

# Antifungal Activities and Some Surface Characteristics of Denture Soft Liners Containing Silicon Dioxide Nanoparticles

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**ABSTRACT** **Objective:** This study aimed at determining the influence of adding silicon dioxide nanoparticles (nano-SiO<sub>2</sub>) to soft relining materials on *C. albicans* adhesion, surface roughness, and contact angle. **Materials and Methods:** Eighty heat-polymerized acrylic resin disks were constructed and relined by using auto-polymerized acrylic soft liners (COE-SOFT, GC Co., Tokyo, Japan). The specimens were categorized into two groups according to the tests conducted. Group A was composed of 40 specimens for evaluating antifungal activity, and Group B was composed of 40 specimens for testing surface roughness and contact angle. Each group was subcategorized into four subgroups ( $n = 10$ ) according to the concentration of nano-SiO<sub>2</sub> added to the soft-liner powder: control, 0.25%, 0.5%, and 1.0% by weight. The colony forming unit (CFU) was used to assess *C. albicans* count. A profilometer was used to measure the surface roughness values (Ra;  $\mu\text{m}$ ). The sessile drop method was used to evaluate the contact angle ( $^\circ$ ) by using a goniometer. Analysis of variance and Tukey's post hoc tests ( $\alpha = 0.05$ ) were used for the data analysis. **Results:** In comparison with the unmodified group, the 0.25% and the 0.5% nano-SiO<sub>2</sub> groups exhibited significantly lower *C. albicans* counts ( $P < 0.001$ ), surface roughness ( $P < 0.001$ ), and contact angles ( $P < 0.001$ ). The exception was the 1% group, which exhibited higher *C. albicans* count, surface roughness, and contact angles than lower-concentration nano-SiO<sub>2</sub> groups; however, these values in the 1% group were still less than their respective values in the control group. **Conclusion:** The addition of 0.25% and 0.5% nano-SiO<sub>2</sub> to an auto-polymerized acrylic soft liner decreased *C. albicans* adhesion, surface roughness, and contact angle.

**KEYWORDS:** Candidiasis, denture liner, SiO<sub>2</sub>-nanoparticles, surface properties, wettability

## INTRODUCTION

Removable dental prostheses are the most appropriate treatment for completely and partially edentulous patients.<sup>[1]</sup> However, with aging, alveolar bone resorption becomes an endless process that negatively affects the denture's retention,<sup>[2]</sup> can also impact a denture's performance (e.g., chewing ability, speech, esthetics), and may induce psychological stress

in elderly denture wearers, in addition to progressive changes in the denture foundation.<sup>[3]</sup> Therefore, it is necessary to correct the alignment between the ill-fitted

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denture base and the residual ridge via denture relining techniques.<sup>[3]</sup>

There are two types of relining procedures: laboratory relining and chair-side relining. The disadvantages of laboratory relining include more visits and the patient being deprived of the denture.<sup>[4,5]</sup> Chair-side relining, which uses auto-polymerized acrylic resin, is faster and superior in reproducing morphological details because it captures the soft tissue directly under the denture base.<sup>[5,6]</sup> Soft liners can be categorized into two composition types: plasticized acrylics and silicone elastomers.<sup>[7]</sup> Long-term soft liners are used for thin, sharp residual ridges with extensive ridge resorption or severe bony undercut cases. However, short-term (temporary) soft liners are used to treat traumatized oral tissue removable denture inner surfaces, or postsurgical problems.<sup>[8]</sup>

Denture-induced stomatitis (DIS) is a common inflammatory reaction of the denture-bearing mucosa.<sup>[1]</sup> DIS is a fungal infection caused by *C. albicans*,<sup>[9]</sup> a pathogen that is also implicated in many nondental medical problems, such as oropharyngeal infections and endocarditis.<sup>[10]</sup> The acrylic denture base is a harbor for microbes that must be removed on a daily basis by mechanical or chemical cleansing. However, in some situations, these microorganisms cannot be completely removed from the denture surfaces.<sup>[1]</sup> Therefore, an antifungal denture base material that resists *C. albicans* adhesion and proliferation could reduce the incidence of DIS.<sup>[9]</sup> Different approaches have been implemented to inhibit DIS, such as topical application of antifungal agents, modification of the resin denture base surface, and incorporation of antifungal agents into the denture base resin.<sup>[11,12]</sup>

