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Original article

Variation in mouthguard thickness due to different heating conditions during fabrication

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Abstract

Purpose: The aim of this study was to evaluate the change in thickness of the mouthguard sheet due to different heating conditions during fabrication.
Methods: Mouthguards were fabricated with ethylene vinyl acetate (EVA) sheets (4.0-mm thick) using a vacuum-forming machine, and six conditions which varied the height of the frame above the surface, reversing the sheet while heating, and controlled power on–off of the heater when a specified level of sagging had been attained were used to determine optimal conditions. The working model was trimmed to a height of 20-mm at the incisor and 15-mm at the first molar. Post-molding thickness was determined for the incisal portion (incisal edge and labial surface) and molar portion (cusp, central groove, and buccal surface). Differences in the change in thickness due to heating condition were analyzed using Scheffé's multiple comparison tests.
Results: The heating condition which the sheet frame was lowered to and heated at 50 mm below the top of the post, the heater was turned off when the sheet sagged by 10 mm, and the sheet was molded when the sagging reached 15 mm showed the thickest, what the decrease in the thickness reduction was approximately 0.40–0.44 mm at the incisal, and that was 0.35–0.40 mm at the molar portions.
Conclusion: When molding a mouthguard using an EVA sheet, the thickness of the incisal and molar portions of the mouthguard can be maintained by adjusting the height of the sheet frame and heating conditions, which may be clinically useful.

Keywords: Mouthguard; Thickness; Heating conditions; Ethylene vinyl acetate co-polymer sheet

1. Introduction

Use of a mouthguard during sports can reduce the chance of injury or concussion of the brain [1–4]. However, the efficacy and safety of mouthguards is greatly influenced by the type and thickness of the material used [5–11]. Ethylene vinyl acetate resin (EVA), the most commonly used material [12], is broadly divided into olefin- and styrene-based thermoplastic elastomers. EVA has many applications owing to its low softening temperature and affordable price. In addition, the many color variations of EVA contribute to its popularity.

The current standard method for producing custom-made mouthguards involves mainly soft-forming of a thermoplastic elastomer sheet which is molded over a working model. This method is relatively simple, but can lead to reduced thickness of the mouthguard sheet. When using an EVA sheet, the sheet should be 3–4 mm thick at the incisal and molar portions to sufficiently reduce the force of any impact [6,8–11]. However, the reduction in mouthguard thickness that occurs along the labial surface of the incisal portion and at the incisal edges is extensive, and the key is how well the thickness reduction in this region can be prevented. To produce effective mouthguards, it is necessary to predict changes in material thickness after molding, select appropriate materials and equipment, and study the design of mouthguards.

Various attempts have been made to limit the decrease in thickness of the incisal portion of a mouthguard [13–15], and such attempts are dependent on the skills of the operator and the change of the sheet shape. In this study, we focused on maintaining material thickness along the incisal and molar portion. We then investigated the molding-induced changes in the thickness of EVA sheets to identify optimal heating conditions.

2. Materials and methods

The mouthguard sheets were EVA sheets (Sports Mouthguard®, 127 mm × 127 mm × 4.0 mm, clear; Keystone Dental

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Inc., NJ, USA). The working model was made by taking an impression of a maxillary dental model (D16FE-500A-QF, Nissin Dental Products Inc., Kyoto, Japan) using a silicone rubber impression paste (Correcsil®, Yamahachi Dental Mfg., Co., Aichi, Japan). Hard gypsum (New Plastone®, GC Co., Tokyo, Japan) was then poured onto the impression. The working model was trimmed to a height of 20 mm at the cutting edge of the maxillary central incisor and 15 mm at the mesiobuccal cusp of the maxillary first molar [16–18]. The model was well-dried more than 48 h in an air-conditioned room at a temperature of about 22.0 °C. Sheets were molded using a vacuum-forming machine (Ultraformer®, Ultradent Products Inc., UT, USA) [16–19]. During molding, the model was set up so that the incisal portion was at the center of the suctioned surface. The following six heating conditions were compared: (1) the sheet was molded when it sagged by 15 mm below the level of the sheet frame where the top of the post as ordinary used (OFP); (2) the sheet was reversed after heating for 50 s and the sheet was molded when it sagged by 15 mm under ordinary used (OFP-re); (3) the heater was turned off when the sheet sagged by 10 mm from the level of the sheet frame, followed by sheet molding when the sagging reached 15 mm below the sheet frame under ordinary used (OFP-10HOF); (4) the sheet frame was lowered to and heated at 30 mm from ordinary used and the sheet was molded when it sagged by 15 mm below the level of the sheet frame (30LFP); (5) the sheet frame was lowered to and heated at 50 mm from ordinary used and the sheet was molded when it sagged by 15 mm below the level of the sheet frame (50LFP); and (6) the sheet frame was lowered to and heated at 50 mm from ordinary used, the heater was turned off when the sheet sagged by 10 mm below the level of the sheet frame, and the sheet was molded when the sagging reached 15 mm (50LFP–10HOF). The descending distance of the sheet was measured with a laser pointer fixed to a three-dimensional coordinate measuring machine (No. 192-201, Mitutoyo Co., Kanagawa, Japan). The sheet was pressed to the model for 2 min and cooled for at least 3 h in an air-conditioned room at a temperature of about 22.0 °C. The sheet was molded after the heater of the molding device and a vacuum unit was confirmed that it was done cooled to room temperature by a radiation thermometer (CT-2000D®, CUSTOM Co., Tokyo, Japan). Six samples were produced under each condition.

