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Original Article
Fabrication of vacuum-formed and pressure-formed mouthguards using polyolefin sheet

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Abstract: Background: Mouthguard should be worn to decrease orofacial trauma. Custom-made mouthguards are usually fabricated using ethylene vinyl acetate sheet or polyolefin sheet. However, the difference of the characteristics of the mouthguard formed by polyolefin sheet has not been cleared enough. The aim of this study was to investigate the characteristics of the mouthguard fabricated by polyolefin sheet with the vacuum-forming method and the pressure-forming method. Material and methods: Mouthguard sheets of polyolefin (3.0 mm thickness) were formed on working model using a vacuum former and a pressure former. Mouthguard thickness was measured at the central incisor (labial surface) and the first molar (buccal surface). The thickness at the first molar (occlusal surface) was also measured. The mouthguard fit was examined at the right central incisor and the right first molar by investigating the distance between the cervical part of the working model and the fabricated mouthguard. Differences in the mouthguard thickness and mouthguard fit fabricated by the vacuum-forming method and the pressure-forming method were analyzed by two-way analysis of variance. Results: Mouthguard thickness was different among the measurement parts on both the central incisors and the first molars ($P < 0.05$ or $P < 0.01$). The mouthguard formed by the pressure-forming method showed smaller thickness on the central incisor (labial surface) than that formed by the vacuum-forming method ($P < 0.01$). The mouthguard formed by the vacuum-forming method showed smaller thickness on the first molar (buccal and occlusal surface) than that formed by the pressure-forming method ($P < 0.05$ or $P < 0.01$). The mouthguard fabricated by the pressure-forming method showed greater fit than that fabricated by the vacuum-forming method ($P < 0.01$). Conclusions: The results of this study suggest that the vacuum-forming method was easy to decrease the mouthguard thickness at the first molar, and the pressure-forming method was easy to decrease the mouthguard thickness at the central incisor but obtain better fit when using polyolefin sheet.

Keywords: Mouthguard, vacuum-forming, pressure-forming, fabrication, polyolefin sheet

Introduction

Mouthguards have been worn to decrease the case of orofacial injury and to avoid severe injury [1-5]. There are three types of mouthguards; boil-and-bite, stock, and custom-made [6]. The boil-and-bite and stock mouthguards can be available with marketing, however, the fit of these mouthguards are inferior. On the condition that the fit of the mouthguard is inferior, the protection of orofacial trauma is not provided enough. On the other hand, custom-made mouthguards which produced by taking an impression at a dental office provide good fit and protection [7]. Thus, custom-made mouthguard is recommended to use. Custom-made mouthguards usually fabricated by thermoforming techniques using ethylene vinyl acetate sheet, and recently polyolefin sheet started to be used for the fabrication of the mouthguard [8]. It is reported that not only the ethylene vinyl acetate sheet but also the polyolefin sheet has satisfactory physical properties in order to use as mouthguard sheet [9]. There are two thermoforming techniques; a vacuum-forming method and a pressure-forming method [10-12]. Vacuum-forming method can be performed easily and is cost effective compared to the pressure-forming method [13]. On the other hand, the pressure-forming method can obtain greater fit [14]. Furthermore, when laminate mouthguard is fabricated by the pressure-forming method, the mouthguard with enough thickness can be prepared [15].

Mouthguard thickness is important to be maintained because it influences the shock absorption ability of the mouthguard [16, 17]. Mouthguard must fit properly because the fit of the mouthguard influences its protection ability [18].

It is necessary to choose the mouthguard sheet material and fabrication method when offering a mouthguard. Ethylene vinyl acetate sheet has been used as the mouthguard sheet material for a long time, and the difference of the characteristics between the mouthguard formed by the vacuum-forming method and the pressure-forming method has been cleared [14, 15]. However, the difference of the characteristics of the mouthguard formed by polyolefin sheet has not been cleared enough.

The purpose of this study was to examine the following null hypothesis: mouthguard characteristics fabricated by polyolefin sheet are not different between the mouthguard formed by the vacuum-forming method and the pressure-forming method.