Despite the advantages of soft liners, they are more difficult to clean than hard denture bases because they cannot be cleaned by using mechanical brushing.<sup>[4,7]</sup> In addition to having reduced resilience and water sorption,<sup>[4,7]</sup> they are easily degradable, prone to the accumulation of microorganisms, and can contribute to the progression of pathological processes that can limit the treatment options for existing infections.<sup>[13]</sup> Soft liners that lack antifungal properties allow the formation of biofilm, which is difficult to remove even using denture cleansers.<sup>[14]</sup> Recently, to overcome this problem, soft liners with antifungal properties have been formulated and proven to reduce *C. albicans* adhesion and prevent DIS.<sup>[10]</sup>

Nanoparticles have invaded the dental field in efforts to develop dental materials with better properties. Silver, titanium dioxide, zirconium dioxide, zinc oxide,

and silicon dioxide nanoparticles all possess proven antimicrobial properties when incorporated into dental materials.<sup>[10,15-17]</sup> A recent study explains the mechanism of the antimicrobial action of nanoparticles in terms of wrapping around the microbial cells (causing disruption of their cell membranes and leading to the inhibition of the normal budding process), producing reactive oxygen, or accumulating in the cytoplasm or on the outer cell membranes of microorganisms.<sup>[1]</sup> Moreover, the antimicrobial activity could be attributed to the disintegration of the cell membranes of *C. albicans* via the formation of pores that cause ion outflow followed by ultrastructural changes and programmed cell death.<sup>[18]</sup>

When nanoparticles are incorporated into dental polymers, they improve the polymer characteristics because of their nano-size, great contact surface, proper bonding, and intermingling with the resin matrix of the polymer.<sup>[19]</sup> Nano-SiO<sub>2</sub> was incorporated into polymethyl methacrylate (PMMA) in different concentrations ranging from 0.05wt% to 5wt%.<sup>[19-21]</sup> Less than 1wt% showed a uniform distribution of nano-SiO<sub>2</sub> within the resin matrix and improved its flexural strength,<sup>[19]</sup> surface properties,<sup>[20]</sup> and antifungal activity<sup>[21]</sup> whereas agglomeration occurred with more than 1%.<sup>[19-21]</sup> Moreover, nano-SiO<sub>2</sub>, when used as a coat for the denture surface, reduced the adhesion of *C. albicans*.<sup>[22]</sup>

The incorporation of nano-SiO<sub>2</sub> as an antifungal agent into soft liners could be promising in reducing the possibility of DIS. Therefore, this investigation evaluates whether adding nano-SiO<sub>2</sub> to a temporary auto-polymerized soft liner would impede the adhesion of *C. albicans* and to evaluate the roughness and contact angle of the nano-SiO<sub>2</sub>-modified soft liner. The null hypothesis was that modification of the soft liner by nano-SiO<sub>2</sub> might not influence the antifungal or surface characteristics.

## MATERIALS AND METHODS

### SPECIMENS' PREPARATIONS

Eighty heat-polymerized acrylic disks (10mm × 2mm) relined with a temporary resilient auto-polymerized soft liner (COE-SOFT, GC Co., Ltd, Tokyo, Japan) were prepared. As per the COE-SOFT soft-liner manufacturer's instructions, each 2.2g of ethyl methacrylate powder was mixed with 1.8g of butyl phthaloylglycerol butyl ester and absolute ethanol liquid. Nano-SiO<sub>2</sub> was silanized as explained in other investigations.<sup>[19-21]</sup> Nano-SiO<sub>2</sub> was measured digitally (Motorized Analytical Balance Scale, Denver Instrument, Bohemia, NY, USA), and it was added at

0.25%, 0.5%, and 1% concentrations to the soft-liner powder, whereas pure specimens constituted the control group. The concentration selection was based on a pilot study using 0.25% to 5%, in which concentrations higher than 1% caused a huge increase in *C. albicans* count. An electric home mixer with a blunt blade was used for powder mixing to ensure the homogenous distribution of nanoparticles within the soft-liner powder.

