Investigating The Impact of Ta_2O_5 Nanoparticles on Hardness and Surface Roughness of Soft Denture Liners

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Abstract

The current study investigates effects of incorporating Ta_2O_5 nanoparticles (NPs) into a PEMA soft denture liner. The objective is to examine the inclusion of Ta_2O_5 NPs affecting the shore A hardness, and surface roughness properties. Results show that adding Ta_2O_5 NPs reduces hardness and roughness, with greater reductions at higher nanoparticle concentrations. The control group has the highest hardness value, while specimens with Ta_2O_5 NPs exhibit progressively lower values. Statistically significant differences were observed among the tested groups. The introduction of Ta_2O_5 NPs as a nanocomposite improves the hardness properties, providing a novel approach compared to traditional methods. Soft denture liners with lower hardness offer better cushioning and adaptability to oral tissues, minimizing trauma. The presence of Ta_2O_5 NPs also influences surface roughness, resulting in a smoother texture. These findings contribute to the development of improved denture materials for enhanced comfort and performance

Keywords: Ta_2O_5 nanoparticles, Shore A hardness, Surface roughness.

1. Introduction

The elderly population worldwide is increasing rapidly, and despite some retaining natural teeth, many suffer from tooth loss [1, 2]. Edentulism, or the absence of teeth, results in difficulties with biting food, leading to poor health, unattractive appearance, and speech problems. These issues cause physical impairment, ultimately affecting the overall health of the patient. Although conventional complete dentures are a common choice for edentulous patients, implants may be more efficient. Medical, psychological, bone quality and quantity, and economic status are all factors that play a vital role in determining the treatment plan [3-7]. Even complete dentures can present problems with stability, retention, and pain during mastication. Especially in patients with an atrophic mandibular ridge and thin mucosa. Soft denture recliners are substances that create a cushioned layer between the hard denture base and the oral mucosa [8, 9]. A soft liner for dentures can be used to provide retention, stability, and support by engaging natural or prosthetic undercuts [10-11].

The commonly used liners are plasticized acrylic resins, which can be heat-activated or chemically activated [10]. The polymers for soft liners are supplied in powder form and mixed with liquids containing a plasticizer, which is typically a large molecular species like dibutyl phthalate or alcohol for short-term tissue conditioners [10, 12]. This plasticizer reduces the entanglement of polymer chains, allowing for changes in the shape of the soft liner and providing a cushioning effect for the underlying tissues. The liquids used in these applications do not contain acrylic monomers, making the resultant liners short-term soft liners or tissue conditioners [10-12].

Heat-activated soft liners are supplied as powder-liquid systems composed of acrylic resin polymers and copolymers for the powder and appropriate acrylic monomers and plasticizers for the liquid. These materials form pliable resins with glass transition temperatures below mouth temperature when mixed. Hardening rates for these liners are associated with the initial plasticizer content, and materials with high initial plasticizer content tend to harden rapidly as the probability of plasticizer loss increases with increasing plasticizer content [10, 11].

Nanotechnology involves the manipulation of matter at a nearly atomic level to create novel structures, materials, and devices. This technology holds the potential for scientific progress in several areas, including medicine, consumer goods, energy, materials, and manufacturing [13, 14]. The term nanotechnology pertains to engineered systems, devices, and structures that operate at a nanoscale, between 1 and 100 nanometers in size. Recently, much attention has been directed toward the incorporation of inorganic nanoparticles into PMMA to improve its properties. The properties of polymer nanocomposites depend on the type of incorporating nanoparticles, their size, and shape, as well as the concentration and interaction with the polymer matrix [15].

