Comparative Evaluation of Color Stability between Three Different CAD/CAM Milled Denture Base Materials: An In Vitro Study

Maha Nagy Mohamed Kamal

1. Lecturer, Removable Prosthodontics Department, Faculty of Dentistry, British University in Egypt (BUE).

Abstract

Purpose to compare the color stability of Polyetheretherketone (PEEK), Acetal resin (polyoxymethylene POM) and Acrylic resin (Polymetylemethacrylate PMMA) denture base material discs milled by CAD/CAM and stored in different storage media. 63 specimens in the form of discs with 12mm diameter and 2 mm thickness were CAD/CAM milled and divided according to the denture base material into 21 specimens for each group. Group I Polyetheretherketone (PEEK), group II Acetal Resin (polyoxymethylene POM), Group III Acrylic resin (Polymetylemethacrylate PMMA). Then specimens were divided equally into 3 subgroups (n=7) according to the media in which the specimens stored into: coffee subgroup, ginger subgroup and distilled water as a control subgroup. A spectrophotometer was used to evaluate and measure color changes of each sample before storage and after 7 days, then color changes (ΔE) were calculated.

It was found that, all materials revealed statistically significant color changes after stored for 7 days in different storage media. In all storage media, Group III (Acrylic resin) recorded the highest statistically significant color changes mean values, followed by Group I (PEEK) mean values, while the lowest color changes mean values were for Group II (Acetal resin). It was also found that coffee stained subgroups recorded higher color changes mean values than ginger stained subgroups. The CAD/CAM milled acetal resin denture base material demonstrated the highest color stability while Acrylic resin denture base material demonstrated the least color stable material. It was also found that coffee demonstrated the highest color changing storage media.

Keywords: CAD/CAM milling, PEEK, acetal resin, acrylic resin, color stability.
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Introduction

Color stability of dental materials reflects its clinical success and considered as essential key factor for its performance inside patients’ mouth.1,2 For denture base materials, any color changes reflect damaged material and/or aging, consequently, denture base color should match the color and appearance of the underlying tissues.3-6 During processing material translucency and its color shouldn’t be affected or lost, also it should not be stained inside the oral cavity. The serviceability of dental materials affected significantly by the stability of its colors. There are many factors could cause color changes either intrinsic or extrinsic or both. Incomplete polymerization with residual monomer left unreacted, high degree of water absorption , deterioration of intrinsic pigments and dissolution of material components can influence color stability and considered as most common intrinsic factors cause color changes, besides, presence of porosity caused by the excessive heating or the change in pressure values during material processing.7 The extrinsic factors are mainly time-related factors and always depend on the type of food being consumed, beverages such as of coffee, tea, cola and wine could cause dicoloration due to the stains adsorption and absorption by the material surface.8,9 The adhesion and absorption of the beverages with staining ability could affects material quality by creating rough surface, collection of debris and aggregation of oral organisms like Candida.
albicans, which-in turn- destruct the underlying hard and soft supporting tissues.

Unpleasant prosthesis appearance, patient disapproval, in addition to reduced prosthesis quality are considered the main drawbacks of material discoloration specially used in removable prosthesis construction either partial or complete.10,11

The conventional Acrylic resin (PMMA) denture base material tends to absorb water from the oral environment depending on its hydrophilic properties and on the degree of humidity of the surroundings, besides, the damaging effects that caused by variations in pH values accompanied by the presence of cariogenic oral organisms, in addition to, the type of diet intake and the different oral enzymes which lead to discoloration problems in terms of water absorption and material staining.12-15

Recently, thermoplastic resins as Polyamides, Polycarbonates, Polyethylene terephthalates and Polyetheretherketone were introduced as denture base products having several superior properties over the standard PMMA, such as increased flexibility, better aesthetics, claspless retention and can also be used in cases where allergy to monomer is present.16

Denture base materials fabricated by computer-aided design/computer-aided manufacturing (CAD/CAM) technology are supposed to have more favorable properties regarding it mechanical and physical aspects compared to the conventionally manufactured ones.17 Therefore, CAD/CAM milled thermoplastic resins are considered as successful substitute to PMMA. However, scientific evidences regarding discoloration properties of CAD/CAM fabricated denture bases are missing so far. It is still unknown whether these newer materials obtain the exact staining ability as PMMA or not? The aim of the current study was to evaluate the staining ability of three different CAD/CAM milled denture base materials upon immersed in different storage media.