Two customized split stainless-steel molds were used for specimens' fabrication. The first mold (10mm × 2mm) was used for heat-polymerized acrylic specimens, whereas the second one (10mm × 3.3mm) was used for soft-liner application. According to the technique used for denture base fabrication, the first mold was used to construct the wax specimens (Vertex Dental B. V., Soesterberg, Netherlands), which were invested by using dental stone (Fujirock EP; GC Corporation, Tokyo, Japan) in a dental flask (61B Two Flask Compress; Handler Manufacturing). All the wax was melted to obtain mold spaces. Heat-polymerized acrylic resin (Major base 20; Prodotti Dentari SPA, Italy) was mixed as per the manufacturer's instructions after the application of a separating medium (Isolmajor, Major Prodotti Dentari SPA, Moncalieri, Italy). The acrylic dough was packed and polymerized by using a short polymerization cycle using a thermal curing unit (KaVo Elektrotechnisches Werk, Leutkirch, Germany). Finishing of completely polymerized specimens was done by using a tungsten carbide bur (HM 79GX-040 HP; Meisinger, Centennial, Colorado) followed by a polishing machine (Metaserve 250 grinder-polisher; Buehler, Lake Bluff, Illinois) to polish one side of the specimen's surface, as described in previous studies,<sup>[20,21]</sup> whereas the other side remained unpolished.<sup>[23]</sup> The dimensions of all specimens were measured via a digital caliber, with 0.01-mm accuracy (Neiko 01407A Electronic Digital Caliper; Neiko Tools US, LaPorte, Indiana), and they were also checked for smooth surfaces free of any porosity by the naked eye of two evaluators. Distilled water was used to keep the approved specimens at 37°C for 48 h.

#### RELINING PROCEDURES

All relining procedures were performed by the same operator for standardization. The specimens' surfaces were polished by using #240 silicon carbide abrasive paper (Silicon grinding paper, Buehler-MIT II, Buehler, Lake Bluff, IL, USA) fixed to a mechanical polisher (Metaserve 250 grinder-polisher, Buehler) in a wet condition.<sup>[20,21]</sup> A detergent was used to clean the abraded surface, and then it was washed under running water and dried.<sup>[24]</sup> Before relining, the prepared specimens were randomly selected and placed in the second mold

with the abraded surface facing up. The primer was painted by using a brush in two layers in one direction, and then the soft liner was mixed and applied in the mold containing the heat-polymerized denture base specimens. A glass slab was placed over the mold and pressed until glass-to-metal contact was obtained, and it was kept under pressure till complete polymerization.<sup>[6]</sup> After the polymerization process was completed, the flashes and edges of the specimens were removed, and the dimensional accuracy was verified as described earlier. Distilled water was used to store the specimens at 37°C for 48 h, and then they were subjected to testing.

#### FUNGAL ADHERENCE ASSAY

*C. albicans* (ATCC 10231) were spread on Sabouraud dextrose plates and cultured at 37°C for 48 h. A single isolated fresh colony was inoculated overnight in 4mL Sabouraud dextrose broth (SDB Acumedia Co., Manufacturers, Lansing, Michigan) at 37°C with shaking for additional 24h followed by centrifugation to collect cells. Phosphate-buffered saline (PBS) was used to wash collected cells twice and then resuspended for concentration standardization by a spectrophotometer to  $1.7 \times 10^7$  colony-forming unit (CFU/mL).<sup>[21,22]</sup>

The acrylic disks were ultrasonically cleaned and then subjected to ultraviolet (UV) light for 30 min.<sup>[10]</sup> For biofilm formation on an acrylic disk, each disk was submerged in the broth (200 µL) and incubated at 37°C for 48 h. PBS was used to wash the acrylic disks twice to eliminate nonadherent cells, followed by placement of the specimens with adherent cells in sterile tubes containing 1 mL of PBS with sonication for 15 min. To remove adherent cells for counting, a vortex was used for 10 min to vibrate the tubes, and then centrifugation was conducted for 5 min at 4,500 rpm. Then, 10 mL of the centrifuged solution was diluted serially and spread on a petri dish containing Sabouraud dextrose Agar and incubated for 24 h at 37°C.<sup>[25]</sup> *C. albicans* colonies in each quadrant were counted by using a marker pen counter (colony counter "Scienceware- bel-art products," Wayne, New Jersey), and the total colonies number was multiplied by the dilution factor displayed Candida count (CFU/mL).<sup>[10,25]</sup>