Tantalum pentoxide, referred to as tantalum (V) oxide, with chemical formula of Ta_2O_5. This substance is a white solid that cannot be dissolved in any solvents except when it is exposed to powerful bases and hydrofluoric acid [16-18]. Despite being a chemically inactive material, Ta_2O_5

possesses a high refractive index and low absorption, which makes it an ideal coating material [19-21]. This study investigates the effects of incorporating Ta_2O_5 nanoparticles into the PEMA soft denture liner. Specifically, the study focuses on evaluating the impact of Ta_2O_5 nanoparticle inclusion on the surface roughness and wettability properties of the soft denture liner material. The ultimate objective is to contribute to the development of improved denture materials for edentulous patients by enhancing comfort, stability, and overall performance.

2. Materials and methods

2.1 Materials

Materials that were used in this study presented in (table1).

Table1: Materials and their sources that used in the current study.

No.	Material	Manufacturer	Source
1	Tantalum oxide nanopowder 99.9 % (Ta_2O_5)	Skyspring Purity: 99.9 % Dia:<1um	USA
2	Acrylic based heat cured soft liner figure	MOONSTAR	Turkey
3	Heat cure acrylic resin (powder and liquid)	veracril	Netherlands
4	Wax sheet	Polywax	Turkey
5	Separating medium	Zhermack	Italy
6	Dental stone type II	Alpha Gold Stone	Germany
7	Distilled water		Iraq

2.2 Equipment and instruments

Equipment and instruments were used in this study presented in (table 2).

Table 2: Equipment's, and materials that are used in the current research.

No.	Equipment and instrument	Source
1	Electronic balance KERN	Germany
2	Surface roughness profilometer tester with (0.001) accuracy, Time 3200 / TR200	China
3	Shore A durometer Time group-TH200	China
4	Finishing burs (acrylic, stone, fissure, and sandpaper).	Germany
5	Rubber bowels, wax knife, and spatula	Germany
6	Dental metal flask (broden).	Sweden
7	Disposable cup, beaker, and Capillary tube	China
8	Prosthetic handpiece	Korea
9	Digital water bath (Lab. tech,).	Korea
10	Clamp (HANUA)	USA

2.3 Mold preparation

Two plastic patterns, each with a cross-sectional area of 10 × 10 mm, were connected using wax that was 3 mm wide. The plastic patterns were covered with a release agent and left to dry. Next, dental stone was prepared according to the manufacturer's instructions (mixing 100 g of powder with 20 mL of water) and added to the bottom part of a dental flask, which was then vibrated to remove any air bubbles. The plastic pattern was then inserted halfway into the dental stone and allowed to dry. Both the plastic pattern and the stone were coated with a release agent and left to dry.

The top part of the flask was placed over the bottom part and filled with stone, which was then vibrated. The flask was covered and left to set. After the stone had set, the flask was separated into two parts, and the plastic patterns were removed to create a mold cavity for acrylic specimens.

The PMMA resin was mixed, packed into the stone mold, and processed in a water bath to produce resin blocks. After polymerization the specimen was removed and sectioned with a handpiece to remove 3 mm from the center. Once the mixture reached the dough stage, the soft liner was packed (table3) into the prepared space, which was 3 mm in size. The top part of the flask, which had been coated with a release agent, was then placed over the bottom part and screwed down until metal-to-metal contact was achieved. The flask was then put in a digital water bath to undergo the curing process.

Table 3: Soft liner preparation.

Sample	Ta_2O_3 / g	Acrylic-based soft-liner powder / gram	Liquid / g
Control	0	10	7.8
0.5 %	0.05	10	7.8
1 %	0.1	10	7.8
1.5 %	0.15	10	7.8

2.4 Surface roughness test

2.4.1 Samples design

Surface roughness test involved the preparation of specimens of acrylic resin with dimensions of 65 mm in length, 10 mm in width, and 2.5 mm in thickness. In accordance with ADA specification No.12 from 1999 (figure 1).

Figure 1: presents the designed specimen.

2.4.2 Procedure

Surface roughness of the specimen was evaluated using a profilometer device that has an accuracy of 0.001 µm. The device comprises a surface analyzer with a sharp stylus made from diamond, which tracks the irregularities of the surface. To conduct the test, the specimens were positioned on a stable and rigid surface. The device was then calibrated such that the stylus only contacts the surface of the specimen and moved for 11 mm at three different points on the specimen to obtain three readings from each specimen. The average of the three readings was taken as the roughness value [22].

