Dental Traumatology 2006; doi: 10.1111/j.1600-9657.2006.00393.x

DENTAL TRAUMATOLOGY

Anterior palatal mouthguard margin location and its effect on shock-absorbing capability

Yamada J, Maeda Y, Satoh H, Miura J. Anterior palatal mouthguard margin location and its effect on shock-absorbing capability. © Blackwell Munksgaard, 2006.

Abstract – The purpose of this study was to evaluate the influence of a mouthguard's (MGs) anterior palatal margin location on its shock absorbing capability. A simulation study was conducted on a maxillary phantom model with maxillary teeth, bone, and soft tissue. Miniature strain gauges were attached to the labial and palatal surfaces of the right central incisor as well as the bone surface on the palatal side. MGs were made with ethylene vinyl acetate sheets, with thickness of 2.0, 3.0, and 4.0 mm, using a pressure-forming machine. The locations of the anterior palatal MG margins were set at 4.0, 2.0, and 0 mm from the cervical margin in three experimental configurations. The control situation was without a MG. A calibrated 7N of shock was applied to the middle portions of the labial and palatal surfaces of the central incisor. The amount of tooth deflection was evaluated. The results were analyzed with one-way ANOVA accompanied by the Scheffe's test and multiple regression analysis ($P < 0.05$), designating the strain as the dependent value. The results indicated that the thickness rather than the location of the anterior palatal margin of the MG has a significant influence on the reduction of tooth deflection against a horizontal blow.

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Key words: mouthguard; anterior palatal margin; shock absorption capability; thickness

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Accepted 25 May, 2005

Mouthguards (MGs) have been widely accepted as effective measures for preventing or reducing the severity of traumatic sports related dent-facial injuries (1, 2).

Although athletes are fairly well informed of the effectiveness of MGs, the actual prevalence of MG usage is not usually very high due to the discomfort they cause, and the speech and breathing difficulties associated with them (3, 4).

In order to reduce or minimize the above mentioned problems, and to increase the trauma prevention capability of MGs, it is crucial to examine the effects of thickness, outline design and border location.

In terms of reducing the speech difficulty and discomfort caused, MGs with cervical margins on the palatal side have been recommended (5). On the other hand, the shortening of the palatal side MG margin may reduce the shock absorbing capability of MGs.

The purpose of this study was to evaluate the influence of a MG's anterior palatal margin location and thickness on its shock absorbing capability using an experimental model.

Materials and methods

A simulation study was conducted on a maxillary phantom model with maxillary teeth, bone, and soft tissue (Nissin Co., Kameoka, Japan), as well as the bone surface on the palatal side. Differences in the cortical layer and cancellus bone were not simulated in this model (Fig. 1). Miniature strain gauges were attached to the labial-cervical surface and palatal-

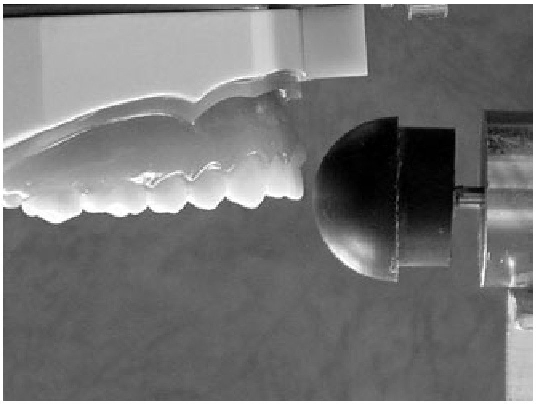

Fig. 1. Picture of a maxillary phantom model with maxillary teeth, bone, and soft tissue.

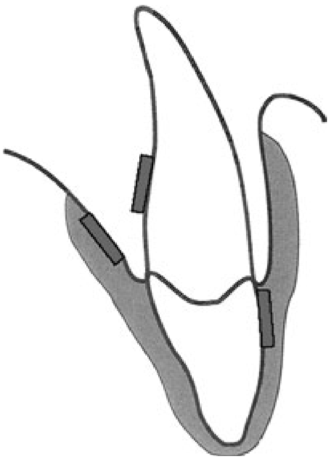

Fig. 2. Position of miniature strain gauges.

