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Abstract.

Aim: Excessive material thinning has been observed in the production of custom-made mouthguards in a number of studies, due to production anomalies that may lead to such thinning. This study investigated the effect of thinning material patterns of custom made mouthguards when the anterior angulation of dental model was increased during the thermoforming process.

Materials & Methods: A total of 60 samples of mouthguard blanks were thermoformed on identical maxillary models under four anterior inclination conditions (n=4×15); control 0°, 15°, 30°, and 45° . Each mouthguard sample was measured, using an electronic calliper gauge, at 3 anatomical points (anterior labial sulcus, posterior occlusion and posterior lingual). Mouthguards were then CT scanned to give a visual representation of the surface thickness.

Results: Data showed a significant difference ($p < 0.005$) in the anterior mouthguard thickness between the four levels of anterior inclination, with the 45° inclination producing the thickest mouthguards, increasing the mean anterior thickness by 75% (2.8mm, SD: 0.16) from the model on a flat plane (1.6mm, SD: 0.34). Anterior model inclination of 30º and 45º inclinations increased consistancies between the thickest and thinnest mouthguards in the anterior region of these sample groups.

Conclusion: This study highlights the importance of standardising the thermoforming process, as this has a significant effect on the quality and material distribution of the resultant product. In particular, greater model inclination is advised as this optimises the thickness of the anterior sulcus of the mouthguard which may be more prominently at risk from sport-related impact.

INTRODUCTION

The primary function of a mouthguard is to protect the dentition and some of the surrounding structures from violent traumatic impacts during sporting activities [1-3]. Of all the types of mouthguards, stock, boil & bite and custom-made, it has been proposed that custom mouthguards provide a superior fit [1]. However, in the process of construction, when forming the mouthguard material over the dental model thinning occurs [4-6]. A common site of excessive material thinning has been reported in the anterior region of finished custom-made mouthguards, using current single layer techniques [3-6].

Reduction within thickness in EVA has been shown to affect the ability to dissipate impact forces, as it has been shown that there is a direct correlation between material thickness and attenuation of force [7, 8]. Westerman et al. [7] found that both 1 mm and 2 mm thickness of unformed ethylene vinyl acetate (EVA) offers lower protection in relation to energy absorption. They reported that a 2 mm thickness of mouthguard material was more than three times less effective of absorbing force than a 4 mm piece of material, (15.70 kN in comparison to 4.38 kN). Increasing the material thickness beyond 4 mm, with 5 and 6 mm blanks reducing transmission forces to 4.03 kN and 3.91 kN respectively, showing marginal differences and hence evidence of a plateau occurring in relation to force absorption.

Del Rossi et al. [6] and Geary et al. [4] observed material stretching and thinning of EVA when forming over the dental cast [4, 6]. Del Rossi et al. [6] examined model height and jaw size from impressions taken of the maxillary dentition of 15 subjects. For each subject three duplicate models were fabricated, and model heights created of 20mm, 25mm, and 30mm. A single 3 mm mouthguard blank was formed over each testing condition, and measurements were taken. In the anterior and canine region of the mouthguard they observed a mean material thinning of: 47% (mean thickness 1.6 mm) with the model at 20 mm in height, 53% (mean thickness 1.4 mm) at 25 mm and 60% (mean thickness 1.2 mm) at a model height of 30 mm. In the molar cusp measurement point the thickness was reported as a constant thickness of 1.6 mm for all three model heights [6]. Their findings suggested, as the model gets higher, the mouthguard material thins’ in the labial (incisal) region thus to reduce these factors the model height should be kept as low as possible [6].

Geary et al. [4] examined more widely the variations in the manufacturing process that may cause stretching (thinning) of the EVA material, i.e. model height, shape, position on thermoforming platform, plasticizing time and dental model inclination. With relation to model height, Geary et al. [4] observed when the model height was increased from 25 to 35 mm there was an additional thinning of the EVA material of 21% (from 1.53 to 1.21 mm) when using a 3 mm blank. This translates to an overall thinning of the material e.g. in the case of the 25 mm model height a mouthguard material thinning to 1.53 mm or by 49%, and with the model height at 35 mm with a material thinning of 1.21 mm or by 60% [4], this is comparable to findings observed by Del Rossi et al. [6] previously mentioned. Geary et al. [4] also altered the dental model position on the mounting platform (insert bowl) from the centre (1.53 mm), with the labial and then the distal aspects of the model placed on the outermost edge of the mounting platform, in two separate testing conditions. They observed that the model position on the mounting platform significantly ($p < 0.01$) increased the stretching of the mouthguard material, from 3 mm to a mean of 1.53 mm for the control (centred model) and 1.31 mm for the model at the edge of the mounting platform, which represents a 49% and 56% material thinning respectively [4]. Geary et al. [4] studied the heating of the EVA material during the thermoforming process with regards to material thinning. They reported that by increasing heating time by 30 seconds, the amount of thinning in the material was in fact reduced, theorising that the EVA material transforms from its elastic plasticised state to its plastic state, on contact with the dental model, earlier than it would have with a shorter heating time [4].