2.5 Shore A hardness test

For the Shore A hardness test, plastic disc-shaped patterns with a diameter of 30 mm and a thickness of 3 mm were utilized. The process for mixing and curing the soft liner was outlined in (table3) and presented in (figure 2). The hardness of the soft-liner samples was measured using a

Shore A durometer. Five readings were obtained for each sample, with a contact time of 15 seconds after each penetration. The average of the five readings was the value of the test.

Figure 2: presents the steps of the sample preparation for the Shore A hardness test.

3. Results

3.1 Rough surface analysis

The work investigated to assess the influence of incorporating Ta_2O_5 nanoparticles (NPs) on the surface roughness integrity. The evaluation of surface roughness was performed for all tested groups, and the results are presented in (figure 3) and (table 4). Notably, the addition of Ta_2O_5 NPs led to a significant reduction in roughness values over the course of the readings.

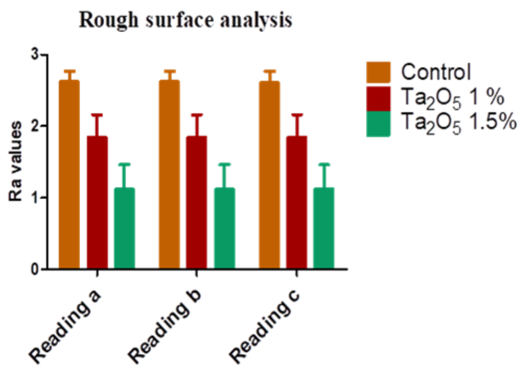

Figure 3: surface roughness reading of all tested groups. Data represented 10 readings each, as well as in mean ± SE.

Table 4: Summarizes the analysis of the surface roughness values using Tukey HSD test.

Tukey's multiple comparisons test	"Mean 1"	"Mean 2"	Mean Diff.	Adjusted P Value	Summary
Control vs. 1 %	2.615	1.839	0.7759	0.001	***
Control vs. 1.5 %	2.615	1.116	1.499	0.005	***
1 % vs. 1.5 %	1.839	1.116	0.7230	0.001	***

*Note: Mean Diff = mean differences, ns: not significant, * = P < 0.01, *** = P <

0.001, **** = P < 0.0001, n = 10, The data represents mean ± SD.

3.2 Shore A hardness results

A total of 10 specimens were tested for each composite variant in the shore A hardness test. The graphical representations of the hardness test and standard error can be found in (Figure 4). The results of the shore A hardness test indicated that the control group exhibited the highest mean value of 46.40, followed by specimens containing 0.5 % Wt. Ta_2O_5 NPs with a mean value of 41.00. For specimens containing 1% Wt. Ta_2O_5 NPs, the mean value was 30.0. The lowest mean value of 22.1 was observed in specimens containing 1.5 % Wt. Ta_2O_5 NPs, as shown in (table 5).

Statistical analysis using the one-way ANOVA test demonstrated a highly significant difference among the means of the tested groups. Furthermore, a comparison of the mean values between each pair of studied groups was conducted using the Post-hoc Tukey Honestly Significant Difference (Tukey HSD) test, as presented in (table 6). The results revealed a statistically significant difference among all groups studied.

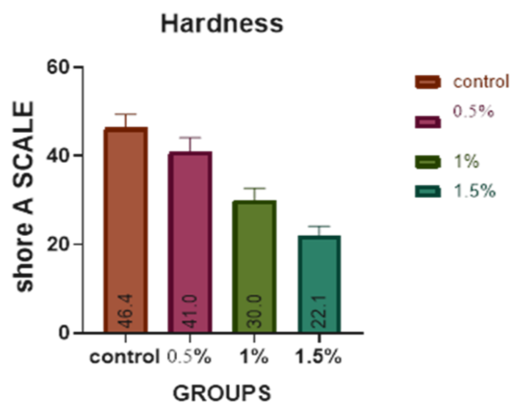

Figure 5: A hardness values of all four tested groups; data presents in mean ± SE.

