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Effect of Strontium Titanate Addition on Antifungal, Physical and Mechanical Properties of Soft-Liners

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Abstract

Objective: Soft denture liners are essential in prosthodontics due to their ability to cushion masticatory forces and provide comfort to patients with compromised oral tissues. Despite their clinical benefits, conventional soft liners suffer from significant limitations, including poor bond strength with the denture base, surface degradation, microbial colonization, and limited mechanical resilience. The goal was to assess improvements in shear bond strength and other related surface properties such as surface hardness, and a reduction in C. albicans adherence. **Material and Methods**: Strontium Titanate ($SrTiO_3$) nanoparticles were obtained from, and a self-cured soft denture liner was sourced from. All procedures were performed under conditions simulating intraoral temperature, following the manufacturer's instructions. A dry-heat oven was used for sample conditioning. A total of 45 specimens were fabricated and equally allocated into three experimental groups containing 0%, 1%, and 1.5% concentrations of strontium titanate ($SrTiO_3$), respectively. **Results**: The results indicated that $SrTiO_3$ can play a valuable role in the development of advanced soft lining materials with enhanced durability, biocompatibility, and clinical effectiveness. **Conclusion**: The incorporation of Strontium Titanate ($SrTiO_3$) nanoparticles at concentrations of 1% and 1.5% significantly improves the mechanical properties, surface roughness, and reduction in antifungal behavior of acrylic-based soft denture liners.

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Introduction

Complete and partial removable dentures have used soft denture liner materials for over a century to disperse functional loads on the supporting tissues of the denture. This has allowed for material manipulation, improving the materials' physical, chemical, biological, and electrical qualities in comparison to their larger-scale counterparts [1]. Function, comfort, and appearance all affect how effective full or partial dentures are. A precise denture foundation that appropriately adapts to the underlying tissue is crucial. When building complete dentures, this is a crucial goal [2]. A complete denture is used when a person has lost all of their teeth, while a partial denture is used if they still have some teeth [3]. The fundamental reason removable dentures may retain their support, stability, and retention is because their bases are fine-suited to the oral mucosa [4]. Strontium titanate ($SrTiO_3$) is a ceramic oxide with remarkable mechanical and thermal properties, making it valuable in various dental applications. Its incorporation enhances strength, hardness, and durability of dental materials without affecting their essential flexibility. This contributes to improved performance and longevity of restorations in the oral environment [5]. Progressive bone resorption compromises denture fit, resulting in discomfort and even significant pain, ultimately affecting the patient's comfort and quality of life [6].

Material and Methods

A total of 45 specimens of a self-cured, room-temperature polymerizing denture liner were prepared for evaluating Candida albicans adherence, surface roughness, and shear bond strength. The specimens were divided equally into three groups containing 0%, 1%, and 1.5% concentrations of strontium titanate ($SrTiO_3$), as shown in the table 1. Surface roughness was assessed using a profilometer, while C. albicans adherence was quantified via optical density measurements using a spectrophotometer. Shear bond strength was evaluated using a testing machine (WDW-50).

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Statistical analysis

Statistical comparisons between groups were performed using one-way ANOVA in the SPSS software, with a significance level set at $\alpha = 0.05$.

The analysis revealed statistically significant differences across all tested parameters, indicating that the incorporation of $SrTiO_3$ had a substantial effect on the mechanical and biological properties of liner material as shown in Table 1.

Shear bond strength test

Sample design

Using acrylic block dimensions, the shear bonding strength between the soft lining material and the acrylic denture base was assessed. Two heat-cured acrylic blocks measuring 75*25*5 mm in diameter, length, width, and Thickness, as well as a stopper that was roughly 3 mm deep, made up the shear bond sample, as shown in Figure 1 [7]. To apply reline material, the two acrylic blocks are positioned one on top of the other, leaving a 25 mm*25 mm* 3 mm space between them. The handle needs to be precisely 13 mm thick to guarantee that the applied forces are parallel and that the testing machine is gripping the sample well [8].

Preparation of the heat-cure acrylic samples

Mold preparation

It is possible to create acrylic blocks using an aluminum template. It was manufactured by employing substances mold and a machine that cuts by laser, in addition to other measuring tools that it is essential to the Inferior portion includes both the pattern and the mold, it belongs to the dental flask of course. However, it includes a dental stone of the third type which originally had been designed to comply with the instructions of the producing party (p/L) ratio of 25ml/100q). As soon as the stone is set, both the stone and the Aluminum model would be covered with an isolating material and thus be liable to dry. The higher section of the flask would later be placed over the lower part. Next, a stone that was recently mixed would be added up. **The aluminum sculpture was extracted from the mold.** Consequently, we can open the flask when we had solidified the stone.

