Objective: Zirconium oxide (ZrO₂) nanoparticles addition to interim fixed prostheses (IFPs) was suggested to improve the mechanical properties. However, the effect of ZrO₂ on the color and surface properties of IFP was neglected. Therefore, this study aimed to investigate the effect of ZrO₂ on the color, hardness, and surface roughness of IFP. Materials and Methods: Customized split-press metal molds were used for the fabrication of forty disk-shaped acrylics (10 mm × 1.5 mm). The salinized ZrO₂ particles were weighed using an electronic balance and added in concentrations of 1wt %, 2.5wt %, and 5wt % of auto-polymerized acrylic polymer powder. Based on ZrO₂ concentrations, specimens were divided into one control group without ZrO₂ and three ZrO₂ study groups 1 ZrO₂, 2.5 ZrO₂, and 5 ZrO₂, respectively. A double beam ultraviolet-visible reflection spectrophotometer was the instrument used for recording the color measurements (CIEDE2000). The Microhardness and surface roughness (Ra, μm) of all samples were tested. ANOVA test was used for data analysis (α = 0.05) Results: Notable changes were seen between the group containing 1% and the other two groups in Δa*, ΔΕab, and ΔΕ00 parameters. Statistically significant differences were observed among the three groups for the ΔL* parameter. No notable changes were seen between the group containing 1% and the group containing 5% for the Δb* parameter. The 1% group showed a statistically significant difference in hardness in comparison to the 5% group. For surface roughness, the 2.5% group presented statistically significant higher surface roughness as opposed to the 0% control group. Conclusions: The addition of ZrO₂ in high concentrations resulted in a noticeable color change in IFP. However, the surface properties did not change hardness and roughness with ZrO₂ addition except roughness increased with 2.5% ZrO₂. Low ZrO₂ addition did not result in a change in color and surface properties of IFP.

Keywords: Color, interim fixed prostheses, nanoparticles, zirconium oxide

INTRODUCTION

In daily dental practice, an interim fixed prosthesis (IFP) is a necessary intermediary step before the fabrication of the final prosthesis. The interim restoration preserves the tooth preparations from encroachment by pathogenic microorganisms and provides external pressure, helping maintain the position of the tooth by preventing drifting and supra-eruption. It serves to also maintain stable occlusal contacts. They also play a role in developing ideal occlusion with opposing teeth, developing proper proximal contacts, and having a close marginal adaptation. They are invaluable in maintaining physiologic axial contours to develop the

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gingiva and provide the option of shade correction when needed.\cite{1-3}

Constant fracture of the prosthesis is a common drawback of poly(methyl methacrylate) (PMMA) resin due to its inadequate mechanical properties.\cite{4} It is necessary to remove these drawbacks and help to improve the properties of PMMA resin to facilitate the use of the material; which can be done by different polymerization techniques, material composition modifications, and/or the addition of reinforcement materials. Enhancing the mechanical properties of the resin material can be done by reinforcing the resin matrix using fibers and fillers as suggested in the literature.\cite{4}

The consequence of adding nanoparticles to PMMA depends on several factors that include particle size of the polymer, the polymer particle interface, fabrication methods, and particle dispersion in the PMMA matrix.\cite{5} Recent trends to derive a nanocomposite material with enhanced mechanical properties is the addition of various nanoparticles. Previous literature shows various studies conducted to evaluate the changes caused by various materials such as glass fiber,\cite{6} polyethylene, and polypropylene fibers,\cite{7} alumina, and zirconium oxide (ZrO$_2$) nanoparticles\cite{8} on PMMA resin.

Incorporating ZrO$_2$ into PMMA has been advised in literature to enhance its properties. It has advantageous properties like fracture toughness, high flexural strength ranging from 900 to 1200 MPa, and fracture toughness of 9-10MPa. The other useful properties that make it a material of choice for polymer reinforcement include abrasion, corrosion resistance, and biocompatibility.\cite{9}

Out of the various, mechanical and physical properties related to PMMA in their use for IFP fabrication, the color stability, hardness, and surface roughness are primarily responsible for the prosthesis’s longevity. Their discoloration may lead to dissatisfaction of the patient and an extra cost for replacement; making it important for aesthetic regions.\cite{10,11}

To the best of author’s knowledge, no previous studies have investigated the effect of ZrO$_2$ on the color and surface properties of IFP. Therefore, the study was conducted with the main objective of evaluating the effect of different concentrations of ZrO$_2$ on the color, hardness, and roughness of auto polymerized IFP. The null hypothesis stated that the addition of ZrO$_2$ addition does not affect the color and surface properties of IFP.