A number of studies have investigated variations in heating conditions, in relation to mouthguard thinning, when using a vacuum forming machine [9-11]. Mizuhashi et al [10,11] and Takahashi et al, [9] tested mouthguard material that was heated on both sides prior to forming [9, 11], the distance from the heat source is increased [9] and the heat source is turned off for a short duration prior to forming [9] and the mouthguard material is lowered over the model in two test conditions: (a) before (b) after the vacuum in applied [10]. Mizuhashi et al, [10, 11] reported no significant change in finished mouthguard thickness in the anatomical measurement sites of interest, i.e. anterior (central incisor) and posterior (first molar), regardless of the thermoforming conditions. However, these authors did report a *"superior fit"* and retention of the mouthguards, using the following adaptions to recommended heating methods: when the vacuum is applied before the mouthguard material is lowered over the dental model [10]. When the heated surface came into contact with the surface of the dental model, in this case the material being heated to a 1.5 cm sag on both sides prior to forming [11], the mouthguard blank was lowered 50 mm from the heat source than ordinarily used. When the blank reached a 10 mm sag, the heat source was turned off until the blank reached a 15 mm sag before forming. Takahashi et al. [9] hypothesised by slightly lowering the mouthguard material from the heat source, this would create slower raise in material temperature which leads to a more uniform softening of the mouthguard blank prior to forming. Their results reported this final test condition also had a 26% reduction in thinning, when using a 4 mm mouthguard EVA blank.

As variations in model height and heating methods have been previously examined, the present study investigated how manipulation of the inclination of a dentate model would modulate the distribution of the EVA material which was visually seen by CT scanning. It was hypothesised that by systematically increasing the anterior angulations of the dental model during the thermoforming process, there would be an increase in the thickness of the anterior sulcus section throughout the mouthguard which could increase impact protection.

MATERIALS & METHOD.

Ethical approval was sought and obtained prior to commencement of the study, from the ethics committee at the Department of Exercise and Sport Science, Manchester Metropolitan University.

Model Selection and Preparation.

A suitable generic average sized model was pre-selected from demonstration models on which appliances are made for training purposes for clinicians. The single master model was duplicated to produce a group of 60 identical models on which the mouthguards were to be formed. Five random duplicate models were chosen from the group and were examined by Computed Tomography (CT) scanning technology (Scanner: GE Medical Systems)(Light Speed 16, Mode of Capture – Helical, Gantry Tilt – 0 Voxel Size – 0.7031 x 0.7031 x 0.5, Matrix Size – 256 x 256, KV – 120, Ma – 90, Reconstructed in 0.625 mm axial slices) to determine the degree of distortion/variability that that can occur during the duplication process. Robin's 3D - 3D Editor Software (Robin Richards, London, UK) was used to establish an algorithm technique to calculate the least square fit points between the two images surfaces [12]. The programme overlays two images as closely as possible to an average number of points (200). The difference between the two surfaces is expressed as a colour chart, which is assigned to a numerical value this can be set from 10.0 to 0.001 mm. Overall, there was a slight distortion of +/-0.2mm observed in the anatomical region between the five duplicate models (Figure 1). However, this was deemed to be within acceptable tolerances within dentistry [13].

< INSERT FIGURE 1 HERE>

A total of 60 mouthguards were segregated into four inclination conditions (n=15 per group) which consisted of 0° (flat), 15°, 30°, & 45°. The mouthguards were fabricated using 4mm thick, EVA, 120 mm Ø (diameter) clear mouthguard blanks (Bracon Dental Laboratory Products, East Sussex, UK). A Drufomat Scan (Dreve Dentamid GMBH, Unna/Germany) was used for the pressure thermoforming process. This was used due to its audible marker that indicates when the mouthguard is to be pressure formed. This feature gives the study consistency as each blank is heated and blown down at the same point in time, thus reducing any further variability and potential experimental error.