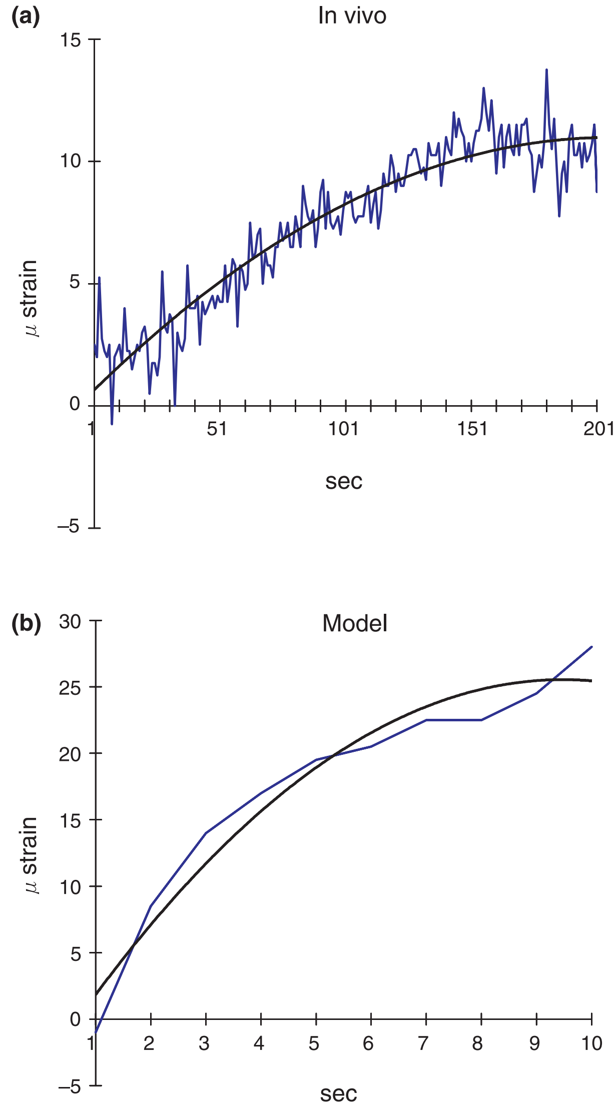

Fig. 3. The mode of deflection under the palatally directed load was the same between *in vivo* and model data. (a) *In vivo* (b) model.

root surface of the right central incisor, as well as the palatal-alveolar bone surface (Fig. 2).

To verify the simulation model, we compared model and *in vivo* tooth deflections as the preliminary study. *In vivo* measurements were performed on an adult volunteer with informed consent. Miniature strain gauges were attached to the labial-cervical surface of the right central incisor in the model. Loads were applied with the tension meter up to 1 Kgf. As shown in Fig. 3a,b, the mode of deflection under the palatally directed load was the same between the *in vivo* and model data. The amount of deflection increased in an almost linear fashion with the load increase of the *in vivo,* and a similar trend was observed in the simulation model.

A working model was prepared by making an impression of the simulator MG for MG fabrication. MGs were made from ethylene vinyl acetate (EVA) sheets (Erkoflex, Erkodent, Prazfrafenweilar, Germany), with thickness of 2.0, 3.0, and 4.0 mm, using a pressure forming machine (Erkopress, Erkodent, Prazfrafenweilar, Germany) (6). The locations of the anterior palatal MG margins were set at 4.0, 2.0, and 0 mm from the cervical margin with three different thickness sheets (Fig. 4). The labial margin of the MG was set at 4 mm from the labial-cervical margin. The posterior palatal margin was set at the cervical margin, and the distal margin was set at the distal surface of the first molar. The control situation was without a MG. A calibrated shock of 7N was applied to the middle portion of the labial surface of the right central incisor in a horizontal direction, and to the middle portion of the palatal surface of the tooth in an upper anterior direction (Fig. 5). The amounts of strain on the tooth and bone were evaluated. The results were analyzed by ANOVA with the Scheffe's test ($P < 0.05$) and multiple regression analysis ($P < 0.05$) by designating the strain as the dependent.

