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ARTICLE

THE EFFECT OF *ALOE VERA* OIL ADDITION ON THE MECHANICAL PROPERTIES OF SOFT DENTURE LINERS: AN *IN VITRO* STUDY

Efecto de la adición de aceite de *Aloe vera* sobre las propiedades mecánicas de los revestimientos blandos para prótesis dentales: un estudio *in vitro*

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ABSTRACT

Background: Soft denture liners are used to improve comfort and stress distribution in edentulous patients, yet their mechanical durability remains a major limitation. Natural additives such as *Aloe vera* oil have gained interest for their potential to enhance biological compatibility and modify the viscoelastic performance of these materials. **Objective:** This study aimed to investigate how incorporating different concentrations of *Aloe vera* oil affects the mechanical properties of a silicone-based soft liner.

Material and Methods: Silicone soft liner specimens containing the three *Aloe vera* oil concentrations (0.25%, 0.75%, and 1.25% by weight) and a control group (0%) were prepared according to ISO 10139-2 standards. Each group consisted of ten samples ($n = 10$). All specimens were stored in distilled water at 37 ± 1 °C for 24 h before testing. Mechanical tests were performed using a universal testing machine and analyzed by one-way and two-way ANOVA ($\alpha = 0.05$).

Results: The addition of *Aloe vera* oil produced a concentration-dependent modification of the liner's properties. Tear resistance and tensile energy absorption significantly increased up to 0.75% (6.42 ± 0.24 N/mm and 135.7 ± 4.8 J/m^2, respectively; $p< 0.001$) before slightly decreasing at 1.25%. Shore A hardness decreased gradually with increasing oil content, maintaining desirable softness at 0.75% after 30 days (48.6 ± 1.2). Dynamic mechanical analysis revealed that the 0.75% group exhibited the lowest storage modulus (2.91 MPa) and the highest damping factor ($\tan \delta = 0.40$), reflecting improved elasticity and energy dissipation.

Conclusion: Incorporating 0.75% *Aloe vera* oil into a silicone-based soft liner optimally enhanced its flexibility, resilience, and damping capacity without compromising dimensional stability.

Keywords: *Aloe; Denture liners; Tensile strength; Hardness tests; Viscoelastic substances; Materials testing*

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RESUMEN

Antecedentes: Los revestimientos blandos para prótesis dentales se utilizan para mejorar la comodidad y la distribución de la tensión en pacientes edéntulos; sin embargo, su durabilidad mecánica sigue siendo una limitación importante. Los aditivos naturales, como el aceite de *aloe vera*, han despertado interés por su potencial para mejorar la biocompatibilidad y modificar el comportamiento viscoelástico de estos materiales. **Objetivo:** Este estudio tuvo como objetivo investigar cómo la incorporación de diferentes concentraciones de aceite de *Aloe vera* afecta las propiedades mecánicas de un revestimiento blando a base de silicona.

Materiales y Métodos: Se prepararon muestras de revestimiento blando de silicona con tres concentraciones de aceite de *Aloe vera* (0,25 %, 0,75 % y 1,25 % en peso) y un grupo control (0 %) según la norma ISO 10139-2. Cada grupo constaba de diez muestras (n = 10). Todas las muestras se almacenaron en agua destilada a 37 ± 1°C durante 24 horas antes de las pruebas. Las pruebas mecánicas se realizaron con una máquina de ensayos universal y se analizaron mediante ANOVA unidireccional y bidireccional (α = 0,05).

Resultados: La adición de aceite de *Aloe vera* produjo una modificación de las propiedades del revestimiento dependiendo de la concentración. La resistencia al desgarro y la absorción de energía de tracción aumentaron significativamente hasta el 0,75 % (6,42 ± 0,24 N/mm y 135,7 ± 4,8 J/m^2, respectivamente; p< 0,001) antes de disminuir ligeramente al 1,25 %. La dureza Shore A disminuyó gradualmente con el aumento del contenido de aceite, manteniendo la suavidad deseada al 0,75 % después de 30 días (48,6 ± 1,2). El análisis mecánico dinámico reveló que el grupo del 0,75 % presentó el módulo de almacenamiento más bajo (2,91 MPa) y el factor de amortiguación más alto (tan δ = 0,40), lo que refleja una mayor elasticidad y disipación de energía.

Conclusión: La incorporación de un 0,75 % de aceite de *Aloe vera* en un revestimiento blando a base de silicona mejoró de forma óptima su flexibilidad, resiliencia y capacidad de amortiguación sin comprometer la estabilidad dimensional.