Fabrication of Angle Blocks.

Angulation blocks were fabricated using vacuum mixed Crystical R dental stone (BPB Formula, Nottinghamshire, UK). These were then trimmed on a Wehmer trimming machine (Model 108; Wehmer corporation, IL, USA), which is often used for orthodontic study models, due to the precision calibrated engraved protractor on the trimming table and an angulation tool for precision trimming of dental stone. The blocks were trimmed to gradients of 15°, 30° and 45° (Figure 2), and then inserted into the machine as shown in Figure 3. The angulation blocks inclinations were checked using a Cephalometric protractor/template (Ortho-Care Ltd, West Yorkshire, UK).

< INSERT FIGURE 2 HERE >

The insert bowl on which the model is normally placed during the forming process was removed to allow for the rotation of the model by 15°, 30°, and 45°, as the current system did not allow enough depth for inclination of the anterior section. For the purpose of this study, three removable plates were cast (Crystacal R) into the base of the “F insert” vessel, to form a stable base on which the models and angulation blocks could be seated. The new plates were made to heights of 27 mm for the 15º, 16 mm for the 30º and 12 mm for the 45º. Thus accommodating the rotation of the model in the “F insert”, creating a constant10 mm gap between the incisal tip of the dental model and the underside of the “plate reception” (Figure 3).

< INSERT FIGURE 3 HERE >

Care was taken not to cover the vent hole in the F insert, which allows the air to escape during the thermoforming as this may alter the function of the pressure forming process. All models were treated with an isolating layer of sodium alginate (Isolant Cold Mould Seal, Dentsply, DeTrey GMBH, Germany) prior to forming the mouthguard, to allow easier removal of the formed EVA blank from the dental model once cooled. The Drufomat Scan provides a barcode programing system that stipulates material specific heating and cooling times, dependant on blank thickness. Amongst the available settings, the ‘Drufosoft 4,0’ program was selected, which involves 2.10mins heating, 7.00mins cooling at a 4.5 bar pressure, as it was comparable to the size and thickness of the 4 mm blank selected for this study. The audible beep by the machine indicated when to apply the pressure and how long to leave the mouthguard material to cool prior to releasing the pressure. All test samples were produced by the same operator and thermoforming machines manufacturers suggested program (as detailed above) to minimise any potential errors and variability during the forming process.

Dimensional Measurements

< INSERT TABLE 1 HERE >

An electronic calliper gauge (External Digital Caliper 442-01DC Series, Moore & Wright, UK) was used to measure the thickness of the finished mouthguards at the measurement points shown in Table 1. The callipers had a range resolution of 0.01 mm. Each anatomical point on the mouthguard was measured three times with a mean value obtained. After each measurement the gauge was zeroed. Callipers were calibrated by the use of a 4 mm steel calibration block, grade 1, ISO-DIN-BS (Cen Dev µm +0.02, Max Dev +0.02, Min Dev -0.11, Variation 0.13) (Alan Browne Ltd) and were used at every measurement session to check the accuracy of the gauges.

CT Scans

A mouthguard from each condition (Control , 15º, 30º & 45º) was scanned using a CT scanner (Make & Model: Scanner: GE medical Systems.)(Light Speed 16, Mode of Capture – Helical, Gantry Tilt – 0 Voxel Size – 0.7031 × 0.7031 × 0.5, Matrix Size – 256 × 256 × 97, KV – 120, Ma – 90, Reconstructed in 0.625 mm axial slices).   The scanned images were then transferred for further analysis using Robin's 3D - 3D Editor Software (V3.1.0.0) (Robin Richards, London, UK). Each image was scaled and the extraneous image noise (unwanted scanned information i.e. the surface the mouthguard was scanned on) from the image was also removed using the program’s edit suite. The Houndsfield threshold of the scanned images were then scaled against the original measurements of the corresponding mouthguard, and the image was saved as an STL data file. The desired STL image was opened in Robin’s Cloud - Polygon Mesh Manipulator program (V3.0.7). The image was sized and rotated to the desired orientation. A copy of each STL image was simultaneously opened. The surface of interest on the first image was highlighted using the 3D edit function within the program, and the foreground discarded.

