration of laryngoscopy was 16.3 s (11.8), mean (SD), the maximally applied force was 35 N (12) and mean applied force was 20 N (6) while the integral of force over time was 324 Ns (194).

Chapter 3 describes the relationships between the laryngoscopic factors and some patient-related characteristics such as height, weight, gender, age, body mass index and the presence (or absence) of maxillary incisors. As expected, height and weight proved to be related to the forces applied during laryngoscopy. Gender and age also showed a positive relationship with these forces, but these could be explained by differences in height, weight and the presence of maxillary incisors. The latter factor was the dominant patient-related characteristic influencing the forces applied and was the only factor influencing the duration of laryngoscopy.

In ***chapter 4***, the relationship between the laryngoscopic factors and their effect on cardiovascular reactions was studied in patients undergoing laryngoscopy with or without intubation. This enabled to differentiate between the cardiovascular effects of laryngoscopy and the effects of tracheal intubation. Laryngoscopy with subsequent intubation had a major effect on cardiovascular reactions, which were only weakly influenced by the duration of laryngoscopy, whereas an influence of the forces applied could not be established. In contrast, laryngoscopy without intubation induced only minor cardiovascular changes. Therefore, it was concluded that in routine procedures tracheal intubation is a more potent stimulus to induce cardiovascular changes than laryngoscopy. The many difficulties encountered in the interpretation of the results of studies addressing this topic are discussed.

Chapter 5 deals with the forces applied during laryngoscopy in children and addresses the questions whether increased upper airway muscle tone, as quantified by these forces, can be demonstrated after the administration of suxamethonium in contrast to the effects of vecuronium, and whether this phenomenon depends on the presence of volatile anaesthetics. The children received either suxamethonium or vecuronium as a neuromuscular relaxant. In addition, they were anaesthetised with propofol, fentanyl and nitrous oxide, avoiding any use of volatiles. In patients of the suxamethonium group ($n = 26$), maximally applied forces were 19% greater, and mean applied forces 23% greater than those in the vecuronium group ($n = 28$). These differences were statistically significant. Therefore, it was concluded that increased upper airway muscle tone after the administration of suxamethonium can be demonstrated and that volatile anaesthetics are not a prerequisite for this. Current views on this phenomenon are discussed and attention is drawn to the unique characteristics of the masseter muscle, knowledge on which might lead to a better understanding of this phenomenon.

In ***Chapter 6***, conclusions based on increased insight into the complexity of the laryngoscopic procedure are presented and discussed. A newly developed measurement technique, basically an adaptation of the previously described technique, demonstrated that current opinion as to how laryngoscopy should be performed is in contrast to common practice. The results show that in the majority of routine uncomplicated intubations of patients, great forces of up to 100 N, are exerted on the maxillary incisors or, when absent, on the maxillary gums. Remarkably, the forces exerted on the maxillary incisors proved to be greater than the forces exerted on the gums in edentulous patients. This means that anaesthesiologists use the maxillary incisors as the fulcrum of leverage, which is considered to be in contradiction to accepted professional standards in anaesthesiology and is sometimes referred to as an act typical for the inexperienced. This study enables to explain why anaesthesiologists perform this movement; it proves to be the most efficient handling of the instrument to enable an optimal view on the glottis. In addition, it explains why the anaesthesiologist is unaware of the amount of force exerted on these teeth during laryngoscopy.

Chapter 7 deals with the influence of the level of experience on the laryngoscopic procedure, most notably on its influence on the forces applied on the maxillary incisors. Five groups with different experience levels were selected. Each group consisted of 15 individuals; 1) anaesthesiologists 2), residents in anaesthesiology, 3) nurse anaesthesiologists, 4) surgeons and 5) medical students. All laryngoscopies were performed on an intubation manikin. It was demonstrated that, although increased experience tends to decrease the duration of laryngoscopy, it seems to have little influence on the forces applied on the maxillary incisors and the tongue. In addition, the results show that in the majority of laryngoscopies, great forces are exerted on the maxillary incisors, confirming our previous observations in patients.

General conclusion: Current biomechanical concepts behind the laryngoscopic procedure have to be updated, particularly when forces applied onto the maxillary incisors are involved . These forces proved to be far higher than thought so far. However, in the studies presented in this thesis, the methods for measuring the forces have limited accuracy when measurements in the individual patient are considered. Moreover, there are forces which, so far, can not be quantified. These include forces perpendicular to the axis of the handle, which might be of importance in relation to damage to the teeth, and the experience level of the intubator. For these and other reasons, the biomechanical picture of the laryngoscopic procedure, although rapidly improving, is still incomplete. This emphasises the need for further studies which might lead to improvements in the design of the laryngoscope, in the manner of performing the procedure and, ultimately, to the greater safety and benefit of the patient.

