APPARATUS

Forces acting on the maxillary incisor teeth during laryngoscopy using the Macintosh laryngoscope

M. J. L. BUCX, C. J. SNIJDERS, R. T. M. VAN GEEL, C. ROBERS, H. VAN DE GIESSEN, W. ERDMANN AND T. STIJNEN

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.

Key words

Equipment; laryngoscope.

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 (MI) [2, 3]; damage to teeth is reported to be the most common single reason for complaints against anaesthetists [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 evaluation of the laryngoscopy technique has not been possible [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 of 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 during laryngoscopy [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 direct observation. 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 prevention of 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.

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Methods
Measurement of the forces on 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 completely 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 could 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 on the teeth exceed the forces on the tongue, the reading will become negative.

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 and compressive underneath. 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:

$$Fs + Fm - Ft = 0 \qquad (1)$$

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:

$$Fm = -Fs + Ft \qquad (3)$$

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 (Fig. 1):

$$Fm = (Fs \times b - Ms)/(a - b)$$

$$Ft = (Fs \times a - Ms)/(a - b)$$

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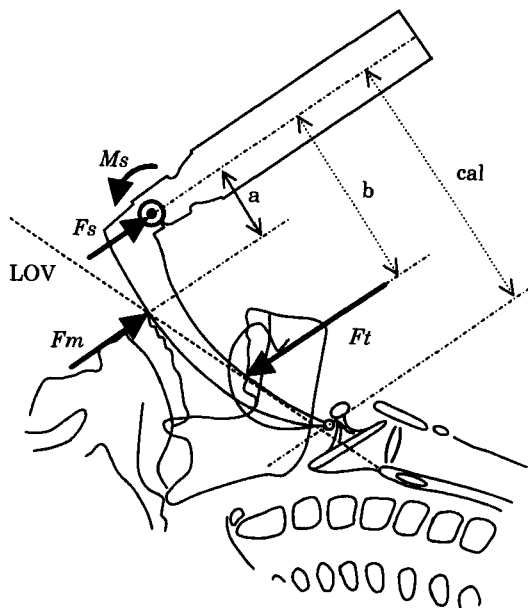
Fig. 1. Biomechanical model of the forces applied during laryngoscopy: moment (*Ms*) and force (*Fs*) are exerted by the sensor on the blade. Force is applied by the maxillary incisor teeth (*Fm*) and the tongue (*Ft*) on the blade. cal, calibration length; LOV, line of vision; *a* and *b*, distance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

the physical characteristics of the patients in whom *Fm* and *Ft* will be determined (measurement group). By placing a scale on 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% CI 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 the 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 formulae describing *Ft* and *Fm*. It was 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 in the handle of the laryngoscope. During measurement, the analogue signal of both sensors was digitised with a sampling 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 min.

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, imitating 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 standardised 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 standardised 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
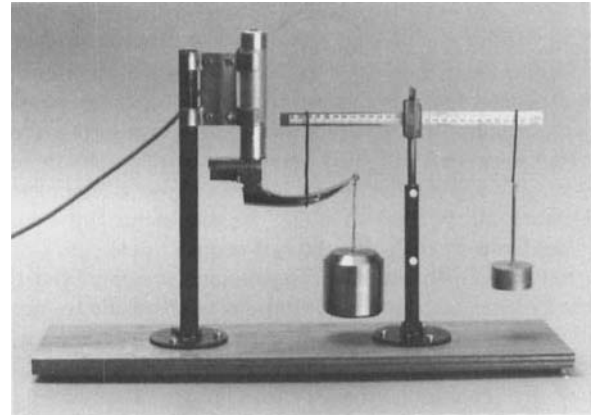

Fig. 2. Test-frame allowing the application of two forces at two different positions in opposite directions on the blade. In this example, at the tip of the blade a downward directed force of 19.6 N is applied. At 4 cm from the tip, an upward directed force of 5.0 N is applied, resulting from a suspended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