Materials and methods

Mouthguard formation

Mouthguard sheets of polyolefin (MG21®, 129 mm × 129 mm × 3.0 mm, Clear, CGK Corp., Hiroshima, Japan) was investigated in this study. A maxillary dental model (500A, Nissin Co., Tokyo, Japan) was taken an impression (Rema Sil®, InterGlobe Co., Osaka, Japan), and gypsum (New Plastone®, GC Co., Tokyo, Japan) was poured into the impression for preparing the working model. The working model was completed by trimming with a height of 20 mm at the right and left central incisors and 15 mm at the right and left first molars [19]. The working model was placed at the center of the former both on the vacuum-forming method and the pressure-forming method. On the vacuum-forming method, the mouthguard was fabricated using a vacuum former (Ultra Former®, Ultradent Products Inc., South Jordan, Utah, USA) (POV condition) with applying the vacuum for 2 min. On the pressure-forming method, a separator (at varnish TF®, Shofu Inc., Kyoto, Japan) was made use of the working model before the forming, and the mouthguard was fabricated using a pressure former (Model-capture Try®, Shofu Inc., Kyoto, Japan) (POP condition) with applying the pressure for 10 min. The temperature of the sheet was controlled to 105°C using an infrared thermometer (CT-2000D®, Custom Co., Tokyo, Japan) referring to the appropriate heating condition of ethylene vinyl acetate as 80-120°C [20] and that of polyolefin as 105°C [19]. Six samples were examined on the vacuum-forming method and the pressure-forming method, respectively.

Mouthguard thickness

The mouthguard thickness was evaluated at the first. A measuring device (No. 21-111; YDM Co., Tokyo, Japan) [21] was used for the measurement of the mouthguard thickness at the central incisors (labial surface) and the first molars (buccal surface and occlusal surface) [21]. For the measurement of the central incisor thickness, the thicknesses at ten parts on mesiodistal center of the central incisor were measured. The ten parts were divided to three parts: the incisal part (three parts at the incisal edge side), the center part (four parts at the center), and the cervical part (three parts at the cervical margin side). The average thickness of each part on the labial surface of the central incisor was analyzed. For the measurement of the first molar (buccal surface) thickness, the thicknesses at six parts of the first molar were measured: the cusp, the center, and the cervical parts of the mesiobuccal and distobuccal cusps. The average thickness of each part on the buccal surface of the first molar was analyzed. For the measurement of the first molar (occlusal surface) thickness, the thicknesses at six parts of the first molar were measured: the cusp (the mesiobuccal, mesiolingual, distobuccal, and distolingual cusps) and the fovea (the mesial and distal fovea). The average thickness of the cusp and the fovea on the occlusal surface of the first molar was analyzed.

Mouthguard fit

The mouthguard fit to the working model was evaluated secondly. The mouthguard was cut at the right central incisor as connecting the

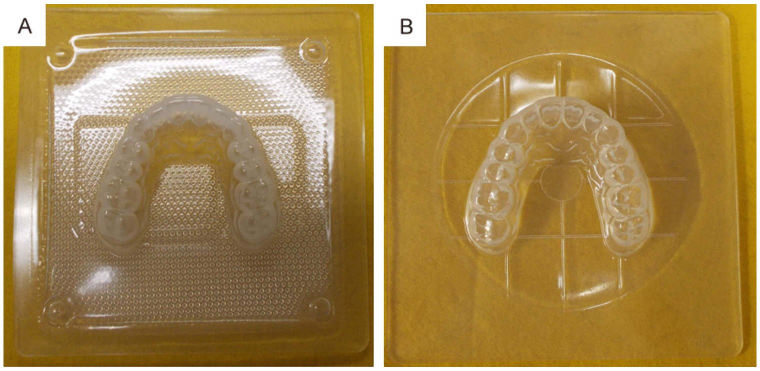

Figure 1. Mouthguards fabricated by vacuum-forming method and pressure-forming method. (A) Vacuum-forming method, (B) Pressure-forming method.

center of the incisal edge and the center of the cervical line. The mouthguard was also cut at the right first molar as connecting the mesial cusp and the cervical line underneath the mesial cusp. The cut mouthguard was set to the original working model, and the pictures of sections were taken at the part of the right central incisor and right first molar by a fixed digital camera including a ruler (M type standard caliper N15®, Mitutoyo, Kanagawa, Japan) in the photograph. The fit of the mouthguard was measured manually as the distance between the cervical part of the working model and the mouthguard using Photoshop® (Adobe Systems, San Jose, CA, USA). After measuring the distance, the value was corrected using the scale of the ruler on the picture [22].

Statistical analysis

The differences in the thickness and fit of the mouthguard fabricated by the vacuum-forming method and the pressure-forming method were analyzed using two-way analysis of variance (ANOVA) and a post-hoc test (Bonferroni method). Statistical analysis was performed using statistical analysis software (SPSS 17.0, SPSS JAPAN, Tokyo, Japan), and differences of $\alpha < 0.05$ were decided significant.