Table 6: Represent means of all the studied groups, data were analyzed by a one-way ANOVA test.

Groups	Control	0.5 %	1 %	1.5 %	P value	F
Number of values	10	10	10	10	< 0.0001	155.7
Minimum	41.00	37.00	27.00	20.00		
Median	48.00	41.00	29.00	21.50		
Maximum	49.00	45.00	34.00	25.00		

Table 7: Summarizes analysis of studied groups of Shore A hardness experiment.

Tukey's multiple comparisons test	"Mean 1"	"Mean 2"	Mean Diff.	Adjusted P Value	Summary
Control vs. 0.5 %	46.40	41.00	5.400	0.0006	***
Control vs. 1 %	46.40	30.00	16.40	< 0.0001	****
Control vs. 1.5 %	46.40	22.10	24.30	< 0.0001	****
0.5 % vs. 1 %	41.00	30.00	11.00	< 0.0001	****
0.5 % vs. 1.5 %	41.00	22.10	18.90	< 0.0001	****
1 % vs. 1.5 %	30.00	22.10	7.900	< 0.0001	****

*Note: Mean Diff = mean differences, * = P < 0.01, *** = P < 0.001, **** = P < 0.0001, n = 10, The data represents mean ± SD.

4. Discussion

Recent advancements in science and nanotechnology have led to the development of Ta_2O_5 nanoparticles (Ta_2O_5 NPs) [23-25]. Although previous studies have examined the impact of incorporating nanoparticles NPs on the compressive, tensile, and flexural strength of acrylic resin, were not investigated the effect of adding Ta_2O_5 NPs to a soft denture liner on its surface roughness and hardness to denture acrylic resin [23, 26-30].

In this current study, an attempt to create a nanocomposite by introducing Ta_2O_5 nanoparticles into the PEMA soft denture liner based on the statistical analysis of the viable count data collected in this research. The objective of this study was to examine how the inclusion of Ta_2O_5 NPs affects the shore A hardness and surface roughness properties of soft denture liners. Surprisingly, findings revealed that all groups with added nanoparticles demonstrated a notable reduction in hardness and surface roughness.

These changes were directly proportional to the concentrations (0.5, 1, 1.5 Wt %) of Ta_2O_5 NPs. The control group had the highest mean shore A hardness value of 46.40 while the experimental specimens contained 0.5 % Wt. Ta_2O_5 NPs, which exhibited a slightly lower mean value of 41.00. The mean value further decreased to 30.0 for specimens with 1 % Wt. Ta_2O_5 NPs. The lowest mean value of 22.1 was observed in specimens containing 5 % Wt Ta_2O5 NPs. To assess the statistical significance of the differences among the means of the tested groups, a one-way ANOVA test was performed.

The analysis demonstrated a highly significant difference among the means, indicating that the variation in Ta_2O_5 NPs content had a significant impact on the shore A hardness values. Furthermore, the Tukey HSD test was conducted to compare the mean values between each pair of studied groups. Interestingly, the results revealed that there was a statistically highly significant difference among all groups studied. Soft denture liners undergo changes in hardness during clinical use, and this characteristic is crucial as it determines their ability to absorb impacts, which increases with enhanced elasticity [31-33].

Therefore, low shore A hardness is an important property of soft-liner denture materials to provide better cushioning and comfort to denture wearers, lower Shore A hardness may have better adaptability to irregularities and contours of the oral tissues and softer materials may help minimize trauma to the oral tissues, especially in cases where patients have sensitive or fragile tissues [34-36].

However, maintaining the desired hardness of soft denture liners poses challenges due to their instability in an aqueous environment. It is important to note that these undesirable effects are associated with the loss of balance between the components and the absorption of liquids, which adversely affect the overall quality and longevity of soft denture liners [37].

