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Reshaping the Macintosh blade using biomechanical modelling  A prospective comparative study in patients

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Summary
It has been demonstrated that during routine use of the Macintosh blade, great forces are exerted on the maxillary incisors. The aim of this study was, by using biomechanical modelling, to modify a standard Macintosh blade in order to reduce these forces. This resulted in a Macintosh blade with a reduced proximal flange. Five anaesthetists performed tracheal intubation in 46 patients using the modified (n = 24) or the standard blade (n = 22). The mean (SD) maximal forces exerted on the maxillary incisors were 12.7 (8.8) N in patients in the modified Macintosh group compared to 25.5 (17.8) N in the standard Macintosh group (p = 0.008). These results demonstrate that reducing the proximal step of the Macintosh laryngoscope results in a reduction of the forces exerted on the teeth and suggest that laryngoscope blades with a high proximal step might be more traumatic than blades in which the proximal step is reduced.

Keywords Anaesthetic techniques; laryngoscopy. Equipment; laryngoscopes. Intubation, tracheal; technique. Larynx; laryngoscopy.

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The Macintosh laryngoscope blade is widely used despite evidence that during its routine use large forces are exerted on the maxillary incisors [1–3]. As a result one of the most frequent complications arising from its use – and that of many other blades – is dental damage [1, 4, 5]. This results from contact between the blade and the teeth and is related to the experience of the intubator [6], anatomical characteristics of the patient's upper airway and the design of the blade. In 1943 Macintosh stated that 'the precise shape or curve of the blade does not seem to matter much . . .' [7]. Thus, the design of the Macintosh laryngoscope has been relatively arbitrary and the same holds for laryngoscope blades in general [8]. Detailed evaluation of the performance of any particular laryngoscope blade is rarely performed and critical analysis virtually nonexistent [2].

Problems of standardisation and reproducibility arise from practical methods of laryngoscope evaluation [8] and, until recently, it has not been possible to quantify some important aspects of the laryngoscopic procedure, such as the forces applied on the tongue and the teeth. It has, therefore, been concluded that a successful evaluation of laryngoscope blades must have a sound theoretical basis [8, 9]. This aspect was first reported by Marks and colleagues [8].

The aims of the present study were: (1) to use biomechanical modelling to modify a standard Macintosh blade (size 3) in such a way as to reduce the forces exerted on the teeth, while preserving its favourable characteristics and (2) to compare the modified and standard blades. For an objective comparison between the blades, a previously described measuring laryngoscope [3] was used to determine the forces on the tongue and on the teeth.

Methods
Modifying the Macintosh blade
During laryngoscopy, in the majority of dentate patients, the flange of the blade will come into contact with the
maxillary incisors, thus creating the potential for damage. When considering changes in the design of the blade to possibly reduce dental damage, it is important to understand the function of this flange which is to guide instrumentation and deflect interfering tissues such as the tongue [1, 2]. This suggests that the flange, or more precisely the height of the step of the flange, should be prominent only along that part of the blade which is in contact with these tissues. However, in patients in the supine position, at the maxillary incisors there are no tissues to be deflected to keep a clear view (Fig. 1). Therefore, at this position reducing the step of the flange, or simply eliminating it, would not be expected to affect the view obtained. This reduces the risk of damage because the distance from the incisors to the blade will be increased (Fig. 1). Thus, a Macintosh blade size 3 (Penlon Ltd) was modified by reducing the web to a minimum starting 8.0 cm from the tip of the blade (Fig. 2) [3].

Reducing the ‘step’ at this position might have another advantage. When the incisor teeth are contacted during laryngoscopy with the modified blade, the view of the glottis may become blocked, forcing the anaesthetist to abandon the attempt and remove the contact. In contrast, with the standard Macintosh blade, the web at the maxillary incisors, guarantees an unobstructed, deep view of the oral cavity whether or not the teeth are touched by the blade [3]. Another advantage of the reduction of the step at this position is that it allows more backward rotation of the handle before the teeth are contacted, enabling a greater degree of forward displacement of the hyoid bone and increased elevation of the epiglottis [3] (Fig. 1). However, this manoeuvre may well make introduction of the

Figure 1 Diagram showing the standard (continuous lines) and the modified Macintosh blade (broken line) projected on top of each other at full exposure of the glottis. In addition, the modified blade (dotted lines) is shown with its flange in contact with the teeth, effectively occluding the view on the glottis. The extra forward displacement of the tip with this manoeuvre is shown. LOV, line of vision; the cross-hatched area represents soft tissues compressed between the blade and the mandible.