#### SURFACE ROUGHNESS (Ra, µm)

A noncontact profilometer (Contour GT; Bruker Nano gmbH, Schwarzschildstrasse, Berlin, Germany) was used to measure Ra. With a standard camera (20×), three areas were scanned and then the average Ra (µm) was calculated for each specimen.<sup>[20,21]</sup>

#### CONTACT ANGLE

The sessile drop method was used to measure the contact angle by a goniometer (DM-501; Kyowa Interface

Science Co., Japan). After specimens' surface dryness, a (2- $\mu$ L) droplet of distilled water was dispensed on the dried surface by using an autopipette. The angle of the tangent to the water droplet surface was measured thrice per specimen, and then the average contact angle was calculated for each specimen.<sup>[21,22]</sup> The interpretation of images was done by using software (Kyowa Interface Science Co., Japan).

#### STATISTICAL ANALYSIS

The Statistical Package for the Social Sciences (SPSS) software program, version 23.0 was used for data entry and analysis. The normality of the data was checked first by using the Shapiro–Wilk test, and insignificant results revealed that the data were normally distributed; thus, parametric tests were used for the analysis. For the descriptive statistics, mean and standard deviations were computed. For the inferential statistics, one-way analysis of variance (ANOVA) was used to test the significance of the relationships between the tested properties and nano-SiO<sub>2</sub> concentration levels, followed by Tukey's post hoc test. *P*-values less than 0.05 were considered statistically significant.

#### RESULTS

The one-way ANOVA results are summarized in Table 1, which showed the significant variation in means due to nano-SiO<sub>2</sub> concentration levels. Tukey's post hoc test is used to test the pairwise comparison of the means [Table 2].

The *Candida* count was lower in nano-SiO<sub>2</sub> groups than in the control group ( $P < 0.001$ ). In addition, there were significant differences between the nano-SiO<sub>2</sub> groups. The *Candida* count was found to be highest in the control group, whereas the lowest *Candida* count was observed in a 0.5% nano-SiO<sub>2</sub> concentration [Figure 1].

In comparison with the control group, Ra significantly decreased with nano-SiO<sub>2</sub> addition ( $P < 0.001$ ), except for the 1% nano-SiO<sub>2</sub> group ( $P = 0.816$ ). However, there was no significant difference in Ra between the 0.25% and the 0.5% groups ( $P = 0.084$ ). The lowest

Ra value was found in the 0.25% concentration group, whereas the control and 1% groups showed the highest Ra values [Table 2].

The contact angles of the nano-SiO<sub>2</sub> groups were significantly lower than the control group ( $P < 0.001$ ). Comparison of the contact angles among nano-SiO<sub>2</sub> groups revealed that the 0.25% concentration group differed from the 0.5% and 1% concentration groups to a statistically insignificant degree ( $P = 0.28$  and  $P = 0.184$  respectively). Moreover, there was a significant difference between 0.5% and 1% concentration levels of nano-SiO<sub>2</sub> ( $P < 0.001$ ). Among the nano-SiO<sub>2</sub> groups, the lowest contact angle was found at the 0.5% concentration level, and the highest contact angles were recorded at the 1% and 0.5% concentration levels [Table 2]. Figure 2 confirms the contact angle finding, as the addition of nano-SiO<sub>2</sub> decreased the contact angle [Figure 2A–C] in comparison to the control group [Figure 2D].

#### DISCUSSION

A combination of soft liner and antifungal agent can facilitate the treatment of DIS by minimizing the tissue trauma induced due to friction with the inner surface of the rigid removable dentures and preventing interaction between oral tissues and contaminated denture surfaces. Thus, the antifungal agents within the soft liner can interrupt the re-infection cycle.<sup>[11]</sup> According to the manufacturer's claims, the soft liner used in the present study polymerizes intra- or extraorally within 15 min and lasts for about three months of clinical use. This study investigated the antifungal activity, surface roughness, and contact angles of soft liners while incorporating different concentrations of nano-SiO<sub>2</sub>. The results reveal that the use of all these nano-SiO<sub>2</sub> concentrations with an auto-polymerized soft denture liner decreased *C. albicans* adherence, surface roughness, and contact angle, with the greatest effects obtained with a 0.5% concentration. Therefore, the null hypothesis was rejected, because all tested properties were influenced by incorporating nano-SiO<sub>2</sub>.

