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Dimensional Accuracy of Nanoparticles Reinforced Denture Base Materials

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Abstract

Aims: The study aims to evaluate the effect of the addition of salinized zirconium oxide (ZrO_2) and silicon oxide (SiO_2) nanoparticles at two concentrations (1% and 3% by weight) on the dimensional accuracy of the heat-cured denture base material. **Materials and Methods**: Fifty samples were prepared in accordance with the manufacturer's instructions and divided into five groups (n=10) according to nanoparticle type and concentration (1 and 3 wt.%). The control, unmodified acrylic resin was used. Dimensional accuracy was measured using a superimposing of 3D software. **Results**: The result showed high significant difference between study groups, which showed less dimensional change in ZR3(3% ZrO_2) and SI1(1% SiO_2) than control group. **Conclusions:** The merging of a 3% concentration of zirconium oxide and a 1% concentration of silicon oxide nanoparticles to heat-cured denture base material improved the dimensional accuracy.

دقة أبعاد المواد الأساسية لأطقم الأسنان المقواة بالجسيمات النانوية

الملخص

الأهداف: تهدف الدراسه الى دراسة تأثير اضافة جسيمات النانوية (اوكسيد الزركونيوم واوكسيد السيليكون) وبتركيزين (1%و3%) على دقة ابعاد قاعدة الطخم الاكليرليكي. **المواد وطرائق العمل** :تم تحضير 50 عينة باتباع تعليمات المصنع وقسمت الى خمس مجموعات (عدد العينات لكل مجموعة=10)حسب تركيز جسيمات النانوية. **النتائج** :اظهرت النتائج وجود فرق معنوي كبير بين المجموعات وقد وجد ان اضـــافة جســيمات اوكســيد الزركونيوم النانوية وبتركيز 3% واوكسيد السليكون وبتركيز 1% قد تسبب بنقصان كبير في تغير دقة ابعاد قاعدة الطخم الالكريلكي.**الاستنتاجات** :أضافة جسـيمات النانوية بتركيز 3%لاوكسـيد الزركونيوم و1% لاوكسـيد السـليكون ادى الى تحسـين في دقة الابعاد لقاعدة الطخم.

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INTRODUCTION

The denture base is the portion of the appliance that rests on the soft tissues. Vulcanite was the most widely used denture base polymer up to 1940. To construct the denture bases today, acrylic resin is widely employed [(1)].

The mechanical qualities of Poly methyl methacrylate dentures include high modulus of elasticity, impact strength, flexural strength, and hardness, appropriate bond strength with artificial teeth, and repairability. PMMA denture bases have advantages of being easy to shape and having good aesthetics [(2)].

The most popular denture material is PMMA, although it has drawbacks such as thermal shrinkage, decreased mechanical and fatigue strength, brittleness upon impact, decreased color stability of self-cured resins, residual monomer allergy, porosity, and poor heat conductivity [(3)].

One of the key factors affecting the quality of complete dentures was denture fitness. A properly fitted set of dentures has advantages in terms of comfort, stability, and retention of the denture, and traumatic ulcer prevention [(4)].

Dimensional changes to the dentures were found to be predictable during denture manufacture. During the denture production process, the occlusion of the denture may change due to a number of laboratory factors, such as inherent properties of the materials and building processes utilized as well as any extrinsic errors made by the dental technician or dentist [(5)]. A variety of techniques, such as linear measurements between two sites, were developed to examine the dimensional accuracy of fixed prosthetic or denture base material [(6 & 7)]. Measuring space in terms of silicone weight [(8)]. These methods were time-consuming and subject to operator error [(9)]. Using denture base adaption and crown fitting via three-dimensional (3D) superimposition is more clinically relevant [(10)].

MATERIALS AND METHODS

In the current study, Triplex® (Ivoclar Vivadent, Liechtenstein). Silicone Oxide Nanoparticles (Sky Spring Nanomaterials, Inc., USA). Zirconium Oxide Nanoparticles (Research Nanoparticles, Inc., USA), were used. A total number were fifty denture bases constructed and separated into 5 main groups, control (no NPs reinforced) and 4 study groups (n=10) 1% ZrO_2, 3%ZrO_2, 1%SiO_2 and3%SiO_2 by weight of NPs reinforced.

Salinization of Nano-Particles

To salinize nano-ZrO_2 particles, the silane coupling agent which is TMSPM (3-(trimethoxysilyl) propyl methacrylate) was dissolved in acetone (0.3 g of TMSPM in 100 ml of added to the solution, and stirred with hot plate magnetic stirrer for one hour at temperature 80ºC, then the solution transferred to the rotary evaporator to remove the solvent under vacuum at 60ºC and 150 round per min, for half an hour, when the

solvent dried, the powder is heated to 120º C for 2 hours then left to cool naturally to get surface-treated ZrO2 nanoparticles [11].

