J. Gifu Dent. Soc.
Vol.48, No.3, 137 ~ 141
February, 2022

ORIGINAL ARTICLES

Changes in Hardness of Mouthguard Materials After Heating and Pressure Molding

WATANABE KAZUHIRO[1], YAMAUCHI MUTSUO[2], MIYAO MOTONOBU[3], WATANABE RYO[3], KASAI TADAKATSU[1], EHARA YUICHI[1], NAGANAWA KOSUKE[1], UKAI AKIRA[1], TAKAHASHI MOE[1], MATSUSITA TAKAHIRO[1], YASUMURA SHINICHI[1], SUMITOMO SHINICHIRO[1], MURAMATSU YASUNORI[1]

Purpose: Mouthguards (MGs) are generally fabricated by heating and molding ethylene-vinyl acetate (EVA) sheets. In this study, we investigated the change in hardness of EVA material by heat-molding MGs.

Methods: Five different EVA sheets were heat-molded on the model to produce MGs. The anterior and molar regions of MGs were cut out for sampling materials. A micro durometer (MD-1, Kobunshi Keiki Co Ltd, Kyoto, Japan) was used to measure the material hardness.

Results: In most samples, their hardness rose after heat-molding, and the hardness level was higher in anterior regions than in molar regions.

Conclusion: The hardness of EVA used in MG materials tended to increase after heat-molding.

Key words : mouthguard, ethylene vinyl acetate, hardness, heating and molding

INTRODUCTION

The main purpose of wearing a mouthguard (MG) is to prevent oral traumas such as tooth fracture and dislocation.[1] Many studies have reported that the shock absorption capacity of MGs was important for preventing such traumas.[2-5] A study also found that the shock absorbing property might alter for the maximum impact force as the hardness of the material increased.[5] A MG is generally heat-molded with an ethylene-vinyl acetate (EVA) sheet.[6] Therefore, the temperature for heat-molding could change the hardness of EVA.[7-9] We investigated the changes in the hardness of EVA after heat-molding in MG fabrication.

MATERIALS AND METHODS

As MG materials, we selected clear EVA sheets (3 mm in thickness) from 5 different manufacturers: Capture sheet (CAP; Shofu Inc. Kyoto, Japan), Drufosoft (DRU; Rinkai Inc. Tokyo, Japan), Disc mouthguard (YAM; Yamahachi Dental MFG., Co. Aichi, Japan), BIOPLAST (BIO; JM ORTHO, Tokyo, Japan), and Erkoflex (ERK; Erkodent, Pfalzgrafenweiler, Germany) (Table 1). We took an impression of an edentulous wax rim model (NISSIN ND-AU.P.39, Kyoto, Japan) with alginate impression material (Aroma Fine, GC, Tokyo, Japan) and then poured high strength dental plaster (New Plaston, GC, Tokyo, Japan) to produce a plaster model (Fig. 1). Each EVA sheet was heated and pressure-molded on the plaster under the same condition by use of a pressure molding machine (DRUFOMAT-SQ, Rinkai Inc., Tokyo, Japan). MG fabrication followed the method described by Ishigami et al.[10] We made two pieces of MG for each material. After molding, 5 mm

[1]*Department of Oral Surgery, Division of Oral Pathogenesis and Disease Control, Asahi University School of Dentistry*
1851 Hozumi Mizuho-city Gifu Japan 501-0296
[2]*Asahi University*
1851 Hozumi Mizuho-city Gifu Japan 501-0296
[3]*Department of Prosthodontics, Division of Oral Functional Sciences and Rehabilitation, Asahi University School of Dentistry*
1851 Hozumi Mizuho-city Gifu Japan 501-0296
(Accepted January 7, 2022)

Table 1. Materials used in this study

Code	Commercial name	Manufacturer
CAP	Capture Sheet	Shofu Inc. Kyoto, Japan
DRU	Drufosoft	Rinkai Inc. Tokyo, Japan
YAM	Disc Mouthguard	Yamahachi Dental MFG., Co. Aichi, Japan
BIO	Bioplast	JM ORTHO, Tokyo, Japan
ERK	Erkoflex	Erkodent, Pfalzgrafenweiler, Germany