SAMENVATTING EN CONCLUSIES

De laryngoscoop is een instrument dat, via de mond ingebracht, gebruikt wordt om het strottehoofd (larynx) alsmede de keelholte te kunnen visualiseren. Voor anesthesiologen is het een belangrijk instrument omdat hiermee de ingang van de luchtpijp (trachea) in beeld gebracht kan worden waardoor het inbrengen van een tube (beademingsbuis) in de luchtwegen mogelijk wordt. Met name bij operaties onder narcose waarbij de patiënt beademd dient te worden (en vooral als hierbij ook sprake is van een verhoogd aspiratie risico) is het verkrijgen van een door een tube 'gezekerde' luchtweg van groot belang.
De laryngoscoop werd ongeveer een eeuw geleden uitgevonden en ofschoon deze tijdens de eerste 50 jaar vele veranderingen onderging, is het de laatste 50 jaar in essentie niet meer gewijzigd. In de praktijk lijkt het gebruik ervan bij de meeste patiënten bevredigende resultaten op te leveren. Bij sommige patiënten echter, is het visualiseren van de ingang van de luchtpijp sterk bemoeilijkt zodat het inbrengen van een tube in de luchtpijp grote problemen kan opleveren. Vooral als dit van tevoren op grond van anatomische kenmerken niet verwacht wordt kan dit leiden tot een levensbedreigende situatie. De kans op het verkrijgen van een 'gezekerde luchtweg' is dan namelijk verkleind met als gevolg dat de patiënt een verhoogd risico loopt om te aspireren en mogelijkerwijs moeilijk op andere wijze goed te beademen is. Bovendien zal in de meeste van dergelijke situaties reeds een spierrelaxans toegediend zijn, waardoor ook spontane ademhaling door de patiënt zelf geen uitkomst meer kan bieden. Een andere helaas veel vaker voorkomende complicatie bij het gebruik van de laryngoscoop is het optreden van letsel aan de snijtanden, met name die van de bovenkaak (maxillaire snijtanden). Gelukkig leidt deze complicatie echter zelden tot levensbedreigende situaties.
Bovengenoemde problemen initieerden dit proefschrift hetgeen als doel heeft een beter inzicht te krijgen in de biomechanische aspecten van laryngoscopie en de relaties hiervan met anatomische structuren en fysiologische reacties.

Allereerst werd door onze onderzoeksgroep een methode ontwikkeld om krachten te meten tijdens laryngoscopie. Als uitgangspunt werd hierbij het gangbare model aangenomen dat ervan uitging dat krachten uitgeoefend op de tong van de patiënt de meest relevante krachten waren, en dat andere krachten geen rol van betekenis speelden. Geleidelijk aan ontstond echter het inzicht dat dit een te simpele voorstelling van zaken was en dat op de tanden uitgeoefende krachten in het model niet mochten worden verwaarloosd. Het biomechanische model werd dan ook aangepast en het aantal te meten grootheden uitgebreid.

Bij de uitvoering van de studies werd het van belang geacht de klinische praktijk zoveel mogelijk te benaderen. De meerderheid van de studies werd dan ook uitgevoerd bij patiënten en er werd veelal gebruik gemaakt van methoden die in de klinische praktijk gangbaar zijn. Bij slechts één van de studies werd gebruik gemaakt van een intubatie fantoom. Tevens werd het van groot belang geacht dat de anesthesiologen, arts-assistenten anesthesiologie, verpleegkundigen, chirurgen en medische studenten, voor zover mogelijk, niet op de hoogte waren van wat er precies gemeten werd.

De meest opmerkelijke bevinding van deze studies is dat het steunen van de laryngoscoop op de tanden van de patiënt, wiens laryngoscopie als eenvoudig beoordeeld wordt, eerder regel dan uitzondering is en dat hierbij over het algemeen grote krachten op de tanden worden uitgeoefend, die waarden kunnen bereiken tot zo'n 100 N (± 10 kgf). Deze bevindingen zijn te meer opmerkelijk daar zij volledig tegensteld zijn aan hoe over het op juiste wijze uitvoeren van een laryngoscopie binnen de anesthesiologie gedacht wordt.

