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Fabricating a better mouthguard. Part I: Factors influencing mouthguard thinning

Del Rossi G, Leyte-Vidal, MA. Fabricating a better mouthguard. Part I: Factors influencing mouthguard thinning. © Blackwell Munksgaard, 2007.

Abstract – There is some concern regarding the amount of material thinning that occurs during the fabrication of custom-fabricated mouthguards. It is unclear if this thinning is merely a consequence of the fabrication process or related to other factors such as jaw size. Thus, the purpose of this study was to evaluate the contribution that various dimensional characteristics of the dental arch and the height of the stone model would have on mouthguard thinning. Fifteen subjects participated in this investigation. Alginate impressions from each subject were used to produce three replicas of the maxillary dentition with only the height of the base varying amongst them. The total height of the three models were 20, 25, and 30 mm. A single mouthguard was produced using each of the stone models. The material thickness of the mouthguard was assessed at the labial and occlusal surfaces. Additionally, the dimensions of the stone models were documented. Pearson product moment correlation coefficients were calculated to determine the linear relationship between material thickness and (i) the height of the stone models, (ii) the arch length and (iii) the area covered by the stone model. Statistical tests performed using the mean thickness values collected from the incisors and canines revealed a high negative correlation between the height of the stone model and material thickness ($r = -0.82$). In addition, a low to moderate positive linear correlation was noted between arch length and occlusal thickness at the molars ($r = 0.57$) and between the area of the stone model with the occlusal thickness ($r = 0.49$). The results of the present study indicate that the height of the model used to fabricate custom mouthguards should be kept as low as possible but still allow for the production of a properly fitting mouthguard.

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The reported functions of an athletic mouthguard include, but are not limited to, shielding the teeth from damage following impact, protecting against intra-oral lacerations by keeping soft tissues away from the teeth, protecting the upper and lower teeth from becoming injured when the mandible is forcibly closed and possibly aiding in reducing the incidence of concussions (1–3). With so many benefits associated with mouthguard usage, it really should come as no surprise to find that these protective devices have become exceedingly popular and widely used among participants of both individual and team sports. And while this increase in mouthguard use is almost certainly due to the implementation of team or league rules, it is also quite possible that athletes are themselves voluntarily choosing to wear mouthguards.

Currently, there are three main types of mouthguards available to athletes. These are stock, mouth formed (i.e. boil-and-bite) and custom-fabricated mouthguards. Stock mouthguards are preformed rubber or vinyl devices (4). Because these mouthguards are preformed and worn as is, they must be held in place or in position by clenching the teeth together. Consequently, this type of mouthguard interferes with both speech and breathing, (5–7) and therefore, is often deemed unacceptable for use in sports (8).

In contrast, boil-and-bite mouthguards are made from a thermoplastic material that is immersed in hot water and then formed in the mouth using the fingers, tongue, and biting pressure (7, 9). While these devices offer better fit and retention, a major complication that seems to arise during the fitting of boil-and-bite mouthguards is that a significant amount of thinning (between 70–90%) occurs at the occlusal surface (10) as a result of excessive or uncontrolled exertion of biting pressure. Nevertheless, the accessibility, affordability and ease of use associated with these devices seems to have swayed a large number of mouthguard users as these types of mouthguard continue to be the most commonly used with 90–95% of all athletes relying on boil-and-bite appliances for protection (5, 11).

In contrast, custom-made mouthguards are not easily produced. To obtain a custom fit, a dentist must take an impression of the athlete's dental arch (typically the maxillary teeth) and fabricate the mouthguard from a stone or plaster model of the dentition. Although custom-made mouthguards are by far the most expensive to fabricate, they do offer certain advantages that the others do not. These include optimal adaptation, maximum retention, superior comfort and minimal interference with both breathing and speech (7). Needless to say, professionally fitted mouthguards have a high acceptance rate (8, 12).

Custom mouthguards can be either vacuum-formed or pressure-formed over a stone or plaster cast model of the dentition (5, 7). Vacuum-formed mouthguards are generally fabricated using a single sheet of ethylene vinyl acetate (EVA) that is softened using low heat and then formed using low to moderate suction (vacuum) pressure. Because of the limited heat and pressure that is used in the fabrication process, the shape of vacuum-formed mouthguards is typically short-lived (5). Once the shape of a mouthguard is lost, so too is fit, retention and comfort. An additional shortcoming of vacuum-formed mouthguards is related to the irregular distribution of mouthguard material, which can occur during the manufacturing process, resulting in a final product that is unevenly thick (5). Takeda et al. (13) have reported that an insufficient covering at the occlusal surface may potentially result in, or predispose the wearer to, mandibular fractures.