**Materials and Methods**

**PMMA/ ZrO$_2$ Preparation**

ZrO$_2$ (Shanghai Richem International Co, Ltd) was treated with a silane coupling agent (Shanghai Richem International Co, Ltd). An electronic device was used to weigh the salinized ZrO$_2$ particles (S-234, Denver instrument, Germany) which were added in concentrations of 1 wt percent, 2.5 wt percent, and 5 wt percent of auto-polymerized acrylic polymer (shade A1 Unifast III, GC Corporation, Tokyo, Japan). To attain homogeneous PMMA/ ZrO$_2$ mixtures with equal distribution of particles, the mixture was thoroughly mixed and stirred for 30 min using an electric mixer. The pure PMMA and PMMA/ ZrO$_2$ mixture were analyzed by SEM to evaluate the distribution of the filler within the PMMA. The former showed clean spheres whereas the latter showed the ZrO$_2$ to which the spheres of PMMA were attached.

**Specimens Grouping and Processing**

According to ZrO$_2$ concentrations, a total of 40 specimens were divided into one control group without ZrO$_2$ and three study groups with 1, 2.5, and 5 wt.% ZrO$_2$ (1 ZrO$_2$, 2.5 ZrO$_2$, and 5 ZrO$_2$). Customized metallic molds were used to manufacture acrylic samples (40) with a 10 mm diameter and 1.5 mm height. According to manufacturer instructions, the polymer was gradually mixed with the monomer and then packed into the molds. Next, the molds were covered by each corresponding metal cover and put into a high-pressure chamber at a temperature of 45°C and subjected to 30 psi pressure for fifteen min. Once the polymerization was completed, the samples were retrieved and stored in distilled water at 37°C for 48 h.

**Testing Procedures**

A two-beam UV–VIS Recording spectrophotometer device was used to carry out the color measurements in the visible spectrum ranging from 380-to 780 nanometers. Using a white BaSO$_4$ (barium sulfate) background, this instrument was calibrated before each measurement was taken. UVProbe 2.21 software (Shimadzu Co., Kyoto, Japan) was employed to receive the R-reflection spectra of the samples. Color Analysis UV-2410PC was then applied for mathematically transforming $a^*$, $b^*$, and $L^*$, whereas Standard Illuminant C (standard lighting option CIE C) made all the conversions. The color differences in their entirety were recorded in MS Excel program according to the formula mentioned below:

$$a \cdot \Delta E_{ab} = \left[ (\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{1/2},$$

where $\Delta L^* = L_1 - L_0$, $\Delta b^* = b_1 - b_0$, and $\Delta a^* = a_1 - a_0$. The terms $a_0$, $b_0$, and $L_0$ denoted the color info of the samples in the control group, and $a_1$, $b_1$, and $L_1$, the info of the samples reinforced with silica.
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\[ b \cdot \Delta F_{00} = \left[ \frac{\Delta L}{K_1S_1} \right]^2 + \left[ \frac{\Delta C}{K_2S_2} \right]^2 + \left[ \frac{\Delta H}{K_3S_3} \right]^2 + R_b \left[ \frac{\Delta C}{K_4S_4} \right] + \left[ \frac{\Delta H}{K_5S_5} \right]^2 \]

where \( \Delta C^\prime \), \( \Delta H^\prime \), and \( \Delta L^\prime \), represent the changes occurring in chroma, hue, and lightness for a couple of samples (CIEDE2000), whereas RT (rotation function) denotes the interplay between chroma and hue as well as their differences observed in the high energy visible blue light region. SH, SL, and SC (the weighting functions) adjust the total color difference for variation where the color difference pair of samples are located in the \( a^\prime \), \( L^\prime \), and \( b^\prime \) coordinates, whereas KH, KL, and KC (the parametric factors), are correction terms for scientific and experimental conditions, set at the value \( (2: 1: 135) \) instead of \( (1: 1: 136) \) which is recommended for research in the field of dentistry.

Before data analysis, a small-scale feasibility study with six samples per group was conducted. Standard as well as Mean deviation for \( a^\ast \), \( L^\ast \), and \( b^\ast \) per group, were calculated, and the color variations among the experimental (with ZrO₂ of matching shade) and control groups were determined using the formula mentioned below:

\[ \Delta E = \left[ (\Delta L^\ast)^2 + (\Delta a^\ast)^2 + (\Delta b^\ast)^2 \right]^{1/2}. \]

With the application of the (G* Power software), the study’s statistical power was calculated to eighty-six percent, therefore eliminating the need to construct additional specimens. Furthermore, three samples from all individual groups were measured two times in a span of 2 h to examine the device as well as researcher reliability. Dullberg statistics were applied by the following formula: \( \sqrt{\Sigma(\alpha(2nd) – \alpha(1st)) / 2N} \), and the Pearson coefficient was used to evaluate the reproducibility of the measurements.

