Difference in pressure-formed mouthguard thickness according to heating condition

Abstract – Purpose: The purpose of this study was to investigate the differences of pressure-formed mouthguard thickness by varying the heating conditions within the proper heating temperature. Materials and methods: The material used in this study was a mouthguard sheet of 3.8-mm ethylene vinyl acetate. The sheets were formed by pressure forming using a vacuum-pressure former. Three heating conditions were varied as follows: the sheet was heated until the center was displaced by 10, 15, and 20 mm from baseline. We measured the mouthguard thickness at the labial surface of the central incisor, buccal surface of the first molar, and occlusal surface of the first molar. Differences in thickness by measurement region of the mouthguards formed under different heating conditions were analyzed by two-way analysis of variance and Bonferroni’s method. Results: We found that mouthguard thickness varied in different regions of the central incisors and the first molars (P < 0.01). The incisal (cusp) region was thinner than the cervical region. There were statistically significant differences among the heating conditions at the labial surface of the central incisor (P < 0.05), and the thickness became larger as the sheet was heated. Mouthguard thickness at the buccal surface and occlusal surface of the first molar did not differ among the three heating conditions. Conclusions: Our results suggest that the best heating condition of the pressure-forming method was the condition that the sheet was heated until its center displaced by 20 mm. This finding is an important fact when fabricating a mouthguard.

Mouthguards are one of the apparatuses to prevent orofacial trauma (1–5). Maintaining the thickness of the mouthguard is important because mouthguard thickness influences the shock absorption and the protection ability of the mouthguard (6). Mouthguard thickness also influences the comfort, ease of speaking, and mouthguard use compliance (7). However, mouthguard thickness becomes thinner after forming with the average amount of thinning about 36% to 60% at the labial surface and about 25% at the occlusal surface (8–12). Therefore, controlling the thickness of the mouthguard during formation is important. It is necessary to understand how changes in the thickness of the mouthguard may occur by forming method, and how the forming method should be selected to control mouthguard thickness.

Custom-made mouthguards can be fabricated by a vacuum-forming process or a pressure-forming process (10, 13). With regard to the heating condition, the displacement of the heating mouthguard material sheets at distances from 10 to 20 mm is regarded as indicating proper temperature (14), and the appropriate heating temperature for ethylene vinyl acetate sheets is 80–120°C (15). In the previous study, the differences of the vacuum-formed mouthguard thickness by the heating condition within the proper heating temperature were demonstrated (16). However, the differences in the thickness of the pressure-formed mouthguard by varying the temperature have not been studied, and the best heating condition of the pressure-forming method has not been demonstrated.

The purpose of this study was to examine the differences of pressure-formed mouthguard thickness by varying the heating condition within the proper heating temperature.

Materials and methods

The material used in this study was 127 mm × 127 mm × 3.8 mm sheets of ethylene vinyl acetate (Sports Mouthguard®, Meinan Dental Trading Co., Tokyo, Japan). A working model was made by taking an impression of a maxillary dentate model (500A; Nissin Co., Tokyo, Japan) using silicon rubber replicate impression paste (Rema Sil®; InterGlobe Co., Osaka, Japan), and filling the impression with gypsum (New Plastone®; GC Co., Tokyo, Japan). The working model was trimmed to a height of 20 mm at the central incisor and 15 mm at the first molar. The sheets were formed by pressure forming using a vacuum-pressure former (Modelcapture Try®, Shofu Inc., Kyoto, Japan) which can be used as a vacuum-forming machine and a pressure-forming machine. After application of a separator for thermo-forming (at varnish TF®; Shofu Inc.),
the model was placed to the center of the former and the heated sheet was pressed onto it. Three heating conditions were examined as follows: the sheet was heated until the center was displaced by 10 mm (MP10), 15 mm (MP15), and 20 mm (MP20) from the baseline. The displacement distance was measured using a laser pointer fixed to a three-dimensional coordinate measuring instrument (No. 192-201; Mitutoyo Co., Kanagawa, Japan) (17). The temperature of the surface of the sheet was measured using an infrared thermometer (CT-2000D; Custom Co., Tokyo, Japan) at the moment when the center of the sheet was displaced by 10 mm (MP10), 15 mm (MP15), and 20 mm (MP20) from the baseline. The pressure was applied and maintained for 10 min. After formation, each sheet was cooled for 1 h. The vacuum-pressure former was allowed to cool between sheets. Three samples from each heating condition were examined.