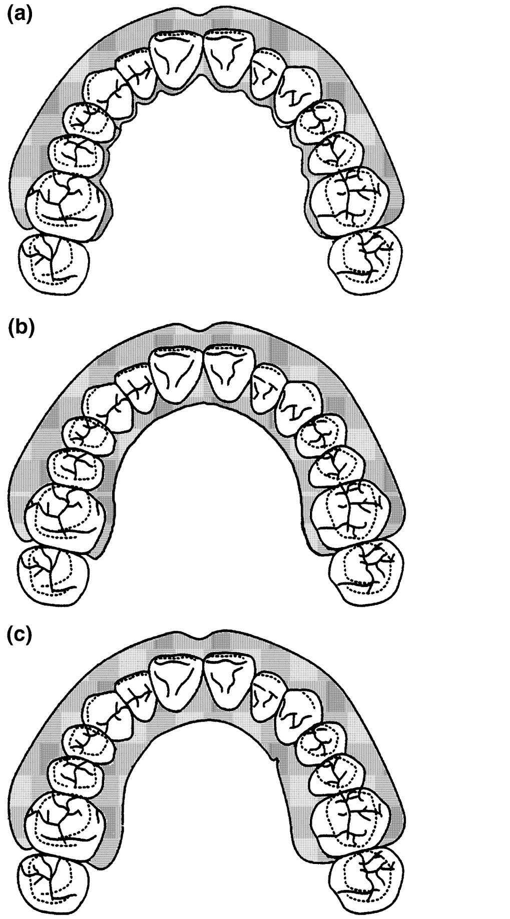

Fig. 4. Location of the anterior palatal MG margins. (a) 0 mm, (b) 2.0 mm, and (c) 4.0 mm.

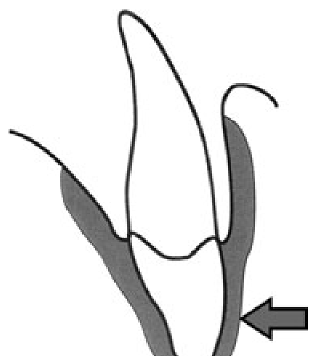

Fig. 5. A calibrated shock of 7N was applied to the middle portion of the labial surface of the right central incisor in a horizontal direction, and to the middle portion of the palatal surface of the tooth in an upper anterior direction.

Results

Figure 6a–c indicates the outputs from three strain gauges with the calibrated shock delivered from the front. Obtained strains at the labial-cervical surface