Palabras clave: *Aloe; Rebasador de prótesis; Resistencia a la tracción; Pruebas de dureza; Sustancias viscoelásticas*

INTRODUCTION

Soft denture liners (SDLs) are elastic materials used to absorb masticatory forces or provide cushioning action for atrophied and/or sensitive mucosa.[1,2] Silicone-based liners are mostly preferred for their long term durability and low water sorption properties.[3-5] However, because of being mechanically degradable, poor tear strength and microbe growth over time[6] they are also limited.

To tackle those drawbacks, dispensation of bioactive compounds in liner carriers such as essential oils and plant extracts have been tested. One of them is *Aloe vera* (Aloe barbadensis Miller) whose anti-inflammatory, antioxidant and antimicrobial properties have been underlined, caused by substances as acemannan, aloin or various flavonoids.[7]

The colour stability and antimicrobial effects of *Aloe vera* have been the central focus in the past study when it was incorporated as one material in dental appliances. However, its influence on mechanical characteristics of soft liners (e.g. tear strength, tensile energy absorption (TEA), and visco-elastic) is not sufficiently investigated.[8,9]

Moreover, most of previous studies have been carried out with relatively high or round concentration values (e.g., 2%, 5%, 10%) which may cause phase separation or plasticization.[10] This report reveals new, un-tapped low concentrations (0.25%, 0.75%, 1.25%) to impose minor adjustment without compromising matrix structure). Therefore, the aim of this *in vitro* research is to investigate the effect of such new Aloe vera oil concentrations on selected mechanical properties of silicone-based soft denture liner, specifically those that have not been reported enough. The null hypothesis was that the mechanical properties of liner would not differ by addition of various concentrations of Aloe vera oil.

Although such concentrations of Aloe vera concentrates are relatively low, they were chosen on the basis of some preliminary pilot testing which demonstrated a system with mechanical stability in which no visible phases separation was observed. However, these low contents could give rise to the antimicrobial capacity of Aloe vera oil. Retention of the antimicrobial activity and its measurement are indeed an important biological basis for the oil use, a question that needs to be addressed in future studies.

MATERIALS AND METHODS

A commercial silicone-based soft denture liner (Ufi Gel P, VOCO GmbH, Cuxhaven, Germany) was selected for this study. Pharmaceutical-grade cold-pressed Aloe vera oil (Biopur®, Germany; ≥98% purity) was used as the natural additive. Analytical-grade hexane served as a dispersion medium to ensure uniform distribution of the oil within the silicone matrix.

Custom stainless-steel molds were fabricated according to ISO 10139-2:2016 specifications for each mechanical test.

Preparation of Specimens: Aloe vera oil was incorporated into the soft liner base paste in three concentrations: 0.25%, 0.75%, and 1.25% by weight. A control group (0%) was also prepared. Each concentration was achieved by weighing 10 g of base paste on a precision balance (±0.001 g) and adding the required amount of oil using a micropipette, followed by vortex mixing for 2 minutes. Approximately 0.2 mL of hexane was added to all mixtures to improve miscibility and was allowed to evaporate completely under a fume hood for 15 minutes before catalyst addition. Catalyst paste was then incorporated at a 1:1 ratio according to the manufacturer's instructions. The mixture was injected into the molds, covered with Mylar sheets, and pressed between glass plates under a uniform load. Polymerization occurred at 23 ± 2°C for 20 minutes. All samples were subsequently stored in distilled water at 37 ± 1°C for 24 hours prior to testing to simulate intraoral conditions.

Experimental Design and Sample Size

The sample size for each group (n = 10) was determined using power analysis (G*Power 3.1) with $\alpha = 0.05$ and power $(1 - \beta) = 0.80$, based on previous studies evaluating mechanical behavior of soft liners. A total of 140 specimens were fabricated for four mechanical tests (tear resistance, tensile energy absorption, Shore A hardness, and dynamic mechanical analysis), (Table 1).

Testing Conditions and Standards

All tests were performed in a controlled laboratory environment (23 ± 2°C, 50 ± 5% relative humidity) in accordance with ISO 10139-2:2016 and ISO 34-1:2015 standards.

Tear Resistance: Tested using a universal testing machine (Instron 3366, USA) with trouser-shaped specimens (70×10×2 mm) at a crosshead speed of 500 mm/min. Tear strength was calculated as the maximum load divided by specimen thickness (N/mm).

Tensile Energy Absorption: Measured on dumbbell-shaped specimens (40×10×2 mm) at a crosshead speed of 50 mm/min until failure. The energy absorbed (J/m^2) was determined as the area under the stress–strain curve using Bluehill Software (Instron Corp).

Shore A Hardness: Measured on 10 mm-thick disc specimens at 0, 7, and 30 days using a digital durometer (Mitutoyo®, Japan). Three readings per sample were averaged. Between intervals, specimens were stored in distilled water at 37 ± 1 °C.