Figure 2 Photograph showing the standard Macintosh blade (top) and the modified blade (bottom).
tracheal tube into the oral cavity more difficult as there will be less space in which to manipulate it.

After approval by the hospital Ethics Committee, 46 patients scheduled for elective surgery, in whom no difficulty with laryngoscopy and tracheal intubation was expected, consented to participate. The study was carried out in the first half of 1994. Before starting the study, five staff anaesthetists, who were unaware of the specific details, were selected and allowed to perform 4–6 laryngoscopies with the modified blade. During the study, these anaesthetists were asked whether any difficulty was expected during laryngoscopy and tracheal intubation. Providing none was expected, the patients were randomly allocated to two groups: group 1, laryngoscopy to be performed with the modified Macintosh blade (modified Macintosh group), and group 2, laryngoscopy to be performed with the standard Macintosh size 3 (standard Macintosh group). When the first attempted laryngoscopy was unsuccessful, the second attempt had to be performed using the standard blade. The result of each intubation attempt was recorded. Premedication and anaesthetic technique were left to the anaesthetist responsible for the patient; only the use of nondepolarising neuromuscular blocking drugs was mandatory. Laryngoscopy was performed 3.5 min after administration of the neuromuscular blocking drug. Standard monitoring of the patient took place throughout the study period.

The duration of laryngoscopy and the forces applied were determined using a recently described measuring laryngoscope [3]. Between the handle and the blade of this laryngoscope a combined moment and shear force sensor, based on the strain gauge technique, is positioned. This configuration of sensors allows an estimation of the forces applied on the tongue ($F_t$) and on the maxillary incisors ($F_m$), provided that the application points of these forces on the blade are known. In patients without maxillary incisors, $F_m$ represents the force on the maxillary gums. During measurement the data are stored on a memory card for later analysis, so that no-one is aware of the results. It was recognised that the patient’s head showed a strong tendency to anteflexion when the modified blade was used. This was in contrast to the standard Macintosh. The anaesthetic nurses were instructed, when necessary, to counteract this movement by exerting gentle pressure on the patient’s forehead. When anteflexion of the head occurred this was noted, as well as when this anteflexion was counteracted by the nurse. In addition, any occasion when the nurse had to retract or move the patient’s lips to allow a clear view was recorded.

The intubator was asked to grade the view on the basis of which (and how much of the) structures in the larynx—pharynx area of the patient were identified. This was graded according to the scheme proposed by Cormack & Lehane [10]; 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.

During laryngoscopy, in order to minimise bias, the investigator refrained from commenting on the laryngoscopic technique.

**Statistical analysis**

To test for differences between groups, the unpaired Student’s $t$-test, Chi-squared or Fisher’s exact test were used. In addition, multiple regression analysis was used to test for differences in the laryngoscopic factors between groups, correcting for the presence of maxillary incisors. Logarithmic transformation to obtain approximately normal distribution was performed when appropriate.

The relation between the tendency towards anteflexion of the head and the forces applied on the maxillary incisors was studied by means of the Spearman rank correlation test. A $p$ value <0.05 was considered statistically significant.

**Results**

There were no relevant differences between the groups (Table 1), except for a higher percentage of patients in the modified Macintosh group in whom the maxillary incisors were present (67%) compared with the standard Macintosh group (50%).

Table 2 presents the laryngoscopic factors of patients in both groups at first attempt, irrespective of the result. The Student’s $t$-test showed that there were no significant differences between the groups for the duration of laryngoscopy and forces exerted on the tongue but that the maximum and mean forces on the teeth were lower in the Macintosh group ($p = 0.008$ and $p = 0.001$, respectively). However, correction by multiple regression analysis for the imbalance between the groups in the distribution of the maxillary incisors showed that the maximum and mean forces on the tongue were lower in the modified Macintosh group ($p = 0.03$ and $p = 0.02$) and for the rest confirmed the results of the Student’s $t$-tests.

