TECHNOLOGY, COMPUTING, AND SIMULATION

The Effectiveness of Preformed Tooth Protectors During Endotracheal Intubation: An Upper Jaw Model

Enrico Monaca, MD*, Norbert Fock, MD†, Manfred Doehn, MD*, and Frank Wappler, MD*

From the *Department of Anesthesiology and Intensive Care Medicine, Hospital Cologne-Merheim, University of Witten/Herdecke, Germany; and †Department of Oral and Maxillofacial Surgery (OMS), University of Vienna, Austria.

Address correspondence and reprint requests to Enrico Monaca, MD, Department of Anesthesiology and Intensive Care Medicine, Hospital Cologne-Merheim, University of Witten/Herdecke, Ostmerheimer Str. 200, D-51109 Köln, Germany. Address e-mail to MonacaE@Kliniken-Koeln.de.

Abstract

BACKGROUND: In anesthetic practice, tooth damage may impair patient safety and is a common reason for litigation. The use of dental shields may reduce this complication. In this study, we examined the effectiveness of dental shields for altering the force on the teeth during endotracheal intubation.

METHODS: Five preformed dental shields (Endoragard, Ormco, Nouveau Dispositif (ND), PEB, and Camo) were evaluated in three different categories: (a) horizontal force reduction, (b) axial force reduction, and (c) impact on the view of the oral cavity. Force reduction was examined by using an upper jaw model. The upper incisors of the model were covered with each of the dental shields and then loaded with a force of 150 N via a blade of a laryngoscope directed to the maxillary left central incisor (tooth 9). The force distributed to the four maxillary central and lateral incisors by the dental shield was also measured by strain gauges placed to estimate the force applied to each tooth. The reduction in oral view was determined by measuring the thickness of each dental shield with a micrometer.

RESULTS: Dental shield Ormco Sports-Guard achieved the highest force reduction results, followed by Camo and Endoragard. ND and PEB showed poor, but statistically significant, force reduction with either the worst axial (ND) or horizontal (PEB) results. In contrast, Ormco was the most voluminous model, followed by ND and Camo. PEB and Endoragard were the thinnest models.

CONCLUSIONS: Preformed dental shields are useful to reduce the force applied to the teeth and potentially reduce the probability of tooth damage during laryngoscopy. However, the shield with the most force reduction capability is rather large and also expensive, making general use impossible. Further prospective studies are needed to evaluate efficacy and safety of tooth protectors.
Introduction

Tooth damage accounts for many adverse events in anesthetic practice (1–3), and is the most common reason for litigation against anesthesiologists (4,5). The incidence of dental injury varies among studies, with documented rates from 0.05% to 12.1% (6,7). About 75% of dental injuries occur during endotracheal intubation, whereas 16% are observed during extubation, and 9% in the recovery phase (7). In patients with severe periodontal disease, even the placement of an oral airway or a laryngeal mask might provoke a dental luxation (8). Numerous studies have shown that the upper incisors are at greatest risk for damage (9). It has also been demonstrated that dental prostheses and restored teeth are more susceptible to injury (10,11).

Poor technique can lead to injury, such as when the upper incisors are used as a fulcrum. However, dental injury may also occur in the case of a difficult intubation or in emergency situations when endotracheal intubation is a life-saving procedure and securing the airway takes precedence over protecting the teeth (12).

Different devices have been proposed to protect the teeth during direct laryngoscopy. Improved laryngoscope designs, e.g., the "Dental Protector Blade" (13), the "Improved Laryngoscope Blade" (14), or the "Callander Laryngoscope Blade" (15) were proposed to reduce dental lesions. These laryngoscope designs have become widely accepted into clinical practice. Two types of dental shields have also been developed. One of these consists of individually adaptable shields using thermoplastic material, cellulose-acetate foil, or ethylenevinyl-acetate. The other group is preformed dental shields, which are the type examined in this study. These shields are fast and convenient; however, individual adaptability to the upper jaw may be limited or impossible.

There are no data that document which model of dental shield is most effective at reducing the risk of tooth damage during endotracheal intubation. The present study was designed to compare different preformed shields in an experimental setting using a modified upper jaw model.

