Original Research

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Impact of two different nanoparticle types on acrylic resin denture base porosity, water sorption, and solubility

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Abstract
INTRODUCTION. Acrylic resins are widely and primarily utilized in prosthodontics as the basis material for dentures. The acrylic resin denture base's porosity is an inappropriate feature. During prosthesis use, water absorbed by the acrylic resin's surface acts as a plasticizer and may cause volume fluctuations
AIM. To assess how adding two different kinds of nanoparticles – silicon dioxide and titanium dioxide – affects the acrylic resin denture base's porosity, water sorption, and solubility.
MATERIALS AND METHODS. Thirty heat-cured acrylic samples were used for the porosity and solubility tests, and each test's samples were split into three set: control group – heat cured acrylic resin alone, heat cured acrylic resin material with 2% of TiO_2 nanoparticles and heat cured acrylic resin with 2% of SiO_2 nanoparticles group. A rectangular sample measuring 50×4×2 mm±1 mm was created for the porosity test, while a disc sample measuring 40×2.5 mm was created for the water sorption and solubility test.
RESULTS. The TiO_2 group had the highest mean porosity test value (2.504), whereas the Control group had the lowest (1.468). The SiO_2 group had the greatest mean value for the water sorption test (1.28572430), whereas the TiO_2 group had the lowest (0.66882004). The control group had the highest mean solubility test score (0.649619315), while the SiO_2 group had the lowest (0.45170539).
CONCLUSIONS. The porosity of heat-cured acrylic resin was not decreased by adding TiO_2 or SiO_2. Water sorption is reduced when TiO_2 is added. Solubility was also reduced by adding 2% SiO_2.

Keywords: porosity, nanoparticles, acrylic resin, water sorption, solubility

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Влияние двух различных типов наночастиц на пористость, водопоглощение и растворимость акрилового базиса зубного протеза

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Резюме
ВВЕДЕНИЕ. Акриловые смолы широко и преимущественно используются в ортопедической стоматологии в качестве материала базиса зубных протезов. Пористость базиса протеза из акриловой смолы является нежелательной характеристикой. Во время эксплуатации протеза вода, поглощаемая поверхностью акриловой смолы, действует как пластификатор и может вызывать изменения объема.
ЦЕЛЬ. Оценить влияние добавления двух различных видов наночастиц – диоксида кремния (SiO_2) и диоксида титана (TiO_2) – на пористость, водопоглощение и растворимость базиса зубного протеза из акриловой смолы.
МАТЕРИАЛЫ И МЕТОДЫ. Для проведения тестов на пористость и растворимость использовали 30 образцов термоотверждаемой акриловой пластмассы. Образцы для каждого теста были разделены на три группы: контрольная группа – только термоотверждаемая акриловая смола; группа

термоотверждаемой акриловой смолы с добавлением 2% наночастиц TiO_2; группа термоотверждаемой акриловой смолы с добавлением 2% наночастиц SiO_2. Для теста на пористость изготавливали прямоугольные образцы размером 50×4×2 мм±1 мм, а для тестов на водопоглощение и растворимость – дисковидные образцы размером 40×2,5 мм.
РЕЗУЛЬТАТЫ. Наибольшее среднее значение пористости было выявлено в группе TiO_2 (2,504), тогда как наименьшее – в контрольной группе (1,468). В тесте на водопоглощение группа SiO_2 показала наибольшее среднее значение (1,28572430), а группа TiO_2 – наименьшее (0,66882004). Наибольшее среднее значение растворимости наблюдалось в контрольной группе (0,649619315), а наименьшее – в группе SiO_2 (0,45170539).
ВЫВОДЫ. Добавление TiO_2 или SiO_2 не приводило к снижению пористости термоотверждаемой акриловой смолы. Добавление TiO_2 способствовало уменьшению водопоглощения. Добавление 2% SiO_2 также снижало растворимость материала.

Ключевые слова: пористость, наночастицы, акриловая смола, водопоглощение, растворимость

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INTRODUCTION

Despite being the most used denture base material, PMMA still has a number of drawbacks. As a result, acrylic resin has undergone modifications to enhance its mechanical, physical and working qualities, as well as to simplify laboratory procedures [1–3]. Nevertheless, the conventional water bath curing method for acrylic resin has a number of drawbacks, such as surface porosity, dimensional instability, residual monomer, low strength, water absorption, color instability, and easy fracture [4–6].