For salinize SiO_2 NPs, the MPS(γ-methacryloxypropyltrimethoxysilane) was pre-hydrolysed in 80 percent ETH for 1 hour at room temperature. The hydrolyzed MPS was added to the NP suspension and mixed at 200 rpm for 2 hours at room temperature (RT), then refluxed for 4 hours at 70°C. After the reaction was completed, the liquid was allowed to cool. The component was dried in an oven (Memmert, Schwabach, Germany) at 505°C by evaporating the solvent [12].

Sample Preparation:

Prosthodontists of American College were selected [4]. To acquire a standardization for identifying the three reference points, the definitive cast was mounted on a surveying and milling machine (SJK Technic U.S.A.) with a cone-shaped diamond bur (Shenzhen Dian Fong Abrasives Co., Ltd. (M037)). To make three crosses "reference points" with two locations: one on the anterior ridge's crest and two on the posterior ridge's crest over each tuberosity such as in Figure (1) [13].

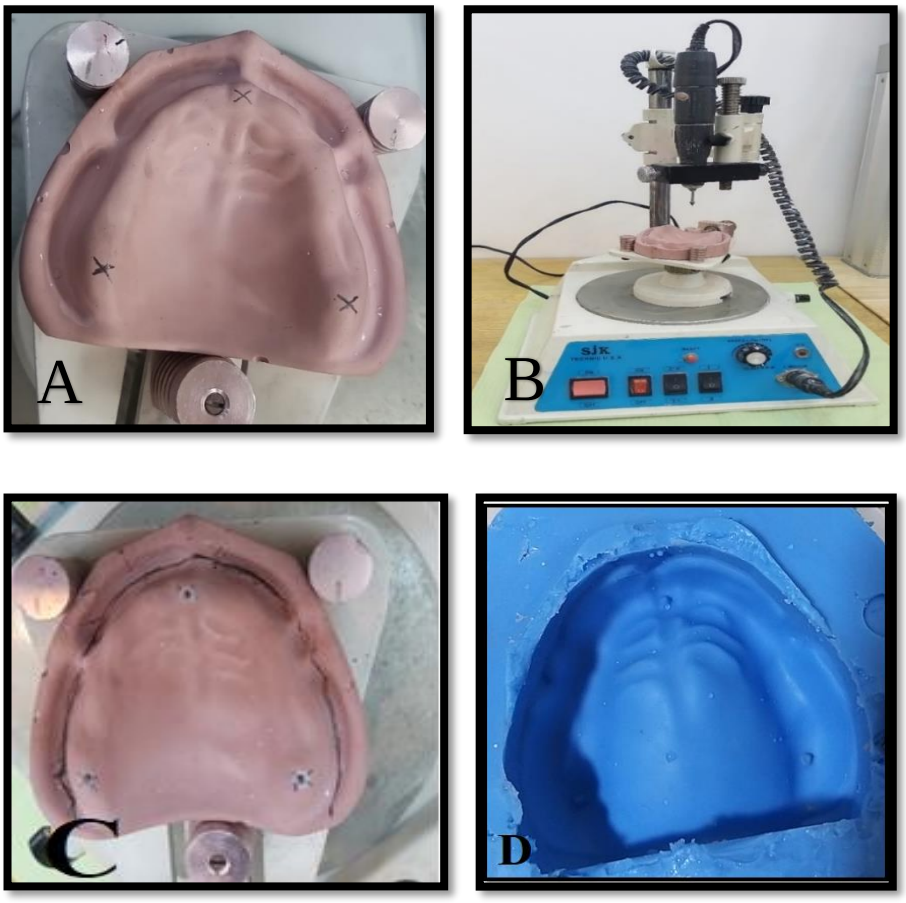


Figure (1): A: Reference cast. **B:** Reference cast on milling machine. **C:** Reference cast after determined the reference point. **D:** Mold of silicon for duplication.

After the definitive cast was modified. The duplication process began using silicone-based duplication material (Dupliflex; Protechno, Girona, Spain) figure (1 D). After obtaining a rubber mold, the 50 stone casts were formed using Type IV scannable dental stone (Single typo 4; GOLDEN BROWN; ITALIA) in accordance with the manufacturer's instructions, the water/powder ratio 20 ml /100 g [14].

We constructed a denture base using visible light curing tray plates with a thickness of 2 mm on the definitive cast to use it as a standard denture base, such in Figure (2) [15].

