Nanocryl Coating of PMMA Complete Denture Base Materials to Prevent Scratching

ABSTRACT

The surface of polymethylmethacrylate (PMMA) is vulnerable to indentation by hard objects that may contribute to abrade the material surface and subject it to wear. This phenomenon promotes an increase in the surface roughness leading to microbial colonisation which can endanger the general health of wearers and damage the intra-oral prosthesis. The aim of this study is to investigate the effect of three different nanocryl coating agents (Easy Glaze, G-Coat Plus and Formulation XP) on surface roughness and thickness of PMMA material after a simulating cleaning process utilizing an electric toothbrush and three different dentifrices (pastes and immersion). Acrylic uncoated discs were used as a control group. The results showed that the G- Coat Plus coating agent had less changes in the surface roughness and thickness layer whereas the immersion cleaner revealed less abrasion effect compared with the paste cleaners which could be considered the most suitable cleaner to provide lower abrasiveness and good removal of organic debris. However, using nanofilled sealants did not demonstrate significant improvement in reducing surface roughness $p > 0.05$. Nevertheless, it could provide some protection against wearing to the acrylic resin surface during tooth brushing and may provide better resistance to microbial colonisation.

1. INTRODUCTION

The history of the restoration of edentulous patients with complete dentures dates back to 700 BC.[1] Polymeric acrylic resin, also known as poly (methyl methacrylate) (PMMA), has been the most commonly used material for the fabrication of denture bases and to replace missing teeth in both partially dentate and edentulous patients for more than 70 years.[2] A range of materials have been used for denture base fabrication, such as vulcanite, epoxy resins, vinyl resin, polycarbonate, polystyrene, nylon, Bakelite and cellulose products.[3] Vulcanite was the first material utilised for the mass construction of dentures. Vulcanite was fabricated by heating sulphur and natural rubber to provide a good surface fitting material; however, its drawback was the undesirable appearance.[3-6] Vinyl resins possess low fracture resistance due to poor fatigue resistance. In the 20th century, Bakelite and cellulose nitrates were introduced and developed as denture base materials. However, those materials had the limitations of unstable colour and difficult processing. In 1937, Walter Wright introduced PMMA resin onto the market as an alternative denture base material to Vulcanite.[7] Since then, PMMA has been widely utilised because of its desirable properties of superior aesthetics and stability, lack of toxicity, low solubility and water sorption, simple processing and ease of repair.[8] Despite these advantages, PMMA has exhibited inferior mechanical

Keywords

Coating
Complete Dentures
Nanocryl
Scratching

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Received: 26.04.2017
Accepted: 05.05.2017

doi: 10.1922/EJPRD_01679Fathi11

properties and thermal conductivity, a high coefficient of thermal expansion, brittleness, lack of toughness and strength, also a low modulus of elasticity, with dentures prone to failure during function.[1] However, acrylic resin is still considered to be the most common choice of denture base material.[1] Recently, PMMA has been used widely in prosthetic dentistry for facings in bridges and crowns, artificial teeth, impression trays, for denture repair, orthodontics devices, temporary crowns, and to record bases.[9,10] van Noort[3] stated that denture base material should have desirable aesthetic and natural appearance, high toughness, strength and stiffness, accurate reproduction of soft tissue details and dimensional stability, inhibit microorganism growth, low saliva absorption and density, free of taste, odour or toxicity, good adhesion with other polymers, metals and porcelain, easy to repair, manipulate and clean and radio opacity, longevity and low cost.

Surface characteristics are important to any denture base material and can be a cause of concern as they affect the health of the oral tissues of denture wearers.[11] PMMA resin surfaces are prone to indentation by different hard objects, which increases the abrasiveness and wear of acrylic base material. These phenomena provide a favourable environment for fungal and bacterial colonisation which is associated with several oral and general diseases.[12] Proper oral hygiene is vital to a prosthetic surface in order to inhibit oral microorganisms (plaque), which promote angular stomatitis, caries, periodontal and systemic diseases.[13]

The most common pathogenic oral microorganism is Candida albicans (C.albicans), which can adhere comparatively easily to hydrophobic PMMA denture prosthesis surfaces.[13]

Several studies of denture base materials have demonstrated a direct link between acrylic surface abrasion, plaque build-up and C.albicans adherence.[8] Also, surface roughness facilitates the adhesion of microorganisms to the restoration and tooth structure.[14]

There are various methods for cleaning denture surfaces to remove plaque accumulation; these can be mechanical (toothpaste and brushing) or chemical techniques (disinfectant brushing or immersion).[8,15] However, the danger of creating acrylic surface roughness is associated with both mechanical and chemical cleaning methods.[8] Denture paste cleaners contain abrasives, flavouring, detergents, and humectants that have different potential effects on the acrylic denture surface. The variation in abrasiveness of the dentifrices is attributed to their component particles as the main abrasive agents used in pastes are calcium carbonate, aluminium oxide and dicalcium phosphate.[15] Prevention and removal of plaque adhesion have been emphasised to avoid denture related diseases. Various glazes have been utilised for sealing dentures, providing a glossy smoother surface and discouraging plaque accumulation by creating hydrophilicity and very low viscosity denture surface.[16] Nanocryl coatings (Easy Glaze, G-Coat plus and Formulation XP) are nano-filled protective varnish that according to the manufacturers are suitable for sealing surfaces of Glass Ionomer, resin composite restorations and provisional composite crowns and bridges.

This study aims to evaluate the effectiveness of different types of nanocryl coating materials and denture cleaners on the surface roughness of Polymethylmethacrylate (PMMA) denture base material.

2. MATERIALS AND METHODS:

2.1 ACRYLIC RESIN PREPARATION

The study samples of 120 disc specimens were prepared using a silicone mould. The specimens of 20mm diameter and 2mm thickness were fabricated from molten wax poured into the silicone mould. The wax discs were invested according to the manufacturer's instructions. Once the gypsum was completely set, the flask was sprayed with boiling water for 10 min. The mould was left to dry for 5 min and then coated with separating medium. Heat cured acrylic resin (Candulor, Switzerland) was prepared according to the manufacturer's instructions (33g: 15ml). Curing was carried out at 70˚C for 5 hrs and then at 95°C for another 3 hrs. After processing, the flasks were left to cool gradually to room temperature. The prepared acrylic discs were finished and polished using the same procedures employed for dentures utilising burs, sandpaper, pumice and Tripoli. Polishing was carried out by Lathe Polishing machine (KAVO, Germany), using pumice and Tripoli (Metrodent, UK). The pumice was softened with water and a bristle brush wheel was used at a running speed of 3000 revolution/min to polish both surfaces of each sample and around the borders. A shiny scratch free final surface was achieved with brushes, wool mops (C.&L,E, Attenborough, LTD. Nottingham, England) and polishing soap using a lathe machine set at a speed of (3000 rpm). All samples in each group were polished by following steps traditionally prescribed by the ISO 20795 standard.[41] Finally, all the prepared polished samples were put into Ultra Sonic Cleaning for 10 min to remove any polishing debris and then the samples were washed with tap water and dried.