Results

Mouthguard thickness

Mouthguards fabricated by the vacuum-forming method and the pressure-forming method are shown in **Figure 1**. The mouthguard thickness at the central incisor (labial surface) was statistically significantly different by the measurement parts ($P < 0.05$) and forming methods ($P < 0.01$). The thickness in the incisal part was less than in the cervical part on the POV condition, and that in the cervical part was less than in the incisal part on the POP condition (**Figure 2**). A statistically significant difference was found between the POV and POP conditions in the center part and cervical part ($P < 0.01$), and the thicknesses at the center part and cervical part were statistically significantly smaller in the mouthguards formed with the POP condition than those formed with the POV condition ($P < 0.01$) (**Figure 2**).

The mouthguard thickness at the first molar (buccal surface) was statistically significantly different by the measurement parts and forming methods ($P < 0.01$), and the thickness in the cusp part was less than in the cervical part (**Figure 3**). A statistically significant difference in thickness was found between the POV and POP conditions in the cusp ($P < 0.01$) and center parts ($P < 0.05$), and the thicknesses at the cusp part and center part were statistically significantly smaller in the mouthguards formed with the POV condition than those formed with the POP condition ($P < 0.01$ and $P < 0.05$) (**Figure 3**).

The mouthguard thickness at the first molar (occlusal surface) was statistically significantly different by the measurement parts and forming methods ($P < 0.01$), and the thickness at the cusp was less than at the fovea (**Figure 4**). The thicknesses at the cusp and fovea were statistically significantly smaller in the mouthguards formed with the POV condition than those formed with the POP condition ($P < 0.01$) (**Figure 4**).

Mouthguard fit

The mouthguard fit at the central incisor and the first molar was statistically significantly different by the forming methods ($P < 0.01$) (**Figure 4**). Though the fit was not different between the central incisor and the first molar ($P = 0.92$), the fit was superior in the POP condition than that in the POV condition ($P < 0.01$) (**Figure 5**).

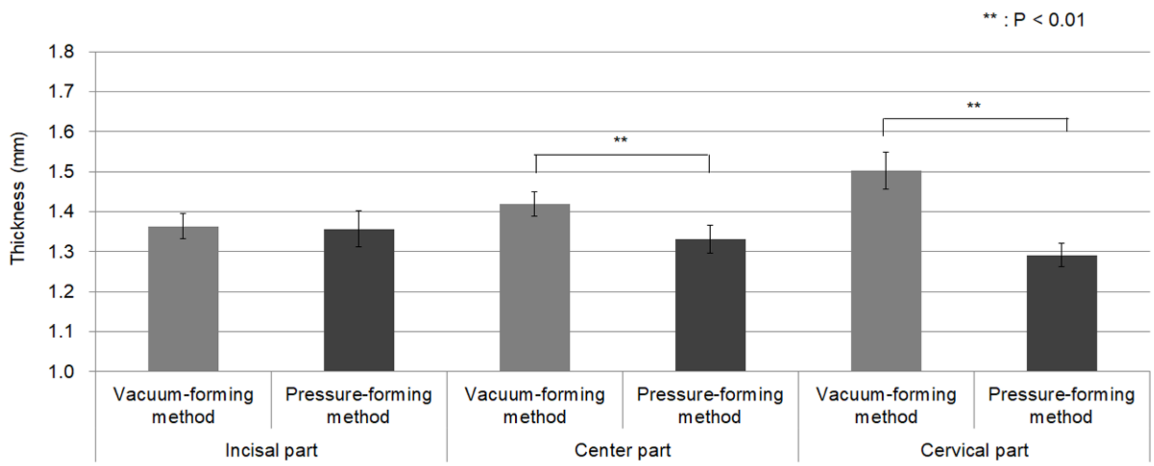

Figure 2. Thickness at the labial surface of the central incisor in each forming method for the three measured regions. Measurements are expressed as mean value ± SD.