Table 1: One-way ANOVA results of tested properties

Property	Group	Sum of square	df	Mean square	F	P
Candida count	Between group	223460750.000	3	74486916.667	270.889	0.000*
	Within group	9899000.000	36	274972.222		
	Total	233359750.000	39			
Surface roughness	Between group	.054	3	.018	110.465	0.000*
	Within group	.006	36	.000		
	Total	.059	39			
Contact angle	Between group	1588.595	3	529.532	70.034	0.000*
	Within group	272.200	36	7.561		
	Total	1860.795	39			

\*Statistically significant at 0.05 level of significance

The displayed antifungal activity of the tested nano-SiO<sub>2</sub>-modified soft liner can be attributed to the large total surface area of the nanoparticles in contact with *C. albicans* cell membranes. This interaction is consistent with the nanoparticle–*Candida* contact theory, which states that nano-SiO<sub>2</sub> may penetrate or disrupt *C. albicans* cell membranes, leading to a change in the membrane permeability and abnormal diffusion of ions.<sup>[26]</sup> This could cause cell structural changes, deterioration of cell metabolism, inhibition of normal budding, and ultimately cell death.<sup>[1,18]</sup>

Although adding 1% nano-SiO<sub>2</sub> to the soft liner reduced *C. albicans* adherence, this antifungal activity was inferior to that exhibited in the lower nano-SiO<sub>2</sub> concentration groups. These results were in agreement to other studies that demonstrated that a homogenous spread of nanoparticles in the resin matrix is required to obtain an improved polymer with efficient, continuous antimicrobial activity.<sup>[27]</sup> Karci *et al.*<sup>[28]</sup> reported that the low density of nano-SiO<sub>2</sub> increased particle amount per unit area when compared with the same concentration of metal oxides, which means that higher concentrations of nano-SiO<sub>2</sub> will lead to their agglomeration in the matrix. Thus, our results can be explained as follows: When nano-SiO<sub>2</sub> concentration was low enough to allow a homogenous, individual distribution in the polymer matrix without clustering, the nanoparticles displayed higher antifungal activity than when the concentration increased until they agglomerated into clusters and thus exhibited reduced total active surface area.<sup>[10]</sup> These results align with those of de Castro

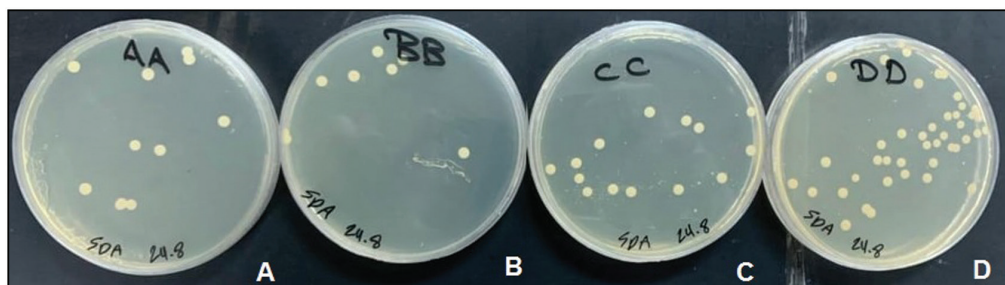
*et al.*,<sup>[29]</sup> who found that increasing the concentration of silver vanadate nanoparticles from 2.5% to 5% and 10% resulted in reduced antifungal activity. As previously mentioned, this can be explained by the clustering of the nanoparticles, leading to a reduction in the total surface area exposed to *C. albicans*.