The discs were finished using both burs and sandpaper to provide a flat and smooth surface on both sides and the borders of each disc.

2.2 MEASUREMENT OF PRE-COATING SURFACE ROUGHNESS AND THICKNESS OF THE SPECIMENS:

Sample distribution in this study was performed by choosing 120 acrylic discs with the smoothest surface for the experiment using Light Microscope (ZEISS,Discovery.V8, SteREO, Achromats 1.5X FWD 28mm). The samples were divided into 4 main groups (30 discs each) according to the nanocryl coating agents (Easy Glaze [A], G-Coat Plus [B], Formulation XP [C] and control (no coating) [D]). Each main group was further sub-divided into 3 sub-groups (10 discs each) according to the dentifrices used (Colgate 1, Steradent active 2, and Dentu-Creme 3), as shown in Figure 1. This provided Colgate sub-group with A1, B1, C1, D1 , Steradent active sub-group with A2, B2, C2, D2 and Dentu-Creme with A3, B3, C3, D3; each set contained 10 discs packed separately in individual labeled bags, with 40 discs in each sub-group, as shown in Figure 1.

Each disc was identified using a permanent black marker on one side to show on which side the measurements were to be taken. A digital Profilometer was used for taking the initial measurements of the surface roughness (Ra) of the individual polished discs.

Initial measurements of each disc were taken in 6 directions, 3 horizontal and 3 vertical, before the coating was applied and an average was taken. Digital micrometer measurements were taken to record the initial thickness of each disc, three measurements for each disc, and then an average was taken.

2.3 COATING PROCEDURE

Three types of nanocryl surface coating agents were used in this study (A, B, C) and D (no coating) as a control group.

Each coated group of A, B and C was cured separately using the light curing and vacuum machine.

In group A, each of the 30 discs was coated on the measured surface with Easy Glaze in one layer and one direction. Each disc was placed in the light curing and vacuum machine for 1 min illumination and vacuum to cure.

In group B, the nanocryl coating material G-Coat Plus was coated on all the samples (30 discs). The brushed specimens were also put in the light curing and vacuum machine for 1 min polymerization and vacuum.

The chosen material for coating the 30 samples in group C was Formulation XP. The specimens were put in the same machine for illumination and vacuum but the light cure was used for 15 min twice (30 min) rather than 1 min, in order to produce a fully cured surface.

Group D was the control group and no coating was applied.

2.4 DENTIFRICE PASTE PREPARATION

Three different types of cleaning materials were evaluated in the study: Colgate toothpaste, Dentu-creme denture cleaner paste and Steradent denture cleaner soak. The two pastes were used at dilution 1:1 with tap water, i.e. 2cc water: 2cc paste. The pastes and water were measured into a small plastic bowl using a calibrated syringe. Both were mixed by circular stirring in order to avoid bubble formation and to provide uniform combination of the paste and water. A specially designed toothbrush holder held two Braun electric toothbrushes. According to the manufacturer's instructions, the number of toothbrush rotations was set as 15,000/min and a constant force of 200g was applied to the brush heads using a weighted plunger on the test jig.

2.5 CALCULATING THE REQUIRED TIME FOR BRUSHING AND IMMERSION:

The aim of this test was to evaluate the average time of brushing and immersion that a full upper denture would receive during a one year period. The number of minutes of brushing the denture's acrylic area, equivalent to the area of the used discs, was calculated using the following formulae:

Where:

$$\frac{\text{Area of whole upper denture } (cm^2)}{\text{Area of acrylic disc } (cm^2)} = X\frac{70\ cm^2}{2.84\ cm^2} = 24.65\ cm^2$$

$$\frac{\text{Average duration of one cleaning cycle } (s)}{X} = Y\frac{90\ s}{24.65} = 3.65\ s$$

Y = number of seconds of daily disc cleaning multiplied by 365 to produce the number of minutes of annual disc cleaning. This was evaluated to be 22 min.

The amount of immersion that might occur during one year was evaluated by multiplying the manufacturer's instructions for each day's immersion time of 10 min by 365 to produce 60 hrs and 8 min.

2.6 IMMERSION DENTURE CLEANER PREPARATION

The Steradent Active denture soak was prepared at a dilution of 1:1 by dissolving one tablet in 200 ml of hot water which, as the manufacturer recommended. Each batch of 10 discs of A2, B2, C2 and D2 (coated and control) was soaked in a separate dish of Steradent Active for 60 hrs and 8 min. The specimens were washed with tap water and dried to re-measure the surface roughness and thickness *(Table 1)*.

Table 1. Dentifrice materials

Dentifrices	Types	Samples No.	Dilution with water	Cleaning time
Colgate 1	Toothpaste	40 discs	1:1 2cc w:2cc Colgate	22 min electric brushing
Steradent-Active 2	Immersion denture cleaning	40 discs	1:1 200ml hot water:1 tablet	60 hrs + 8 min immersion
Dentu-crème 3	Denture cleaning paste	40 discs	1:1 2cc w:2cc dentu-creme	22 min electric brushing