Figure (2): visible light curing (standard record base).

Mixing, Packing, Curing and Deflasking: For control samples, the liquid was measured with a graduated beaker and poured into a glass mixing jar. The powder is weighed with an electronic balance, added and stirred with a wax knife. While we measure the predetermined quantity of NPs for the groups of samples that contain ZrO_2 and SiO_2 NPs Table (1). The NPs were added to the monomer liquid, covered, and submerged in an ultrasonic bath for 15 minutes to ensure proper distribution [16 & 17].

Added to liquid as soon as it is removed from the ultrasonic bath. The mixture was covered and allowed to reach the dough stage. Using a thermostatically controlled water bath, according to the manufacturer's instruction, a curing procedure (heat to 100°C for 90 minutes, then let boil for 45 minutes) was used [18].

The flasks were removed and allowed to cool on the bench before being even opened (ADA No.12, 2002). After being carefully removed from the molds, the heat-polymerized acrylic denture bases were washed and any remaining stone fragments were removed and cleaned, such as in Figure (3) [19].

Table (1): Percentage and amount of NPs.

Percentage of nano SiO2 & ZrO2 by weight	Weight of PMMA powder	Weight of PMMA liquid	Weight of nano SiO2 &ZrO2
0%	23.4	10	0
1%	23.16	10	0.234
3%	22.69	10	0.702
1%	23.16	10	0.234
3%	22.69	10	0.702

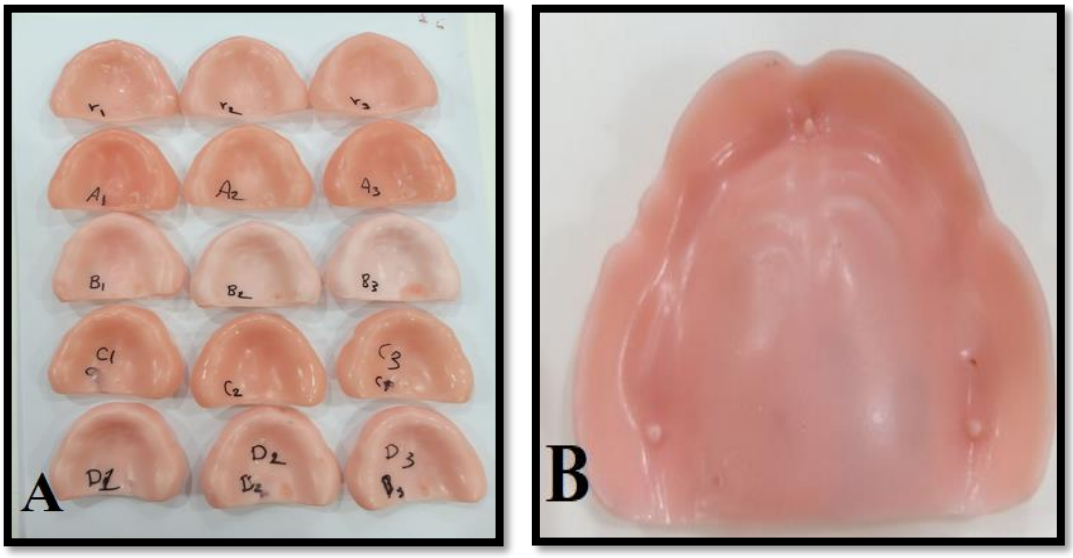


Figure (3) A: Outer surface of acrylic denture base. **B:** Inner surface show three reference point.

Scanning of Samples

Each denture base's intaglio surface was scanned using a 3Shape E1 scanner, such as in Figure (4).

Three-Dimensional Analysis:

The engineering program (3D Analysis Software (Geomagic control X) USA, 3D System) was used to import the standard tessellation language (STL) formatted 3D scanned data of the denture bases. The STL file of each intaglio surface of the denture base was overlaid with the scanned file of the master stone cast.

The matching denture-bearing region of the master cast was superimposed with the full tissue surfaces of the denture bases. Four anatomical landmarks, including the buccal frenum, incisive papillae, and fovea palatine on both surfaces, were point-to-point matched to achieve superimposition. Following automatic registration and global registration using the software's nearest point technique for fine-tuning.

The accuracy was evaluated by using a best-fit alignment method to superimpose the data sets such as in Figures (5-7).