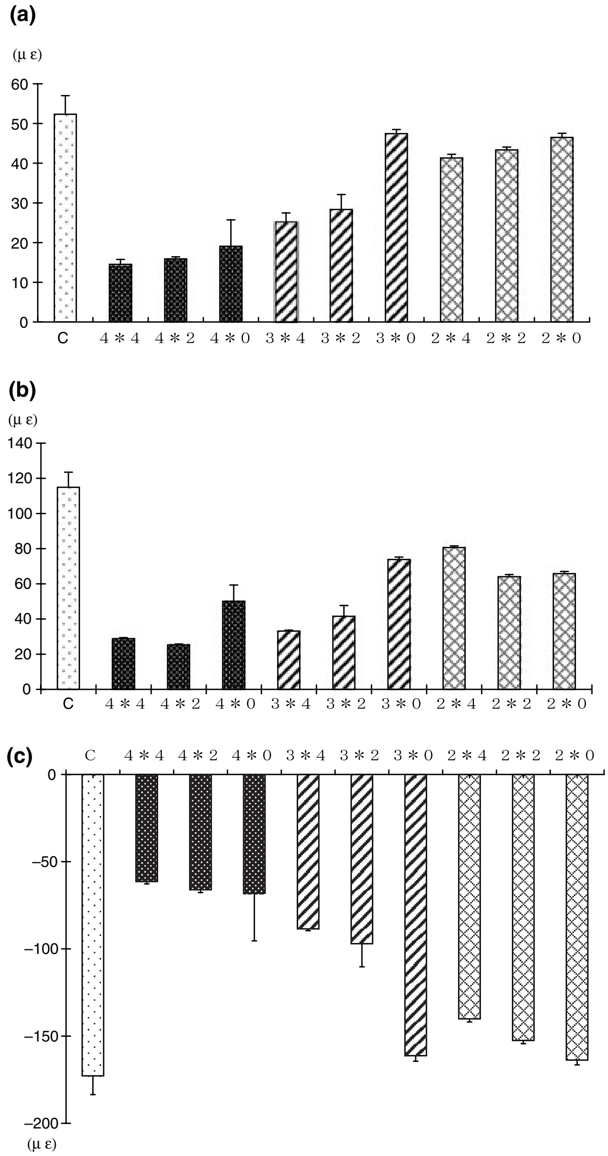

Fig. 6. (a–c) Outputs from three strain gauges with the calibrated shock delivered from the front (the thickness of the sheet * the palatal margin location). (a) Strains at the labial-cervical surface, (b) strains at the palatal-root surface, and (c) strains on the palatal-alveolar bone surface.

(Fig. 6a) and palatal-root surface (Fig. 6b) were tensile, while they were compressive on the palatal-alveolar bone surface (Fig. 6c).

MGs with a 4 mm thickness showed about 30% of the control strain value ($P < 0.05$) at the labial-cervical surface and palatal-root surface, while 2 mm thickness MGs showed no statistical difference. With 3 mm thick MGs, except for the palatal cervical margin, the stress values became statistically smaller than the control values. On the palatal root surface, 4 mm thick MGs showed the largest reduction in strain values, while 2 and 3 mm thick MGs showed smaller reductions.

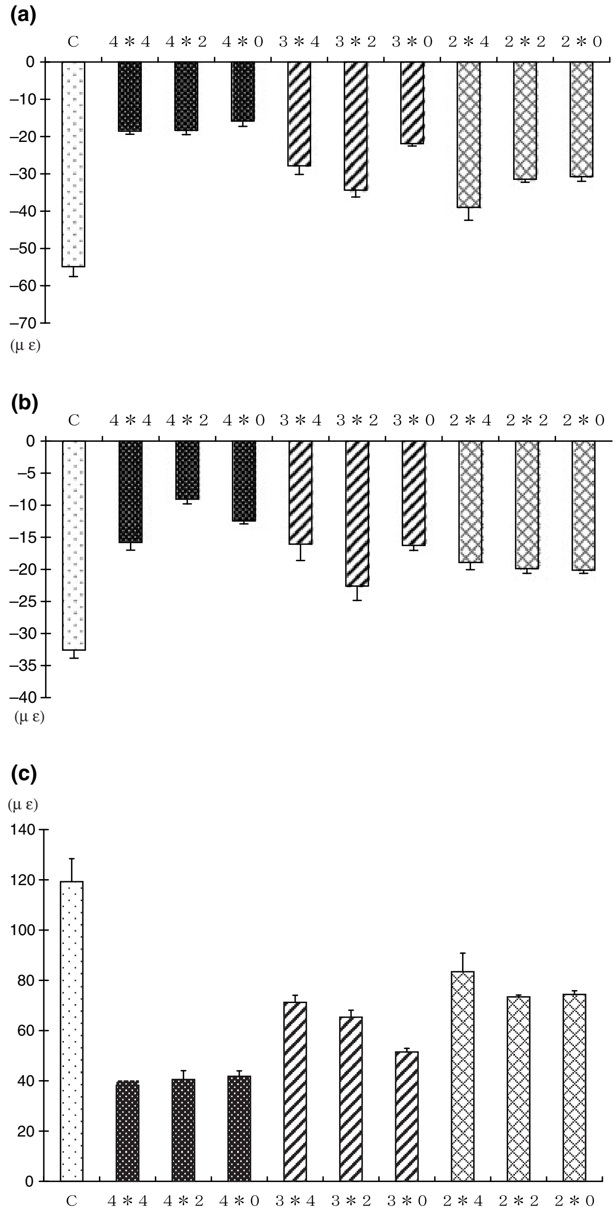

Fig. 7. (a–c) Outputs from three strain gauges with the calibrated shock delivered in the upper anterior direction (the thickness of the sheet * the palatal margin location). (a) Strains at the labial-cervical surface, (b) strains at the palatal-root surface, and (c) strains on the palatal-alveolar bone surface.