In acrylic resin bases, porosity is a major concern because too much porosity weakens prostheses and increases their vulnerability to stress-related deterioration [5; 7].

Also surfaces with porosity compromise oral health and appearance by encouraging bacteria colonization and material retention. Additionally, sorption in acrylic resins can reveal changes in volume and the release of soluble as a product, which could irritate oral tissue [5; 8].

Nanotechnology has significantly changed the healthcare sector, and its applications are beneficial to dental science and modern medicine. Futuristically, it is expected that it will pervade and further revolution in the art and science of dentistry and will expand all the aspects of oral diseases, diagnosis, prevention and treatment. Nano materials are now successfully being used in caries inhibitors, antimicrobial resins, hard tissue remineralizing agents, targeted drug delivery, scaffolds, biomembranes, restorative cement, bioactive glass, tissue wires and nano composites [9].

Inorganic carriers like Titanium dioxide (TiO_2) nanoparticles have been used as additives to biomaterials due to its certain characteristics such as white color, low toxicity, antimicrobial properties, high stability and efficiency as well as availability and low cost. Among compounds as inorganic carriers, such as apatite, zeolite, and phosphate. Silicon dioxide (SiO_2) is more hopeful due to its porous structure and adsorption properties. Nano SiO_2 particle possess extremely high surface activity and adsorb various ions and molecules [10].

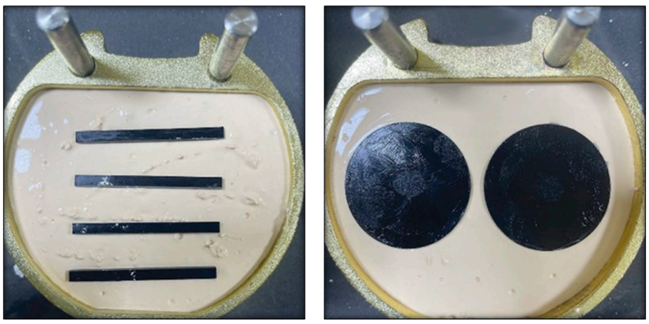
The purpose of this study was to assess how adding two different kinds of nanoparticles – SiO_2 and TiO_2 – affects the porosity, solubility and water sorption, and solubility of heat cure acrylic.

MATERIALS AND METHODS

For the porosity and solubility tests, thirty heat-cured acrylic resin specimens were created and split to two main groups (5-specimens). Following that, each major group was divided into the following three groups:

– heat cured acrylic alone (5-specimens);
– heat cured acrylic with 2% SiO_2 (5-specimens);
– heat cured acrylic l with 2% TiO_2 (5-specimens);

A rectangle samples measuring 50×4×2 mm±1 mm (Fig. 1, *A*) in length, width, and thickness were prepared for the porosity test in compliance with ASTM regulations [11]. The disc's diameter and thickness were 40 mm by 2.5 mm (Fig. 1, *B*) for the water sorption and solubility test [12].



A B

Fig. 1. The rectangular bar (*A*) and disc (*B*) during rinsing

Рис. 1. Прямоугольный брусок (*A*) и диск (*B*) во время ополаскивания

Dental stone was poured into the flask after separating media was sprayed on the flask's lower half. CNC templates (cutting by CNC machine) were inserted into the stone in the correct location. After coating the first layer of dental stone with separating medium and pouring the second layer of stone, the flask was sealed tightly. waiting for the hard stones to set.

Group 1 of samples were made from mixing heat-cured acrylic resin only (control) according to manufacturer instruction. Group 2, the heat-cured acrylic contains 30 nm silicon dioxide nanoparticles (Changsha Santech Materials Co.). Group 3 contain 30 nm titanium dioxide nanoparticles (Qingdao Hesiway Industrial Co.) 100 g of powder polymer (2 g of nanoparticles plus 98 g of polymer) is added to 40 ml of liquid monomer weighed using a sensitive balance (±0.000 g, Radwag, Type AS 220.R1) in accordance with the suggested PMMA 3:1 polymer to monomer mixing ratio.

The second and third groups' specimens were created by combining the nanoparticles with monomer.