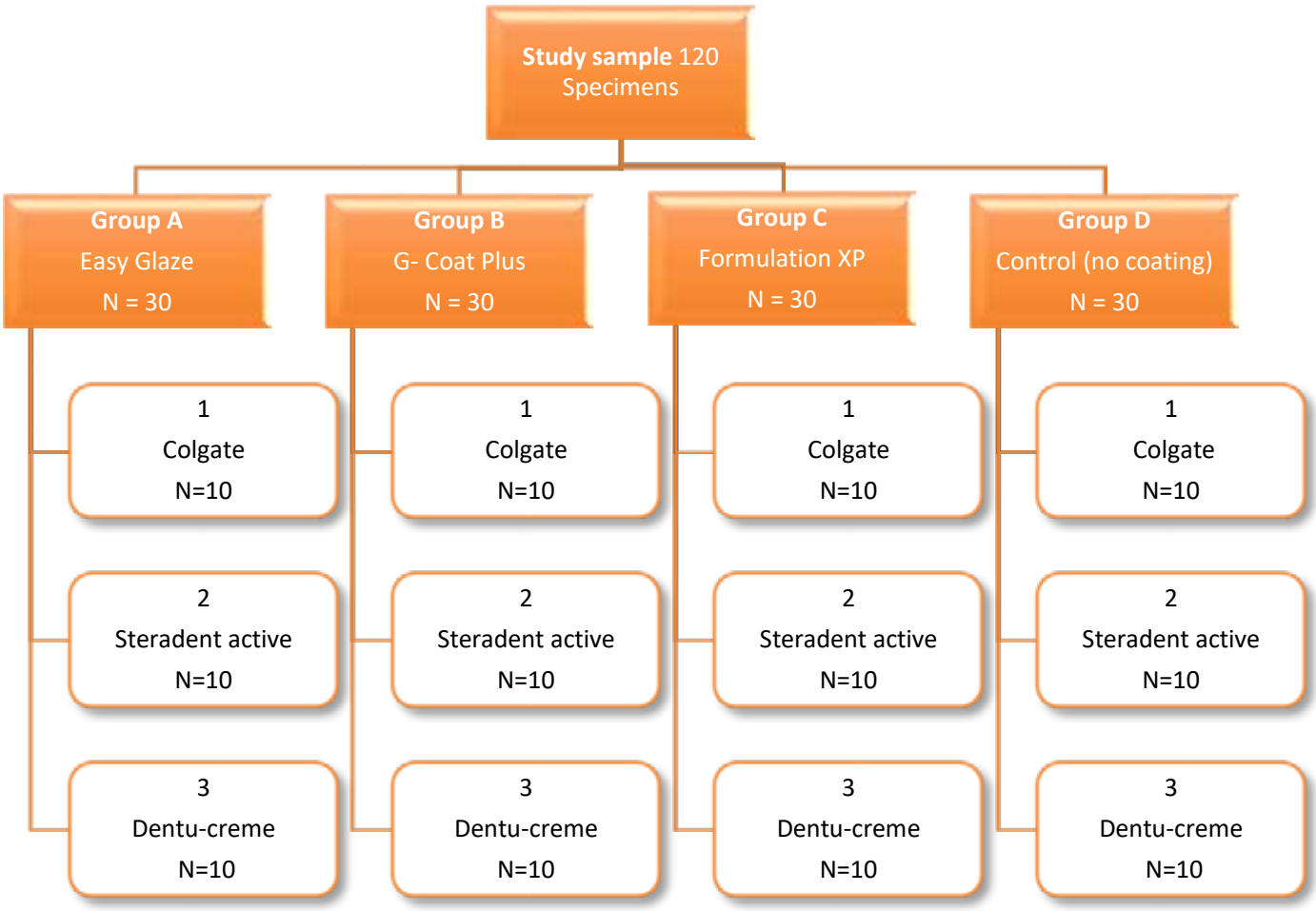

Figure 1: Sample distribution

2.7 DENTIFRICES PASTE TESTING PROCEDURE

The study sample discs and slurry were placed into the wells of the test jig during testing. Each disc was submerged in slurry and a small piece of Blu-tack was used to hold the disc securely in place in the well. The brush heads were pressed onto the discs by means of a plunger which provided a constant load of 200g; this was estimated to be the amount of pressure exerted by people cleaning their teeth. The time for running the toothbrushes was set for 22 min, with 15000 cited rotations per min.

The brushing process was repeated for each disc group (coated and control) with the two cleaning pastes (Colgate and Dentu-crème).After brushing and soaking, the discs were cleaned and the surface roughness and disc thickness re-measured.

2.8 SCANNING ELECTRON MICROSCOPY (SEM)

SEM was used to visualise the surface topography of the experimental samples (pre-coating, post-coated, post-brushed and control samples), one sample from each group was chosen. Each sample was scanned to determine the depth of grooves, scratches and surface roughness condition. Before scanning the samples were placed on aluminum stubs by utilising carbon adhesive discs. The discs were gold spatter coated and visualised with SEM at 200 magnifications.

The data produced were analysed statistically utilising one-way (un-stacked) analysis of variance (ANOVA), at confidence level of 95% (P=0.05). (Minitab, release 14; Minitab, State College, PA, USA). Paired T-Tests were also used to indicate any differences.

3. RESULTS

3.1 THE EFFECTS OF COMBINATIONS OF NANOCRYL COATING AGENTS WITH VARIOUS DENTIFRICES ON SURFACE ROUGHNESS

Figure 2 (1-4) demonstrates the differences in the mean Ra of the prepared acrylic discs after equivalent finishing and polishing.

Figure 2 (1) illustrated a significant (P<0.05) difference in the samples after being coated with nanocryl materials, Easy Glaze [A], G-Coat Plus [B], Formulation XP [C], compared with pre-coated ones. However, samples coated with G-Coat Plus showed the highest increase in the Ra whereas, the coated samples with Formulation XP revealed the lowest Ra in this regard.