Proportioning and mixing of heat cure acrylic

MAARC DENTAL rapid heat-cure acrylic was used to create the acrylic sample. The mixture was combined in a dry, clean glass container with a powder-to-liquid monomer ratio of 10 cc of powder per 5 mL, as directed by the manufacturer. After being covered, the mixture was let to solidify into dough.

Packing

We covered the two parts of a flask with an isolating material that will be dried up later. Next, we erased the sculpture and locate the dough like acrylic resin into a hollow room. Later, we cover the acrylic with a polythene layer. We close thus the flask. A hydraulic pressure is employed to scatter the substance equally within the mold. So, it can get pressure step by step.

Curing

We used a digital water bath, as shown by the producer, in order to cure the material of the acrylic resin. The resin is then placed in a water bath at 74°C for approximately 120 minutes. Subsequently, the temperature is increased to 100 °C to complete the curing process. Since cooling is achieved at normal heat of room. For 30 minutes, we soak the metal flask in a faucet water, then we can get it from the flask.

Preparation of final samples for shear bond strength test

Mold preparation

One sample was created by using two acrylic blocks to test the shear bonding strength. When the two blocks are brought together, they make a space of 25mm × 25mm × 3mm (length, width, and depth accordingly), as shown in Figure 1. This space is then filled with material. Then, the samples were entirely covered with laboratory silicone and allowed to set properly the acrylic blocks and silicone mold are placed together after the silicon has been set in a custom-made flask filled with freshly mixed type III dental stone The custom flask was made from and consisted of upper and lower parts with a dimension of (33cm length, 23cm width, and 4cm height) for each part. The parts came together and tightly screwed until edge-to-edge contact was achieved.

Incorporation of $SRTIO_3$

In a dry, clean glass container, the strontium titanate nanoparticles were weighed with an electronic balance. After being measured using a medical syringe, the soft-liner monomer was applied to the nanoparticles. After that, the mixture was put through a probe sonication device. For 3 minutes at 120W and 60 KHz to break up the nanoparticles into separate particles [9]. To avoid particle aggregation, the resultant $SRTIO_3$-soft liner monomer dispersion was combined right away with soft liner powder. By deducting their weight from the soft-liner polymer powder, it was thought that adding $SRTIO_3$s to the monomer would result in the proper P/L ratio.

Soft liner application

We weigh the ($SrTiO_3$) within a spotless, dry glass container using an electronic balance. Next, we measure employing a medical syringe, thus later we expose the soft-liner monomer dispersion suddenly with soft liner powder. It was believed, through reducing the weight from the soft-liner polymer powder, that if we add $SrTio_3$ soft liner monomer would cause the cause the suitable P/L percentage, as shown in Table.

Curing

According to the manufacturer's instructions, the material should be placed at a temperature like that of the mouth. The samples were placed in the designated places in the mold and transferred to the oven for 4 to 5 minutes at a temperature of 37 degrees Celsius. The samples were then removed from the oven and removed from the mold**.**

Testing procedure

The models underwent testing at, utilizing an Instron testing machine (WDW-50 from Laryee Technology Co., a computer-controlled electronic universal testing machine) with a load cell possessing a capacity of 50 KN and the crosshead speed set to 0.5 millimeters per minute, as shown in Figure 1. According to ASTM specification D-638m, the shear bond values were determined by dividing the ultimate load needed to cause sample failure by the samples' cross-sectional area [10].

Surface Hardness Test

Sample design and preparation

The disc like plastic pattern was manufactured to comply with ISO 10139, 2, 2016, it had a diameter of 35 millimeter and 6 thickness. We employ the plastic models to create laboratory soft denture liner manipulation samples as templates. Those soft lining substances of samples were created, mixed, stuffed in and dried in compliance with the manual [11].

