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A method to maintain the thickness of the mouthguard after the vacuum forming process: changes of the holding conditions of the mouthguard sheet

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Abstract – The aim of this study was to investigate differences in the thickness of the mouthguard sheet according to the holding conditions during heating. The material used in this study was Sports Mouthguard (3.8 mm thickness), and two holding conditions of the sheet were undertaken: one was the condition that the sheet was held all around the periphery and the other was that the sheet was held at only four points. The sheets were formed using a vacuum former when the sheets were heated until they hung 2.0 cm from the baseline. We measured the thickness of each part of the mouthguard and calculated the ratio of changes in the thickness. The difference in the thickness by the holding conditions at the area of the sheet that fitted over the anterior teeth, palate, and posterior teeth was analyzed by the paired *t*-test. The results showed that the thickness of the sheet differed statistically and significantly at the regions of the sheet that fitted over the anterior teeth and posterior teeth ($P < 0.01$) and the palate ($P < 0.05$) according to the holding conditions of the sheet. The thickness of the condition that the sheet was held all around the periphery was thinner than that of the condition that the sheet was held at only four points. These results suggested that the thickness of the sheet was maintained by holding the sheet only at four points, and this new method could be an effective way to maintain the thickness of the mouthguard in clinical use.

The mouthguard is an effective device for the prevention from stomatognathic trauma during sports (1–4). The thickness of the mouthguard influences its preventive effects from injuries. The thickness of the mouthguard also has influence on the feel of fitting as well as pronunciation, which will affect whether one continues to use mouthguards or not (5). Therefore, it is necessary to grasp the thickness of the mouthguard. There have been some reports investigating the thickness of mouthguards (6–10). Park et al. (6) reported that the average amount of thinning at the occlusal surface of the mouthguard was 25% and that of the labial surface was 50%. Guevara et al. (7) described a 36% rate of thinning along the incisors. Del Rossi et al. (9) showed that the average amount of thinning that occurred at the occlusal surface overlying the molars was approximately 46%, and the amount of thinning along the labial surface of the central incisors and canines ranged between 47% and 60%. Geary et al. (10) revealed that the sheets of 3 mm EVA stretched by 52% during the thermoforming processes, and the material stretched by 72% at incisal sites, reducing thickness to <1 mm. In 2003 (11) and 2004 (12), we reported how the thermoplastic mouthguard sheet elongated and how the thickness of the sheet changed depending on the heating condition and concluded that it was difficult to maintain the thickness of the anterior teeth area of the mouthguard. We also made it clear that the thickness of the mouthguard sheet lessened when the height of the working model was enlarged (13).

In recent years, some methods have been reported to maintain the thickness of the anterior teeth area of the mouthguard. Some mouthguard sheets have steps to maintain the thickness of the anterior teeth area. Takeuchi et al. (14) developed a mold transposition technique, which could maintain a uniform thickness of the anterior teeth area.

Thickness of the mouthguard decreased because the mouthguard sheet was stretched, as it was bound by clamp along the periphery and pressed on the working model during the forming process. We set up a hypothesis that if the anterior margin of the mouthguard sheet was free, stretching of the sheet at the anterior teeth area would be reduced. In the past study, we reported that elongation of the mouthguard sheet decreased by changing the holding condition of the sheet (15). The aim of this study was to examine the difference in the thickness of the mouthguard sheet according to the holding conditions of the mouthguard sheet during heating.

Materials and methods

The material used in this study was Sports Mouthguard® (127 × 127 × 3.8 mm, ethylene vinyl acetate sheet; Meinan Dental Trading Co., Tokyo, Japan). Cross-stripes (10 × 10 mm) were painted on each sheet, and these were used as mensuration points. A working model was made by taking an impression of a maxillar dentate model (500A; Nissin Co., Tokyo, Japan) using silicone rubber replicate impression paste (rema Sil®; InterGlobe Co., Osaka, Japan), and then we poured the gypsum (New Plastone®; GC Co., Tokyo, Japan) into the impression. The working model was trimmed to the height 20 mm at the point of the anterior teeth and 15 mm at the point of the posterior teeth. Two holding conditions of the sheet were prepared: the sheet was held all around the periphery (S) and the sheet was held only at four points (C). Regarding the condition C, the mouthguard sheet was cut 1 cm at the anterior and posterior margins, and 1 cm at the right and left margins with a length of 7 cm (Fig. 1). The sheets were formed using a vacuum former (Ultra Former®; Ultradent Products Inc., South Jordan, Utah, USA). The working model was put on the center of the former, and the heated sheet was pressed on it. Plastic tape was stuck on the stage of the former except for the part of the working model and the part of the palate on the condition C. The sheets were heated until its center was reduced by 2.0 cm from the baseline. The hanging distance was measured using a laser pointer fixed to a three-dimensional coordinate measuring instrument (No.192-201; Mitutoyo Co., Kanagawa, Japan) (11). The sheets were pressed onto the working model for 2 min and then cooled for 1 h. Three samples were examined for each condition.