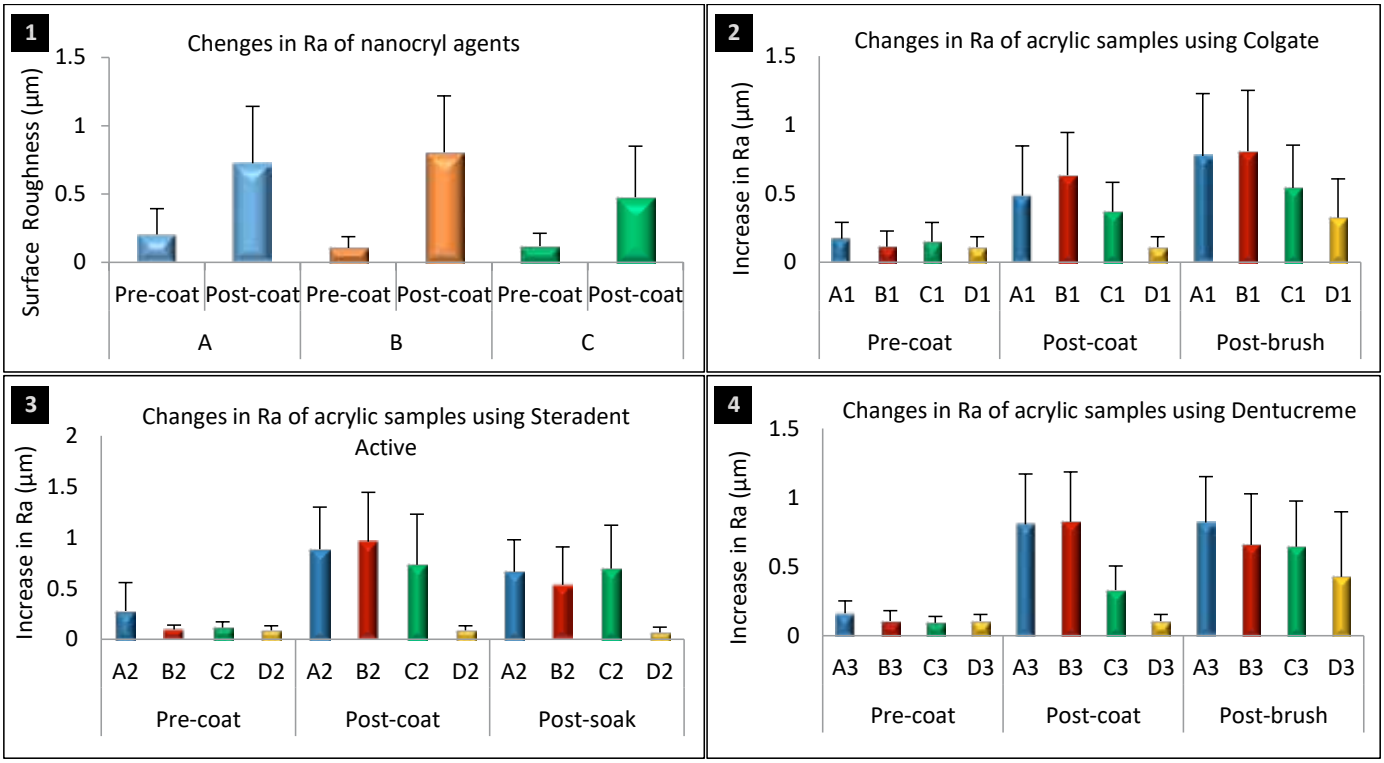

Figure 2: (1-4): diagram (1) shows changes in Ra before and after coating with nanocryl materials A, B and C ; diagrams (2,3 and 4) show changes in Ra values for acrylic discs pre-coating, post-coating and post-brushing/soaking groups according to nanocryl coating agents and dentifrice types. Each cleaning agent is presented in a separate diagram 2, 3, 4. Results are presented as mean+ standard deviation (SD) of each group. Coating materials are classified as A group: Easy glaze, B group: G-Coat Plus, C group: Formulation XP, D group: Control group.

Figure 2 (2) shows a significant (P<0.05) increase in Ra of the coated groups A1, B1 & C1 compared with pre-coating ones, except control group D1 (no coating). However, B1 after being coated with G-Coat Plus (0.63 +/- 0.31), showed the highest Ra value compared with other groups, whereas samples coated with Formulation XP (C1) showed the lowest Ra value (0.63 +/- 0.31) compared to the other groups. All samples showed an increase in Ra after brushing with Colgate of roughly 0.2 µm compared to the post coating group. B1 samples displayed the highest increase in Ra (0.81 +/- 0.44), whereas C1 samples revealed the lowest increase (0.54 +/- 0.31) compared with other post brushing sub groups. Also, the control group D1 specimens showed an increase in Ra after brushing with Colgate.

Figure 2 (3) shows that there were significant (P<0.05) changes in Ra for the main groups (A2, B2 & C2) across the three treatment methods: pre-, post-coating and post-soaking discs, when using Steradent Active immersion. After coating, the lowest Ra was in C2 sub group (0.73 +/- 0.50), while the highest Ra in all samples was in B2 group (0.96 +/- 0.49), showing an increase of about 0.8 µm after coating with various nanocryl materials.

After soaking in Steradent Active for 60 hrs and 8 min, A2, B2 and C2 samples showed a general decrease in Ra over 1 year's estimated immersion compared to the post coating samples. Sub-Group B2 showed the highest reduction (0.54 +/- 0.37) in Ra, of about 0.3 µm after 1 year of immersion, whereas, A2, and C2 showed no significant decrease. D2 sub -group revealed a very slight decrease in Ra after soaking.

Figure 2 (4), shows significant differences in Ra (P<0.05) between the pre-, post-coating and post brushing groups cleaned with Dent-Cream dentifrice. After coating, the Ra of A3, B3 and C3 groups increased in comparison with the pre-coated samples. B3 showed the highest increase (0.82 +/- 0.4) in Ra, of 0.6 µm, post coating with G-Coat Plus, whilst the Ra of C3 increased by approximately by 0.2 µm to show the least change in Ra (0.33 +/- 0.17).

After B3 sub group had been brushed with Dentucreme, the Ra decreased by about 0.2 µm compared to post coating, whereas the Ra of C3 group increased by about 0.4 µm after a similar brushing routine. A3 recorded the least increase in Ra in comparison with post coating samples to show the highest Ra in this regard. Samples of C3 showed the least change in Ra (0.64 +/- 0.33) over the other coated ones.The control group D3 showed an increase in Ra after brushing with Dentucreme paste. Generally, control groups demonstrated the lowest Ra over all other coated groups.

3.2 SCANNING ELECTRON MICROSCOPY (SEM)

SEM analysis was carried out on the acrylic samples to determine the differences in surface roughness compared with results using light microscopy at 200 magnifications, as shown in Figure 3 (1-4), while, SEM of Ra variations micrographs were shown in Figure 4.[1-12] SEM and light microscopy were used to support the statistical results.

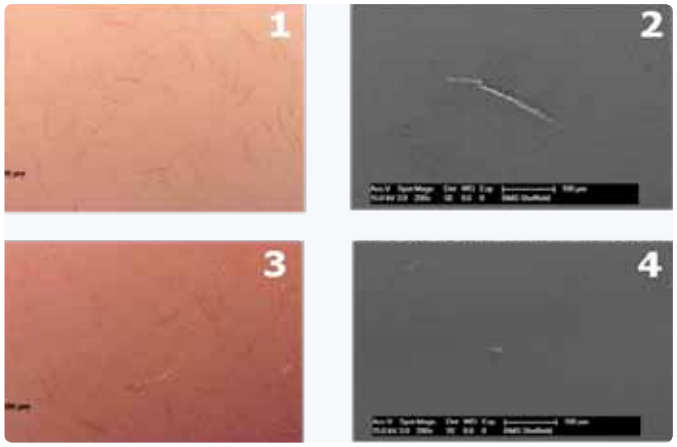

Figure 3 (1-4): 1, uncoated acrylic sample under light microscope after finishing and polishing of surface (1X); 2, flat surface with visible scratch may produced by finishing and polishing procedures (SEM-200 X); 3, acrylic samples 3 and 4 coated with G Coat Plus under light microscope (1X) and SEM (200 X) respectively, showing smooth surfaces similar to the uncoated acrylic samples.