Testing

Surface hardness testing was carried out in accordance with ISO 10139-2:2016, which is the International Organisation for Standardisation (ISO) guideline for permanent soft denture liners. Before being measured, all samples were incubated for five minutes in a perfect oven setting that about matched the manufacturer's recommended oral temperature [12]. The hardness was measured using the Shore A durometer (produced by Zwick, Germany); it was calibrated in compliance with ASTM D2240. We reported the data using shore units. The device is comprised of a 1.6 mm cylinder that gradually shrinks to a blunted indenter with a diameter of 0.8 mm. An indentation point-holding lever is connected to a scale with gradations from 0 to 100 units. Zero signifies that the indenter has completely pierced the sample, whereas 100 denotes no penetration at all. To test the discs, five locations were selected. The sample was loaded evenly across its surface, away from its edges, to determine the average shore hardness [13]**.**

Fabrication of soft-liner specimens to evaluate C. albicans adherence ability

Specimen preparation

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Disk-shaped plastic patterns, each measuring 10 mm in diameter and 2 mm in thickness, were used to prepare the soft-liner specimens [14]. These plastic disks were positioned in the lower half of a dental flask already filled with dental stone. Once the stone had fully set, the surface—including the plastic patterns—was coated with a thin layer of separating medium and allowed to dry. Subsequently, the upper half of the flask was assembled and filled with dental stone using vibration to eliminate any air bubbles, then sealed with its cover. After the second layer of stone had completely set, the flask was opened, and the plastic disks were carefully removed [15].

Proportioning and mixing of room temperature Acrylic Based Soft liner

Control negative specimens' preparation

According to the manufacturer's instructions (powder-to-liquid ratio of 2.2 g:1.8 ml), the required amounts of soft-liner powder and liquid, as shown in Figure 3 were measured and mixed in a clean, dry glass jar, then covered with a lid. Both the upper and lower halves of the dental flask were coated with a separating medium to prevent the soft liner from adhering to the stone. Once the mixture reached the dough stage, it was hand-kneaded and adapted onto the lower half of the flask in preparation for packing.

Positive Control Specimen preparation

To comply with the producer's recommendation, powder to liquid percentage of 8.6, 8.1ml.wt% of Nystatin powder was precisely calculated and taken out of the total weight of the sift liner powder. We add the left soft liner powder with Nystatin and mix all with the soft liquid by a tiny electric manual mixer for 60 seconds. By doing so, the targeted quantity of monomer will be added up to the mixture [16].

Incorporation of $SRTIO_3$ nanoparticles

We weigh the $SrTiO_3$ nano particles within a spotless dry glass container then add up the soft-liner monomer. The total mixture will be exposed to probe sonification for almost 3 minutes at 120 and 60 Khz to scatter. Those nano particles by dividing up any agglomerates and attaining uniform distribution [10]. To prevent particle aggregation, the resulting $SrTiO_3$–soft liner monomer suspension was immediately mixed with the soft-liner powder. To maintain the manufacturer's specified powder-to-liquid (P/L) ratio, the weight of the $SrTiO_3$ nanoparticles was subtracted from the total weight of the soft-liner powder. A medical syringe was used to measure the volume of the monomer, while an electronic balance was employed to accurately weigh the $SrTiO_3$ nanoparticles and soft-liner powder.

Packing

Since the soft liner gets into the dough period. We knead it by hand and used this for the ready mold. We put a polyethylene sheet over the substance. The lid will be placed on the top part of the flask. To guarantee the uniform scattering of the soft lining material in the mold to get rid if any extra value we use hydraulic press to maintain permanent pressure of 100kg/cm^2. Fir about 5 minutes. The mixture will be positioned inside an oven with a temperature that's close to the oral environment. This will be achieved to comply with the manual recommendations. When cutting is over, we opened the flask after I was totally cold, and we took the specimen out of the mold [10]. After curing completion, the flask was opened when became completely cold and the specimens were removed from the mold.

Finishing and Sterilization

After trimming the excess material from the specimens using a sharp blade, they were finished using a 240-grit silicon polishing bur followed by fine-grit sandpaper. The specimens were then rinsed with distilled water, properly positioned, and sterilized under UV light for 20 minutes on each side at a wavelength of 254 nm. Finally, the specimens were stored in test tubes containing 250 ml of distilled water for 24 hours [10].

Isolation of C. albicans

Candida albicans was collected from the oral cavities of patients showing clinical signs of denture stomatitis who visited the Prosthodontics Clinic at the College of Dentistry, Kufa University, for treatment. Sterile cotton swabs were used to gently collect samples from oral lesions, which were then cultured on Sabouraud Dextrose Agar (SDA), a standard medium for fungal growth. The culture plates were incubated at 37°C under aerobic conditions for 48 hours. Following incubation, the fungal isolates were preserved at 4°C for future testing [17,18].