Mouthguard thickness 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 the mouthguard during measurement. Mouthguard thickness was measured at specific sites on the central incisor and the first molar. Thickness at the central incisor was measured at ten points on the labial surface. The measurement points were evenly spaced along lines at the mesiodistal center of the central incisor from the incisal edge to the cervical margin. The ten points measured were classified into three regions: the incisal region (three points nearest the incisal edge), the center region (four center points), and the cervical region (three points nearest the cervical margin). The mean thickness at the right and left central incisors was calculated and used for analysis. Mouthguard thickness at the first molar was measured at six points on the buccal surface: the cusp, center, and cervical regions of the mesiobuccal and distobuccal cusps. The mean thickness of the mesiobuccal and distobuccal cusps was calculated, and the mean value at the right and left first molars was calculated and used for analysis. The thickness at the first molar was also measured at six points on the occlusal surface. The measurement points were the cusp (the mesiobuccal cusp, the mesiolingual cusp, the distobuccal cusp, and the distolingual cusp) and the fovea (the mesial fovea and the distal fovea). The mean thickness of the cusp and the fovea was calculated, and then the mean thickness of the right and left cusp and fovea was calculated and used for analysis.

The differences in the thickness at the labial surface of the central incisor, buccal surface of the first molar, and occlusal surface of the first molar by the measurement region and heating condition were analyzed by two-way analysis of variance (ANOVA) and a post hoc test (Bonferroni’s method).

Table 1 shows the results of two-way ANOVA at the central incisor. There were statistically significant differences among the measurement regions ($P < 0.01$) and the heating conditions ($P < 0.05$). The thickness in the incisal region was less than in the cervical region (Fig. 1), and the thickness became larger as the sheet was heated (Fig. 2).

Table 2 shows the results of two-way ANOVA at the buccal surface of the first molar. There was a statistically significant difference among the measurement regions ($P < 0.01$). Mouthguard thickness in the cusp region was less than in the cervical region (Fig. 3). Statistically significant differences were not found among the heating conditions (Fig. 4).

Table 3 shows the results of two-way ANOVA at the occlusal surface of the first molar. There was a statistically significant difference in thickness between the measurement regions ($P < 0.01$). The mouthguard became thinner at the cusp than at the fovea (Fig. 5). Statistically significant differences were not found among the heating conditions (Fig. 6).

Discussion

Mouthguard thickness influences the preventive effect from stomatognathic injuries during sports; therefore, fabricating a mouthguard without the loss of its thickness is important. In this study, we examined the differences of the pressure-formed mouthguard thickness by the heating condition within the proper temperature. We found that the heating condition within the proper temperature did not influence the thickness at the buccal surface and the occlusal surface of the first molar, but the mouthguard thickness became larger as heated at the labial surface of the central incisor.

The heating condition was set at a displacement distance of 10 mm, 15 mm, and 20 mm from the baseline. The displacement distances from 10 to 20 mm are regarded as indicating proper temperature (14), and the proper temperature for ethylene vinyl acetate sheets is reported as 80–120°C (15). The temperature of the surface of the mouthguard sheet at the MP10 condition was approximately 71.0°C, that at the MP15 was approximately 97.2°C, and that at the MP20 was approximately 110.5°C. The three heating conditions were considered almost appropriate.