Difference of surface command compared the background of the edited image (first) against the foreground of the second image, effectively comparing the fit surface of the mouthguard against its outer most surface, giving a single image, containing a colour map of thickness of the mouthguard (Figure 7). The comparison range on the output image was set at 4.000 mm. Finally, the comparison image was captured using Photoshop and saved as a JPEG file. Figure 7 served purely as a visual comparison of the thickness changes over the whole of the anterior section of the mouthguard in each testing condition.

Statistical Analysis

Statistical analysis was performed using PASW® Statistics 18 (SPSS Inc., Chicago, IL, USA). Sphericity checks were carried out using the Mauchly's test and Greenhouse-Geisser corrections applied where the assumptions were violated, i.e. sphericity not assumed. To identify any impact of dental model anterior inclination on the variability in mouthguard thickness, a repeated measures ANOVA was performed at each discrete anatomical measurement site. Post-Hoc pairwise comparisons, with Bonferroni corrections, where carried out where a main effect was identified. Data are presented as mean ± STDEV unless otherwise specified. Statistical significance was accepted at $\alpha \leq 0.05$. Z-score analyses were also carried out on the outliers in Figures 4, 5 and 6.

Results

Measurements from all levels of inclination are reported in Table 2 and expressed in Figures 4-6, values are expressed as mean thickness dimensions for the anterior, posterior-lingual, and occlusal regions.

< INSERT TABLE 2 HERE >

Anterior Section (Site A, Table 1):

The results showed that there was a highly significant difference, ($p< 0.0001$), in anterior mouthguard thickness, between the varying degrees in anterior inclination of the dental model (Figure 4). Post-hoc pairwise comparisons showed a significant difference greater than $p< 0.005$ in the anterior mouthguard thickness, between all four groups, when inclining the anterior region dental model by 15°, 30° and 45°. In the anterior measurement section, there was a mean value decrease from baseline (flat) in thickness of the 4mm single laminate sheet by 60%, 15º inclination by 53%, 30º inclination by 40%, and 45º inclination by 30% respectively (Table 2).

< INSERT FIGURE 4 HERE >

Occlusal Section (Site B, Table 1):

The results showed that there was a highly significant difference, $p< 0.0001$ in the occlusal mouthguard thickness, between the varying degrees of anterior inclination (Figure 5). The ANOVA showed a significant difference of $p< 0.0001$ between all groups but the post hoc tests were used to identify where those differences were and showed non-significance for inclination groups 15° and 30° (Table 2 and Figure 5). In the occlusal measurement section, there was a mean value decrease from baseline (flat) in thickness of the 4mm single laminate sheet by 45%, 15º inclination by 55%, 30º inclination by 52%, and 45º inclination by 62% respectively (Table 2).

< INSERT FIGURE 5 HERE >

Posterior-Lingual Section (Site C, Table 1)

The results showed that there was a significant difference, ($p< 0.0001$) in posterior-lingual mouthguard thickness, between the varying degrees in anterior inclination of the dental model (Figure 6). The ANOVA showed a significant difference of $p< 0.05$, in posterior-lingual mouthguard thickness between all groups but the post hoc tests were used to identify where those differences were and showed non-significance for inclination groups 15° and 30° (Table 2 and Figure 6). In the posterior-lingual measurement section, there was a mean value decrease from baseline (flat) in thickness of the 4mm single laminate sheet by 37%, 15° inclination by 42%, 30° inclination by 47%, and 45° inclination by 60% respectively (Table 2).

< INSERT FIGURE 6 HERE >

CT scans of mouthguards

Four typical CT scanned images show the thickness typography of the finished mouthguards for each angulation group (Figure 7). As the mouthguard thickness increases, the mouthguard image changes from a light blue, denoting approximately 1.6 mm to a red which denotes a thickness of 2.8 mm (Figure 7). The scanned images are purely visual representations to illustrate the thickness distribution, over the whole anatomy of the finished mouthguard, for each test variable and degree of anterior inclination. The scanned image was scaled to the thickness of each of the selected mouthguards to set anatomical measurement points in the anterior sulcus and posterior occlusion.