Materials and methods

A wax pattern specimen in the form of disc with 12 mm diameter and 2 mm thickness was fabricated and scanned using digital scanner (SHERA eco-scan 7, SHERA WORKSTOFF Technologies, Germany), then the standard tessellation language (STL) files contain the basic milling setting (specimens dimensions) were loaded onto the CAD software (FreeForm; Sensable). 21 disc-shaped specimens were CAD/CAM milled for each material group. PEEK (Bredent, Germany), Acetal resin (Bredent, Germany) and acrylic resin blanks (Ivoclar Vivadent Inc. USA) directly inserted in the same 5 axis milling machine (shera eco-mill 5 axis machine, SHERA WORKSTOFF Technologies, Germany). After the end of milling procedure, the blanks were removed from the machine and the discs were retrieved, finished and polished according to manufacturer instructions. Fig 1,2,3.

Baseline Color Assessment

The specimens’ color measurements was performed by Reflective spectrophotometer (Model RM200QC, X-Rite, Neu-Ilsenburg, Germany). Fig 4.

The aperture size was adjusted to be 4 mm and the specimens were placed in the center of the measuring port. A white background (CIE L*= 88.81, a* = -4.98, b* = 6.09) was selected and
measurements were recorded according to the CIE \( L^*a^*b^* \) color space relative to the Commission Internationale de l’Eclairage (CIE) standard illuminant D65, where \( L^* \) refers to the degree of lightness (0-100), \( a^* \) to the color on the red/green axis and \( b^* \) to the color yellow/blue axis. The spectrophotometer was calibrated before each measurement. For each specimen 3 color measurements were recorded and the average was calculated.

Figure 4. Reflective spectrophotometer device.

Staining Protocols: Specimens of each group were divided equally into 3 subgroups (n=7) according to the immersion medium (coffee, ginger solution and distilled water). To prepare the coffee solution, 20 g of coffee (Nescafe Classic, Nestle Egypt) was poured into 1000 ml of boiled distilled water. The solution was stirred every 5 minutes for 10 seconds until its temperature decreased to room temperature, and then filtered by using filter paper. Ginger solution was prepared by pouring 20 g of ginger (Royal, Egypt) into 1000 ml of boiled distilled water. The solution was stirred every 5 minutes for 10 seconds until its temperature decreased to room temperature, and then filtered using a filter paper. Distilled water (Health Aqua, Alexandria, Egypt) was used as the 3rd immersion medium. After preparation, the pH values of the prepared solutions were measured using a pH meter (AD11, Adwa, Romania) and determined to 5.5, 8, 6.9, for the coffee, ginger solution and distilled water respectively. Specimens were immersed individually in closed small containers, made of glass, containing 5 ml of each immersion medium and stored in an incubator (CBM. Torre Picenardi (CR), Model 431/V, Italy) at 37°C for 7 days. In order to avoid micro-organism overgrowth and multiplication as bacteria or yeast, the immersion media were daily freshened. The solutions were stirred two times per day to prevent the precipitation of the staining solution particles. By the end of the immersion period, specimens were rinsed under running distilled water and dried with gauze. Color was then re-assessed.

Color Change (\( \Delta E \)) Assessment and measurements

Specimens' color was evaluated after the different staining protocols as described for baseline measurements. Color change (\( \Delta E \)) of each specimen was calculated by the following formula: \( \Delta E = [(L^* \text{ after staining} - L^* \text{ baseline})^2 + (a^* \text{ after staining} - a^* \text{ baseline})^2 + (b^* \text{ after staining} - b^* \text{ baseline})^2]^{1/2} \). The specimens' colors were measured using a reflective spectrophotometer (X-Rite, model RM200QC, Neu-Isenburg, Germany). The aperture size was set to 4 mm and the specimens were exactly aligned with the device. A white background was chosen, and color changes were measured according to the CIE \( L^*a^*b^* \) color space relative to the CIE standard illuminant D65. The color changes (\( \Delta E \)) of the specimens were calculated using the following formula: \( \Delta E_{\text{CIELAB}} = (\Delta L^*^2 + \Delta a^*^2 + \Delta b^*^2)^{1/2} \) Where: \( L^* = \) lightness (0-100), \( a^* = \) (change the color of the axis red/green) and \( b^* = \) (color variation axis yellow/blue).