Many previous approaches employed reduce the Shore A hardness of soft-liner denture materials such as adding plasticizers and fillers and reinforcements, but most of them came out with inconsistent results. The novelty of our work was creating a nanocomposite by introducing Ta_2O_5 nanoparticles into the PEMA soft denture liner. Interestingly, Ta_2O_5 NPs significantly improves the hardness properties of the soft-liner denture materials. No previous studies have tried to examine the effects of nanocomposite by introducing Ta_2O_5 nanoparticles into the PEMA soft denture liner on the hardness features.

However, our results consistent with several previous attempts that used different nano agents such as silica nanoparticles, silver nanoparticles, Titanium dioxide and gold nanoparticles [38-43], for example, the presence of silica nanofillers can improve the flexibility and reduce the Shore A hardness of the material. The silica nanoparticles help to create a more homogeneous structure, which can enhance the softness and adaptability of the soft liner [41-45]. A 3 mm thickness soft denture liner was chosen based on clinical recommendations. The material thickness is less than 2 mm; it tends to reflect the hardness of the supporting materials rather than the properties of the soft liner itself [46]. Similarly, higher thickness cannot be used as they can interfere with denture rigidity [46]. The decrease in hardness value observed in the study can be attributed to a couple of factors.

The scission or breaking of polymer chains in the soft denture liner increases the freedom of molecular movement, resulting in a softer material [46]. This increased mobility of molecules contributes to the observed decrease in hardness. Furthermore, the absorption of water by the soft denture liner acts as an additional plasticizer, enhancing the material's resiliency. Water absorption can cause swelling and changes in the molecular structure of the material, leading to a decrease in hardness [46].

The shore A hardness values for resilient relining materials were recognized to range from 25 to 50 units after 24 hours of aging in distilled water at 37 degrees Celsius. Hardness is an important property of soft denture liners as it is used to measure their modules of elasticity or softness. Soft liners with high levels of hardness are generally considered undesirable because they are less effective in absorbing impact. Therefore, there is a preference for utilizing low hardness materials [47-48]. It is important to note that the specific ranges and values mentioned for hardness are based on the study's findings and may vary depending on the specific materials and clinical requirements [47-48]. Overall, the selection of an appropriate soft denture liner with the desired hardness and resilience is crucial for optimizing denture performance, comfort, and longevity. Nanoparticles can also contribute to surface roughness and porosity.

The presence of nanoparticles on the surface of the soft-liner material creates a rougher texture, which increases the effective surface area [49-52] When the initial surface roughness of a material is greater than the size of the nanoparticles being used, it is possible for the roughness to decrease because of the nanoparticles depositing onto the surface pores [53].

This phenomenon occurs due to the filling of the voids and irregularities on the surface by the nanoparticles. The nanoparticles, being smaller in size compared to surface roughness, can effectively penetrate and settle into the pores and crevices of the soft lining surface [54-57]. As they deposit, they fill up the gaps and irregularities, resulting in a more even and smoother surface.

Incorporation of Ta_2O_5 NPs in soft denture liners showed promising results in terms of reducing hardness and roughness of surface. These findings contribute to the ongoing research on nanocomposites for denture materials, providing insights into improving the comfort and performance of dentures for edentulous patients.

5. Conclusion

Incorporating Ta_2O_5 nanoparticles (Ta_2O_5 NPs) into soft denture liners showed promising results by significantly reducing hardness and roughness of surface. This study's findings contribute to ongoing research on nanocomposites for denture materials, offering insights into improving comfort and performance for edentulous patients. The presence of Ta_2O_5 NPs improved the softness and adaptability of the denture liner, addressing the challenge of maintaining desired hardness in an aqueous environment. The use of nanoparticles in denture materials presents exciting possibilities for enhancing denture performance and the overall quality of life for denture wearers.

6. References

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