Physical properties expressed by the contact angle, such as surface roughness and wettability, can affect *C. albicans* accumulation and adhesion to the soft-liner surface. The greater the surface roughness, the higher the probability of biofilm formation due to the increased surface area, the greater the quantity of retained microorganisms, and the increased surface irregularities present to protect microorganisms against the shear forces applied during cleaning procedures.<sup>[30]</sup> The results reveal a correlation between surface roughness and nano-SiO<sub>2</sub> concentration, in which the addition of low concentrations up to 0.5% resulted in reduced surface roughness and thus smoother soft-liner surfaces. These results are consistent with the reduction of *C. albicans* count that occurred when nano-SiO<sub>2</sub> was added to the soft liner at concentrations of 0.25% and 0.5%. This could be explained by the ability of low concentrations of nano-SiO<sub>2</sub> to be distributed homogeneously within the resin matrix as well as their proper wetting via silane coupling agent, which resulted in its good chemical bonding to the ethylene methyl methacrylate (EMMA) resin of the soft liner and, in turn, prevented the plucking of fillers from the surface and enhanced the surface's resistance to roughening.

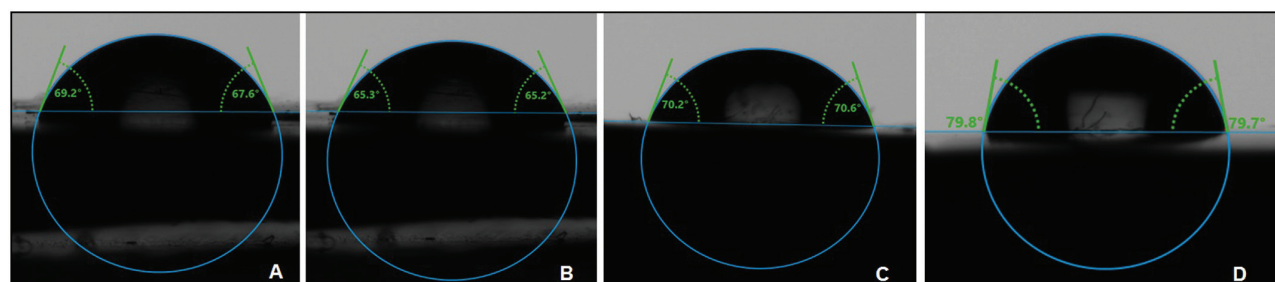
**Table 2: Mean (standard deviation) and significance between groups for tested properties**

Concentration	Mean(SD)		
	Candida count (CFU/mL)	Surface roughness (µm)	Contact angle (°)
Control	8290 (747.5)	0.19 (0.013) <sup>a</sup>	82.0 (4.1)
0.25%	3590 (515.2)	0.11 (0.015) <sup>b</sup>	67.9 (2.5) <sup>a,b</sup>
0.5%	1830 (368.3)	0.12 (0.01) <sup>b</sup>	65.6 (2.2) <sup>a</sup>
1%	4800 (374.2)	0.19 (0.013) <sup>a</sup>	70.4 (1.7) <sup>b</sup>

The same alphabets in each column showed statistical insignificance ( $P < 0.05$ )



**Figure 1:** Direct culture count of tested groups according to nano-SiO<sub>2</sub>%, (A) 0.25% nano-SiO<sub>2</sub>, (B) 0.50% nano-SiO<sub>2</sub>, (C) 1% nano-SiO<sub>2</sub>, and (D) unmodified group (0% nano-SiO<sub>2</sub>)



**Figure 2:** Contact angle of tested groups according to nano-SiO<sub>2</sub>%: (A) 0.25% nano-SiO<sub>2</sub>, (B) 0.50% nano-SiO<sub>2</sub>, (C) 1% nano-SiO<sub>2</sub>, and (D) unmodified group (0% nano-SiO<sub>2</sub>)

The 1% concentration of nano-SiO<sub>2</sub> increased the surface roughness when it was added to the soft liner, which can be explained by the agglomeration and clustering of these nano-filler particles. These results align with those of Alzayyat *et al.*,<sup>[21]</sup> who proved that adding nano-SiO<sub>2</sub> to PMMA at higher concentrations increased its surface roughness. The results of another study also show that surface roughness increased after the addition of nano-SiO<sub>2</sub>; however, lower filler concentration resulted in higher surface roughness.<sup>[31]</sup> It was reported that a surface roughness of 0.2 μm can increase the microbial adherence considerably; therefore, Ra values lower than 0.2 μm can be considered clinically acceptable.<sup>[32]</sup> For this study, 1.0% nano-SiO<sub>2</sub> added to the soft liner resulted in the highest reported Ra value, but it was still satisfactory relative to the maximum clinically acceptable value, as previously mentioned.