**Table 1** Patient characteristics. Values are mean (SD) [range] where appropriate.

<table>
<thead>
<tr>
<th></th>
<th>Modified Macintosh blade</th>
<th>Standard Macintosh blade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men: women</td>
<td>9:15</td>
<td>9:13</td>
</tr>
<tr>
<td>Age; years</td>
<td>45 (16.7) [21–77]</td>
<td>52 (14.8) [29–79]</td>
</tr>
<tr>
<td>Height; cm</td>
<td>169 (6.7) [158–182]</td>
<td>171 (8.8) [154–188]</td>
</tr>
<tr>
<td>Weight; kg</td>
<td>73 (10.2) [52–94]</td>
<td>71 (12.4) [50–88]</td>
</tr>
<tr>
<td>Maxillary incisors present: absent</td>
<td>16:8</td>
<td>11:11</td>
</tr>
</tbody>
</table>
In four patients in the modified Macintosh group, tracheal intubation was unsuccessful at the first attempt. In all four patients maxillary incisors were present; in three a grade 1 view of the glottis was obtained and in the other a grade 3 view. There was a moderate tendency toward anteflexion in three patients and a strong tendency in the other. The anteflexion required countermeasures in all four patients. None of the four anaesthetists concerned were able to give a satisfactory explanation for the failures. The second intubation attempt, using the standard Macintosh blade, was successful in all four patients. At the cost of an increase in force on the teeth and the tongue, the patient with a grade 3 view improved to grade 2. The view of the glottis in the three other patients, as well as the forces applied, remained the same. Anteflexion of the head did not occur in any of these four patients.

Table 3 presents the laryngoscopic factors of patients in the modified Macintosh group at the first and second attempt at tracheal intubation. In contrast to the modified Macintosh group, tracheal intubation was successfully performed in all patients in the standard Macintosh group. The difference in intubation success between the groups, however, did not reach statistical significance (p = 0.68).

At the first intubation attempt, in patients of the modified Macintosh group anteflexion of the head was absent in one, moderate in 12 and severe in 11 patients. In the standard Macintosh group, the numbers of patients were 20, 2 and 0, respectively (p < 0.0001). Anteflexion was counteracted in 17 (71%) patients of the modified Macintosh group and in only one patient (5%) of the standard Macintosh group (p < 0.0001). There was a statistically significant relationship between the tendency towards anteflexion and the mean forces exerted on the maxillary incisors ($r = -0.42, p = 0.004, n = 46$).

At the first intubation attempt, the upper lip was retracted or moved out of the way by an assistant in 17 (71%) patients in the modified Macintosh group and in 13 patients (59%) in the standard Macintosh group (p = 0.40).

**Discussion**

The results of this study indicate that reducing the flange at the proximal end of the Macintosh blade results in a view of the glottis being graded in 20 patients as grade 1, in two patients as grade 2 and in two other patients as grade 3. In the standard Macintosh group, the numbers of patients were 19, 2 and 1, respectively (p = 0.68).

### Table 2
Mean (SD) [range] laryngoscopic factors at the first tracheal intubation attempt.

<table>
<thead>
<tr>
<th></th>
<th>Modified Macintosh blade (n = 24)</th>
<th>Standard Macintosh blade (n = 22)</th>
<th>p*</th>
<th>p†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of laryngoscopy, s</td>
<td>16 (7.9) [5–33]</td>
<td>13 (5.5) [7–26]</td>
<td>0.16</td>
<td>0.24</td>
</tr>
<tr>
<td>$F_{\text{tmax}}$, N</td>
<td>42 (14.6) [16–68]</td>
<td>47 (16.0) [23–83]</td>
<td>0.23</td>
<td>0.03</td>
</tr>
<tr>
<td>$F_{\text{tmean}}$, N</td>
<td>23 (7.8) [8–36]</td>
<td>26 (8.0) [12–42]</td>
<td>0.15</td>
<td>0.02</td>
</tr>
<tr>
<td>$F_{\text{mmax}}$, N</td>
<td>13 (8.8) [3–34]</td>
<td>26 (17.8) [4–73]</td>
<td>0.008</td>
<td>0.007</td>
</tr>
<tr>
<td>$F_{\text{mmean}}$, N</td>
<td>4 (2.8) [0–12]</td>
<td>12 (8.3) [1–31]</td>
<td>0.001</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