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
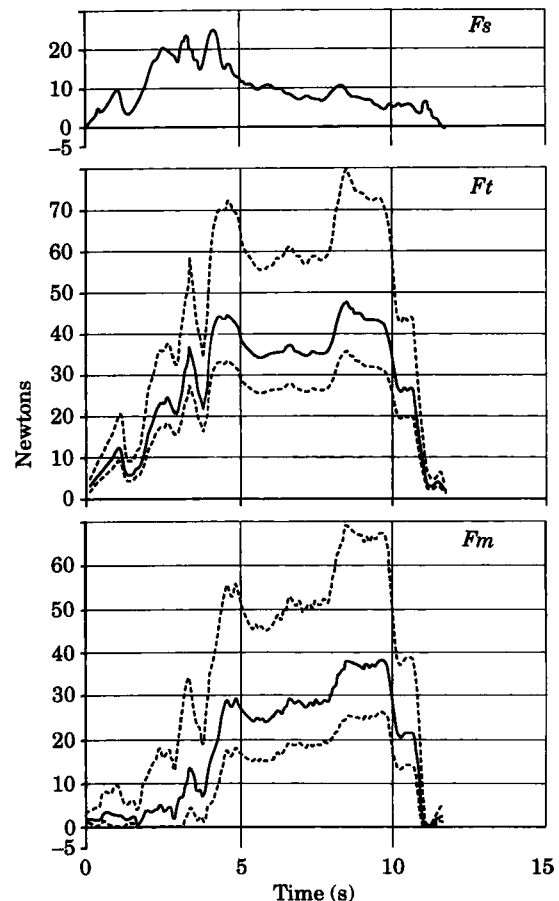

Fig. 3. Typical recording of the forces applied during laryngoscopy. *Fs*, force of blade on sensor; *Ft*, force of blade on tongue; *Fm*, force of blade on maxillary incisors. The 95% confidence intervals of *Fm* and *Ft* are shown (dotted lines).

addition, it calculated maximal and mean values and the areas under the curves.*

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 tracheal intubation was expected. Patients in whom tracheal intubation proved difficult or was not achieved at first attempt, were not studied. Before laryngoscopy the patient's head was placed in the 'sniffing' position. A Macintosh blade size 3 (Penlon Ltd) was used in all patients.

In order to minimise bias the anaesthetists 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 anaesthetist during laryngoscopy, asked no questions about levering on the maxillary incisors or 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 patients' age, weight, height, gender and the presence or absence of maxillary and mandibular incisor teeth were noted.

Laryngoscopy was performed, in the measurement group, by 12 staff anaesthetists each of whom carried out a minimum of four and a maximum of six laryngoscopies. In patients in the reference group, laryngoscopy was performed by the investigators (M.B., R.v.G., C.R.). Laryngoscopy was graded using the system of Cormack and Lehane [12]: grade 1, most of the glottis visible; grade 2, less than half of the vocal cords visible; grade 3, only the epiglottis visible; grade 4, not even the epiglottis visible. The intubating conditions were scored as follows: 3 = excellent (jaw relaxed, vocal cords abducted, no movement), 2 = good (same as 3, except slight cough or movement), 1 = poor (jaw poorly relaxed, vocal cords moving, bucking), 0 = unable to intubate [13, 14].

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

Statistical analysis

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 were performed. In addition, univariate regression analysis was used to examine 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 subject to logarithmic transform-

*The computer program was written by our group and is available from the author on request.

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

	Measurement	Reference
n	65	75
Age; years	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 incisor teeth

ation to obtain approximate normal distribution when appropriate.

Results

Two patients in the reference group were not studied; 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 omitted as tracheal intubation was not possible 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 cm 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 ($a = 11.9 - 0.04 \times$ 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 ($b = 16.4 - 0.03 \times$ height) ($p = 0.002$) ($r = -0.35$), gender (mean (SD) b in men was 10.5 (1.00) 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 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 forces in 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 Fs mean results.

Table 2. Mean (SEM) (range) 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

Concerning the forces on the maxillary incisors, with a probability 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 laryngoscopic forces 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 × 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 × Fmmax + 17.2) (p < 0.0001) (r = 0.87) and between Ftmean and Fmmean (Ftmean = 0.77 × Fmmean + 12.3) (p < 0.0001) (r = 0.87).