A Vickers Hardness Tester (Otto Wolpert, Germany) was used to obtain the Micro-hardness measurements for all specimens. It consists of a pointed indenter a with base (usually pyramidal or square-shaped), a 30-g load, and a 30-s timer. The impression of the two opposite pyramid diagonals comes onto the samples by this pointed indenter. Immediately, their lengths are read and a minimum duration of 10 s is allowed between two successive readings, which are then measured and noted by the operator. Owing to the even surface of the samples, the operator was able to properly visualize and appreciate the two diagonals while carrying out the readings. A total of 8 dents at various points were created on each sample and the average is taken into account, followed by the determination of the Vickers Hardness Number for all the samples. Furthermore, the average of each sample was analyzed, ultimately giving the operator a cumulative average value of the materials in a specific scientific setup.

A surface roughness profiler and profilometer (Rug-03, Prazis, Buenos Aires, Rep. Argentina) were employed to assess the average surface roughness in micrometer units. It is calculated by taking the mean of the profile height of the irregularities present on the surface, read from a mean line within a pre-determined length of the sample. The needle when passed through the 0.8-millimeter length with 0.5 mm/s speed, gave a reading. This process was performed two more times, keeping the position the same, to obtain 3 final measurements (each comprising 3 lengths of 0.8 millimeters giving a final reading of 2.4 millimeters). As the average surface roughness was determined at 4 distinct positions, the mean surface roughness was noted and the average of all the individual samples was taken into account. A custom-made positioning jig was designed to create and maintain a universal and standardized position of the stylus on the sample for repeated measurements ensuring reproducibility and precision. The surface hardness, as well as the average surface roughness measurements, was taken during the first hour with a prerequisite temperature of –2°C or 23Å+ and sere conditions.

**Statistical analysis**

IBM SPSS 19 software was used for analysis with the statistical significance level set at \( P < 0.05 \). With the application of a one-sample t-test, notable changes were observed in both \( \Delta E_{00} \) and \( \Delta E_{ab} \) (measured) as well as their predetermined threshold values, 3.3 and 2.7, respectively, for \( \Delta E_{ab} \) and 1.8 for \( \Delta E_{00} \). Furthermore, the One-way Analysis of Variance (ANOVA) test along with the Bonferroni test (used specifically for performing multiple comparisons) were used to assess notable differences involving \( \Delta E_{eb} \), \( \Delta E_{00} \), \( \Delta L^* \), \( \Delta a^* \), and \( \Delta b^* \) among the various shades. In addition, the index eta square (\( \eta^2 \)) was used as the chief indicator showing the effects of the material (effect size index) on \( \Delta E_{eb} \), \( \Delta E_{00} \), \( \Delta a^* \), \( \Delta L^* \), and \( \Delta b^* \) and the %age of the variability of the measurements as a result of the four materials.37 Levene’s test of homogeneity of variances (LTHV) was applied for evaluating homogeneity, whereas Shapiro–Wilk test \( (n < 50) \) was used to evaluate the normal distribution. Both Tukey’s and Analysis of Variance tests were applied to analyze the results obtained for roughness and hardness. The student’s t-test was selected to analyze the information recorded from the water-immersed samples. Data analysis took place at a ninety-five confidence level.

**Results**

Table 1 shows statistically significant differences between the groups with respect to all the studied
color parameters \( (P = 0.000) \), hardness \( (P = 0.011) \), and surface roughness \( (P = 0.045) \). The means and standard deviations of \( \Delta L^* \), \( \Delta E_{ab} \), \( \Delta E_{00} \), \( \Delta a^* \) and \( \Delta b^* \) are reported in Table 2. There were notable changes in \( \Delta E_{00}, \Delta a^* \), and \( \Delta E_{ab} \) parameters between the group containing 1% and the other 2 groups containing 2.5% and 5%. These were also observed among the three groups for the \( \Delta L^* \) parameter. However, no remarkable changes were noted between the group containing 1% and the group containing 5% for the \( \Delta b^* \) parameter.