METHODS

In this experimental study, an upper jaw model introduced by Frasaco (Tettnang, Germany) was used to simulate conditions that may affect the front teeth during endotracheal intubation and to measure axial and sagittal paraxial forces at each incisor (Fig. 1). The tooth-jaw connections of the model were relatively rigid, and natural tooth movement was simulated by embedding the teeth in a silicone layer (Sta-Seal, Dentax Company, Karlsruhe, Germany).

Figure 1. Arrangement of the upper jaw model without a dental shield in the test equipment. The arrow directs to tooth 9.
The maxillary central and lateral incisors (teeth 7—lateral right, 8—central right, 9—central left, and 10—lateral left), which are the most frequently injured, were fitted with strain gauges (Type 6/120 LD20, Hottinger Baldwin Messtechnik, Darmstadt, Germany). The gauges were fixed with a special adhesive medium (HBM Z 70, Hottinger Baldwin Messtechnik, Darmstadt, Germany) on the lingual side of each tooth (Fig. 1). For measurement of the horizontal acting forces, strain gauges were aligned at the transition of the mesial and distal crown root similar to the enamel-cement border of a natural tooth. The gauge-connecting cables were shifted so that a correct measurement could be ensured. For measurement of the forces acting in axial direction, a screw was inserted into the lower root portion of the respective synthetic tooth. The extended root axis of the tooth was connected with a copper strip, which was arranged and fastened in the chewing plain (Fig. 2). These copper sheet strips were also affixed to strain gauges using the special adhesive. The axial load of the incisors could now be measured by buckling of the copper sheet strips and measuring the stretching of the strain gauges fastened to them.

The measurements were performed using material test equipment (Mod. 1441, Zwick Company, Einsingen über Ulm, Germany). The upper jaw model was positioned on the measuring table so that the force exerted by the laryngoscope blade was applied to the maxillary central left incisor, tooth 9, (Fig. 1) covered by each of five dental shields consecutively (Fig. 3; Table 1). The shields were positioned between the blade and the upper jaw. The strain gauges were connected to an amplifier (SAK 34, Bedo Company, Neuss, Germany). Data were transmitted to a computer and processed by evaluation software (Signalys Company, Ziegler-Instruments, Moenchengladbach, Germany), which produced a graphic recording from each strain gauge. The equipment was temperature-calibrated between 23.9°C and 24.8°C before measurements were taken to avoid spreading of results caused by the temperature sensibility of the strain gauges. Then, the force calibration process started with the positioning of the measuring table to ensure that axial and horizontal components of the loading force were initially of the same value (150 N) without a dental shield. This was ensured with a tripod—measuring table—angle of 25 degrees.

Figure 2. Sectional drawing of one tooth of the upper jaw model.

Figure 3. Compilation of used dental shields in this study: 1—Endoragard; 2—Ormco; 3—Nouveau Dispositif; 4—PEB; 5—Camo
First, the upper jaw was loaded with a force indicated by the strain gauges of 150 N in direction to tooth 9, followed by the consecutive covering of each dental shield. Each measurement was performed over 16 s. The loading force was applied gradually over 10 s and the maximum load maintained for 1 s. The unloading phase was 5 s thereafter. The resulting voltage changes generated by the strain gauges, and thus horizontal and axial force reduction as well as force distribution from teeth 7 to 10, was simultaneously recorded. Each measurement was taken 10 times.

The reduction of the incisor cutting edge distance was measured by evaluating the thickness of the dental shield using a micrometer (Mitutoyo, Neuss, Germany). The thicker the shield, the more the view to the oral cavity could be impaired.

Data of the simultaneous recorded force reduction from teeth 7 to 10 were used for determining the force that was distributed by each dental shield from tooth 9 to the adjacent teeth. This force distribution enabled an analysis of the participation of each tooth of the loaded force. Four of the five dental shields (without Nouveau Dispositif [ND]) were selected and tested for this investigation.

For each statistical comparison, an unpaired, single sided $t$-test was performed using "Stat View 4.57" software (Abacus Concepts, Inc., Berkeley, CA). First, the dental shields with the poorest results along the horizontal and axial force vector were compared with the reference load to show if even those may have significant force-reducing properties. Then, the two shields with the best force-reducing results were compared, to identify the overall best shield in the axial and horizontal direction.