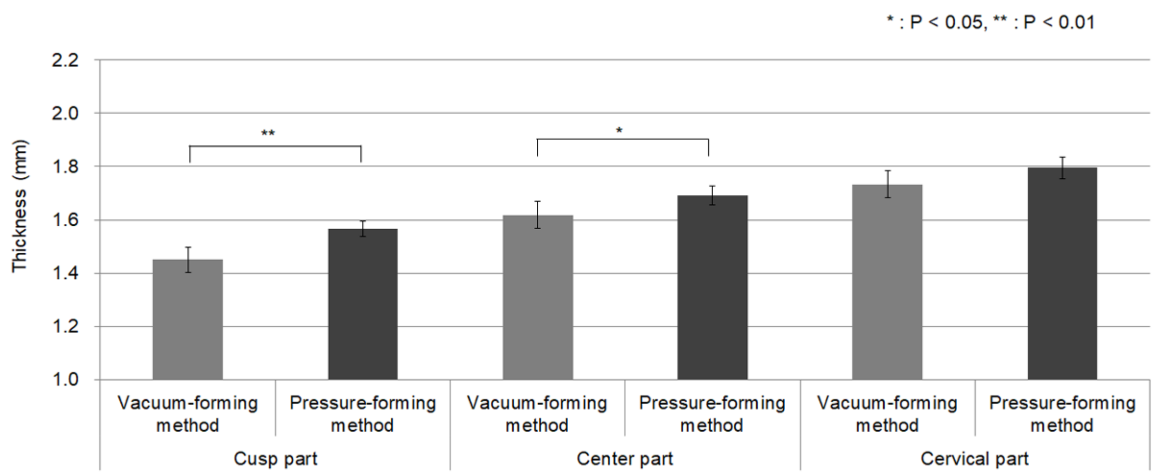

Figure 3. Thickness at the buccal surface of the first molar in each forming method for the three measured regions. Measurements are expressed as mean value ± SD.

Discussion

This study used the polyolefin sheet and investigated the differences in the mouthgurard thickness and fit fabricated by the vacuum-forming method and the pressure-forming method. The results revealed that the forming method influenced the thickness and fit of the mouthguard fabricated by polyolefin sheet.

The heating condition in this study was controlled at 105°C referring to the heating condition on ethylene vinyl acetate sheet as 80-120°C [20] and polyolefin sheets as 105°C [19].

Mouthguard thickness was significantly different at different parts of the central incisors. The thickness in the incisal part became less than the cervical part on the POV condition, and that in the cervical part became less than the incisal part on the POP condition. The heated sheet contacts the incisal part at the first and elongates from the part, and then, the thickness of the incisal part would be smaller than that of the other parts on the POV condition. On the other hand, the thickness in the cervical part would be smaller than the incisal part on the POP condition because of the higher pressure at the time of forming. The level of pressure on the POP condition was larger than the vacuum on the POV condition, and then the sheet would be elongated after touching the incisal edge of the central incisor, and then the thickness at the cervical part would be smaller.

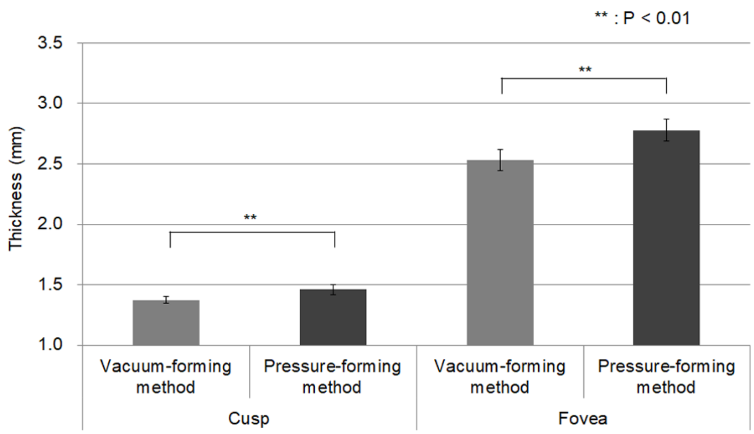

Figure 4. Thickness at the occlusal surface of the first molar in each forming method for the two measured regions. Measurements are expressed as mean value ± SD.

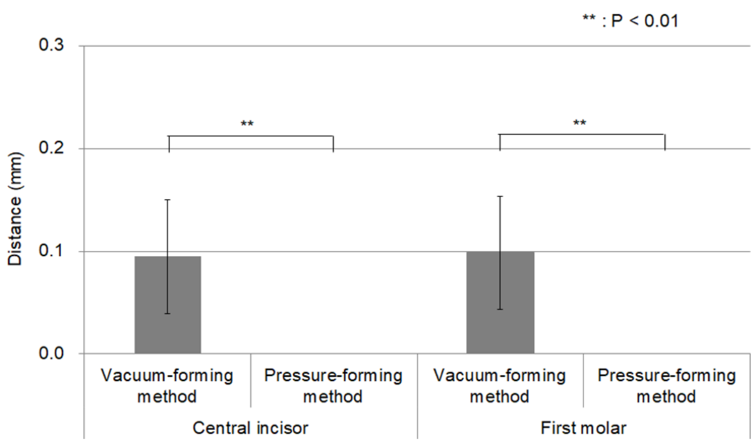

Figure 5. Distance between the mouthguard and cervical margin of the working model at the central incisor and the first molar in each forming method. Measurements are expressed as mean value ± SD.