Results

The results were analyzed using Graph Pad Instat (Graph Pad, Inc.) software for windows. A value of \( P < 0.05 \) was considered statistically significant with the satisfactory level of power set at 80% and a 95% confidence level. Continuous variables were expressed as the mean and standard deviation. After homogeneity of variance and normal distribution of errors had been confirmed, three-way analysis of variance ANOVA was performed. One-way ANOVA was
done for compared subgroups followed by Tukey’s pairwise (if showed significant) and student t-test were used between groups interaction. Descriptive statistics of color changes test results measured in (ΔE) showing mean values and standard deviation for all materials and staining solution types are collected in table (1) and graphically drawn in figure (5).

Table 1. Color changes test results (Mean±SD) for all materials as function of staining solution types.

<table>
<thead>
<tr>
<th>Denture base Material</th>
<th>Staining solution</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coffee</td>
<td>Ginger</td>
</tr>
<tr>
<td>Group I (PEEK)</td>
<td>Mean</td>
<td>8.12</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.003</td>
</tr>
<tr>
<td>Group II (Acetel resin)</td>
<td>Mean</td>
<td>4.87</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.149</td>
</tr>
<tr>
<td>Group III (Acrylic resin)</td>
<td>Mean</td>
<td>12.73</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.634</td>
</tr>
</tbody>
</table>

Regardless to staining solution types, it was found that Group III (Acrylic resin) recorded the highest color changes mean values followed by Group I (PEEK) mean values while the lowest color changes mean values were for Group II (Acetel resin). The difference between materials groups was statistically significant as indicated by three-way ANOVA followed by pair-wise Tukey’s post-hoc tests (p =<0.0001< 0.05).

Discussion

When color alteration is being assessed, visual examination may be considered as an individual psychological, physiological and emotional process while using the spectrophotometer device for determination of color alteration not only eliminates personal explanations but also allows recognition of minor color changes can’t be seen by naked eye. A color system named “The Commission Internationale de l’Eclairage (CIE)” where; L*a*b is a constant color scale that includes all the colors visible to the human eye was used in the present study, hence, it is suitable for studying color changes in different dental materials present in the markets.

Color is considered as an important criteria of any denture material, consequently, its stability during material’s entire survivability time considered as a major factor of prosthesis success or failure. Color changes were determined for all the denture base materials and it increased at all groups through the immersion time. There are multiple reasons that might cause color changes to denture base materials, it could be divided into intrinsic and extrinsic factors including material chemical composition, the residual monomer present, water absorption, the decomposition of intrinsic pigments, the leach out of its components, stain accumulation and material surface roughness. However, polishing ability and material structure not the only parameters providing color stability for a longer period of time but also types food intake are also a key factor.

All discs examined in the present study were CAD/CAM constructed to eliminate the technical errors of the conventional techniques that would probably affect the final density, porosity and hence roughness of the restoration. Also standardization of polishing step seemed to produce a clean, smooth, regular surface and play crucial role in reducing pigmentations. On the other hand, being semi-
crystalline, both acetal and PEEK could have similar degrees of pigmentation since degree of crystallinity, is one of the main factors affecting the ability of the materials for water or staining solution sorption.24,25

The color stability of CAD/ CAM milled PEEK, acetal resin and acrylic resin specimens were compared after storage for 7 days in different storage media using coffee representing an acidic media, ginger representing an alkaline media and distilled water (control group) because basically these are the PH range of beverages which routinely taken by people. The denture base materials which were examined in this study showed different color change values after being stored in these media.

Results of the current study revealed that acrylic resin denture base material recorded the highest color changes mean values ($\Delta E^*$) 12.73, 9.37 and 3.84 in coffee, ginger and distilled water respectively, followed by PEEK denture base material mean values ($\Delta E^*$) 8.12, 4.24, 2.07 while the lowest color changes mean values ($\Delta E^*$) were for Group II Acetal resin denture base material 4.87, 2.86 and 1.94. Results were similar to the study done by Ozkan et al. who studied the color changes ($\Delta E^*$) of acetal and acrylic resin materials and reported that acrylic resin showed higher color changes compared to acetal resin material.26

Douglas et al. also claimed that ($\Delta E^*$) values greater than 5.6 are visually noticed and clinically unacceptable.27 According to this, Acetal Resin showed clinically acceptable ($\Delta E^*$) values ranging from 2.86 to 4.87 after storage in ginger and coffee media respectively, however acrylic resin material showed visually perceptible and clinically unacceptable ($\Delta E^*$) values ranging from 9.37 to 12.73 after storage in ginger and coffee media respectively, while PEEK material showed clinically unaccepted ($\Delta E^*$) values 8.12 with coffee staining solution only, this could be due to the water sorption susceptibility of the acetal resin denture base material, with subsequent hydrolysis that might alter the original color of the tested material. This water sorption is important sign since if the resinous material is capable of absorbing water, it can also absorb other fluids.28,29