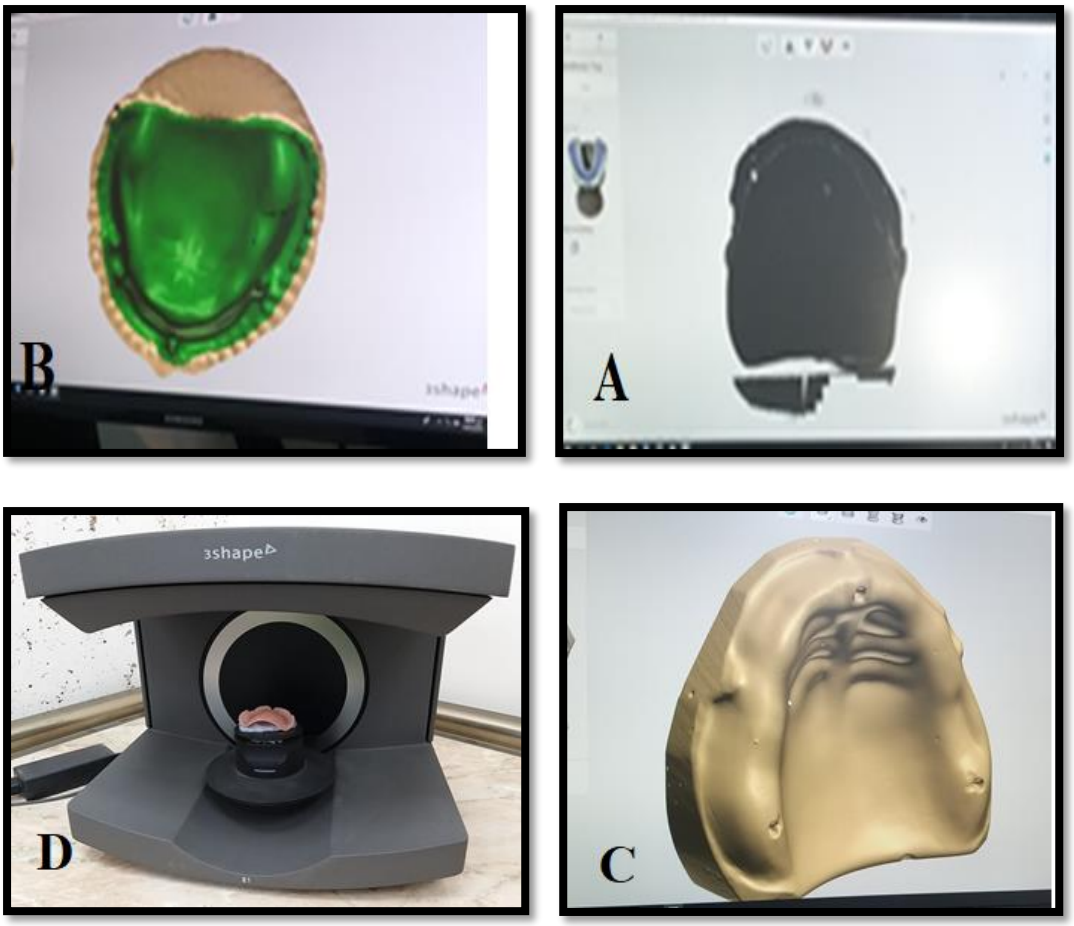


Figure (4): Scanning steps. **A.** Primary scanning. **B.** Target areas. **C.** Completed scan. **D.** Acrylic denture base in the scanning stage.

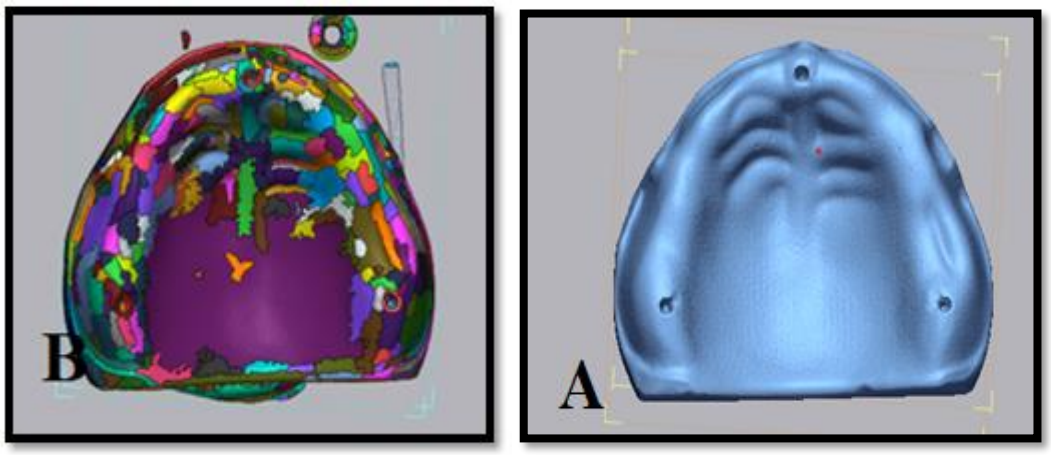


Figure (5): A. Import cast reference data. **B.** Selection of target area.