## RESULTS

The dental shields used in this investigation differed markedly with respect to their ability to decrease forces applied to tooth 9 (Fig. 4). Forces transmitted to tooth 9 were reduced to $75.7 \pm 2.1\%$ (PEB) and $45.4 \pm 2.0\%$ (Ormco) in the horizontal axis, respectively, and to $67.5 \pm 1.8\%$ (ND) and $35.5 \pm 1.9\%$ (Ormco) in the axial direction. After the Ormco shield, in the order of decreasing horizontal force reduction were ND, Camo, Endoragard, and PEB shields. Second to fifth-placed shields for decreasing axial force reduction were Camo, Endoragard, PEB, and ND.

![Figure 4](image4.png)

**Figure 4.** Loading of tooth 9 with 150 N: the forces transmitted along the concerning vector using different shields. Data are presented as mean ± sd.

![Figure 5](image5.png)

**Figure 5.** Horizontal force distribution by different dental shields during loading of tooth 9 with 150 N.
Figure 6. Axial force distribution by different dental shields during loading of tooth 9 with 150 N.

The diagram of axial force distribution (Fig. 6) also showed a similar curve progression. The highest point of each curve was identified on tooth 9 representing the highest residual force. As shown in the results of horizontal distribution, no force was detected on tooth 7. In particular, the most residual force was detected with Camo (17.1 ± 0.98 N) on tooth 8, followed by Ormco (14.1 ± 1.03 N) and Endoragard (1.4 ± 0.05 N), and PEB (0 N), PEB (7.2 ± 0.18 N), Endoragard (6.7 ± 0.15 N), and Camo (0.1 N) distributed hardly any axial-directed force to tooth 10, in contrast to Ormco, which showed a residual force of 13.1 ± 0.61 N.

The incisor cutting edge distance also showed remarkable differences among shields (Fig. 7). PEB and Endoragard as the thinnest models decreased this distance by only 1.5 and 1.7 mm, whereas Ormco is the most voluminous shield with 4.0 mm reduction. Camo and ND showed values between 2.7 and 3.3 mm.

Figure 7. Reduction of the cutting edge distance by the respective tooth protection model.

DISCUSSION

Tooth-protecting measures have been recommended to reduce the incidence of intubation-related dental injuries in order to increase patient safety (10,11). Additionally, the Medical Defense Union (USA) has suggested the routine use of dental shields during intubation, and it may be expected that courts could rate this use in the future as a standard of good clinical practice (18). However, only 2% of anesthesiologists use dental shields (19). There is no question that a dental shield protects teeth from trauma, which can be caused by a direct contact of the laryngeal blade with even a small force at the wrong angle. The steel of the blade affects the enamel more often than expected, as shown by a detailed postoperative dental inspection (20). If more force is loaded, fracture of crowns or roots, partial luxation, and avulsion are frequent consequences (21). However, the relation between the force applied and the force required to provoke dental injury to a patient remains unclear. Also, diseased teeth seem to require very little force for injury. Retrospective analyses showed a decrease in dental injury when using a tooth protector (22). Therefore, the use of such devices has been proposed. However, which type of dental shield should be used is still controversial. An in vitro experimental setup to analyze sports-related dental trauma to sheep mandibular segments was described some years ago (23). Also, previous investigators measured forces at laryngoscopy by modifying laryngoscope handles in real-life situations (24). Others determined the forces on the maxillary incisors during laryngoscopy in adult patients in a clinical
setting, which were 49 N on average (25). However, experimental studies to prove evidence of force reduction of a variety of tooth protectors and to quantify the forces acting on the upper incisors have not been performed. The present study was designed to demonstrate the capability of preformed dental shields to reduce loaded force on tooth 9 and to distribute it to the adjacent tooth.

Measuring of both horizontal and axial force reduction was an essential element of this examination. The artificial reduction of multiple force vectors occurring during an intubation into two main vectors simplified the setting to support reproducible results. Nevertheless, for interpretation of the results it is important to consider that the modified Frasaco upper jaw model corresponded only to an idealized upper jaw, and that the limitations of the synthetic materials used could not exactly match the characteristics of human tissue. The use of the modified Frasaco model produced reliable results with a narrow standard deviation. Limitations of synthetic materials to match the breaking and bending characteristics of a natural tooth and its bracing in a human jaw were reduced by embedding the synthetic teeth in a silicone layer for emulating natural mobility as far as possible.