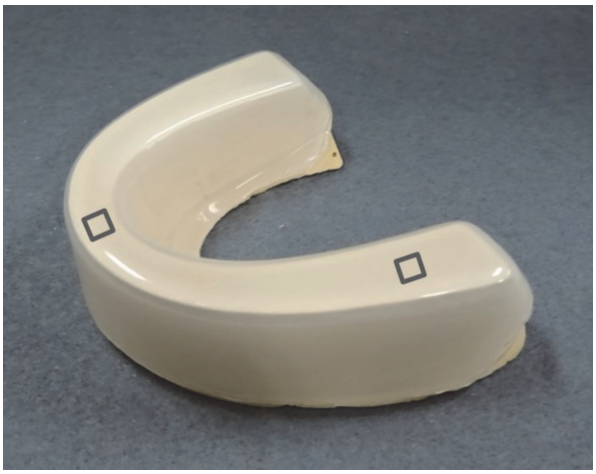

Fig. 1. Working model and sampling site

squares of samples were cut out from the anterior and molar regions of each MG (Fig. 1). A micro durometer (MD-1, Kobunshi Keiki Co Ltd, Kyoto, Japan)[11] was used to measure type A durometer hardness before and after heat-molding. Each sample was measured 5 times, and the mean values of the measurement were calculated (Fig. 2). In addition, the thickness of EVA products could change before and after heat-molding, so the influence from heating was assessed by measuring the difference of hardness before and after heat-molding. The means of hardness were calculated for each material to obtain the change rate. Statistical analyses were performed by employing Scheffé's method (StatView5.0, HULINKS, Tokyo, Japan), and the statistical significance was determined for coefficients at a 5 percent level.

Fig. 2. Durometer (MD-1, Kobunshi Keiki Co Ltd, Kyoto, Japan)

RESULTS

Fig. 3 shows the result of hardness measurements. After heat-molding, the hardness of the anterior region tended to rise in all materials. In CAP, DRU, and YAM, the hardness of the anterior region after heat-molding was significantly higher than that before heat-molding. The hardness of the molar region tended to rise in CAP, DRU, and YAM. In

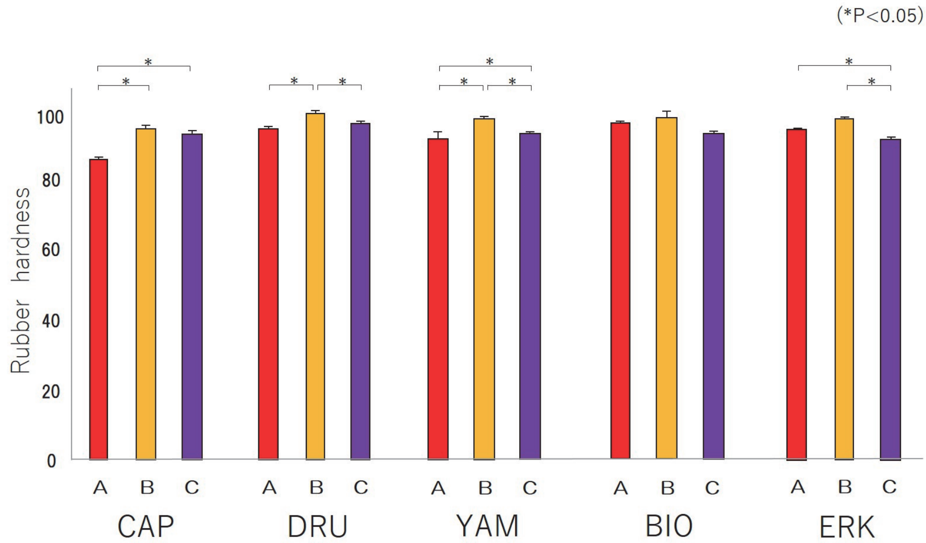

Fig. 3. Comparison of hardness before and after heat-molding

A: Before heat-molding

B: Anterior region after heat-molding

C: Molar region after heat-molding

CAP and YAM, the hardness of the molar region was significantly higher than that before heat-molding, whereas, the hardness of the molar region decreased in BIO and ERK, and the hardness of the molar region in ERK after heat-molding was significantly lower than that before heat-molding. In all materials, the hardness of the anterior region tended to be higher than that of the molar region and was significantly higher in DRU, YAM, and ERK, compared with the other materials. Fig. 4 shows the ratios of change in the hardness due to heat-molding. The change ratio was largest in CAP, and the change ratios of BIO and ERK were significantly smaller, compared with the CAP's change ratio.