< INSERT FIGURE 7 HERE>

Discussion

The thickness of a mouthguard has been shown to directly correlate with the rate at which energy is absorbed [7, 8], therefore it is imperative to obtain the optimal material thickness when manufacturing custom-made mouthguards and thereby increase their protective potential against orofacial trauma from impact in sport. A proposed solution to address the thinning problem, seen with finished mouthguards, is to laminate the material using one or more layers to increase the finished thickness of the mouthguard [4, 14]. However, the lamination technique, where a second mouthguard blank is formed over the initial formed mouthguard, can sometimes suffer from poor bond strength between two layers of mouthguard material leading to delamination of the finished mouthguards, especially with vacuum formed mouthguards [15]. Model selection for this study was verified by two studies, that of Mills, [16] and Uysal et al, [17]. Mills, [16], in a study where 230 males aged 17-21 years were assessed. They reported a mean maxillary arch width of 35.13 ± .20 mm in the inter-canine region, 41.60 ± .17 mm in the region of the first premolars, 47.05 ± .18 mm in the region of the second premolars and an arch length of 32.79 ± .20 mm. Uysal et al. [17] also examined a mixed gender cohort of 150 participants (males 72, females 78) with a normal occlusion, the mean arch with in the inter-canine region was 34.4 (SD: 2.1) mm, 42.1 (SD: 2.5) mm in the first pre-molar region and 50.7 (SD: 3.7) mm in the maxillary inter-molar width. The selected master model used in this study, had an arch width of 34.5 mm maxillary inter-canine, 40.5 mm maxillary inter first premolar width, 46 mm maxillary inter second premolar, 49 mm maxillary inter-molar width and arch length from the midline of the central incisors and the gingiva of the mesio-palatal first molar cusp is 32 mm, at the same measurement points respectively. From both Mills, [16] and Uysal et al, [17] studies the maxillary model measured within ±1.7 mm at the same measurement points.

Influence of the Degree of Inclination on Thickness.

By elevating the anterior section of the model by 15°, 30° and 45° there was a statistically significant ($p < 0.005$) reduction in thinning in the anterior region of the mouthguard material during the forming process, Table 2 and was illustrated in Figure 7. A 45° anterior angulation of the dental model produced the mean thickest mouthguards in the anterior region 2.8 mm with a reduction of original laminate thickness of 30% (SD: 0.16). However, the anterior increase in thickness came predictably at the expense of the occlusal mouthguard thickness which reduced to 1.5 mm with a reduction of original laminate thickness of 62% (SD:0.10). In addition, the posterior-lingual region reduced to 1.6 mm with a reduction of original laminate thickness of 60% (SD: 0.15).

In relation to the CT scans when the model was kept flat on the forming platform, the anterior flange of the mouthguard can be seen to be predominantly green, turning to blue towards the edge of the mouthguard flange (Figure 7). This indicates that the material is less than 2 mm thick in this region, and in the case of the blue, less than 1 mm. With the model held at a 15° angle, there is a greater proliferation of yellow, denoting that the thickness has increased to greater than 2 mm in this region. However, the edge of the anterior flange of the mouthguard is still green and therefore less than 2 mm in this region. When the model was placed at a 30° angle the lingual anterior flange the finished mouthguard is generally yellow, showing the mouthguard is above 2 mm in this region. Also, there is a greater degree of red in the gingival and inter dental spaces, indicating the material thickness has increased to approximately 3 mm in this region. Finally, when the model was placed at a 45° angle, Figure 7d, a greater prevalence of red/orange is seen denoting the finished mouthguard has increased thickness between 3-4 mm within this region (Figure 7).

It has been postulated that mouthguards could offer protection against concussion, through the shock absorbency quality of the mouthguard between the occlusion, preventing or lowering the transmission of traumatic impact forces from the mandible to the maxilla and subsequent cranial vault [18].

However, Benson, Hamilton, Meeuwisse, McCrory & Dvorak. [19] report there is no strong evidence to support as to whether mouthguards do reduce the risk of concussion. The current new technique reduced the mean occlusal thickness of the mouthguard from 2.2 mm, with the model flat on the forming table (0º), to 1.5 mm with the anterior of the model inclined to a 45º angle. The posterior lingual/palatal section of the mouthguard is a region of the oral cavity that would be at a much reduced risk of impact due to its inaccessibility. Therefore, we considered that the thickness of the mouthguard in this region could may be 'sacrificed' and redistributed to the anterior region of the mouthguard where the majority of the thinning is normally observed. What is more, anterior orofacial injuries are highly prevalent in sport, with this region most at risk of a traumatic impact from an opponent, via a punch, kick, elbow, or equipment i.e. ball, bat, handlebars, racquet [20-22].