Alternatively, mouthguards can be pressure-formed using high heat and high pressure. Because of the quality of adaptation that results with this method of fabrication, pressure-formed mouthguards generally offer the best fit of all (5). Another benefit of pressure-formed mouthguards is that they may be laminated (i.e. multi-layered). The advantage of fusing or laminating sheets of mouthguard material together is that the manufacturer can control the final thickness of the mouthguard, and therefore, make certain that with appropriate adjustments the desired or necessary thickness is obtained.

Even though custom-made mouthguards are generally accepted as the best available product on the market, there is still some concern regarding the amount of thinning that results during the fabrication process. Park et al. (10) reported that in the course of manufacturing custom-made mouthguards, there was an average decrease in material thickness of 25–50%. It is unclear if this thinning is merely a consequence of the fabrication process (thermoforming effect) or perhaps related to other factors such as jaw size. Thus, the purpose of this study was to evaluate the contribution that various size characteristics of the maxillary dental arch as well as the height of the stone model had on mouthguard thinning.

Materials and methods

Using alginate material, a dentist (MLV) took impressions of the maxillary dental arch of 15 subjects, all of whom consented to participate in this investigation. Three matching stone models were then produced from each of the impressions. One of the three duplicate models was trimmed to an overall height of approximately 20 mm and the others to a height of 25 and 30 mm (Fig. 1). Upon fabrication of the stone models, various size or

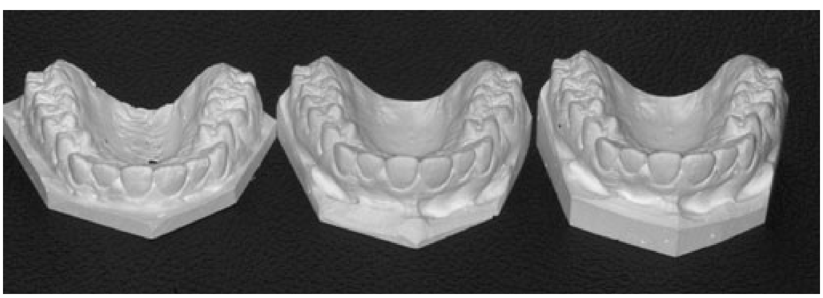

Fig. 1. Varying heights of stone models.

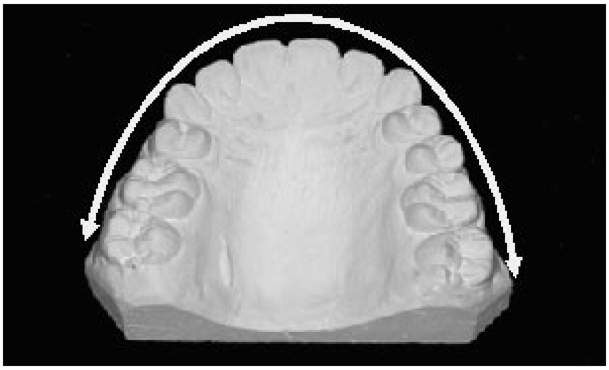

Fig. 2. Measurement of dental arch.

Fig. 3. Measurement of area covered by stone model.

dimensional characteristics of the finished product were recorded. Among the features that were measured were the length of the dental arch (Fig. 2) as well as the length and width of the stone model. The latter two measurements were important for estimating the area covered by the stone model. In order to approximate the area covered by the stone model we used the formula for an ellipse and then halved the value that was obtained (Fig. 3).

Mouthguards were fabricated using a Dreve Drufomat (Type TE/SQ, Dreve-Dentamid GMBH, Unna, Germany) pressure-thermoforming unit. Clear colored, standard ethlylene vinyl acetate sheets that were approximately 3 mm thick were used to fabricate the test mouthguards. To better assess the level of thinning that results during mouthguard fabrication, only single-layer mouthguards were produced for this investigation. All of the mouthguards were constructed following established manufacturer guidelines. First, the EVA sheet was softened for 3 min using the self-contained heat source. Upon expiration of the heating time, the assembly housing the heat source was swiveled away from its location over the EVA sheet, and the chamber enclosing the stone model and the softened mouthguard material was immediately pressurized to approximately 6×10^5 Pa (6 bar). As the chamber pressurized, the mouthguard adapted to the shape of the stone model. In accordance with specifications outlined by the manufacturers of the Dreve Drufomat, the pressure was maintained for a total of 10 min. Once the EVA had cooled and set, the pressure was released and the mouthguard was trimmed and labeled. As three stone models at varying heights were produced for every impression that was taken, this process was repeated 44 times to produce all of the required mouthguards.