No notable changes were observed in the \( \Delta E_{ab} \) values as opposed to the clinically acceptable values, 3.3 and 2.7, for the group containing 1% [Table 2]. However, significantly higher values were detected in \( \Delta E_{ab} \) for the other two groups when values were compared to these acceptable values \( (P = 0.045 \text{ in Table 2}) \). \( \Delta E_{00} \) value showed significant differences between the 2.5% and the 5% groups when compared with the intraorally acceptable value of 1.8 \( (P = 0.045 \text{ in Table } 2) \).

The mean and standard deviations and significance between groups regarding hardness and roughness are summarized in Table 3. The addition of \( \text{ZrO}_2 \) showed no significant differences between unmodified \( \text{ZrO}_2 \)-modified groups \( (P > 0.05) \). In between \( \text{ZrO}_2 \)-modified groups, 1% \( \text{ZrO}_2 \) showed the lowest hardness value and exhibited a significant decrease in hardness when compared with 5% \( \text{ZrO}_2 \) \( (P<0.001) \). For surface roughness and in comparison to the control group, the addition of \( \text{ZrO}_2 \) did not show significant differences between groups \( (P > 0.05) \) except for control vs. 2.5% \( \text{ZrO}_2 \) \( (P<0.001) \) which showed the highest Ra value \( (0.45 \pm 0.03 \mu m) \).

### Discussion

\( \text{ZrO}_2 \) was added to IFP aiming to improve the mechanical properties as reported in a previous study.\[12\] Due to the highest aesthetic demands of IFP, this study was done to select the most appropriate concentrations resulting from proper mechanical properties and at the same time showed good color and surface properties. Therefore, this study was done to evaluate the effect of \( \text{ZrO}_2 \) addition on the color and surface properties.
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Based on the finding of this study, the null hypothesis was partially rejected where color and roughness were affected while no change in hardness. Based on the finding of the present study, it was found that there were notable changes amongst the group containing 1% and the other 2 groups containing 2.5% and 5% in Δa*, ΔEₐₐb, and ΔE₀₀ parameters. Notable changes were seen in the three groups for the ΔL* parameter. However, no such changes were observed in the ΔEₐₐb values as opposed to the intraorally acceptable values of 3.3 and 2.7 for the group containing 1%. However, significantly higher values were detected in ΔEₐₐb for the other two groups when values are compared to these acceptable values (P = 0.045). ΔEₐₐb value showed significant differences between the 2.5% and the 5% groups when compared with the intraorally acceptable values of 1.8 (P = 0.045). Most of the color changes when comparing the samples of the control and experimental group were found to the lightness of the specimen and the change in color around the b axis, that is, the yellow and blue spectrum of color. These color changes were more significantly seen in specimens with more wt.% of the zirconia oxide, that is, the 2.5% and 5% groups.

The color of the specimens did not show a clinically discernible change in color on the addition of ZrO₂; however, its complete effect can only be understood by recording its response to various colored liquids over stipulated time intervals as done in studies conducted by Haselton et al., Givens et al., and Sham et al.[13-17] An increase in surface roughness instigates the adherence of Candida Albicans onto the surface.[18] On comparing the roughness and hardness of the specimens it was seen that the 1% group showed a statistically significant difference in hardness in comparison to the 5% group. For surface roughness, the 2.5% group presented statistically significant higher surface roughness as opposed to 0% in the control group. The result of adding nanoparticles on surface roughness and hardness was indirectly related to the concentration of nanofiller content. In this study as the concentration of nanofillers increased the surface roughness has also increased except for the 5% group which has seen a slight decline in the surface roughness. Various factors that caused the increase of the surface roughness include the clustering property of the nanoparticles as the concentration increases which often leads to a decrease in the homogenous nature of the matrix and the particles. This cluster formation causes the particles to disengage during the polishing procedure leading to holes and voids.[19-21] The reinforcement procedure is highly affected by the concentration of nanoparticles added to the resin matrix, according to the results of this study. The surface roughness in this study was not affected by the concentration of the nanofillers at low concentrations, however, at higher concentrations, they affected the surface roughness. An increase in the nanofiller content causes an increase in the hardness as well.