In een aantal deelonderzoekingen werden aan de biomechanica gerelateerde aspecten zoals anatomische karakteristieken, cardiovasculaire reacties, spiertonus in de bovenste luchtwegen en mate van ervaring van de intubant bestudeerd. De resultaten daarvan zijn in artikelen vastgelegd welke hierna worden samengevat. De opeenvolgende artikelen geven niet alleen een beeld van de diverse deelaspecten, maar illustreren ook het toenemende inzicht in de materie. Zo wordt in de hoofdstukken 6 en 7 een aantal conclusies uit de voorafgaande hoofdstukken enigszins afgezwakt.

Hoofdstuk 1 is de introductie tot het onderwerp van dit proefschrift en beschrijft de doelstellingen van deze studie.

In ***hoofdstuk 2*** wordt een sensor beschreven waarin gebruik gemaakt wordt van rekstrookjes en die het mogelijk maakt om schuifkrachten te meten optredend in een richting evenwijdig aan de lengteas van het handvat van de laryngoscoop. Door het meten van deze krachten werd het mogelijk om enkele aspekten van laryngoscopie te kwantifiseren; deze zullen in het vervolg aangeduid worden als de laryngoscopie parameters zoals onderscheiden worden: 1) de duur van de laryngoscopie; 2) de maximaal uitgeoefende kracht; 3) de gemiddeld uitgeoefende kracht en 4) de integraal van kracht over de tijd (oppervlakte onder de curve). De metingen in 49 patiënten waarbij de laryngoscopie zoals gebruikelijk en zonder complicaties verliep leverden de volgende waarden op: de duur van de laryngoscopie was 16.3 s (11.8), gemiddelde (SD), de maximaal uitgeoefende kracht was 35 N (12) (1N ≅ 0.1kgf), de gemiddeld uitgeoefende kracht was 20 N (6) en de integraal van kracht over de tijd was 324 Ns (194).

Hoofdstuk 3 beschrijft de relatie tussen de laryngoscopie parameters en enkele patiënt-karakteristieken zoals lengte, gewicht, geslacht, leeftijd, Quetelet-index en de aan- of afwezigheid van maxillaire snijtanden. Zoals verwacht waren lengte en gewicht gerelateerd aan de uitgeoefende krachten tijdens laryngoscopie. Geslacht en leeftijd bleken eveneens een positieve relatie met deze krachten te vertonen echter, dit kon verklaard worden op basis van verschillen in lengte, gewicht en de aanwezigheid van maxillaire snijtanden. De laatst genoemde bleek de patiënt-karakteristiek te zijn die de meeste invloed had op de uitgeoefende krachten, bovendien was het de enige karakteristiek die de duur van de laryngoscopie beïnvloedde.

In ***hoofdstuk 4*** wordt onderzocht wat de relatie is tussen de laryngoscopie parameters en de cardiovasculaire reakties optredend bij patiënten die laryngoscopie ondergingen mèt en zonder intubatie. Dit maakte het mogelijk om onderscheid te maken tussen het effect van de laryngoscopie en het effect van de endotracheale intubatie. Laryngoscopie met hierop volgende intubatie bleek grote cardiovasculaire reakties op te wekken, de invloed van de duur van de laryngoscopie was hierbij echter gering en een invloed van de uitgeoefende krachten kon al helemaal niet vastgesteld worden. In tegenstelling tot deze resultaten bleek laryngoscopie zonder intubatie slechts te leiden tot geringe cardiovasculaire reakties. Er werd dan ook geconcludeerd dat, onder de gegeven omstandigheden, de endotracheale intubatie meer effekt heeft op het cardiovasculaire systeem dan de laryngoscopie zelf. Het interpreteren van de resultaten van studies die zich met dit onderwerp bezighouden blijkt nogal wat valkuilen te bevatten welke dan ook besproken worden.

Hoofdstuk 5 behandelt de krachten die tijdens laryngoscopie worden uitgeoefend in kinderen en gaat na in hoeverre een tonus verhoging van spieren van de bovenste luchtwegen, gekwantifiseerd door deze krachten, optreedt na toediening van succinylcholine, dit in vergelijking met de effekten van vecuronium. Tevens wordt nagegaan of het optreden van dit fenomeen afhankelijk is van de aanwezigheid van dampvormige anesthetica. De kinderen kregen òf succinylcholine (n = 26) òf vecuronium (n = 28) toegediend als spierrelaxans. Tevens kregen zij allemaal propofol, fentanyl en lachgas toegediend. Inhalatie-anesthetica werden niet gebruikt. De maximaal en gemiddeld uitgeoefende krachten in kinderen van de succinylcholine groep waren respectivelijk 19 en 23% groter dan die in de vecuronium groep. Beide verschillen waren statistisch significant. Er werd dan ook geconcludeerd dat een verhoging van de tonus van spieren van de bovenste luchtwegen optreedt na toediening van succinylcholine en dat dit niet afhankelijk is van de aanwezigheid van inhalatie-anesthetica. De huidige inzichten achter dit fenomeen worden besproken. Wij zien in de bijzondere eigenschappen van de masseter mogelijke verklaringen van dit fenomeen.