In order to prevent particle agglomeration, the heat-cured polymer powder was transferred to a ceramic jar and manually mixed after the nanoparticles were added to liquid monomer and vibrated for five minutes. After reaching the dough stage, it was carefully kneaded and packed.

Curing was done then finishing and polishing according to manufacturer instruction.

Porosity test

The standard sorption method was employed in this study to assess porosity. Fifteen samples with dimensions of (50×4×2) mm were generated, five from each group. These samples experienced a thorough drying process within a desiccator including silica gel under vacuum conditions then using an analytical balance, accurate to 0.0001 g, was performed two weight measurements were taken: one with the samples that were exposed to air and the samples that were immediately immersed in distilled water and weighted. Then the samples were put in distal water at 37 °C in incubator and weighted.

The following formulas were used to calculate porosity [13; 14]:

$$Vs_{dry} = \frac{m_d - m'_d}{\rho_{water}};$$

$$Vs_{wet} = \frac{m_w - m'_w}{\rho_{water}};$$

$$\text{Porosity\%} = 100 \times \frac{Vs_{dry} - Vs_{wet}}{Vs_{dry}},$$

where ρ_{water} (g/mL) is the density of water; Vs_{wet} (mL) is the volume of the wet specimen; m_d (g) is the mass of the dry specimen recorded in air; m'_d (g) is the mass of the dry specimen recorded with the specimen instantly submerged in water; the mass of the wet specimen measured in air is denoted by m_w (g), while the mass of the wet specimen recorded with the specimen immediately submerged in water is denoted by m'_w (g).

This computation was based on the water's density as well as the mass and volume of each sample both before and after immersion [15].

Water sorption and solubility

For each material, fifteen circular specimens with a diameter of 40 mm and a thickness of 2.5 mm were made.

For thirty minutes, the specimens were kept at room temperature. The initial weight of each specimen (M1) was determined weighing using an analytical scale with an accuracy of 0.0001 g in a water bath maintained at 37 °C until a consistent weight (M2) was achieved.

Then samples were dried at 37 °C in an incubator and weighed (M3). The values for water sorption (*Wsp*) and solubility (*Wsl*), expressed in μg/mm^3, were determined using the subsequent formulas [15; 16]:

$$Wsl \quad \frac{M1 \quad M3}{V};$$

$$Wsp = \frac{M2 - M3}{V}.$$

RESULTS

1. Test of porosity: for the three groups' means and standard deviations are shown in Table 1 and 2. The TiO_2 group had the highest mean porosity test value (2.504), whereas the control group had the lowest (1.468).

Table 1. Descriptive statistics for all groups in porosity test

Таблица 1. Описательная статистика по всем группам в тесте на пористость

Groups	N	Mean	SD
Control	5	1.468	0.2701296
SiO_2	5	2.262	0.3212009
TiO_2	5	2.504	0.9671301

Table 2. *T*-test and *p*-value between groups in porosity test

Таблица 2. *T*-критерий и *p*-значение между группами в тесте на пористость

Between groups	*t*-value	*p*-value	Value
Control vs SiO_2	−4.23	0.0028	Sig
Control vs TiO_2	−2.35	0.046	Sig
SiO_2 vs TiO_2	−0.54	0.60	Non sig

2. Test of water sorption: the three groups' mean values and standard deviations are shown in Table 3 and 4. The SiO_2 group had the highest mean water sorption test (1.28572430), while the TiO_2 group had the lowest (0.66882004).

Table 3. Descriptive statistics for all groups in water sorption test

Таблица 3. Описательная статистика по всем группам в тесте на водопоглощение

Groups	N	Mean	SD
Control	5	0.92878302	0.272598629
SiO_2	5	1.28572430	1.144199596
TiO_2	5	0.66882004	0.051539575

Table 4. *T*-test and *p*-value between groups in water sorption test

Таблица 4. *T*-критерий и *p*-значение между группами в тесте на водопоглощение

Between groups	*t*-value	*p*-value
Control vs SiO_2	−0.71	0.50
Control vs TiO_2	2.10	0.06
SiO_2 vs TiO_2	−1.25	0.25

3. Test of solubility: the three groups' mean values and standard deviations are shown in Table 5 and 6. The control group had the highest mean solubility test (0.649619315), while the SiO_2 group had the lowest (0.45170539).