The thickness of the mouthguard was measured using a measuring device (No.21-111; YDM Co., Tokyo, Japan). The spring of the measuring device was removed to prevent distortion of sheet during measurement. We measured the thickness at five different points at each cross-stripe line (10 mm length) in both the anteroposterior and bilateral directions, and the mean value of the five points was calculated (TL). Then, the thickness of each cross-stripe area (TA) was obtained by calculating the mean value of TL that encircled each cross-stripe. The ratio of changes in TA was calculated according to the formula: $(TA' - TA)/TA \times 100$ (%) (TA' = the value after forming, TA = the value before forming), and these were used for analysis. The area of the sheet that fitted over the anterior teeth was 3E–G and 4E–G (Fig. 1), and the area of the sheet that fitted over the palate was 5E–G and 6E–G (Fig. 1). The area of the sheet that fitted over the posterior teeth was C5–8, D5–8, H5–8, and I5–8 (Fig. 1). The differences in the ratio of changes in TA at the region of the sheet that fitted over the anterior teeth, palate, and posterior teeth were analyzed by the paired *t*-test.

The adaptation of the mouthguard to the working model was also examined. The mouthguard was cut to sagittal direction at the center of the right and left central incisor and frontal direction at the right and left mesial cusp of the first molar. The mouthguard was fitted to the working model, and the pictures of the cross-section of the mouthguard were taken with a fixed digital camera incorporating a ruler. The pictures were observed using Photoshop® (Adobe Systems, San Jose, CA, USA), and the distance between the mouthguard and the cervical margin of the working model was measured. The difference in the distance between the mouthguard and the cervical margin according to the holding conditions was analyzed by the Student's *t*-test.

Results

Figures 2 and 3 show the results after the mouthguards were formed. Observation of the cross-stripes painted on the sheet showed that the sheet of condition S was elongated more than that of condition C.

The ratio of changes in the thickness of each cross-stripe area is shown in Fig. 4. The mean value of the ratio of changes in the thickness of the region that was pressed on the working model was −26.0% for condition S and −17.9% for condition C. The changes in the thickness were small for condition C, especially at the part of the sheet that fitted over the anterior teeth. Fig. 5

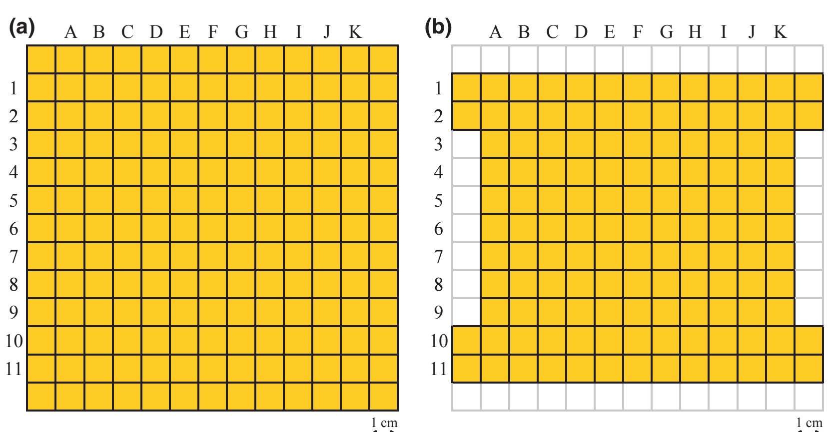

Fig. 1. The shape of the mouthguard sheet. A to K, and 1–11 indicate the measurement area number. (a) Original sheet: The sheet was held all along the periphery (S). (b) The modified sheet was cut 1 cm at the anterior and posterior margins, and 1 cm at the right and left margins with a length of 7 cm: The sheet was held at only four points (C).