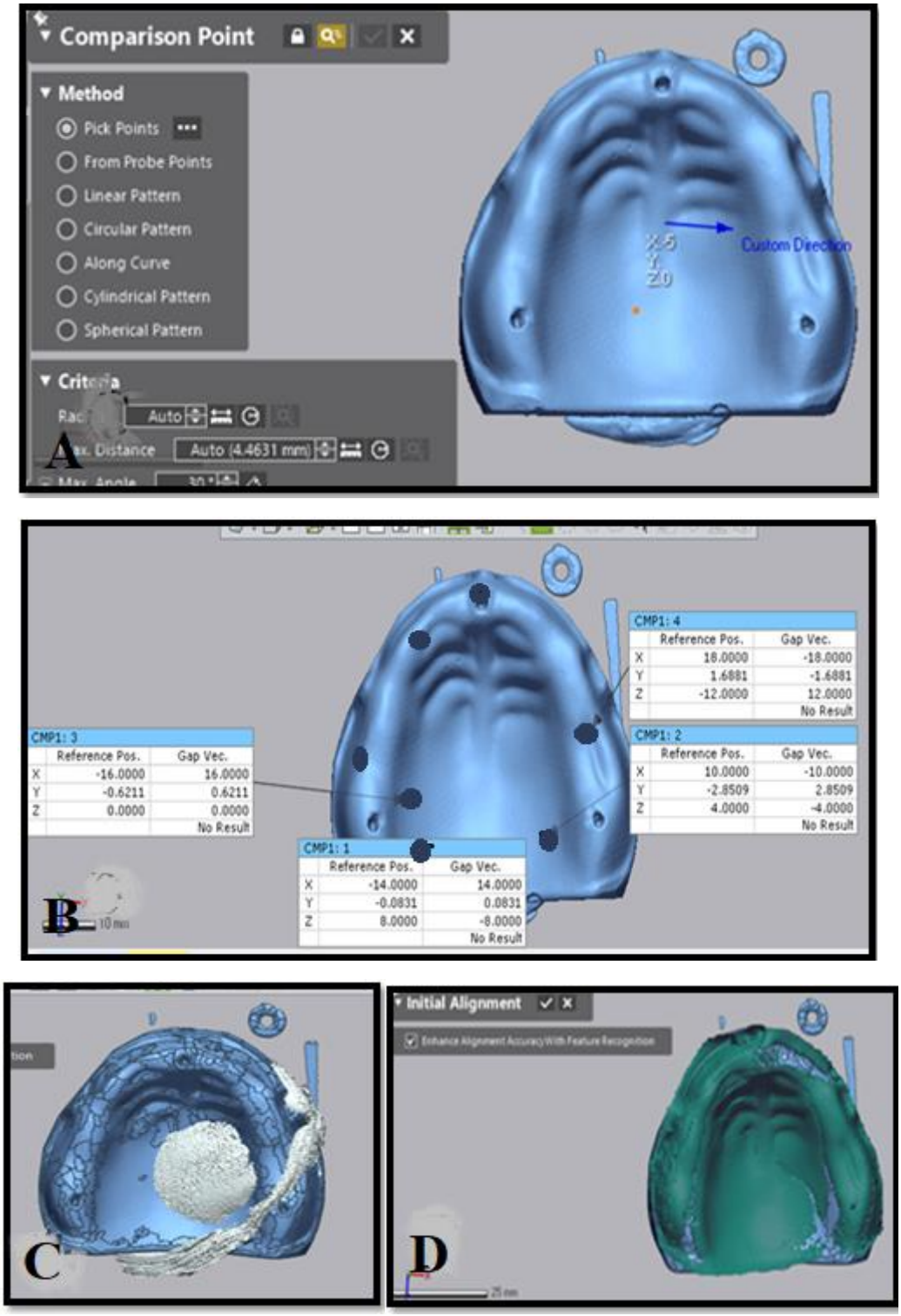


Figure (6): A. Selection of comparison points. **B.** Location of measure points. **C.** Importing measure data. **D.** Initial alignment automatically.