Figure 7a–c indicates the outputs from the strain gauges with the calibrated shock delivered in the upper anterior direction. Obtained strains at the labial-cervical surface (Fig. 7a) and palatal-root surface (Fig. 7b) were compressive, while they were tensile on the palatal-alveolar bone surface (Fig. 7c).

As the thickness of the MG increased, the obtained strain value decreased. Within the same thickness samples, the three locations of the palatal margin (4.0, 2.0, and 0.0 mm from the cervical margin) did not show significant differences in strain values for both force directions (Figs 6 and 7) in general.

When the strain values with MGs were compared with the control, they were significantly smaller when the MG thickness was more than 3 mm, except for the MG with a 3 mm thickness and a 0.0 mm margin on the palatal side.

Table 1 indicates the results of the multiple regression analysis, where Y was the obtained strain value from the strain gauge on the labial tooth surface, X_1 was the thickness of the sheet and X_2 was the palatal margin location. In both load directions, the thickness (X_1) showed the most significant influence on reducing the strain on the labial tooth surface.

Table 2 indicates the results of the one-way ANOVA accompanied by Scheffe's test.

Discussion

Although the location of the border or outline of MGs is critical in terms of increasing comfort and reducing speech disturbance, it hasn't been thoroughly discussed when compared to research on other removable prosthodontic appliances.

McCelland et al. (7) and Sato et al. (5) studied the wearability and comfort of MGs in relation to the outlined location (Fig. 4a–c). Yamanaka et al. (8) suggested that the posterior border should extend as distally as possible to distribute the shock to the anterior segment of the dental arch. This experimental study used a dry skull and the modal analysis method.

As we indicated in the preliminary study, the simulation model utilized in this study showed the same kind of tooth deflection where the labial cervical margin area showed the largest tensile strain. Although there are some limitations using this simulation model, *in vivo* tooth deflection trends can be estimated from their results. The possibility exists that individual morphological differences might contribute to the efficacy of MG protection.

The magnitude of the calibrated shock was decided from *in vivo* load deflection test, where up to a 350 gf (3.5N) slow speed load was applied. If the same load were applied at high speed as a shock, the acceleration would be calculated as 700 gf (7N). Two loading directions were selected because most traumatic blows are directed against the face in these loading configurations. Although the magnitudes of the loads were relatively small compared to Takeda's report (9, 10), results using a larger load can be estimated from our current data since the deflection increased in an almost linear fashion under the high speed shock.

In regard to the thickness of the MG, many studies (11–14) have been done to examine its effect

Table 1. Results of the multiple regression analysis from the front and in the upper anterior direction

Load direction	Equation	*R*-value	R^2-value
Labial-cervical surface			
Front	$Y = -9.091X_1 - 1.916X_2 + 61.378$	0.869*	0.755
Upper anterior	$Y = 9.341X_1 - 1.197X_2 - 52.346$	0.946*	0.895
Palatal-root surface			
Front	$Y = -18.16X_1 - 3.994X_2 + 114.024$	0.907*	0.823
Upper anterior	$Y = 4.558X_1 - (2.33E\text{-}03)X_2 - 30.678$	0.879*	0.773
Palatal-alveolar bone surface			
Front	$Y = 28.04X_1 + 6.010X_2 + -203.661$	0.850*	0.723
Upper anterior	$Y = -19.914X_1 - 1.855X_2 - 116.338$	0.967*	0.934

Y, the obtained strain value from the strain gauge on the labial tooth surface; X_1, the thickness of the sheet; X_2, the palatal margin location.
*$P < 0.05$.