The thinning of the mouthguard material within these specific anatomical regions may reduce the protective efficiency of the mouthguard and leave the wearer more susceptible to orofacial injury [4]. Conversely, the increase in material thickness has been shown to reduce force absorption, which would therefore increase the protective potential of the finished mouthguard [7]. Therefore, the 45° angulation of the model seems to be the optimum model rotation as it increases the anterior region of the mouthguard to a mean thickness of 2.8 mm, and the mean occlusal reduced thickness of 1.5 mm. However, a thicker mouthguard blank could potentially increase the occlusal surface. In other words, with increased angulation, despite the 'sacrificed' thickness in the posterior lingual/occlusal region, the mouthguard's ability to dissipate commutable impact forces between the mandibular and maxillary dentition and substructure is still maintained.

In the current study the thicknesses in the anterior region of the finished mouthguards were more consistent, (mean Coefficient of Variation = 5.9%) when the model was inclined at 45º

(Figures 4 – 6). Figure 4 shows at 0° there is a large variation between the upper and lower ends of the whiskers of the box plot chart. In contrast, with angles 15°, 30° & 45°, there is a much closer gap between the upper and lower extremes of the whiskers of the box plot, indicating greater consistency in these samples. This leads to the assumption that the inconsistency of anterior mouthguard thickness could may decrease if the proposed technique of angling the anterior section of the dental model by 45° was employed.

There seems to be very little published data on this subject matter for comparative analysis. Geary et al. [4] as part of their study examined model inclination and orientation variables that can affect mouthguard thinning. Geary et al. [4] took measurements in 12 anatomical regions, 5 in the anterior and 7 posteriorly. They examined both inclination of the anterior and posterior sections of the model by tilting 10 mm and 20 mm. This had the effect of stretching the material to 1.26 mm ($P < 0.001$) in the first instance and to 1.17 mm ($P < 0.001$) in the second. They reported a significantly higher degree of material thinning in the incisal anterior and cuspal posterior region of the finished sample mouthguard [4].

As one of their testing conditions, Geary et al. [4] tilted the dental model posteriorly by 10 mm, effectively rotating the model, increasing the elevation of the anterior section of the dental model, as seen within this current study. Geary et al. [4] also inclined the anterior of the model, by tilting the posterior down by 10 mm. To achieve a comparison between Geary's study [4] and this current study, a model from the present study, that is believed to be a fair representation of the average size of maxillary dentition, was subjected to the same preparation technique by reducing the posterior portion of the models by 10 mm. When using an orthodontic cephalometric protractor (Ortho-Care Ltd, West Yorkshire, UK) this would equate to a 9° inclination of the anterior section as opposed to the much higher angulation of 15°, 30° and 45° used in the current study.

The technique used in the current study used removable plates and angulations blocks, which employed greater accuracy and consistency during the manufacture of the test samples. However, this technique cannot be easily incorporated on all vacuum-forming machines. The dental model may therefore be placed in lead shot at the proposed angle of 45°, or alternatively when the initial model is cast, the angle of the impression tray can be based to achieve a 45° anterior inclination to save time and materials. In future thermoforming machine manufacturers may wish to include a forming table that can be angled, by as high as 45º. In addition, future studies could test the proof of principle using thicker blanks of 5mm or 6mm, in terms of determining the optimal degree of angulation. Furthermore, it is our recommendation that the technique of anterior model inclination to reduce material thinning, be tested in laminated mouthguard production, since the properties of laminated models are expected to differ from those used in the present study.

Conclusion

Excessive thinning of the mouthguard material has been observed in a number of studies [4, 5, 6, 9-11, 23] could be redistributed to areas at less risk of direct impact, through the angulation of the anterior section of the dental model. Correspondingly, the thickest section of mouthguard is created over the anatomical site of the dental model that is at greater risk of direct impacts i.e. the anterior sulcus. There is a significant increase in difference in thickness of mouthguards ($P < 0.05$) when the anterior section of the dental models are elevated by varying degrees. The optimum increase of dental model angulation, in the anterior section, was by 45°, increasing the finished thickness of a mouthguard by as much as 75% in the anterior sulcus region. Even though there were slight reductions in other measurement sites these could possibly increase by using a thicker mouthguard blank. This technique whereby the dental model should be held with an anterior inclination can easily and at no extra cost be implemented to maximise the protective function of the mouthguard in the anterior region.

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