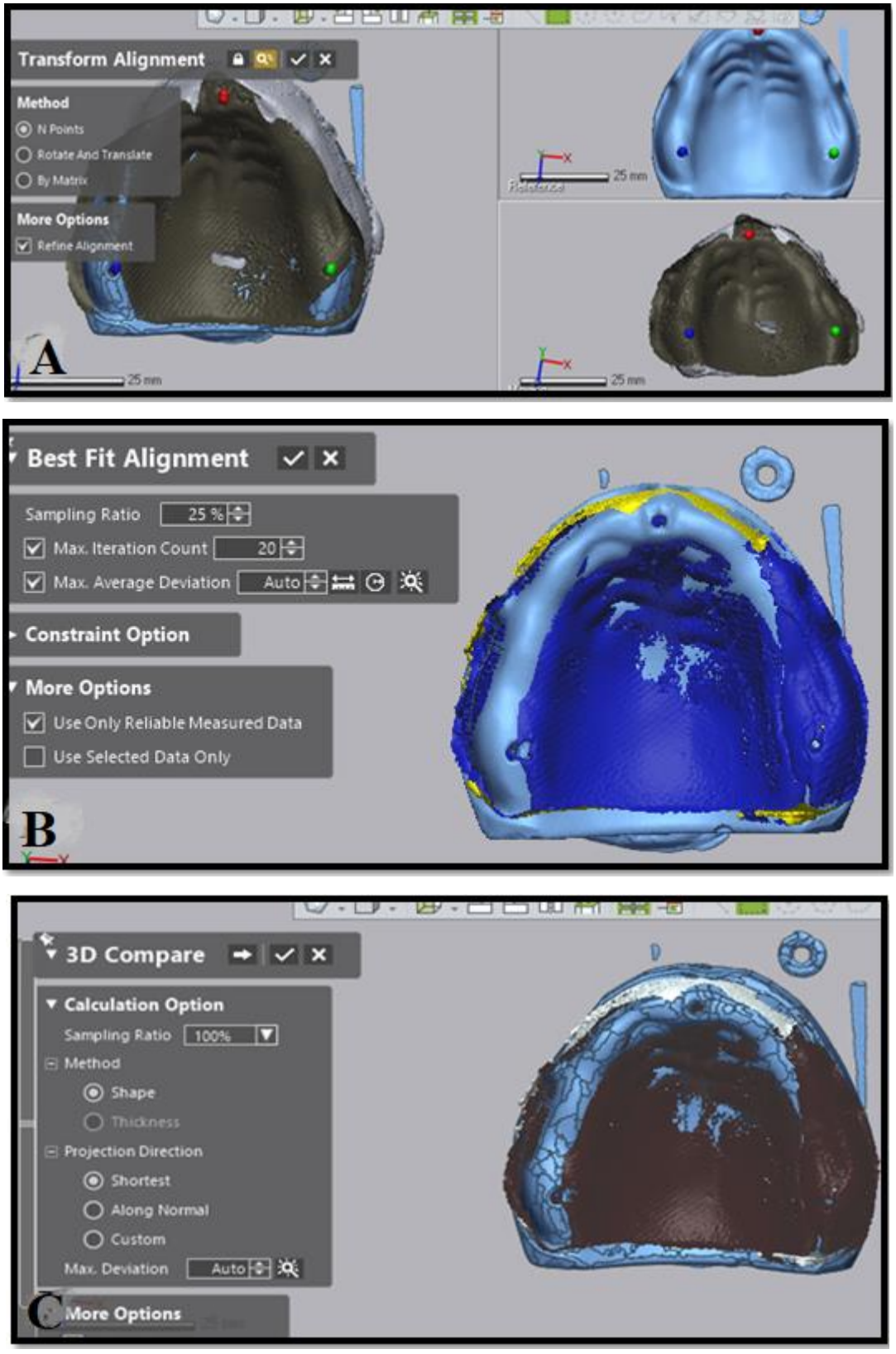
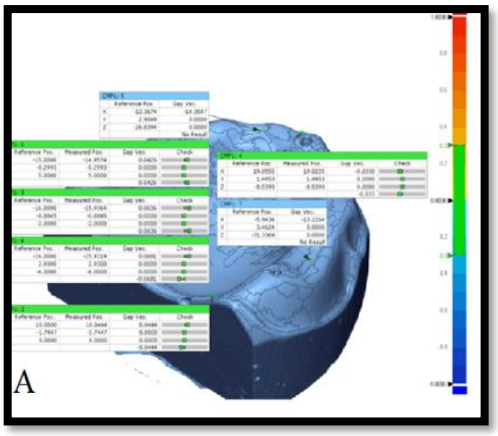


Figure (7): A. Transform alignment (Three reference points determined for manual initial alignment). **B.** Best fit alignment. **C.** 3D comparison.