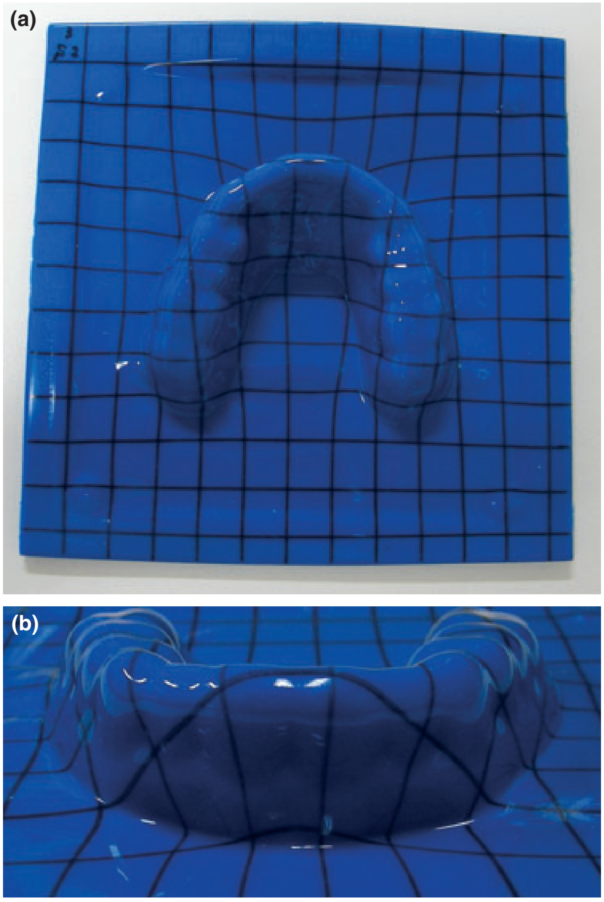

Fig. 2. The mouthguard sheet mounted on the working model (S). (a) Occlusal view. (b) Frontal view.

shows the mean value of the ratio of changes in the thickness at the area of the sheet that fitted over the anterior teeth, palate, and posterior teeth. The results of analysis by the paired *t*-test showed that the ratio of changes in the thickness was different between each condition at the region of the sheet that fitted over the anterior teeth and posterior teeth ($P < 0.01$), and palate ($P < 0.05$).

The adaptation of the mouthguard was not statistically significantly different between condition S and C. The mean value of the distance between the mouthguard and the cervical margin of the working model was 0.31 ± 0.06 mm for condition S and 0.20 ± 0.05 mm for condition C at the central incisor, and 0.42 ± 0.03 mm for condition S and 0.33 ± 0.04 mm for condition C at the mesial cusp of the first molar.

Discussion

It is important to maintain the thickness of the mouthguard to prevent stomatognathic trauma during sports. The thickness of the mouthguard decreases especially at the anterior teeth area. In this study, we developed a new method to maintain the thickness of the mouthguard sheet by changing the holding condition of the sheet to prevent a decrease in thickness after forming,

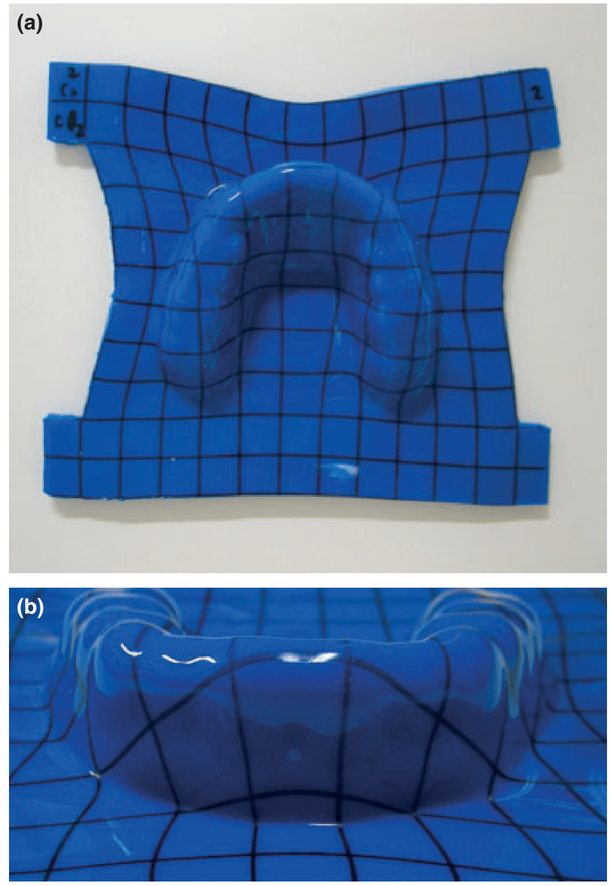

Fig. 3. The mouthguard sheet mounted on the working model (C). (a) Occlusal view. (b) Frontal view.

and this was achieved at all parts of the mouthguard sheet.