The difficulty of laryngoscopy was scored as grade 2 in four patients, the other 61 patients were scored as grade 1. The intubation conditions were excellent in 56 patients, good in eight patients and poor in one patient.

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

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 anaesthetists 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 anaesthetists 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 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 true. 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 were 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 in the measurement group, it is likely that their application points were also similar.

Having shown that, on occasions, anaesthetists find it necessary to 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, will not improve the view. 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 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 of 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 cannot be moved beyond the inner boundary of the jaw (Fig. 4), and as there will always be soft tissues compressed between the blade and this inner boundary, the extreme upward point of movement is positioned slightly down to 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 cannot 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 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 of the glottis. Naturally, this does not mean this is always the preferred technique. In many
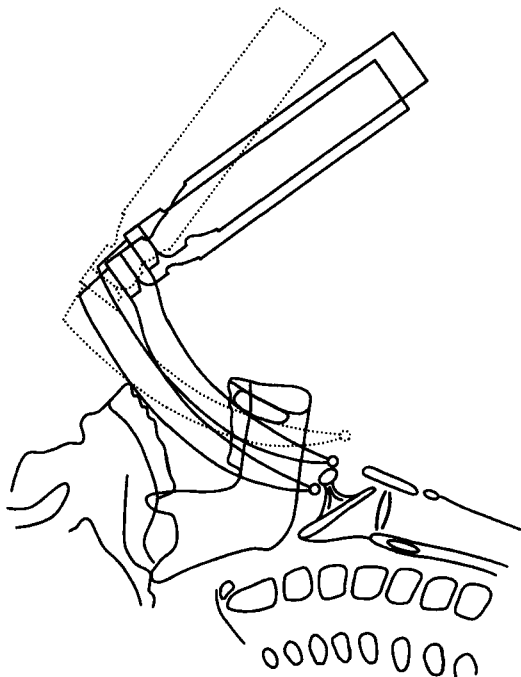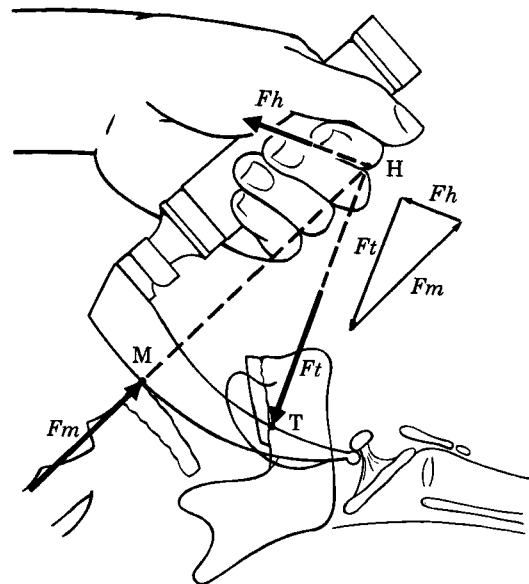

Fig. 5. Diagram showing the forces applied by the anaesthetist when no moment is exerted at the wrist; the forces exerted by the hand are magnified and passed on to the teeth. *Fh*, force exerted by the hand; *Ft*, force of blade on tongue; *Fm*, force of blade on maxillary incisors.

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 good 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 visualised are 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 laryngoscopes which can provide additional lift at the tip of the blade and new designs have been reported [19, 20].

This investigation shows that many anaesthetists have a poor awareness of the large forces which they sometimes apply to the maxillary incisors. The reason may be that the human hand is not designed to exert large moments to the handle of a 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 when 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 HTM. The triangle of forces shows the mutual proportion of *Fh* and *Fm*, which in this example reflects a magnification of more than two times. In this situation, the force on the teeth will even exceed the force on the tongue! Although this is an extreme example, the majority of anaesthetists are probably unaware of the manner in which the forces become magnified.

Do experienced anaesthetists differ from novices in respect of the forces they apply to the maxillary incisors? Recently, it was observed that these were similar and not

Fig. 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 compressed between the blade and the inner boundaries of the lower jaw.

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 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.

Acknowledgments

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