Preparation of Sabouraud dextrose agar

According to the manufacturer's instructions, 62 g of Sabouraud Dextrose Agar (SDA) was weighed and fully dissolved in 1000 ml of distilled water. The mixture was then sterilized using an autoclave at 121°C and 15 psi for 15 minutes. After sterilization, the medium was allowed to cool to approximately 47 °C to prevent damage to the Petri dishes. To inhibit bacterial growth, 0.05 g of the broad-spectrum antibiotic chloramphenicol was added per 1000 ml of prepared medium. The SDA was then poured into Petri dishes, allowed to cool and solidify, and subsequently stored at 4 °C until use [19].

Identification of C. albicans

Morphological examination

A smooth, creamy, and pasty Candida colonies appear in Sabouraud dextrose agar medium.

Microscopical examination

A small amount from a single isolated Candida colony was picked and mixed with a drop of normal saline on a clean glass slide to create a suspension. This suspension was evenly spread across the slide, left to air dry at room temperature, and then heat-fixed by passing the slide several times through the flame of a Bunsen burner. Gram staining was performed according to the method outlined by Marler (2001) [23], as follows:

1. The slide was stained with crystal violet for one minute, then rinsed with distilled water.
2. Gram's iodine was applied for one minute and rinsed off.
3. Decolorization was carried out using acetone-alcohol until the dark violet color lightened, followed by a rinse with distilled water.
4. The slide was counterstained with safranin for one minute, rinsed again, and left to dry. Microscopic examination under a light microscope revealed Candida as round or oval cells. The prepared slide was examined under a light microscope, where *Candida* appeared as round or oval-shaped cells [26].

Germ tube formation

A loopful of yeast cells was taken from a single colony and suspended in tubes containing 0.5 ml of serum. The tubes were then incubated at 37 °C for 3 hours. After incubation, a drop of the suspension was placed on a clean glass slide and examined under a light microscope to observe the presence of germ tubes [22].

Biochemical Identification

The VITEK 2 system is a fully automated device that utilizes sensitive fluorescence-based technology for the identification of microorganisms. Before testing, a yeast suspension was prepared in sterile saline, adjusted to a turbidity equivalent to a 2.0 McFarland standard, as verified using the DensiChek instrument. The VITEK ID-YST card was then automatically filled with the suspension, sealed, and incubated at 35.5°C for 18 hours within the VITEK 2 system. Optical density readings were taken automatically every 15 minutes throughout incubation. After completion, the results were compared with the device's database, enabling identification of the unknown microorganism. Final identifications labeled in the laboratory report as "very good "were considered accurate [23].

Preparation of Sabouraud dextrose broth (SDB)

According to the manufacturer's instructions, 30 g of broth powder was dissolved in 1000 ml of distilled water and sterilized by autoclaving at 121°C and 15 psi for 15minutes. After sterilization, the broth was cooled to 47°C, and to prevent bacterial

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growth, 0.05 g of chloramphenicol antibiotic was added [24].

Evaluating the effect of Chitosan / soft denture liner specimens on adherence of C. albicans adherence

Sterile tubes were filled with freshly prepared Sabouraud Dextrose Broth (SDB), into which a small amount of the isolated yeast culture was introduced. The yeast suspension was then adjusted to a 0.5 McFarland standard using a McFarland densitometer. Pre-sterilized soft lining material specimens were immersed in the inoculated broth and incubated at room temperature for one hour. After incubation, the specimens were carefully removed and gently rinsed with phosphate-buffered saline (PBS) for one minute with mild rocking to remove loosely attached yeast cells, then dried using filter paper. The adherent Candida cells were fixed on the lining surface using methanol, stained with crystal violet for 60 seconds, rinsed again with PBS for 30 seconds, and finally dried with filter paper. Microscopic examination was carried out using an inverted light microscope [25]. For each specimen, the attached Candida cells were counted in two standardized microscopic fields, and the mean value of the two counts was calculated and recorded.

Results and Discussion

Scanning electron microscope (SEM) (Figure 1)

Results demonstrated that the incorporation of $SrTiO_3$ at concentrations of 1% and 1.5% contributed to improved surface morphology and reduced porosity. The nanoparticles exhibited good dispersion at the lower concentration, while slight agglomeration was observed at the higher concentration. These surface modifications may enhance the bond strength between the soft liner and the denture base, as well as improve mechanical properties such as hardness and resistance to fungal adhesion.