The thickness of the mouthguard influences on impact absorption and the preventive effect against stomatognathic injury (16). Therefore, it is necessary to maintain the proper thickness of the mouthguard. There have been some reports concerning the thickness needed (17–20). The mouthguard sheet over the facial surface of anterior teeth requires a thickness of 3–4 mm, and the sheet over the buccal surface of posterior teeth and the occlusal surface needs a thickness of 2–3 mm (17). Hoffman et al. (18) reported that a minimum layer thickness of 3 mm was required. Tran et al. (19) suggested that appliances should be at least 4 mm thick to optimize their protective qualities. Westerman et al. (20) revealed a preference for 4 mm thickness over critical areas such as incisal edges and tooth cusps. In our previous study, we investigated elongation and the thickness of the mouthguard under different heating conditions and clarified that the thickness of the sheet becomes thinner as heat is applied to the sheet, and it is difficult to maintain the proper thickness (12).

Custom-made mouthguard can be either vacuum-formed or pressure-formed. Because of the limited heat and pressure that is used in the fabrication process, the vacuum-formed mouthguard results in a final product that is unevenly thick, and smaller thickness in comparison with the pressure-laminated mouthguard (8, 21). Therefore, the pressure-laminated mouthguard that the

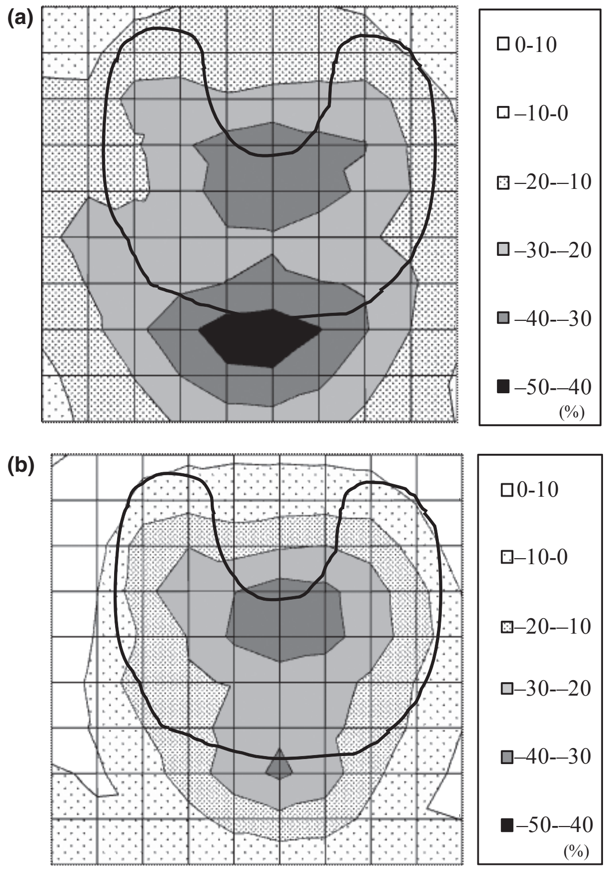

Fig. 4. The ratio of changes in the thickness of each cross-stripe. (a) Condition S. (b) Condition C.

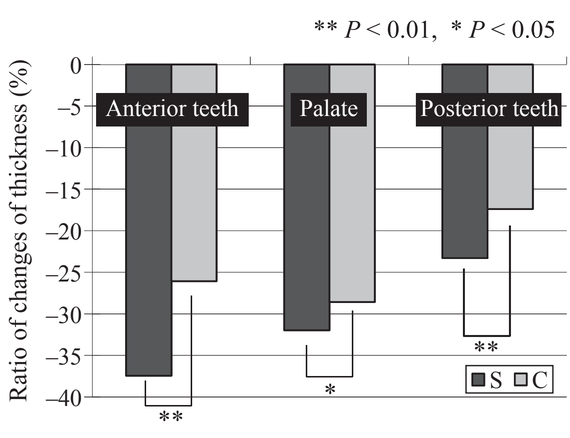

Fig. 5. The mean value of the ratio of changes in the thickness at the area of the sheet that fitted over the anterior teeth, palate, and posterior teeth.

manufacturer can control the final thickness of the mouthguard is recommended. However, vacuum-formed mouthguard are made use of too often. In case of fabricating vacuum-formed mouthguard, some devises would be needed to maintain the appropriate thickness of the mouthguard. One of the devise is to use the mouthguard sheet that has steps to maintain the thickness of the anterior teeth area, and the other devise is to perform the mold transposition technique (14). In this study, we considered a new method to maintain the thickness of the vacuum-formed mouthguard by devising novel ways to shape the mouthguard sheet and change the way clamp holds the sheet.