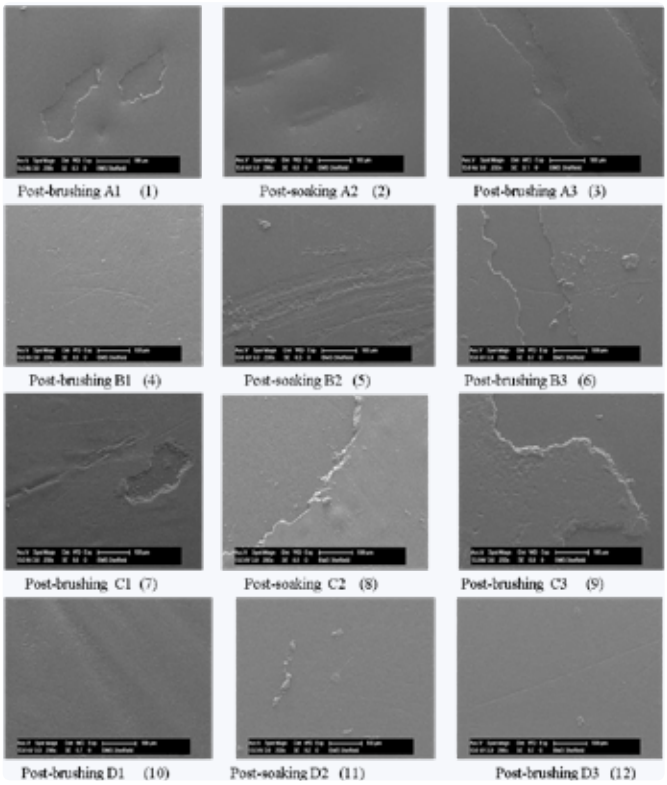

Figure 4 (1-12): SEM analysis of the variations in Ra of coated acrylic discs with Easy Glaze [A], G-Coat Plus [B], Formulation XP [C] and non-coated group [D] after brushing with Colgate (1), Dentucreme (3) and soaking in Steradent (2), (SEM-200 X) . Images (1&3) show the scratches and degradation formed in coated material after brushing with abrasive pastes, while image (2) shows smooth and uneven coated surface after cleaning with non abrasive immersion. (4, 5) display smooth scratches and rough surface post brushing and soaking procedures, image (6) shows scratches and degradation in the coating surfaces, after brushing mechanism. Images (7, 8 & 9) illustrate cracks, detachment and scratches with some voids in image (9) on the coated material post brushing and soaking methods. Images (10, 11 & 12) revealed flat surfaces with very smooth scratches and visible debris.

3.3 THE EFFECTS OF COMBINATIONS OF NANOCRYL COATING AGENTS WITH VARIOUS DENTIFRICES ON THICKNESS LAYER.

Figure 5 (1-4) demonstrates the differences in mean thickness of the prepared acrylic discs based on digital micrometer measurements.

Figure 5 (1) shows significant differences ($P<0.05$) in the thickness values of the coated groups, A with Easy Glaze and C with Formulation XP compared with pre-coated ones. However, group B coated with G-Coat Plus illustrates non-significant differences ($P>0.05$) in the thickness.

Figure 5 (2) shows that after being coated with different nanocryl materials, the A1, B1 &C1 group samples demonstrated statistical significant differences ($P<0.05$) compared with pre-coating; Group samples coated with G-Coat Plus (B1) showed the least changes in thickness (μm) compared to other groups (1.9830 ± 0.2170), whereas samples coated with Easy Glaze (A1) displayed the greatest thickness compared to other groups (2.22 +/- 0.14).

Generally, post-brushing sub-groups A1, B1 & C1 and D1 with Colgate demonstrated non-significant differences ($P>0.05$) compared with coating group, except D1. Also, post brushing B1 group (2.02 +/- 0.21) revealed the least thickness changes while the A1 samples (2.24 +/- 0.13) showed the highest thickness value in this phase. There were no significant changes ($P>0.05$) in thickness layers within pre, post coating and post soaking among sub-groups of discs coated with Easy glaze A2, G-Coat Plus B2 and Formulation XP C2 and the samples soaked in Steradent Active, as seen in Figure 5 (3). However, samples of A2 (2.25 +/- 0.41) showed the highest changes in the thickness of post-coating and soaking groups while, C2 (2.0817 ± 0.2210) illustrated the lowest changes in the thickness in both post-coating and soaking groups for 60 hrs and 8 min.

Figure 5 (4) shows significant differences ($P<0.05$) in the samples thickness among the post coating and post brushing sub-groups. However, pre-coating displayed non significant change in the thickness. Samples coated with Easy Glaze (A3) and brushing with Dentucreme showed the least change in the thickness (2.13 +/- 0.35). However, samples coated with Formulation XP (C3) and brushing with Dentucreme showed the most change in the thickness (2.42 +/- 0.49) compared to the other groups.

4. DISCUSSION

4.1 SURFACE ROUGHNESS CHANGE ANALYSIS

PMMA is an old acrylic resin commonly utilised in construction of denture bases. The material surfaces are prone to indentation caused by other objects and easily abraded. This causes surface roughness and wearing of the PMMA surface, creating a suitable environment for plaque accumulation and poor oral hygiene.[12]