* p values without correction for differences between groups in presence of maxillary incisors (Student’s t-test). † p value after correction for differences between groups in presence of maxillary incisors (multiple regression analysis). $F_{\text{tmax}}$ – maximum force on the tongue; $F_{\text{tmean}}$ – mean force on the tongue; $F_{\text{mmax}}$ – maximum force on the maxillary incisors; $F_{\text{mmean}}$ – mean force on the maxillary incisors.

### Table 3
Mean (SD) [range] laryngoscopic factors in patients in the modified Macintosh group.

<table>
<thead>
<tr>
<th></th>
<th>First intubation attempt (modified Macintosh blade)</th>
<th>Second intubation attempt (standard Macintosh blade)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Successful</td>
<td>Unsuccessful</td>
</tr>
<tr>
<td>Duration of laryngoscopy, s</td>
<td>14 (6.8) [5–33]</td>
<td>26 (3.7) [22–30]</td>
</tr>
<tr>
<td>$F_{\text{tmax}}$, N</td>
<td>39 (13.2) [16–62]</td>
<td>57 (8.3) [45–68]</td>
</tr>
<tr>
<td>$F_{\text{tmean}}$, N</td>
<td>22 (7.2) [8–35]</td>
<td>30 (6.3) [20–36]</td>
</tr>
<tr>
<td>$F_{\text{mmax}}$, N</td>
<td>11 (7.0) [3–27]</td>
<td>22 (9.4) [8–34]</td>
</tr>
<tr>
<td>$F_{\text{mmean}}$, N</td>
<td>3 (2.6) [0–12]</td>
<td>6 (2.1) [3–9]</td>
</tr>
</tbody>
</table>

$F_{\text{tmax}}$ – maximum force on the tongue; $F_{\text{tmean}}$ – mean force on the tongue; $F_{\text{mmax}}$ – maximum force on the maxillary incisors; $F_{\text{mmean}}$ – mean force on the maxillary incisors.

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reduction of the forces exerted on the maxillary incisors, confirming our biomechanical concept. The effect of this modification has been predicted previously \[2, 11\] but this is the first study in which the effect is demonstrated. However, as some anaesthetists still applied significant forces on the maxillary incisors using the modified blade, leveraging on these teeth is still not eliminated. Apparently, the concept of 'built-in safety' originating from our two-dimensional models has its limitations when the actual laryngoscopic manoeuvre in three dimensions is concerned; the line of vision used by the anaesthetist might be angled in the sagittal plane, explaining the results obtained.

Another result of the modification of the blade was that the head of the patient showed an increased tendency towards anteflexion which required counter-balancing. This can be explained by studying the forces acting on the head in relation to the centre of rotation, which is in the occipitoatlantoaxial complex \([R]\) (Fig. 3). The forces exerted by the blade on the tongue \((F_t)\) will induce a moment at the centre of rotation \((R)\) which, when unopposed, will result in anteflexion of the head. However, this moment will be counterbalanced by moments resulting from the weight of the head \((F_g)\), friction between the head and the pillow, downward directed forces on the forehead by an assistant and forces exerted by the blade on the maxillary incisors \((F_m)\). When the modified Macintosh laryngoscope was used the maxillary incisors were subject to lower forces than with the standard blade and so there was a tendency towards anteflexion. Anteflexion of the head will restrict the visualisation of the glottis because a greater part of the tongue will lie behind (posterior to) the line of vision.

Although there was no statistical difference in the success of intubation between the blades, the possibility that a larger study might reveal a difference cannot be discounted. The most likely explanation for the four failures is the increased tendency for anteflexion to occur. In addition, when using the modified blade less force on the tongue is needed to visualise the glottis and this reduces the space available for manipulation of the tracheal tube. An anaesthetist who is unaccustomed to the blade and who may be insufficiently aware of its characteristics may find it difficult to pass the tube despite having a good view of the
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