DISCUSSION

The composition of MG materials includes EVA, polyolefin, and polystyrene. These are provided as a sheet to be heated and pressed or suctioned by use of a molding machine to fabricate MGs.[12] Among these materials, we selected EVA because it was frequently used as a material for MG. In addition, we selected clear sheets because Takahashi et al.[9] reported that when EVA sheets in different colors were heat-molded under the same condition, the measured values of Shore A differed according to the color, even for products from the identical manufacturer. They also reported that the hardness varied depending on the manufacturer, if similar colored EVA sheets were used. Shore A hardness was mainly selected for measuring hardness.[3-5, 9] As we have been using a micro durometer[11] that could measure hardness in a short time with high accuracy, we used the measurement device in this present study. The rubber hardness values could not directly reflect the Shore A hardness, because the Shore hardness represented the repulsive hardness but the durometer hardness represented the indentation hardness. However, there was no inconvenience for comparing the EVA rubber hardness measured by the durometer hardness.[11] Hardness of material sheets changed over time[3] therefore, the measurement was performed on the day of MG fabrication.

Our results showed that the hardness changed after heat-molding. Most of the hardness increased, although in some cases the rubber hardness was unchanged, and the increasing tendency was not similar between the regions. We fabricated MGs for this study following the same method as we fabricated them for patients and collected the samples. Their

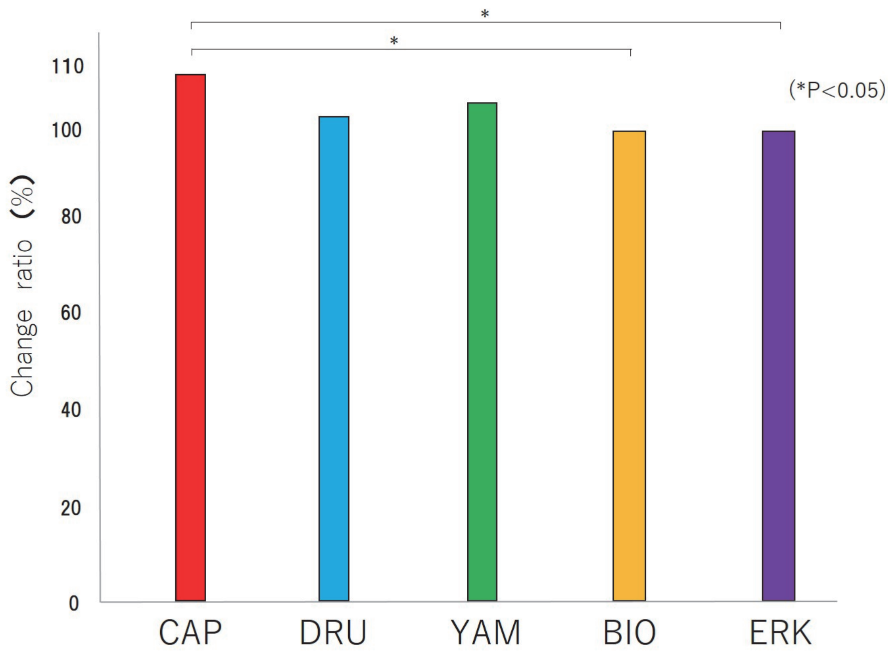

Fig. 4. Change ratios in EVA hardness after heat-molding

thickness varied before and after heat-molding.[13] The rubber hardness increased and its difference between the anterior and the molar teeth was observed with a difference in width due to pressure molding.[14] Tomita et al.[5] found that the impact resistance increased as the Shore hardness increased, but it was difficult to determine the Shore hardness required for the impact resistance of the MG. Since the molded MG itself had the shock absorption characteristics, the change ratio did not show a significant difference except for one product due to heat-molding. Thus, we considered that there was not much effect on the characteristics. We were able to obtain useful data for selecting materials for MGs.

Kuwahara et al.[15] reported that the crystal content of polymer materials increased with temperature, heat-molding, and continuous use, which changed the characteristics of MG. We observed the changes in hardness, because of heat-molding, which presumably altered the number of crystals in the materials. Further studies are needed to investigate changes in the hardness over time while a patient puts a MG in their mouth. The characteristics of EVA differed according to the copolymerization composition of vinyl acetate.[16] The content of vinyl acetate in EVA for MG materials was 20% to 30%, and the higher the content, the stronger the elasticity.[12] The composition of the EVA sheets used in this study was not fully understood, and this could be the reason why there were differences among the products. Also, there are other materials for MG sheets, such as polyolefins and polystyrenes, so we should investigate these materials in the future.