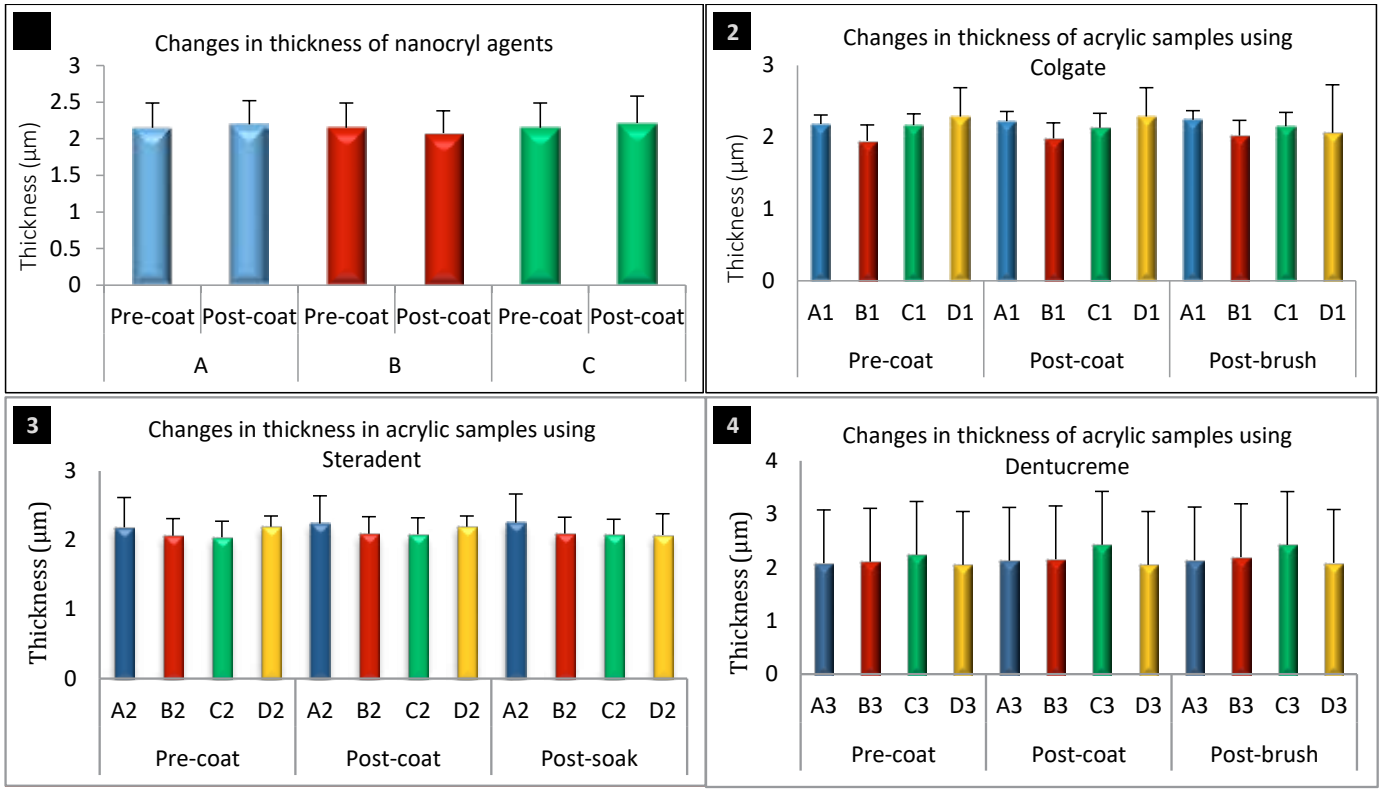

Figure 5 (1-4): (1) shows changes in thickness before and after coating with nanocryl materials A, B and C; (2, 3 and 4) show changes in thickness values for pre-coating, post-coating and post-brushing/soaking acrylic discs groups according to nanocryl coating agents and dentifrice types. Each cleaning agent is presented in a separate (2, 3, and 4). Results presented as mean and standard deviation (SD) for each group. Coating materials classified as A group: Easy glaze, B group: G-Coat Plus, C group: Formulation XP, D group: Control group.

This study evaluated whether coating separate groups of acrylic samples with three types of nanocryl agents would potentially affect the surface roughness and thickness after an estimated one year of cleaning with either paste or by immersion. Generally, a reduction in denture surface roughness could possibly inhibit the risk of biofilm colonisation. Also, application of nanocryl coating materials in fabrication of removable or fixed acrylic prostheses might improve the life span of dentures by delaying the progress of surface roughness and loss of PMMA material due to cleaning, chewing or other forms of abrasion.[12]

The results obtained on surface roughness in this study revealed statistically significant differences between the samples coated with nanocryl materials (Easy Glaze [A], G-Coat Plus [B], Formulation XP [C]) compared with pre-coating. Other than in the control group D (no coating), there was a large increase in mean surface roughness compared with pre-coating, particularly in the group [B] samples coated with G-Coat Plus.

The general increase in the surface roughness of the coated samples was probably associated with the procedure of adding nanocryl coating using a varnish brush, which created visible grooves and roughness within the coating layer. The constituents of the nanocryl coating material, the duration of light curing, and the polymerisation process could also have played a role in increasing the surface roughness of the coated discs.

The most irregular surfaces among the post coated groups were in samples [B] that were coated with G-Coat Plus and this was possibly related to the 1 minute illumination that led to quickly drying and formation of a rigid polymerised layer with an inhomogeneous, rougher surface.

This finding contrasts with that of Agnihotri *et al*[17] who found that G-Coat Plus reduced the gaps formed by polymerisation shrinkage and provided a smooth uniform surface.[17] However, the SEM and Light microscopy results did not support the statistical analysis because the images for samples coated with G Coat Plus obtained under light microscope (1X) and SEM (200 X) exhibited smooth surfaces. This finding is similar to the hypothesis of Agnihotri *et al*.[17]

On the other hand, the lowest coated surface roughness was displayed in group C samples coated with Formulation XP. Possibly a certain intrinsic property or chemical behaviour led to adhesion and cohesion of the coating material during polymerisation. According to van Noort,[3] adhesion is referred to the force that attracts two dissimilar materials together whereas cohesion can be defined as the binding between two similar molecules within the same material.[3]

These findings resemble Owens and Johnson[18] hypothesis that the effectiveness of sealants is based on their penetration into the underneath substrate microstructure before completion of the polymerisation process, which in turn is based on the material's viscosity and capacity to spread over and fill in irregularities.[18] Also, Takeuchi *et al*[19] confirmed their suggestion. However, this could limit the efficiency of the coating materials to compensate all the types of irregular surfaces in order to make them smoother.[20,21]

Heintze *et al*[22] found a strong good correlation between the composition of underneath substrate and increase in surface roughness. Also, they reported that insufficient polishing and finishing procedures considerably influence on surface roughness, potentially supporting the results of this study; whilst this study examined samples of varying surface roughness measurements, however they were prepared similarly.[20,22]

After brushing the coated samples with Colgate or Dentucreme paste or soaking them in Steradent, the statistical analyses demonstrated significant differences in surface roughness, indicating that these treatments considerably affected surface roughness over an estimated 1 year of cleaning. By comparing the coated samples of A1, A2 and A3, group (A2) that coated with Easy Glaze and soaked in Steradent for 60 hrs and 8 min exhibited less surface roughness than the samples brushed with Colgate (A1) or Dentucreme (A3) for 22 min.

Moreover, the same finding emerged with the samples (B2) coated with G-Coat Plus in that those soaked in Steradent exhibited smoother surfaces compared with those brushed with Colgate (B1) or Dentucreme (B3). However, samples coated with Formulation XP and brushed with Colgate (C1) exhibited lower surface roughness than the other two groups cleaned with different dentifrices.