Many studies studied the water sorption properties of acetal resin material according to ISO 1567-199941 specification and concluded that acetal resin had significant lower sorption properties compared with acrylic resin material after immersion of both materials in the aqueous cleansing media.30,31 When acrylic resin absorbs water molecules, its mechanical resistance is subjected to be reduced and damaged, water acts as a plasticizer leads to microcracks formation and hydrolytic decomposition of the resin polymer structure, as a result, the linked polymer chains split with gradual breakdown of its internal structure.32 Another study was done to compare color stability of conventional PMMA, high impact resin and thermoplastic resin using coffee and cola as staining solution, revealed that thermoplastic resin showed more color stability when compared to conventional polymethylmethacrylate PMMA and high-impact resin.33 Many other studies revealed that polymerization methods and chemical components forming the resin matrix have a considerable influence on its staining ability.34-36

Another study investigated the effect of cleaning solutions on color stability, water sorption and material solubility of two different types of denture resilient liners and concluded that there was a significant color change between the two resilient liners and it is probably because of the unique characteristics of each liner regarding water sorption which causes stain absorption and accumulation.37

While, on the other hand, Heimer claimed that PEEK material showed the significantly lowest color changes after one week immersion in the following media; red wine, curry, and chlorhexidine as compared to PMMA and composite, he confirmed that PEEK material have a reduced degree of discoloration.38 Moreover, in a study conducted to evaluate color stability of acrylic resins denture base material with flexible one after using different denture cleansers, I was found that flexible denture base material specimens showed more color change as compared to acrylic resins after immersion for one month, a slight change in color was observed with all denture cleansers in all the specimens.39

Another study tested the influence of coffee on the color changes of different CAD-CAM milled acrylic resins, similar to the current study, it was confirmed that clinically unacceptable staining and color changes results were obtained in all the acrylic resin groups.40 In this study, coffee solution was used for
staining the specimens. It has been reported that coffee increases the staining of dental materials significantly and has a color changing effect on materials with polymer structure. Staining with coffee found to be accompanied with surface sorption, although coffee obtains hydrophobic properties, small percentage of coffee colorants have the potentials to enter inside the materials deeply. The dissimilarity in staining ability of the denture base materials used in this study could be due to the reduced water absorption capabilities of the pre-formed blocks as notified by their manufacturers in addition to the hydrophilicity of each material used.41, 19

There is a strong proof that artificial coloring agents add to beverages and other types of food may cause acrylic resin discoloration and staining. The beverages low PH with its dark pigments could result in drastic discoloration and negatively affects the surface integrity through softening the resin matrix. Similarly, Imirzalioglu et al. compared the staining ability and color changes of acrylic resins stored in coffee, tea, and nicotine, results showed visual stained samples with various degrees of color changes. 19

Many previous studies investigated the staining effect of coffee and green tea on denture base materials showed that the brown pigmentation in coffee solution caused more color changes. Its low polarity causes complex interactions between absorption and adsorption properties of the material and the coffee solution, however, the discoloration caused by green tea is related to adsorption properties of the materials.42 In accordance with this finding, all materials specimens stored in coffee solution showed more strong color changes compared to those stored in ginger solution. It was also found that, the minimum color change was found in specimens stored in distilled water. This situation is explained by the absence of coloring substances in distilled water which the cause discoloration in materials, besides its neutral pH that does not cause any surface roughness of the tested materials. 43, 44 Lai et al also studied the color stability of four removable flange materials, his results showed that all tested materials obtained stable color in air and water.45 Material solubility and water absorption properties are seemed to be intensely correlated to the acrylic resin hydrophilic behavior. In the current study, the specimens immersed in distilled water exhibited the least color changes. However, during clinical use, denture base materials are subjected to water sorption from saliva and cleansing agents. Care should be taken as water sorption may affects the color stability and other physical and mechanical properties of the materials. 46

Conclusions

Within the limitation of this in vitro study, it could be concluded that 1- The least color changes were represented by Acetal resin denture base material followed by PEEK denture base material while the highest color changes were represented by Acrylic resin denture base material. 2- Coffee solution (acidic PH) caused the higher discoloration values compared to gingers solution (alkaline PH). 3- Finally, Acrylic resin and PEEK denture base materials showed visible color changes and discoloration at the end of storage time.

Declaration of Interest

The authors report no conflict of interest.

References