RESULTS

Data represents statistical analysis and details for colour maps are exported after report preparation such as in Figure (8).



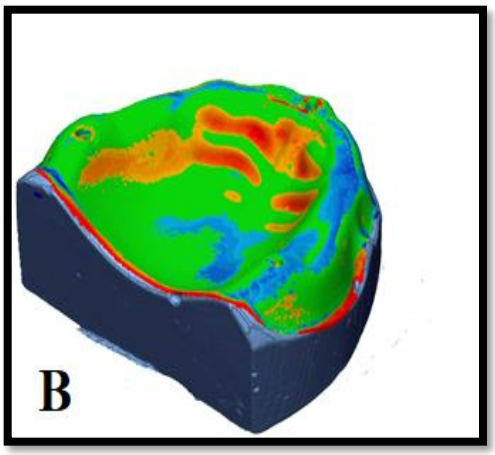


Figure (8): After superimposition of the report, **A:** Represents the gaps between the measure points (7 points) of the reference cast and acrylic denture base, **B:** Blue color (negative deviation) shows misfit with impingement, Red color (positive deviation) shows misfit with space, green The color shows an ideal fit.

Areas in the yellow to red spectrum showed shrinkage of the denture base and produced a space (away from the cast). Areas in the light-to-dark blue spectrum showed expansion of the denture base and form impingement (toward the cast). Whereas areas in the green spectrum indicate shape change within the allowed limits (from -0.3 to 0.3 mm) [4 & 10].

Shapiro-Wilk test of normality (mentioned at the end of the research) was used to determine the optimum statistical tests to assess the outcomes. The results showed the data was parametric and normally distributed.

The mean values and standard deviation of the control group, ZrO_2 and SiO_2 NPs reinforced groups. The results showed lower mean gap distance in SI1 group (more dimensional accuracy when the mean value would be closed to zero) when higher mean gap distance in SI3 group, such as in Table (2).

One-way analysis of variance (ANOVA) showed highly significant difference such as in Table (3).

Duncan's multiple comparison test for overall study groups showed a highly significant difference ($P \leq 0.01$), the least significant dimensional change (lower mean gap distance) in ZR3 and SI1 groups then followed by the control group, while higher significant dimensional change in SI3 group, such as in Table (2).

Upon evaluating each study group with respect to the location of seven measure points. The ZR1 and ZR3 had approximate mean values at all tested locations no significant difference between them ($P>0.05$). The SI1 showed a lower gap distance at the posterior crest ridge and anterior crest ridge points highly significant difference between them ($P \leq 0.01$).

Table (2): Means gaps(mm), standard deviations, and Duncan's multiple comparison test of seven measure points among study groups.

	N	V0	ZR1	ZR3	SI1	SI3	p-value
Point one	50	-.131±.074 Dc	.406±.384 ab	-.114±.071 c	.205±.224 BC bc	.507±.432 Ba	.009
Point two	50	-.314±.271 CD	-.632±.616	.331±.204	.270±.292 B	-.532±.321 B	.138
Point three	50	.567±.305 B	-.465±.419	.299±.172	.238±.158 BC	.532±.321 B	.078
Point four	50	-.496±.218 BCb	.294±.238 c	-.277±.160 c	.079±.048 CDd	-.810±.231 Aa	.000
Point five	50	-.898±.688 Aa	-.898±.688 a	.200±.080 b	.038±.038 CDb	-.142±.150 Cb	.000
Point six	50	-.221±.167 Db	-.445±.146 a	-.532±.378 a	.532±.378 Aa	-.555±.163 Ba	.015
Point seven	50	-.521±.356 BCb	-.526±.356 b	.394±.363 c	.555±.163 Ab	.942±.157 Aa	.000
Overall		.431±.321 b	.523±.462 ab	.279±.216 c	.198±.259 C	.574±.352 a	.000
p-value		.000	.089	.067	.000	.000	

Table (3): One way-ANOVA of Dimensional Accuracy test (mm) for study groups.

SOV	SS	Df	MS	F	p-value
Between Groups	18.812	34	.553	6.538	.000
Within Groups	26.658	315	.085		
Total	45.469	349			

SOV: source of variance; SS: Sum of Squares; df: degree of freedom; MS: mean square, **: highly significant at (P ≤ 0.01).

The SI3 showed a lower gap distance at the anterior crest ridge point as a highly significant difference between them (P≤0.01). The V0 showed the lowest mean value at the posterior seal area at two quadrants highly significant difference between them (P≤0.01), such as in Table (2).