Generally, after brushing or soaking, the G-Coat Plus samples with Steradent soak (B2) exhibited smoothest surfaces among all the post brushing/soaking groups, followed by C1 and A2. The lower surface roughness in (B2) samples could be attributed to the unique advantages offered by the combination of nanocryl G-Coat Plus and Steradent soak.

A study by Diem *et al*[23] examined and also highlighted the advantage of G-Coat Plus in providing a smooth, translucency glossy surface and good sealing that offer protection from staining, discoloration and water contamination.[23] According to Diem *et al*[23] G-Coat Plus is a methyl methacrylate photopolymerised resin and a new low viscosity nanofilled varnish used as a coating for GIC and resin composite restoration.

On the other hand, as Harrison *et al*[15] pointed out, Steradent is composed mainly of effervescent peroxide and does not contain abrasive particles and this possibly contributed to the greater smoothness displayed by the (B2) samples in the current study.[15] In addition, a review article has asserted that applications of light polymerised glazing agents are able to resist variations in water balance and water movement during setting of GIC.[24] Hence, the nanofilled coating material of the B2 samples was rigid and more stable in the soak compared with the brushing procedure; this could also have reduced the surface roughness of the coated acrylic discs. However, the smoothness exhibited by the samples coated with Formulation XP and brushed with Colgate (C1) could relate to the toothbrushing procedure. These results appear to be supported by a finding from another study by Cilli *et al*,[25] which found that the toothbrushing procedure had a smoothening effect on the samples' surfaces.[25] Further potential support is provided by Balsamo[26] statement that nanofilled light cured varnish is designed to adhere chemically to the restoration surface and thereby provides wear resistance, toughness and a translucent glossy surface.[26] Conversely, samples of Easy Glaze brushed with Dentucreme (A3) and G-Coat Plus brushed with Colgate (B1) showed the highest surface roughness value in both post brushed groups. This finding appears to be supported by Zimmerli *et al*[27] claim that the toothbrushing process has a significant influence on increasing the surface roughness.[27] The acrylic uncoated control samples (D) exhibited an increase in surface roughness after brushing with Colgate and Dentu-creme.

In contrast, after soaking in Steradent, group D2 displayed less difference in surface roughness. This could relate to the fact that Steradent contains no abrasive particles that could increase surface roughness.[15]

The greater surface roughness exhibited by the uncoated samples (Control groups) brushed with Colgate (D1) or with Dentu-creme (D3) as well as by the post brushed coated samples could be attributed to the abrasiveness of Colgate and Dentu-creme pastes, which contain particles with high concentrations of calcium carbonate. According to Harrison *et al*[15] the size, diameter and hardness of the particles is greater in Dentu-crème than in Colgate.[15] Additionally, the diameter, size and hardness of the bristles of the electric head brush and brushing mechanism might contribute to surface roughness and loss of coating materials.[15,27] In addition, Harrison *et al*[28] affirmed that people tend to brush their dentures in the same surface area every time, which creates an area of concentrated abrasion similar to that produced by the electric toothbrush machine on the study samples used in this study.[28] Also, Lopes *et al*[29] observed that some surface sealants may not provide sufficient protection against toothbrushing mechanism, which suggests that the brushing process in association with the abrasive cleaning pastes increased surface roughness of the coated samples.[29]

Moreover, measuring processes could all contribute to simulated surface roughness.[27] Regarding the current study, the digital Profilometer and digital micrometer respectively were used before and after coating and after brushing with pastes or after immersion in soak to evaluate changes in surface roughness and thickness of the acrylic samples, which might have led to create some changes in surface roughness.[27]

The dilution used in this study, both for pastes and immersion, was 1:1. This weak dilution permitted the abrasive particles to move and manoeuvre more easily and rapidly over the acrylic surface discs. This velocity might contribute significantly to creation of abrasiveness, whilst the force and speed of brushing are other important factors. Although, in this *in vitro* study the applied brushing force was almost constant (200g) for all the groups, it is possible that movement of the disc away from the brush head in the slurry might have led to variations in the forces applied to the samples as well as in the surface roughness.

The informative SEM (200X) micrographs obtained of post brushing/soaking coated samples visually detected the variations in the abrasive surfaces, grooves and scratches formed by different cleaning agents.

The SEM images of acrylic discs coated with Easy Glaze and brushed with Colgate or Dentu-creme paste (A1 and A3) illustrated small clear pools of the coated surface and degradation which appeared tobe as a result from insufficient coverage of the disc surface during varnish application, which might have created an inhomogeneous sealant layer, an explanation similar to that given by Tjan *et al*.[20,27.30] The samples coated with Easy Glaze and soaked in Steradent (A2) displayed smooth and uneven surfaces with visible debris. Based on Harrison *et al*[15] the smoothness of the soaked sample might be due to absence of abrasive particles in the Steradent.[15]

The SEM images of the samples coated with G-Coat Plus B1 exhibited flat surfaces with numerous smooth scratches that might have been caused by the Colgate brushing process, and debris was also evident. Meanwhile, the sample coated with G-Coat Plus and brushed with Dentu-creme B3 exhibited clear detachment in the treatment surface and small scratches in the exposed acrylic surface and in the coating material. These findings could be related to the abrasive action of Colgate and Dentu-creme during the brushing process and are similar to the obtained statistical results.[27,31,32]

According to Zimmerli *et al*[27] the detachment of the surface coated with G-Coat Plus may have been the result of sensitivity to dryness during roughness measurement, whilst it also may have been linked to the polymerisation process or brushing procedure.[27]

However, the surface of the sample soaked in Steradent B2 were rough with shallow grooves and scratches, and debris was also visible under SEM (200X). Conversely, the statistical findings for these samples group B2 showed them to have the smoothest surfaces of all the coated groups, but the scratches might relate to the fact that the selected original sample already had rough surfaces from the finishing and polishing process, whilst the frequent measurement of surface roughness and thickness might have contributed to these scratches, as could sensitivity of the sample to dryness or the application by brush of varnish to the discs.[27]

Several clinical studies have reported that sealants might not provide such good compensation for rough and irregular surfaces as conventional polishing mechanisms.[19,20]

According to Harrison *et al*[15] grooves formed in surface roughness may have been produced by both the abrasive pastes but this does not explain the surface roughness obtained with Steradent immersion. Their hypothesis may support the results obtained in this study.