Generally, the mouthguard sheet is held along the periphery of the sheet by clamp. The sheet is heated during the forming process and start to droop from the center and become elongated. Then, the sheet is pressed upon the working model and suctioned, which finishes the forming process. It was considered that the thickness of the mouthguard was decreased by this elongating process of heating and suctioning. Elongation occurs because the sheet is held by clamp all along the periphery. Therefore, the hypothesis that changes in the holding condition would reduce elongation of the mouthguard sheet during the vacuum forming process was established. In this study, the mouthguard sheet was held only at four points with a width of 2 cm by cutting the sheet 1 cm at the anterior and posterior margins, and 1 cm at the right and left margins with a length of 7 cm. The anterior margin of the mouthguard sheet was free, so elongation of the mouthguard sheet by heating during the forming process would be reduced. Further, elongation of the mouthguard sheet during the suctioning process would be reduced by decreasing the part held by clamp. Reduction of elongation would lead to reduction of a decrease in thickness. The method of this study does not require any special material or technique and is an effective method to maintain the thickness of the mouthguard after formation.

The heating condition was set at a hanging distance of 2.0 cm from the baseline, because a hanging distance of 1.0–2.0 cm was regarded as the proper heating condition (22). The temperature of the surface of the mouthguard sheet was about 108°C when the hanging distance was 2.0 cm. There is a report showing that the appropriate heating temperature of the ethylene vinyl acetate sheet is 80–120°C (23).

The results of this study showed that the ratio of changes in the thickness was small regarding condition C, especially at the region of the sheet that fitted over the anterior teeth. The reason for this result would be that the anterior margin of the mouthguard sheet was free under condition C, and the anterior part of the mouthguard sheet did not become elongated when the sheet was heated or hung down, but just pressed on the working model just as it was. And it was also considered that because the anterior margin of the mouthguard sheet was not held by clamp, elongation of the anterior part of the sheet during the suctioning process was reduced, and hence the thickness of the sheet was maintained in comparison with the condition S.

The results of statistical analysis demonstrated that the ratio of changes in the thickness was different between the condition S and C at the area of the sheet that fitted over the anterior teeth, palate, and posterior teeth, and the changes in thickness of condition S were larger than that of condition C. Changes in thickness in the area of posterior teeth were slight regarding condition C. The reason for this result would be that holding of the sheet had only four points under condition C, and elongation at the lateral area of the sheet during the heating process and during the suctioning process was reduced. Changes in the thickness in the region of the sheet fit to the palate decreased under condition C. The reason for this result would be that the anterior and posterior margin of the mouthguard sheet was not held by clamp, and the anterior and posterior part of the sheet did not become elongated during the heating process, and the sheet drooped to the palate just as it was. Reduction in elongation at the anterior and posterior part of the sheet during the suctioning process by holding the sheet at only four points was also considered as the reason for only slight changes in thickness in the area of the palate under condition C.

The average decrease in the thickness of the mouthguard sheet in this study was 37.43% (Condition S) and 26.06% (Condition C) at the anterior teeth area, 31.97% (Condition S) and 28.57% (Condition C) at the palate area, and 23.29% (Condition S) and 17.39% (Condition C) at the posterior teeth area. Park et al. (6) reported that in the course of manufacturing custom-made mouthguards, there was an average decrease in material thickness of 25–50%. Guevara et al. (7) described a 36% rate of thinning along the incisors, and Del Rossi et al. (9) showed that the average amount of thinning at the occlusal surface was approximately 46%, and the average amount of thinning of the labial surface ranged between 47% and 60%. In comparison with these reports, a new method of changing the holding condition of the sheet could improve the decrease in the thickness during the forming process. Improvements in the palate area were slight, but a major improvement was observed in the anterior and posterior teeth areas.

The adaptation of the mouthguard was not different between conditions S and C. This result suggested that the mouthguard fabricated by the method of changing the holding condition of the sheet would not have trouble with the adaptation in clinical situation.

Concerning limitations of this study, we made it clear that a new method of changing how the mouthguard sheet is held by clamp could help to maintain a uniform thickness without the lack of the adaptation. In future investigations, we will investigate some different holding conditions to maintain the thickness of the mouthguard. The holding condition of completely free situation will also be investigated, and this situation could lead to maintaining the thickness of mouthguard additively.

Conclusion

Mouthguard thinning during the forming process is a problem because the thickness of the mouthguard influences impact absorption and the preventive effects on stomatognathic injury. In this study, a new method of devising the shape of the mouthguard sheet and changing the area held by clamp was investigated as a way to maintain the thickness of the mouthguard. The results of this study revealed that these methods could help maintain the thickness of the mouthguard, especially in the anterior teeth area, and be an effective method in clinical use.

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