This result was different from the result of the previous study which investigated the characteristics of the mouthguard formed by ethylene vinyl acetate sheet [14]. The previous study [14] showed that the thickness in the incisal part was less than the cervical part both on the vacuum-forming and the pressure-forming methods when ethylene vinyl acetate sheet was used. The reason of the difference between the previous study [14] and this study would be caused by the difference of the sheet hardness. The ethylene vinyl acetate sheet is harder than that of the polyolefin sheet [9]. Therefore, the elongation of ethylene vinyl acetate sheet would not be so large after the heated sheet was contacted to the incisal edge of the central incisor, and then the thickness in the incisal part became less than in the cervical part both on the vacuum-forming and the pressure-forming methods in the previous study [14].

Mouthguard thickness was significantly larger on the cervical part than that on the cusp part both on the POV and POP conditions at the first molar (buccal surface). The heated sheet contacts the cusp part at the first and elongates from that part, and then, the thickness of the cusp part became less than that of the other parts. Though the level of pressure was larger than the vacuum, the height of the first molar is lower than that of the central incisor, therefore, the elongation after the heated sheet touched to the cusp would not be so large, and then the thickness of the cusp part became less than that of the other parts both on the POV and POP conditions. Mouthguard thickness was significantly smaller on the cusp than that on the fovea at the first molar (occlusal surface). Because the shape of the cusp is sharp, the sheet material gathers from the cusp to the fovea which shape is concave during the forming process, and then the fovea became thicker than the cusp.

The thickness of the central incisor differed between the POV and POP conditions at the center and the cervical parts, and the thickness on the POP condition became smaller than that on the POV condition. This result would be occurred because the level of pressure on the POP condition was larger than the vacuum on the POV condition. The heated sheet on the POP condition would be elongated after touching the incisal edge with the higher pressure, and then the thickness became smaller. On the other hand, the thickness at the first molar became smaller on the POV condition than that on the POP condition both on the buccal surface and the occlusal surface. The height of the first molar was lower than the central incisor; therefore, the higher pressure during the pressure-forming would not bring large influence to the elongation of the sheet at the part of the first molar. More than that, the heated sheet at the part of the first molar would be elongated by the continuing vacuum for 2 min, and the sheet thickness on the POV condition would be smaller. These results were contrary to the results reported in the previous study [14]. The thickness on the first molar was smaller on the pressure-forming method than that on the vacuum-forming method in the previous study using the ethylene vinyl acetate sheet [14]. The polyolefin sheet is softer than the ethylene vinyl acetate sheet [9], therefore, it was considered that the elongation of the polyolefin sheet is larger than that of the ethylene vinyl acetate sheet, and the polyolefin sheet would be more elongated by the continuing vacuum applying, and the sheet thickness at the part of the first molar would be smaller on the POV condition.

Concerning the mouthguard fit, the POP condition showed greater fit in comparison with the POV condition. The difference of the fit between the POV and POP conditions would be occurred because of the difference of the pressure on fabrication. The vacuum-forming machine showed the pressure lower than 1 atm and the pressure-forming machine showed the pressure of 0.3 MPa (2.96 atm) [14]. The higher pressure of the pressure-forming method would result better fit. This result was consisting with the previous study [14] which investigated the mouthguard fit using the ethylene vinyl acetate sheet.

These results of this study suggested that the pressure-forming method is easy to decrease the mouthguard thickness at the central incisor and vacuum-forming method is easy to decrease the thickness at the first molar when polyolefin sheet was used. The mouthgurard fit was greater when the mouthguard using the polyolefin sheet was fabricated by pressure-forming method. These results are necessary information for selecting the mouthguard forming method using the polyolefin sheet. In the future study, it is necessary to clarify other characteristics of the mouthguard formed by the polyolefin sheet for establishing the mouthguard using the polyolefin sheet.

Disclosure of conflict of interest

None.

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