Statistical analysis showed significant differences in mouthguard thickness at different regions of the labial surface of the central incisor, the buccal surface of the first molar, and the occlusal surface of the first molar. The thickness of the incisal or cusp region was less

<table>
<thead>
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<th>Source</th>
<th>df</th>
<th>MS</th>
<th>$F$ value</th>
<th>$P$ value</th>
</tr>
</thead>
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<tr>
<td>Measurement region (A)</td>
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<td>0.277</td>
<td>173.853</td>
<td>&lt;0.001</td>
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<tr>
<td>Heating condition (B)</td>
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<td>0.027</td>
<td>9.472</td>
<td>0.014</td>
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<tr>
<td>A × B</td>
<td>4</td>
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<td>1.766</td>
<td>0.201</td>
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<tr>
<td>Error (A)</td>
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<td></td>
<td></td>
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<td>Error (B)</td>
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<td>0.003</td>
<td></td>
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</tbody>
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than that of the cervical region because the sheet first contacts the incisal or cusp region and extends from there. The cusp region would become thinner than the fovea region because the heated sheet material gathers in the concave shape fovea.

The mouthguard thickness at the labial surface of the central incisor became greater as the sheet was heated. On the other hand, the thickness at the buccal surface and the occlusal surface of the first molar was not influenced by the heating conditions. As the sheet was heated, the temperature of the mouthguard sheet became higher, and the heated sheet was elongated before the sheet was pressed onto the working model. Therefore, the elongation of the sheet after pressed onto the working model would be smaller as the sheet was heated, and the elongation of the part of the labial surface of the central incisor became less as the sheet was heated and the thickness became greater as the sheet was heated. On the other hand, the alveolar tubercle on the buccal surface of the first molar and the occlusal surface of the first molar

**Table 2. Two-way ANOVA results (buccal surface of the first molar)**

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
<th>F value</th>
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<td>182.644</td>
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<td>Error (A)</td>
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<td>Error (B)</td>
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<td>0.012</td>
<td></td>
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</tbody>
</table>

Fig. 1. Thickness at the labial surface of the central incisor in each measurement region under the three heating conditions. Measurements are expressed as mean value ± SD. MP10, the sheet was heated until the center was displaced 10 mm; MP15, the sheet was heated until the center was displaced 15 mm; MP20, the sheet was heated until the center was displaced 20 mm. Inc., incisal region; Cent., center region; Cerv., cervical region.

Fig. 2. Thickness at the labial surface of the central incisor under the three heating conditions. Measurements are expressed as mean value ± SD. MP10, the sheet was heated until the center was displaced 10 mm; MP15, the sheet was heated until the center was displaced 15 mm; MP20, the sheet was heated until the center was displaced 20 mm.

Fig. 3. Thickness at the buccal surface of the first molar in each measurement region under the three heating conditions. Measurements are expressed as mean value ± SD. MP10, the sheet was heated until the center was displaced 10 mm; MP15, the sheet was heated until the center was displaced 15 mm; MP20, the sheet was heated until the center was displaced 20 mm. Cus., cusp region; Cent., center region; Cerv., cervical region.
would prevent the elongation of the sheet after pressed onto the working model by their flat shape. Therefore, the reduction of the thickness after pressing would be restricted at the buccal surface and the occlusal surface of the first molar, and the thickness was not differing among the heating conditions. In the previous study, it was shown that the vacuum-formed mouthguard thickness became greatest when the sheet was heated until the center of the sheet displaced by 20 mm (16). The results of the present study showed the same tendency to the previous study.

These results of this study suggested that the best heating condition to maintain the pressure-formed mouthguard thickness was the condition where the sheet was heated until the center of the sheet displaced by 20 mm at 110.5°C. These results are necessary information when forming a pressure-formed mouthguard sheet. In the future research, the differences in the pressure-formed mouthguard thickness by the position of the working model should be investigated.

**Conclusion**

The differences of pressure-formed mouthguard thickness by varying the heating condition within the proper temperature were investigated. The results of this study indicated that the thicknesses of the labial surface of the central incisor became greatest when the sheet was heated until the center of the sheet displaced by 20 mm at 110.5°C. The thickness of the buccal surface and the occlusal surface of the first molar was not influenced by the heating conditions. This finding is necessary information when fabricating a pressure-formed mouthguard sheet.
References