A decrease in surface hardness can open the prosthesis to damage due to wear.[22] In this current study, it

### Table 2: Statistical analysis of the ΔEₐₐb value for each group compared to the intraorally accepted values (=3.3, =2.7, and =1.8)

| Test value | Group | t    | df  | Sig. (two tailed) | Mean     | 95% Confidence interval of the difference |
|------------|-------|------|-----|------------------|----------|------------------------------------------|
|            |       |      |     |                  | Lower    | Upper                                    |
| = 3.3      | 1%    | 0.0604 | 9   | 0.9532           | 3.326    | 2.351788                                 |
|            | 2.5%  | 17.7788 | 9   | 0.0000           | 6.797    | 6.352044                                 |
|            | 5%    | 13.5985 | 9   | 0.0000           | 6.41     | 5.892641                                 |
| = 2.7      | 1%    | 1.4536 | 9   | 0.1800           | 3.326    | 2.351788                                 |
|            | 2.5%  | 20.8292 | 9   | 0.0000           | 6.797    | 6.352044                                 |
|            | 5%    | 16.222 | 9   | 0.0000           | 6.41     | 5.892641                                 |
| = 1.8      | 1%    | -0.6523 | 9   | 0.5305           | 1.672    | 1.228122                                 |
|            | 2.5%  | 17.6841 | 9   | 0.0000           | 3.742    | 3.493579                                 |
|            | 5%    | 11.9704 | 9   | 0.0000           | 3.305    | 3.020586                                 |

### Table 3: Mean values and SD of roughness and hardness of tested groups

| Tested properties | NZR concentrations |
|-------------------|--------------------|
|                   | 0%     | 1%     | 2.5%   | 5%     |
| Hardness (VHN)    | 20.28 (0.28) | 19.81 (0.51) | 21.39 (0.45) | 22.07 (0.67) |
| Surface roughness (µm) | 0.31 (0.04) | 0.36 (0.03) | 0.45 (0.03) | 0.40 (0.04) |

Same letter indicated significant difference pairwise comparison between groups (P < 0.05)
can be observed that the hardness insignificantly increased with 2.5 and 5% ZrO₂ and this increase was concentration-dependent. The increase in hardness can be attributed to the number of nanoparticles added to the resin matrix which in turn affects the homogeneity of the mix. This often causes an increase in the cross-linking density of the matrix which makes it impervious to penetration.

The findings of this study about surface roughness and hardness are in agreement with the other literature available.[23-27]

The tests in this study were not performed under the stimulation of the oral environment which is a major limitation for the evaluation of the properties. Hence further research must be conducted to evaluate the effect of various concentrations of nanoparticles on commercially available resins under a simulated oral environment.

**Conclusion**

The addition of ZrO₂ in 2.5% and 5% concentrations resulted in a noticeable color change in IFP. ZrO₂ addition did not change the hardness of IFP, whereas surface roughness increased with 2.5% ZrO₂. Low ZrO₂ concentration addition (1%) did not result in a change in color and surface properties of IFP which make it suitable for IFP reinforcement.

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**Conflicts of Interest**

The author declares that he has no conflicts of interest.

**Authors Contributions**

A single author.

**Ethical Policy and Institutional Review Board Statement**

Not applicable.

**Patient Declaration of Consent**

Not applicable.

**Data Availability Statement**

The data used to support the findings of this study are available from the author upon request.