Different uppercase letters are black color in the same column and different lowercase letters are red colour in the same raw. Point one -Posterior palatal seal at quadrant one; point two- Posterior palatal seal at quadrant two; point three -6mm from denture border at palate; point four- Crest of the posterior ridge; point five - Crest of the anterior ridge; point six -Buccal slope; point seven -Incisive papillae.

DISCUSSION

From a clinical point, investigating of dimensional accuracy during denture processing was essential to producing an accurate occlusal contact, retention,

aesthetics, health, and processed quality of full denture [10 & 20].

The results in Table (2) demonstrated a highly significant difference in dimensional accuracy test between control and ZrO_2 and SiO_2 NPs reinforced groups. The results showed a reduction in dimensional change in 3% conc. of ZrO_2 and 1% conc. of SiO_2 NPs reinforced group compared to the control group. The 3% conc. of ZrO_2 reinforced had smaller denture spacing in proportion to the cast than control group. The change occurred because the fillers replaced the resin, which caused less water resorption. After all, the ZrO_2Np was hydrophobic and therefore, would decrease change in dimension. However, the presence the filler which resulted in less polymerization shrinkage [21 & 22].

The results agree with result of Abd El Hameed [20] who discovered the ZrO2 reinforced group exhibits smaller spacing than the control. The results were also in agree with the results of Begum et al. [23] They observed that the change in vertical dimension of occlusion was less in ZrO_2Np reinforced than in control which resulted in higher denture adaption. Moreover, Cal *et al*. [24] found the PMMA denture bases were reinforced with continuous, unidirectional glass fibers in woven form, the polymerization shrinkage and water sorption of denture base polymers were reduced. The lowest dimensional change was associated with the highest fiber content.

The results agree with the results of Aljubori *et al*. [25] who observed when dental stones treated with 2% pure silica NPs without functionalization would reduce their linear dimensional changes. Moreover, Junior *et al*. [26] who found that the dimensional stability in silica reinforced polyurethane resin has been shown to be higher than in two synthetic type IV and type V plasters. Also agree with the result of Hamouda [27] who found the addition of chopped glass and metal fillers to the PMMA denture base would reduce the changes in linear dimension. The results disagree with the resul of Basima and Aljafery [28] they found the ZrO_2-Al_2O_3NPs mixture reinforced would increase the gap when compared to control. This difference was explained because a mixture of ZrO_2-Al_2O_3 NPs was used. Also, the results disagree with the result of Vallittu [29] Who observed that PMMA reinforced with glass fiber would cause reduced dimensional accuracy. This difference is because of who used another type of nanoparticles.

CONCLUSION

The addition of 3% concentration of zirconium oxide and 1% concentration of silicon oxide NPs to heat cured denture base material were improved the dimensional accuracy.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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Appendix: Normality test of dimensional accuracy test.

Groups	Statistic	df	Sig.
Point 1 (V0)	.255	10	.065
Point 2 (V0)	.231	10	.138
Point 3 (V0)	.159	10	.200*
Point 4 (V0)	.228	10	.150
Point 5 (V0)	.241	10	.105
Point 6 (V0)	.251	10	.074
Point 7 (V0)	.224	10	.166
Point 1 (ZR1)	.220	10	.186
Point 2 (ZR1)	.188	10	.200*
Point 3 (ZR1)	.208	10	.200*
Point 4 (ZR1)	.184	10	.200*
Point 5 (ZR1)	.198	10	.200*
Point 6 (ZR1)	.187	10	.200*
Point 7 (ZR1)	.261	10	.052
Point 1 (ZR3)	.227	10	.153
Point 2 (ZR3)	.222	10	.177
Point 3 (ZR3)	.197	10	.200*
Point 4 (ZR3)	.230	10	.144
Point 5 (ZR3)	.174	10	.200*
Point 6 (ZR3)	.214	10	.200*
Point 7 (ZR3)	.192	10	.200*
Point 1 (SI1)	.184	10	.200*
Point 2 (SI1)	.135	10	.200*
Point 3 (SI1)	.173	10	.200*
Point 4 (SI1)	.228	10	.150
Point 5 (SI1)	.190	10	.200*
Point 6 (SI1)	.242	10	.101
Point 7 (SI1)	.214	10	.200*
Point 1 (SI3)	.253	10	.069
Point 2 (SI3)	.246	10	.088
Point 3 (SI3)	.191	10	.200*
Point 4 (SI3)	.220	10	.186
Point 5 (SI3)	.257	10	.059
Point 6 (SI3)	.262	10	.050
Point 7 (SI3)	.243	10	.098