SEM results for group C samples coated with Formulation XP, post brushing and soaking showed clear detachment and cracks on their coated surfaces post brushing with Colgate C1, Dentu-creme C3 or soaking in Steradent C2. The pool that formed on the Formulation XP coating seemed to be the result of inadequate coverage of the disc surface during varnish application could be due to the low varnish viscosity, which may have created an uneven sealant layer. Similarly, the coated surface of the disc brushed with Dentu-creme C3 was rough and irregular with visible voids. This could relate to the previous interpretations about abrasive cleaning pastes.[20,27,30]

The sample soaked in Steradent C2 produced cracks and detachment of the surface as well as smooth scratches in the acrylic and coated surfaces, with evidence of debris. These findings could be associated to ineffective penetration of the sealant. Similarly, according to Sesma *et al*,[16] the detachment of the glazed surface on the acrylic disc could have been due to brittleness, thinness, and rigidity of the glazed layer that encouraged cracking and loss of the glazed surface during the toothbrushing process.[16] Furthermore, the detachment could have been due to variation in the tension between the sealant and the surface underneath.[20,30] Therefore, annual recoating of dentures has been recommended by other studies.[16] In contrast, a study by Fergus *et al*,[33] showed that PMMA samples coated with Parylene-C coating resulted in a statistically significant decrease of surface roughness, and seemingly resisted theroughening effect of Steradent cleanser which caused greater change in Ra than the neutral peroxide cleanser.

The coating also resulted in an increase of surface free energy, with the exception of the samples treated with Steradent where a decrease was observed.[33]

Finally, control group D (no coated) exhibited uneven acrylic surfaces with smooth grooves after brushing with Colgate; also small areas of debris were visible on the surface.

4.2 THICKNESS CHANGES ANALYSIS

In general, according to the statistical analysis results, there were significant differences in thickness between the pre-, post-coated and post-brushed/soaked samples.

Post coating the Easy Glaze (A) and Formulation XP (C) samples displayed significant differences in thickness compared with the pre-coated groups. These findings could be due to the addition of the layer of nanocryl sealant to the surface of the acrylic samples or could be caused by the coating material failing to penetrate within the acrylic structure effectively during polymerisation. Additionally, the polymerisation process of the nanofilled coating materials might have an influence on increasing the thickness dimensions. This finding is supported by Sadamori *et al*[34] who reported that the heat cured acrylic resin, which was used in this study, generated heat during the polymerisation reaction led to an increase the thickness of the acrylic specimens.[34]

In contrast, post-coating, the G-Coat Plus (B) samples exhibited no significant difference in thickness, which might be due to effective penetration of the coating material within the microstructure of the acrylic surface and good chemical adherence. Similarly, Zimmerli and Balsamo *et al* [26,27] reported that the nanofilled light cured varnish is designed to adhere chemically to the underneath substrate in order to provide adequate toughness and a translucent glossy surface.[26,27] However, samples coated with G-Coat Plus (B) illustrated very slight reduction in the thickness layer which could be related to the curing duration. These findings appear similar to those by Polukoshko and co-workers *et al* [35] who reported that the second cure of acrylic denture base at low temperatures of about (60°C) produced very slight dimensional changes (shrinkage),[35] whilst Brewer *et al* [36] confirmed this suggestion.

Another supporting study by Wong *et al* [37] revealed that changes in dimensions of acrylic resins tend to occur as a result of water immersion which leads to water sorption and saturation.[37]

In contrast, Friedl *et al*[38] examined the performance of GIC in posterior restorations coated with G Coat Plus during a period of 2 years and identified a loss of volume in the GIC.[38] These results could relate to the behaviour of G Coat Plus in terms of loss of acrylic volume with the passing of time, which is opposite to the finding on B1.

Samples (A2, B2, C2 and D2), post coating and soaking in Steradent, exhibited in general no significant statistical differences in thickness compared with post coating. However, the acrylic discs in control group D2 decreased slightly in thickness, which could related to an intrinsic property of the acryl during the immersion process in Steradent solution with regular refreshed warm water, for 60 hrs and 8 min that might be associated with the acrylic polymerization. Seo *et al* [39] observed that denture base shrinkage could be affected by microwave disinfection, which supports the finding of the current study. It is possible that the fungicidal cleaning agents (Sodium hypochlorite) in the Steradent produced acrylic shrinkage.[39]

According to Harman and Pittsburgh,[40] temperature increases occur in acrylic resin samples because of the exothermic property of the polymerisation reaction, which can be evaluated by changes in the thickness and surface area of the samples. This phenomenon could have resulted from the continuous release of intrinsic stress from the samples.[40]

Finally, there was a statistically significant difference in the thickness of the coated samples (A3, B3, C3 and D3) after brushing with Dentu-creme for 22 min compared with post coating. Samples coated with Easy glaze and brushed with Dentu-creme (A3) recorded the lowest thickness values post coating and post brushing. It is possible that the composition of the Dentu-creme and the brushing process affected the thickness of the samples.[15] However, the C3 samples recorded the highest thickness value after coating and brushing, which might relate to water sorption during the brushing process.[37]

5. CONCLUSION

The finding of this *in vitro* experiment using different nanocryl coating materials (Easy Glaze [A], G-Coat Plus [B], Formulation XP [C]) and control group [D] showed:

Significant difference in surface roughness and thickness before and after brushing/soaking using different dentifrices (Colgate, Steradent, Dentucreme) for an estimated one year.

The nanofilled sealant materials demonstrated little effect on preventing surface roughness and changes in thickness dimensions on the coated samples compared with the conventional polished acrylic discs, uncoated control group (D).

Regarding to the used dentifrices, Steradent could be recommended as the most appropriate method of cleaning the acrylic denture due to the absent of abrasive particles and the potential cleaning ability with less surface roughness.

Colgate showed the least abrasive effect on the coated and acrylic samples rather than Dentucreme paste. On the other hand, the acrylic un-coated control group revealed the lowest surface roughness compared with the other coated tested samples either in post brushing or soaking process.

Coating agents provided good wear protection to the acrylic discs from peeling away and prevented the loss of acrylic surface during brushing procedure.

As a result of these findings, nanofilled sealant materials may improve the life span of acrylic denture by delaying the progress of surface roughness and the loss of PMMA material during chewing and cleaning procedures. Also, glazing materials could be applied as useful glossy sealants covering the acrylic denture to provide a good wear resistance and avoid the abrasion of the acrylic base and teeth.

Coating materials could provide good sealing to the microleakage in order to reduce the food accumulation, inhibit biofilm colonisations and facilitate the oral hygiene. Additionally, sealant agents provide glossy appearance and super aesthetic parameter, particularly in the anterior teeth.

Finally, this limited study did not conclusively prove the potential effect of the three different nanocryl coating materials in providing smooth sealant surface of acrylic complete denture.

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