Ormco Sports-Guard was the most effective dental shield for reducing the loaded force in the axial and horizontal directions. The reason for this performance could be the possibility to adapt this model to an upper jaw individually, which is in contrast to all other designs. In addition, another shield with acceptable force-reducing capabilities, Camo, is featured with an existent, but more limited, individual adaptability than Ormco. This fact could support the preceding statement that the key for higher force reduction capability lays in the individual adaptability of a dental shield model. For example, ND, as a quite rigid and hard shield, showed an excellent horizontal force reduction, but it does not provide an equivalent axial force reduction. This hypothesis requires further studies. PEB and Endoragard seem to significantly reduce the loaded force in comparison with a pure 150 N load, but when compared with the other dental shields they could be regarded as not as effective. They may be too thin and rigid to buffer the load of a laryngoscope and to distribute the force away from tooth 9.

In the ideal case, the forces acting on a tooth should be distributed evenly over the entire row of teeth covered by a dental shield; however, none of the shields investigated achieved this goal. Force transmission to tooth 7 revealed only poor distribution abilities. Thus, a force distribution took place only on the next direct teeth 10 and 8. However, tooth 7 should also be covered by the shield for stability. It can be concluded that the size of the dental shield could be limited to cover teeth 7, 8, 9, and 10.

The usefulness of preformed dental shields is not only determined by the reduction of loaded forces, but also by a minimal reduction in the oral cavity view. The reduction of applied forces to teeth derives from material thickness. For tooth protection, it is important to consider both comfort for the anesthesiologist and protection for the patient's teeth. Increased thickness, however, is associated with a reduced view of the oral cavity. In clinical practice, this may be aggravated by other factors, e.g., patients with an already impaired mouth opening (maxillary prognathism, micropgnosia) caused by a small interdental distance or a large tongue (Marfan or Hurler-Pfaundler syndrome). A mouth opening with a diameter <35 mm is not regarded as practicable (17). Additionally, reduced oral space might be associated with a higher risk of life-threatening complications (26). Otherwise, the impairment of oral sight is only important in the case of an already reduced laryngoscopic visualization, in contrast to a protection of e.g., fragile caps in a patient with no further reduced sight. Ormco, the biggest model, not only reduced this distance by 4 mm, but Ormco's angular profile also requires additional space in the horizontal plane further compromising access. Endoragard and PEB reduced the distance by only 1.6 mm. Using a less voluminous dental shield, as e.g., Endoragard, the anesthesiologist could expect a minimal view and entrance handicap to the oral cavity. According to Aromaa et al. (10), Camo can also consume remarkable space in the oral cavity in addition to the cutting edge distance reduction. The right angular edge emerged as a relatively frequent obstacle, so during practical use it had to be cut in some cases.
In addition to these results, even though litigation could be an expensive issue, the very high cost of the Ormco protector makes general use in all patients at risk for a dental injury impractical ($23.01 per piece). Given 10,000 general anesthesia per year and an incidence of 1% of dental injury, a total amount of $230,000 would be needed to prevent 100 patients from these incidents (mean costs of $2301 per "saved" patient). However, this calculation is only correct if a dental shield protects the teeth without any failure, which still remains to be proved. Camo is less likely than Ormco to impair the oral view and entrance considering the cutting edge distance. However, its price, even half of Ormco's, is relative expensive for general use recommendation ($12.15 per piece).

Despite the evidence of force reduction and redistribution under experimental conditions, this study does not provide proof of protection from dental injury in a clinical setting. There is no obvious relationship between the force applied and the force required to cause dental injury to a patient. However, the results of this investigation show that dental shields can decrease the force of a laryngoscope affecting the upper incisors. This reduction could correspond to a protective effect, as demonstrated by a potential reduction in horizontal as well as axial forces, and thus may contribute to patient safety. However, the model with the best results in this examination could not be recommended for routine use because of cost considerations. Rather, it should be considered individually if the patient's teeth need protective measures. This could be the case in particularly endangered teeth, such as a full set of crowns or bondings on the incisors, periodontal disease, marked overbite, micrognathia, or near-edentulousness. It is also reasonable to use a dental shield during expected difficult intubation, which could lead to tooth injury.

Footnotes

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