Upon the fabrication of each mouthguard, various thickness measurements were recorded. To accurately assess mouthguard thickness, dimensional measurements were obtained using a spring-loaded caliper gauge with the capacity to detect small differences (as small as 1/10th of a millimeter). The occlusal thickness of the mouthguards was assessed by taking measurements from the mesiobuccal, mesiolingual, distobuccal and distolingual cusps of the first molars. Measurements of the labial thickness were collected from the central incisors and both the right and left canines. In all cases, the average mouthguard thickness from each of the regions (calculated from the measurements of both the right and left sides) was used for statistical analysis.

In this study, Pearson product-moment correlation coefficients were calculated to evaluate the linear relationship between mouthguard (EVA) thickness and dimensional characteristics of the maxillary arch or of the stone reproduction. In addition, a one-way analysis of variance (ANOVA) was used to evaluate any difference in thickness that may have occurred in each of the regions of the mouthguard as a result of modifying the height of the stone model. *Post hoc* pairwise *t*-tests with Bonferroni adjustment were calculated when necessary for further comparisons. For this investigation the level of significance for all statistical tests was set, *a priori*, at $\alpha \leq 0.05$.

Results

Descriptive statistics of the data collected in this study are presented in Table 1. Statistical tests

Table 1. Descriptive statistics

Height of model (mm)	n	Incisors thickness, [mm; Mean (SD)]	Canine thickness, [mm; Mean (SD)]	Molar cusp thickness, [mm; Mean (SD)]
20	15	1.6 (0.09)^{x}	1.6 (0.11)^{y}	1.6 (0.06)
25	15	1.4 (0.11)^{ax}	1.4 (0.10)^{by}	1.6 (0.08)^{ab}
30	15	1.2 (0.15)^{cx}	1.2 (0.10)^{dy}	1.6 (0.08)^{cd}

All data sharing the following letters are significantly different (P < 0.05): x,y,a,b,c,d

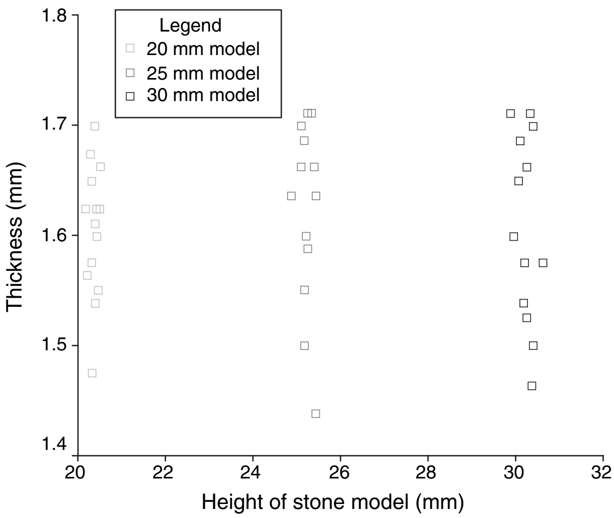

Fig. 4. Height of model vs occlusal thickness (molars).

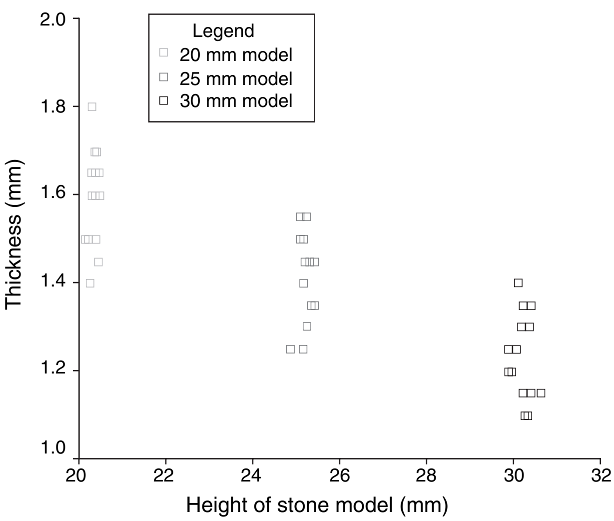

Fig. 5. Height of model vs facial thickness (canines).

performed on the mean thickness values collected from the incisors and canines revealed a significant main effect for the height of the model ($F_{2,28} =$ 85.28, $P < 0.0001$; $F_{2,28} = 146.89$, $P < 0.0001$; respectively) (Fig. 4–6). *Post hoc* tests revealed significant differences between all three heights. Statistical tests also revealed that material thickness varied significantly between the occlusal surface and labial surface when the height of the stone model was either 25 or 30 mm high ($F_{2,42} = 20.77$, $P <$ 0.0001; $F_{2,42} = 62.32.89$, $P < 0.0001$; respectively).