In ***hoofdstuk 6*** wordt het toegenomen inzicht in de complexiteit van de laryngoscopie gepresenteerd en besproken hetgeen verkregen werd door gebruik te maken van een nieuwe meetmethode tijdens deze procedure. Met behulp van deze meetmethode, welke in wezen een modificatie is van de reeds tevoren beschreven techniek, kon aangetoond worden dat er een discrepantie bestaat tussen de manier waarop laryngoscopie volgens de gevestigde ideeën uitgevoerd moet worden en de manier waarop dit in de praktijk gebeurt. De resultaten tonen namelijk aan dat bij de meeste routinematige ongecompliceerde laryngoscopieën, grote krachten tot zo'n 100 N, worden uitgeoefend op de maxillaire snijtanden of, bij afwezigheid hiervan, op het maxillaire tandvlees. Opmerkelijk is bovendien dat de krachten uitgeoefend op de snijtanden groter blijken te zijn dan de krachten op het tandvlees bij tandeloze patiënten. De resultaten geven aan dat anesthesiologen de tanden als steunpunt gebruiken tijdens laryngoscopie hetgeen beschouwd wordt als een onjuiste techniek die typisch zou zijn voor beginners. In deze studie verklaren wij waarom dit gedaan wordt; het blijkt de meest efficiënte methode te zijn om een optimaal zicht op de ingang van de trachea te krijgen. Bovendien wordt door ons verklaard waarom anesthesiologen zich niet bewust zijn van de hoeveelheid kracht die zij tijdens laryngoscopie op de tanden uitoefenen.

Hoofdstuk 7 behandelt het effekt van de mate van ervaring op de uitvoering van de laryngoscopie en wel in het bijzonder op het effekt op de krachten die op de tanden worden uitgeoefend. Vijf groepen deelnemers met een verschillende mate van ervaring werden geselecteerd. Elke groep bestond uit 15 deelnemers; 1) anesthesiologen, 2) arts-assistenten anesthesiologie, 3) anesthesie medewerkers, 4) chirurgen en 5) medische studenten. Alle laryngoscopieën werden uitgevoerd op een intubatie fantoom. De resultaten geven aan dat het effekt van de mate van ervaring op de duur van de laryngoscopie slechts gering is. Bovendien kon een groot effekt van de mate van ervaring op de krachten op de maxillaire voortanden niet aangetoond worden. Wel werd door ons aangetoond dat in de meerderheid van de laryngoscopiën grote krachten op de maxillaire voortanden van het fantoom werden uitgeoefend waardoor onze eerdere observaties bij patiënten bevestigd werden.

Als algemene conclusie van de biomechanische studies kan worden gesteld dat enkele huidige denkbeelden omtrent laryngoscopie aan revisie toe zijn. Zo blijken de tijdens laryngoscopie op de tanden uitgeoefende krachten, welke tevoren niet gemeten konden worden, vele malen groter te zijn dan werd aangenomen. Hierbij dient echter niet onvermeld te blijven dat de methoden om krachten te meten, zoals gebruikt in deze studies, een beperkte nauwkeurigheid hebben hetgeen met name het inzicht bij individuele metingen beperkt. Bovendien zijn er nog steeds krachten die niet gekwantifiseerd kunnen worden. Hierbij valt te denken aan krachten die verlopen in het vlak dwars op de as van het handvat van de laryngoscoop. Deze krachten zouden een belangrijke rol kunnen spelen bij het optreden van tandletsels en gerelateerd kunnen zijn aan het ervaringsniveau van de intubant. Vanwege deze maar ook om andere redenen is het biomechanische beeld achter deze procedure nog steeds onvolledig ofschoon het wel duidelijk verbeterd is. Dit benadrukt het belang van vervolg studies die zouden kunnen leiden tot verbeteringen in het ontwerp van laryngoscopen en de manier waarop we er mee omgaan, hetgeen uiteindelijk zal leiden tot een vergroting van de veiligheid van de patiënt.

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