The contact angle reflects the surface wettability of dental materials. Ethyl methacrylate (EMA) polymer, which is the major component of soft denture liners, is similar to PMMA in its hydrophobic nature. The hydrophobic interaction between PMMA and the hydrophobic *C. albicans* has been proven to be an important factor in *C. albicans* adherence.<sup>[33]</sup> *C. albicans* adheres less to hydrophilic surfaces than to hydrophobic ones.<sup>[33,34]</sup> The acrylic denture base surface properties of hydrophilicity and roughness have been shown to affect *C. albicans* adherence, which precedes the development of DIS.<sup>[35]</sup> In addition, microorganisms are more difficult to remove from hard-to-clean hydrophobic surfaces than from easily washable hydrophilic surfaces. It has been proven that increasing the hydrophilicity of the acrylic resin surface decreases *C. albicans* adherence and, thus, reduces the probability of DIS.<sup>[22]</sup> AlBin-Ameer *et al.*<sup>[22]</sup> proved that coating nano-SiO<sub>2</sub> on the surface of PMMA dentures reduces the contact angle, enhances wettability, and lowers the adhesion of *C. albicans*. In addition, Hirasawa *et al.*<sup>[36]</sup> found that the incorporation of nano-SiO<sub>2</sub> into PMMA lowered *C. albicans* adherence due to increased surface

hydrophilicity, expressed by a reduced contact angle in comparison to that of the conventional polymer.

In this investigation, adding nano-SiO<sub>2</sub> at 0.25% and 0.5%, reduced the contact angle, indicating increased surface wettability of the soft liner. This can be attributed to a reduction in surface tension by the hydrophilic nano-SiO<sub>2</sub> particles. These results align with those of Alzayyat *et al.*,<sup>[21]</sup> who found that nano-SiO<sub>2</sub> enhanced PMMA wettability. In addition, our results align with those of Martínez-Pérez *et al.*,<sup>[37]</sup> who proved that nano-SiO<sub>2</sub> increased surface wettability by decreasing the contact angle as compared with the control; however, the lowest contact angles were correlated with the highest added nano-SiO<sub>2</sub> concentrations, which was not the case for our study. For our study, the highest added concentration of nano-SiO<sub>2</sub> (1%) increased the contact angle, however it was below the contact angle of the control group. This increase in the contact angle reflects a reduction in surface hydrophilicity, which could be caused by a reduction in the total surface area of the nano-SiO<sub>2</sub> particles due to their agglomeration into clusters.

Correlating surface roughness and contact angle to the decreased *C. albicans* adherence proves the antifungal efficacy of soft liners containing nano-SiO<sub>2</sub> at low concentrations and demonstrates that such liners could be used to prevent DIS and is employed after surgical procedures to decrease the possibility of infection.

The limitations of this investigation include using a single type of soft liner, and absence of the simulation of the oral environment such as occlusal loading, thermal changes, and variations of pH that could affect the properties of soft liner with antifungal activities. Therefore, further investigations of various properties (viscoelastic and bond strength) of different brands of soft liner with low nano-SiO<sub>2</sub> concentrations in simulating real oral conditions are recommended.

## CONCLUSION

Incorporating 0.25 and 0.5wt% nano-SiO<sub>2</sub> into temporary auto-polymerized soft liners led to a

significant decrease in *C. albicans* adhesion, surface roughness, and contact angle. In contrast, higher nano-SiO<sub>2</sub> concentrations reduced antifungal efficiency and increased the surface roughness and contact angle.

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Not applicable.

#### FINANCIAL SUPPORT AND SPONSORSHIP

Not applicable.

#### CONFLICTS OF INTEREST

None.

#### AUTHORS' CONTRIBUTIONS

Not applicable.

#### ETHICAL POLICY AND INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable.

#### PATIENT DECLARATION OF CONSENT

Not applicable.

#### DATA AVAILABILITY STATEMENT

In addition to the data mentioned in the article, additional data can be made available on request.

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