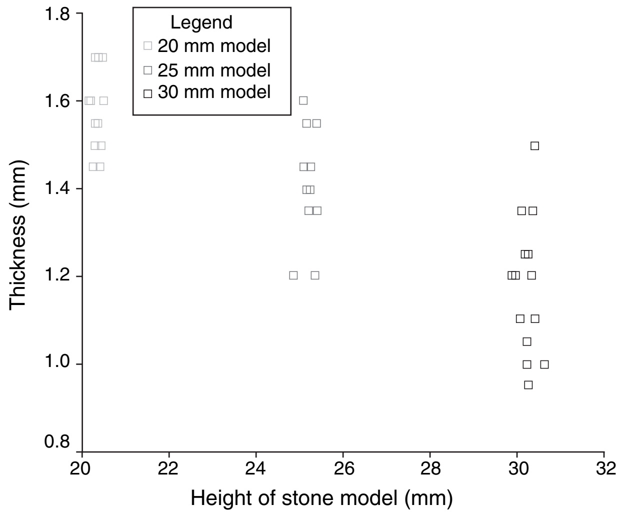

Fig. 6. Height of model vs labial thickness (incisors).

Table 2. The relationship between various dimensional factors and mouthguard thickness

Measurement	Pearson product moment correlation coefficients (P-values): Height of model, (n = 45)	Arch length, (n = 15)	Area covered by model, (n = 15)
Molar thickness	0.014 (0.926)	0.570 (0.027)*	0.488 (0.065)
Incisor thickness	−0.817 (<0.0001)*	−0.172 (0.540)	−0.233 (0.404)
Canine thickness	−0.815 (<0.0001)*	−0.148 (0.598)	−0.248 (0.373)

*P < 0.05

Correlation coefficients calculated to assess the relationship between various dimensional factors and mouthguard thickness can be found in Table 2. As expected, our data revealed a high negative correlation between the height of the stone model and the mouthguard thickness at both the incisor and canines. In addition, a low to moderate positive linear correlation was noted between arch length ($P = 0.027$) and the area of the stone model ($P = 0.065$) with the occlusal thickness (molars). No other correlations were identified.

Discussion

It is well-documented that the actual final thickness of a mouthguard is fairly important in reducing the transmission of impact forces to the teeth (14–17). Impact testing has repeatedly demonstrated an inverse relationship between material thickness and force transmission. Park et al. (10) reported that by decreasing the thickness of a mouthguard by just half a millimeter (i.e. from 1.5 to 1.0 mm), the peak impact forces generated with a drop ball test increased by roughly 48%. The relationship between the dimensional characteristics of a mouthguard and the degree of protection that it offers certainly becomes a matter of some concern when one considers that mouthguard thinning is an inevitable effect of the thermoforming process. Clearly, every attempt must be made to keep the amount of thinning and the concomitant reduction in protection that results to a minimum. So that the protective effects of a mouthguard are not lost during the manufacturing process, the mouthguard manufacturer must either make the appropriate provisions so that the appliances do not undergo extreme or excessive thinning during the fabrication process or correct for the thinning that does eventually take place. However, to be able to take action in anticipation of the thinning that may occur requires an understanding or knowledge of the factors that cause a reduction in material thickness. Only then can these factors be addressed so that they do not severely impact the quality of the mouthguard that is produced.