Table 5. Descriptive statistics for all groups in solubility test

Таблица 5. Описательная статистика по всем группам в тесте на растворимость

Groups	N	Mean	SD
Control	5	0.649619315	0.196428937
SiO_2	5	0.45170539	0.19876589
TiO_2	5	0.53692591	0.238198283

Table 6. *T*-test and *p*-value between groups in solubility test

Таблица 6. *T*-test и *p*-значение между группами в тесте на растворимость

Between groups	*t*-value	*p*-value
Control vs SiO_2	2.24	0.038
Control vs TiO_2	1.15	0.26
SiO_2 vs TiO_2	−0.85	0.40

DISCUSSION

Owing to its advantageous properties, processing simplicity, precise stability and fit in the oral cavity, affordability, and better aesthetics, PMMA continues to be the preferred material for denture base production. However, there is an ongoing need to enhance some of its physical and mechanical properties [17]. One strategy to address this challenge involves incorporating nanoparticles into the denture base polymer matrix. This approach has shown promising results in improving the material's properties [18].

Porosity is a complicated phenomenon that can be linked to a number of factors, including laboratory methodology and the combination of material and polymerization procedure [19].

The results showed that adding TiO_2 and SiO_2 nanoparticles increased porosity rather than decreased it. Cevik & Yildirim-Bicer agreed with our findings [17]. They claimed that adding 1% silica would cause acrylic to have more voids, as shown by SEM, which would reduce flexural strength. Our findings were rejected by Hameed & Abdul Rahman [18] and AL-Shakarchi & Hasan [20] who discovered that porosity decreased when ZrO particles were added to the acrylic denture foundation. Nevertheless, the mechanical characteristics decreased as the SiO_2 nanoparticle content increased [21]. The synergistic interaction between ZrO_2 and TiO_2 resulted in a reduced apparent porosity value for 3 weight percent ZrO_2–TiO_2 [22]. Porosity is associated with numerous causes that involve the trapping of air during mixing, contraction of the monomer during polymerization, vaporization of a monomer, linked to reaction that is exothermic, insufficient monomer and polymer mixing, high temperature during processing and inadequate compression in the flask [23]. Occurrence of porosity may be revealed to the incidence of porosity in a polymer is determined by the concentration of the initiator, which is frequently benzoyl peroxide have been linked to reduced mechanical qualities, unsightly appearance, possible organism harboring, and fluid retention, depending on the polymerization circumstances [24].

Denture base acrylic resins were extremely unstable and continuously interacted with their surroundings once they had polymerized. Since the dentures were frequently immersed in aqueous disinfection treatments or bathed in saliva, the significant reaction took place with water. Two opposing processes occurred as a result of water diffusing into the matrix: water leached out unbound, unreacted monomers and ions [25].

One of the main drawbacks of acrylic resin denture bases is that they go through a series of processes that include water absorption and component filtering out both during and after curing and implantation, these modifications are thought to be one of the primary causes of denture failures [26]. After adding both kinds of nanoparticles, the water solubility in this study decreased.

When TiO_2 is introduced, water sorption reduces, but it increases when SiO_2 is added. This indicates that different kinds of nanoparticles produce different outcomes, and concentration may also have an impact. According to our findings, the addition of TiO_2 to the acrylic denture base reduced its water solubility when compared to the control group. Our findings were unaccepted by Giti et al. [27].

Chladek et al. discovered that raising the concentration of nanosilver improved the soft lining material's sorption and solubility [28].

Alwan & Alameer found that adding 3% weight of treated TiO_2 nanoparticles to heat-cured acrylic resin reduced water sorption and solubility [29]. Abdelraouf et al. found that the self-cured acrylic resin's flexural strength was increased and its water-sorption was decreased by adding 5% weight TiO_2 nanoparticles without affecting the surface roughness and microhardness [30].

CONCLUSION

1. When 2% concentrations of TiO_2 and SiO_2 are added to heat-cured acrylic, the porosity increases.

2. Water solubility is reduced when 2% SiO_2 and TiO_2 are added.

3. Water sorption decreased when TiO_2 was added at a concentration of 2%, whereas water absorption increased when SiO_2 was added at a concentration of 2%.

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