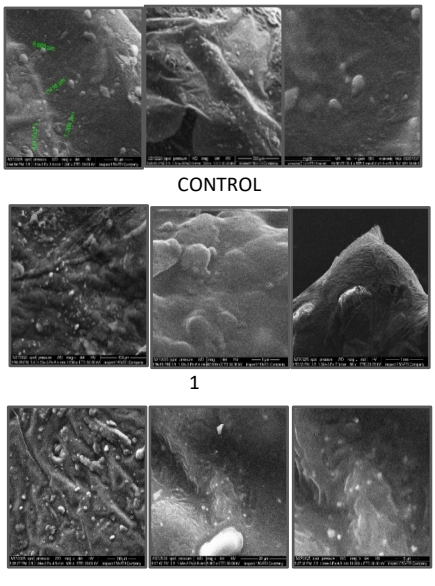

Figure 1. SEM images of soft liner (control,1%1.5%).

Candida albicans Adherence

The results of the multiple comparison table using the Games-Howell test designated significant differences between group means ($p < 0.05$), confirming the heterogeneous variances. This demonstrated a clear effect of Strontium Titanate addition on the soft liner in comparison with the control group. Among the tested groups, Nystatin exhibited the greatest antifungal efficacy, followed by 1.5% and then 1% Strontium Titanate, all of which significantly outperformed the control in reducing Candida growth (Figure 2).

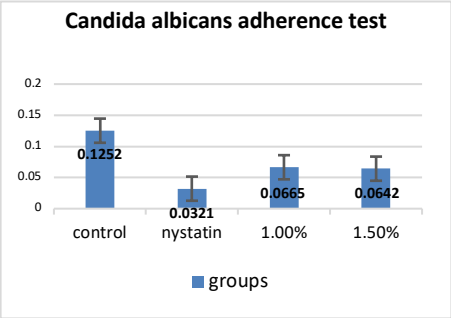

Figure 2. Candida albicans adherence.

Shore A Hardness

The source of the difference was more investigated by the analysis of the data, tukey (Figure 3). Through the mean differences, we noted the superiority of the group followed by 1.5 and then 1% over the control group in increasing hardness.

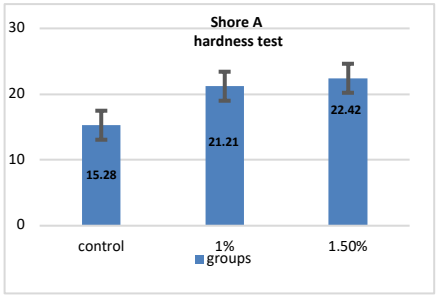

Figure 3. Differences in hardness.

Shear Bond Strength

Statistically significant changes in shear strength of bonding between the control group and the groups treated with either 1% or 1.5% Strontium Titanate was observed, according to Tukey's post hoc analysis. The findings indicate that both concentrations improved shear bond strength compared to the control, with the 1% concentration demonstrating the highest mean value, outperforming even the 1.5% group (Figure 4).

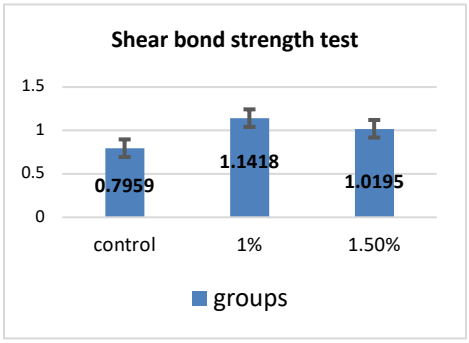

Figure 4. Differences in shear bond strength.

Conclusion

Within the parameters of this study, it was shown that addition silicone impression material can be safely disinfected by immersion in TTO for ten minutes without affecting the details of the reproduction and dimensional accuracy of the impressions.

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Table 1. The mixing ratios of SrTio3 nanoparticles, Soft Liner(PMMA)(MMA), Nystatin.

Test	Selected concentration %	Amount of SRTI O_3 powder (g)	Amount of polymer powder (g)	Amount of monomer liquid (ml)
Shear	Control	0	10	8.1
	1	0.1	9.9	8.1
	1.5	0.15	9.85	8.1
Hardness	Control	0	10	8.1
	1	0.1	9.9	8.1
	1.5	0.15	9.85	8.1
Candida albicans	Control	0	10	8.1
	Control + 1.wt.% nystatin	1.4	8.6	8.1
	1%	0.1	9.9	8.1
	1.5%	0.15	9.85	8.1