In our study, the average amount of thinning that occurred at the occlusal surface overlying the molars was approximately 46%. Comparatively, this was much greater than the magnitude reported by Park et al. (10) who revealed that the average amount of thinning at the occlusal surface of custom fabricated mouthguards was 25%. Additionally, our data revealed that the amount of thinning along the labial surface of the central incisors and canines ranged between 47% and 60% (Table 1). This change between the thickness of the initial mouthguard material and the final thickness of the end product was in agreement with the findings of Park et al. who reported a difference of 50%, but noticeably greater than the magnitude of change reported by Guevara et al. (18) who described a 36% rate of thinning along the incisors. Park et al. maintained that a greater decrease in thickness should be expected on the sides of the teeth as compared with the occlusal surface because with positive molding (the stretching of heated material over a mold) the greatest amount of stretch takes place along the sections of material that have the greatest depth or distance to travel. Increasing the overall height of the entire stone model could, in theory, compound the problem as the distance that must be traveled by the EVA as it adapts to the model increases even more. The results of our study confirmed that the amount of thinning that occurs along the labial surface of the incisors and canines is indeed dependent to some degree on the height of the stone model used to fabricate the mouthguard.

Interestingly, we noted that by using a stone model that was approximately 20 mm high, we were able to keep the average amount of thinning at the labial surfaces of both the canines and incisors equal in magnitude to the thinning that occurred at the occlusal surface of the molars. This suggests that keeping the height of the stone model low will not only minimize the amount of thinning that occurs during the thermoforming process, but may also allow for the production of a mouthguard that has uniform thickness throughout.

Perhaps the biggest problem with producing mouthguards that are non-uniformly thick is that those areas with minimal coverage are more susceptible to injury. Takeda et al. reported that having insufficient and/or non-uniform material thickness at the occlusal surface of the mouthguard may result in severe distortion of the mandible with subsequent fracture. And while a small differential in material thickness may be remedied by fabricating a laminated mouthguard, one could just as easily complicate matters. That is, in an attempt to adjust the inconsistency in thickness by laminating the mouthguard, those areas that may already be sufficiently covered or protected may become thicker. This in turn may give rise to yet another problem: non-compliance or lack of mouthguard acceptance. One of the disadvantages of markedly increasing mouthguard thickness (especially at the occlusal surface of the molars) is that athletes start complaining of speech and breathing impairment as well as a general feeling of discomfort or nausea (19).

Certainly, the most unexpected outcome of this study was the positive relationship uncovered between jaw size (i.e. arch length and area) and mouthguard thinning. It would seem that an increase in jaw size would increase the magnitude of thinning as a greater surface would need to be covered by the EVA. Instead, the opposite occurred. Although not sure why this may have happened, this occurrence may be related to the heating process. Close examination of the heating process reveals that the central area of the EVA sheet begins to sag as the material warms up. As the material sags, it also thins. This thinner portion of the EVA sheet then comes to rest on the occlusal surface rather than the palatal area of the smaller models resulting in a decrease in the total amount of material available in that area (Fig. 7).

It must be noted that only thickness measurements collected from the mouthguards produced with the 20 mm models were used in the assessment of the relationship between jaw size and mouthguard thinning. It was decided that as model height

Fig. 7. Mouthguard material sags as it is heated.

impacted thinning, it would be best to calculate Pearson product correlation coefficients from data that was not greatly influenced by this factor. As a result, the linear relationships described above were calculated from a sample size of only fifteen. We recognize that in order to soundly assess a linear correlation between factors, a much larger sample size would normally be required. Nevertheless, a low to moderate relationship was still observed in two cases and thus reported. Certainly, a larger sample size would have improved the likelihood of obtaining more robust correlation data. We, therefore, encourage and recommend others to replicate our study so that more definitive results can be obtained regarding jaw dimensions and mouthguard thinning.

While the purpose of this study was to identify factors that may contribute to thinning of athletic mouthguards, we limited the scope of our investigation to only those factors related to the dimensional characteristics of the maxillary jaw and to the stone reproduction used to fabricate the mouthguards. There may be other factors such as the length of time that the mouthguard material is exposed to the heating element and also the amount of pressure that is used to adapt the material to the stone mold that may contribute to thinning of athletic mouthguards (19). Future research should certainly examine these factors so that construction guidelines can be revised if necessary and the thinning that occurs during the fabrication process can be kept to a minimum.

Conclusion

Mouthguard thinning is an inevitable consequence of the thermoforming process. Given that the efficacy of athletic mouthguards is due in large part to its structural quality, the amount of thinning and subsequent reduction in protection that results during the manufacturing process should be kept to a minimum. The results of the present study indicate that the height of the stone model used to fabricate custom mouthguards should be kept as low as possible while still allowing for the production of a mouthguard that is functional, retentive and fits properly. Furthermore, our study also revealed a low to moderate relationship between the size of the jaw or stone reproduction and mouthguard thinning, but admittedly, our sample size was small to be able to obtain robust correlation data.

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