**References**

1. Astudillo-Rubio D, Delgado-Gaete A, Bellot-Arcís C, Montiel-Company JM, Pascual-Moscardó A, Almerich-Silla JM. Correction: Mechanical properties of provisional dental materials: A systematic review and meta-analysis. PLOS One 2018;13:e0196264.
2. Ferro KJ, Morgano SM, Driscoll CF, Freilich MA, Guckes AD, Knoernschild KL, et al. The glossary of prosthodontic terms: Ninth edition. J Prosthet Dent. 2017;117:e1-105.
3. Kang SY, Park JH, Kim JH, Kim WC. Accuracy of provisional crowns made using stereolithography apparatus and subtractive technique. J Adv Prosthodont 2018;10:354-60.
4. Yadav P, Mittal R, Sood VK, Garg R. Effect of incorporation of silane-treated silver and aluminum microparticles on strength and thermal conductivity of PMMA. J Prosthodont 2012;21:546-51.
5. Keys WF, Keirby N, Ricketts DJ. Provisional restorations—A permanent problem? Dent Update 2016;43:908-12, 914.
6. Hamouda IM, Beyari MM. Addition of glass fibers and titanium dioxide nanoparticles to the acrylic resin denture base material: Comparative study with the conventional and high impact types. Oral Health Dent Manag 2014;13:107-12.
7. Yu W, Wang X, Tang Q, Guo M, Zhao J. Reinforcement of denture base PMMA with zr02(2) nanotubes. J Mech Behav Biomed Mater 2014;32:192-7.
8. Arora P, Singh SP, Arora V. Effect of alumina addition on properties of poly-methyl methacrylate - A comprehensive review. Int J Biotech Trends Technol 2015;5:7-12.
9. Asar NV, Albayrak H, Korkmaz T, Turkyilmaz I. Influence of various metal oxides on mechanical and physical properties of heat-cured polymethyl methacrylate denture base resins. J Adv Prosthodont 2013;5:241-7.
10. Asopa V, Suresh S, Khandelwal M, Sharma V, Asopa SS, Kaira LS. A comparative evaluation of properties of zirconia reinforced high impact acrylic resin with that of high impact acrylic resin. Saudi J Dent Res 2015;6:146-51.
11. Kawai N, Lin J, Youmaru H, Shinya A, Shinya A. Effects of three luting agents and cyclic impact loading on shear bond strengths to zirconia with tribochemical treatment. J Dent Sci 2012;7:118-24.
12. Alshahrani FA, Gad MM, Al-Thobity AM, Akhtar S, Kashkari A, Alzoubi F, et al. Effect of treated zirconium dioxide nanoparticles on the flexural properties of autopolymerized resin for interim fixed restorations: An in vitro study. J Prosth Dent 2021:S0022-3913(21)00559-X. doi: 10.1016/j.prosdent.2021.09.031.
13. Köroğlu A, Sahin O, Dede DÖ, Yilmaz B. Effect of different surface treatment methods on the surface roughness and colour stability of interim prosthodontic materials. J Prosthodont 2016;11:447-55.
14. Elagra MI, Rayyan MR, Alhomaidi MM, Alanazzy AA, Alnafia MO. Color stability and marginal integrity of interim crowns: An in vitro study. Eur J Dent 2017;11:330-4.
15. Sham AS, Che FC, Chai J, Chow TW. Color stability of provisional prosthodontic materials. J Prosthodont 2004;9:447-52.
16. Givens EJ, Neiva G, Yaman P, Dennison JB. Marginal adaptation and colour stability of four provisional materials. Journal of Prosthodontics: Official Journal of the American College of Prosthodontists. 2008;17:97-101.
17. Haselton DR, Diaz-Arnold AM, Dawson DV. Color stability of provisional crown and fixed partial denture resins. J Prosthodont 2005;93:70-5.
18. Bollen CM, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: A review of the literature. Dent Mater 1997;13:258-69.
19. Gad MM, Fouda SM, ArRejaie AS, Al-Thobity AM. Comparative effect of different polymerization techniques on the flexural and surface properties of acrylic denture bases. J Prosthodont 2019;28:458-65.
20. Gad MM, Rahoma A, Al-Thobity AM. Effect of polymerization technique and glass fiber addition on the surface roughness and hardness of PMMA denture base material. Dent Mater J 2018;37:746-53.
21. Abuzar MA, Bellur S, Duong N, Kim BB, Lu P, Palfreyman N, et al. Evaluating surface roughness of a polyamide denture base material in comparison with poly (methyl methacrylate). J Oral Sci 2010;52:577-81.
22. Alnamel HA, Mudhaffer M. The effect of silicon dioxide nano-fillers reinforcement on some properties of heat cure polymethyl methacrylate denture base material. J Baghdad Coll Dent 2014;26:32-6.
23. Ergun G, Sahin Z, Ataol AS. The effects of adding various ratios of zirconium oxide nanoparticles to poly(methyl methacrylate) on physical and mechanical properties. J Oral Sci 2018;60:304-15.
24. Fatalla AA, Tukmachi MS, Jani GH. Assessment of some mechanical properties of PMMA/silica/zirconia nanocomposite as a denture base material, IOP Conference Series: Materials Science and Engineering, Volume 987, 2020, Art. No. 012031, doi: 10.1088/1757-899X/987/1/012031.
25. Gad MM, Abualsaud R, Al-Thobity AM, Baba NZ, Al-Harbi FA. Influence of addition of different nanoparticles on the surface properties of poly(methylmethacrylate) denture base material. J Prosthodont 2020;29:422-8.
26. Mangal U, Kim JY, Seo JY, Kwon JS, Choi SH. Novel poly(methyl methacrylate) containing nanodiamond to improve the mechanical properties and fungal resistance. Materials (Basel, Switzerland) 2019;12:1-17.
27. Cevik P, Yildirim-Bicer AZ. The effect of silica and prepolymer nanoparticles on the mechanical properties of denture base acrylic resin. J Prosthodont 2018;27:763-70.