CONCLUSION

The hardness of EVA used for MG material tended to increase after heat-molding, and it was suggested that there was not much effect on the characteristics of MGs.

COI

The authors declare no conflicts of interest associated with this manuscript.

REFERENCES

1) Yasui T, Maeda Y, Tanaka Y, Ishigami K, Ueno T, Matsuda N, Masaru M, Tsukimura N, Takeuchi M, Takeda T, Nukaga Y and Bando Y. A Large-scale Survey of the Preventive Effect of Mouthguards against Traumatic Oral Injury during Sports; An Interim Report. *J Sports Dent.* 2013; 17: 9-13.

2) Tanabe G, Churei H, Wada T, Takahashi H, Uo M

and Ueno T. The influence of temperature on sheet lamination process when fabricating mouthguard on dental thermoforming machine. *J Oral Sci*. 2020; 62: 23-27.

3) Takamata T, Satou M, Kikuchi T, Kasahara T, Kagiya S, Komeda K, Ohigashi S, Tsuchida M, Shoumura M, Osuga N and Ara T. A study on the Application of Polymeric Biomaterials to Sports Mouthguards. *J Sports Dent*. 2018; 22: 1-9.

4) Kagiya S, Sasayama C, Takamata T, Kasahara T, Shoumura M, Osuga N, Nakamura T, Tomida M, Taniguchi H and Nagasawa S. A study of physical and mechanical properties for experimental sports mouthguard materials. *Int J Sports Dent*. 2013; 6: 28-36.

5) Tomita T, Tsukimura N, Ohno S, Umekawa Y, Sawano M, Fujimoto T, Takamura M, Majima A, Katakura Y, Kurata A, Ohyama T and Ishigami T. Shock Absorption of Mouthguard Materials -Influence of Temperature Conditions and Shore hardness on Shock Absorption-. *J Jpn Prosthodont Soc*. 2006; 50: 200-209.

6) Takano Y, Kita K, Kurokawa K, Mizuhashi F, Matsuda S, Momose Y, Yano A, Shibata Y, Iimori T and Tsujimura M. Standardized, Properly-made Mouthguards Based on the Consensus Statements Formed by the Japanese Academy of Sports Dentistry in 2014, Working Group 2: Thermoforming Process, Sheet Material, Removal and Trimming. *J Sports Dent*. 2015; 18: 77-78.

7) Takebayashi C, Wakami M, Nihei H and Aida M. Recycled Mouthguard Sheets Produced by Microwave Heating -Chemical Analyses and Physical Evaluation-. *J Sports Dent*. 2013; 16: 38-42.

8) Takebayashi C, Nihei H, Wakami M, Watanabe T, Kaneya H and Aida M. Physical evaluation of recycled Mouthguard Sheets Made by a New Device. *J Sports Dent*. 2008; 11: 78-81.

9) Takahashi M, Koide K and Mizuhashi F. Influence of color difference of mouthguard sheet on thickness after forming. *J Prosthodont Res*. 2012; 56: 194-203.

10) Ishigami K; Takeda T, Nakajima K, ed. New Techniques for Fabrication of Custom-made Type Mouthguard. 1st ed. Tokyo: ISHIYAKU PUBLISHERS, INC.; 2014: 30-63.

11) Nishizawa M, Sakai M, Yamauchi M and Nagasawa T. Hardness Change of Tissue Conditioner Relined to the Denture Base. *J Gifu Dent*. 2002; 28: 318-331.

12) Ishigami K, Ueno T, Kawara M, Maeda Y, Yasui T, ed. Summery Sports Dentistry (Japanese). 2nd ed. Tokyo: IGAKU JOHO-SHA Ltd.; 2020: 99-102.

13) Okabayashi M, Shimizu K and Morita O. Study on Laminate Mouth Guard Materials: Water Absorption, Deformation under Loading, Thickness before and after Forming. *J Jpn Prosthodont Soc*. 2001; 45: 179-188.

14) Mizuhashi F, Koide K and Takahashi M. Difference in vacuum-formed mouthguard thickness according to heating condition. *Dental Traumatol*. 2015; 31: 233-237.

15) Kuwahara R, Nakajima K, Takeda T, Uehara H and Yamanobe K. Changes in the Physical Properties of Etylene-vinyl Acetate Copolymer Mouthguards during Routine Use. *J Sports Dent*. 2017; 20: 19-26.

16) Kosaka Y. Etylene-vinyl Acetate group (Japanese). *Nippon Gomu Kyokaishi*. 1978; 51: 702-709.