Table 2. Results of one-way ANOVA accompanied by the Scheff's test ($P < 0.05$) (the thickness of the sheet * the palatal margin location). (a) Strains at the labial-cervical surface from the front, (b) strains at the palatal-root surface from the front, (c) strains on the palatal-alveolar bone surface from the front, (d) strains at the labial-cervical surface in the upper anterior direction, (e) strains at the palatal-root surface in the upper anterior direction, and (f) strains on the palatal-alveolar bone surface in the upper anterior direction

(a)

	c	2*0	2*2	2*4	3*0	3*2	3*4	4*0	4*2	4*4
c			*	*		*	*	*	*	*
2*0						*	*	*	*	*
2*2	*					*	*	*	*	*
2*4	*					*	*	*	*	*
3*0						*	*	*	*	*
3*2	*	*	*	*	*			*	*	*
3*4	*	*	*	*	*				*	*
4*0	*	*	*	*	*	*				
4*2	*	*	*	*	*	*	*			
4*4	*	*	*	*	*	*	*			

(d)

	c	2*0	2*2	2*4	3*0	3*2	3*4	4*0	4*2	4*4
c		*	*	*	*	*	*	*	*	*
2*0	*			*	*			*	*	*
2*2	*			*	*			*	*	*
2*4	*	*	*		*		*	*	*	*
3*0	*	*	*	*		*	*	*		
3*2	*				*		*	*	*	*
3*4	*			*	*	*		*	*	*
4*0	*	*	*	*	*	*	*			
4*2	*	*	*	*		*	*			
4*4	*	*	*	*		*	*			

(b)

	c	2*0	2*2	2*4	3*0	3*2	3*4	4*0	4*2	4*4
c		*	*	*	*	*	*	*	*	*
2*0	*			*		*	*	*	*	*
2*2	*			*		*	*	*	*	*
2*4	*	*	*			*	*	*	*	*
3*0	*					*	*	*	*	*
3*2	*	*	*	*	*				*	*
3*4	*	*	*	*	*			*		
4*0	*	*	*	*	*		*		*	*
4*2	*	*	*	*	*			*		
4*4	*	*	*	*	*			*		

(e)

	c	2*0	2*2	2*4	3*0	3*2	3*4	4*0	4*2	4*4
c		*	*	*	*	*	*	*	*	*
2*0	*				*		*	*	*	*
2*2	*				*		*	*	*	*
2*4	*					*		*	*	
3*0	*	*	*			*		*	*	
3*2	*			*	*		*	*	*	*
3*4	*	*	*			*		*	*	
4*0	*	*	*	*	*	*	*		*	
4*2	*	*	*	*	*	*	*	*		*
4*4	*	*	*			*			*	

(c)

	c	2*0	2*2	2*4	3*0	3*2	3*4	4*0	4*2	4*4
c				*		*	*	*	*	*
2*0						*	*	*	*	*
2*2						*	*	*	*	*
2*4	*					*	*	*	*	*
3*0						*	*	*	*	*
3*2	*	*	*	*	*			*	*	*
3*4	*	*	*	*	*					*
4*0	*	*	*	*	*	*				
4*2	*	*	*	*	*	*				
4*4	*	*	*	*	*	*	*			

(f)

	c	2*0	2*2	2*4	3*0	3*2	3*4	4*0	4*2	4*4
c		*	*	*	*	*	*	*	*	*
2*0	*				*			*	*	*
2*2	*				*			*	*	*
2*4	*				*	*	*	*	*	*
3*0	*	*	*	*		*	*		*	*
3*2	*			*	*			*	*	*
3*4	*			*	*			*	*	*
4*0	*	*	*	*		*	*			
4*2	*	*	*	*	*	*	*			
4*4	*	*	*	*	*	*	*			

on the shock absorbing capability. Most of these studies dealt with EVA material and showed that a thickness of 3 mm is needed to obtain a sufficient shock absorbing. Our results also indicate that the minimal thickness of a 3 mm is required for a significant reduction of the deformation under shock treatment.

The stiffness or rigidity, increased with the sheet thickness, is also an important factor in MG design, because this factor distributes or disperses the stress to a wider area as Hoffmann et al. reported (15). In this regard, thicker materials have an advantage over thinner ones.

Conclusions

Our results suggest that MG thickness has a greater influence than the anterior palatal margin location on the shock absorbing capability of MGs.

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