The temperature of the surface of the mouthguard sheet (heating surface or non-heated surface) was measured by a radiation thermometer (CT-2000D®) under each heating condition. The following five parts of the sheet were measured: the center, the area about 40 mm from the anterior end and 30 mm from either side, and the area about 20 mm from the posterior end and 30 mm from either side (Fig. 1).

Thickness of the mouthguard sheets after fabrication was measured with a measuring device (21-111, YDM Co., Tokyo, Japan) [16–18]. Measurement points for the incisal portion were defined at the right and left central incisor positions as follows: 5 points were spaced equally from the proximal to distal end of the incisal edge, and 10 points were on the labial surface, including 5 points spaced equally from the cervix to the incisal edge along a line located one-third of the distance from the proximal edge and corresponding to 5 points along a line located one-third of the distance from the distal edge.

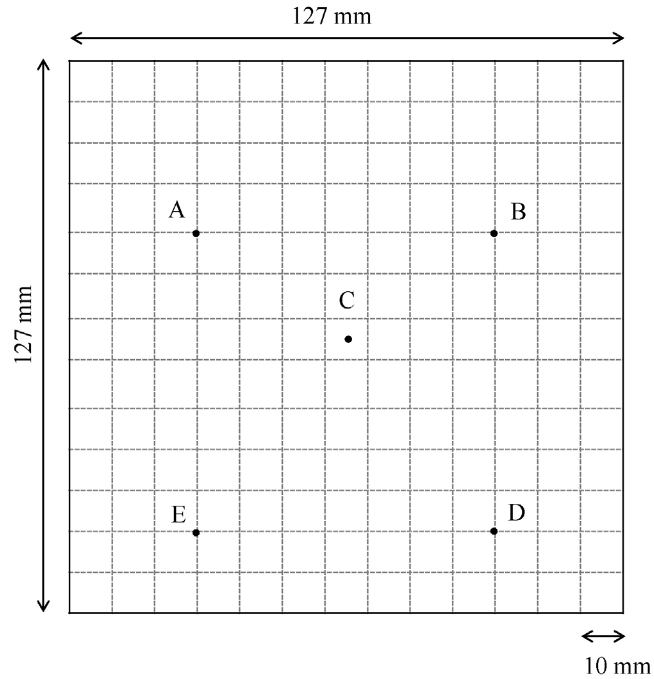

Fig. 1. Measurement points for temperature on the surface of the sheets (A–E). (A and B) The front point. (C) The center point. (D and E) The backward point.

Measurement points for the molar portion were defined in the left and right first molars as follows: 4 points were on the cusp, including the proximal and distal buccal cusps and distal lingual cusps; 5 points were spaced equally in the central groove from the proximal to distal end; and 10 points were on the buccal surface, including 5 points spaced equally from the cervix to the tip of the cusp along a line located one-third of the distance from the proximal end and corresponding to 5 points along a line located one-third of the distance from the distal end. The measurement was one time under each sample and used it for analysis for the mean value of the thickness.

Additionally, the fit of the mouthguard to the working model was observed macroscopically after formation, as recommended in a study by Mizuhashi et al. [20].

Statistical analysis was performed using SPSS 17.0 software (SPSS Japan Inc., Tokyo, Japan). Differences in the thickness change of mouthguards molded in response to different heating conditions of the sheets were analyzed by the Shapiro–Wilk test for normality of distribution and by Levene's test for homogeneity of variance. Normality and equality of variance were found for each item. The data were analyzed by one-way analysis of variance (ANOVA) followed by Scheffé's multiple comparison tests. Significance was set at $p < 0.05$ for all analyses.

3. Results

Table 1 shows the mean temperature on the surface of the sheet under each heating condition. For OFP and OFP-re, the sheet temperature was almost the same in both the heating surface and non-heated surface. For 50LFP, the difference of