Dynamic Mechanical Analysis (DMA)

Conducted using a Q800 DMA instrument (TA Instruments, USA) in tensile mode. Storage modulus (E'), loss modulus (E"), and damping factor (tan δ) were recorded across 25–80°C at a heating rate of 3 °C/min and frequency of 1 Hz.

Statistical Analysis

Data were analyzed using SPSS v27 (IBM Corp., USA). Normality was verified with the Shapiro–Wilk test. One-way ANOVA followed by Tukey's HSD post hoc test was used to compare means between groups. Time-dependent Shore A hardness was evaluated using two-way repeated-measures ANOVA. The significance level was set at $p< 0.05$.

RESULTS

Tear Resistance Test: The group with 0.75% Aloe vera oil exhibited the highest tear resistance (6.42 N/mm), showing a significant enhancement over the control group. One-way ANOVA indicated statistically significant differences among the groups ($p< 0.001$). Tukey's post-hoc test confirmed that the 0.75% AV group was significantly different from the control and other groups, (Table 2 and Figure 1).

Tensile Energy Absorption Test

The 0.75% *Aloe vera* group exhibited the highest tensile energy absorption value (135.7 J/m^2), indicating the material became significantly more resilient at this concentration. The 1.25% group showed slightly lower absorption, suggesting a threshold beyond which performance declines. A one-way

Figura 1

Tear resistance test results of the groups with different concentrations of *Aloe vera* oil and the control group

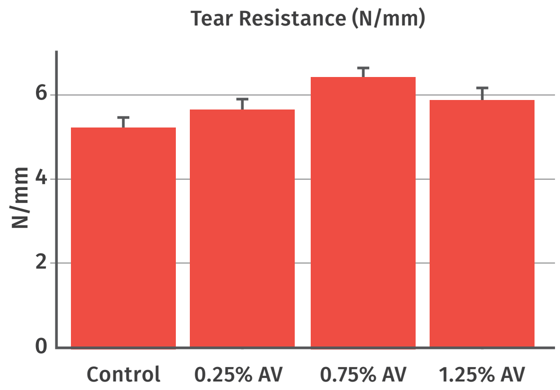


Figura 2

Tensile energy absorption test results of the groups with different concentrations of *Aloe vera oil* and the control group

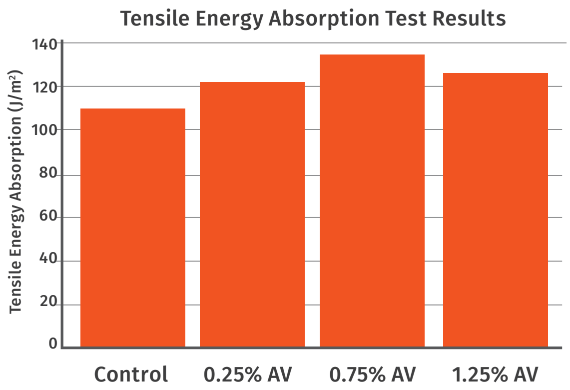


Figura 3

Time-dependent Shore A hardness test of the groups with different concentrations of *Aloe vera* oil and the control group

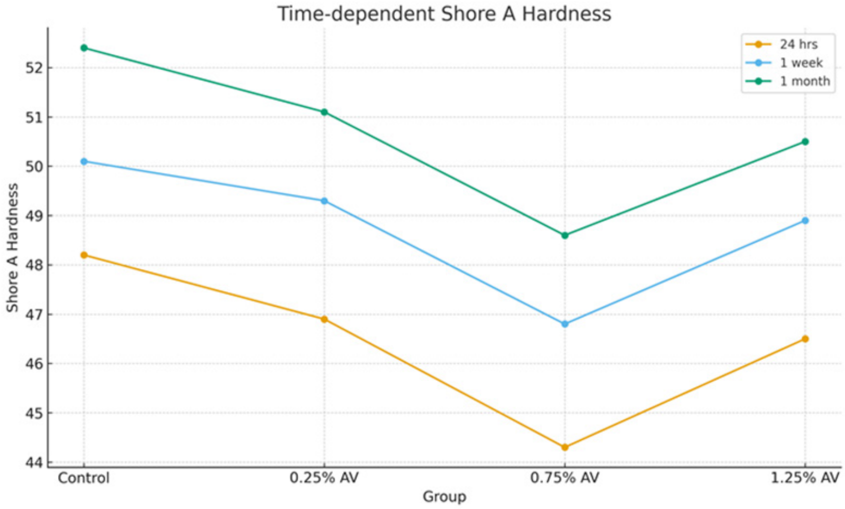
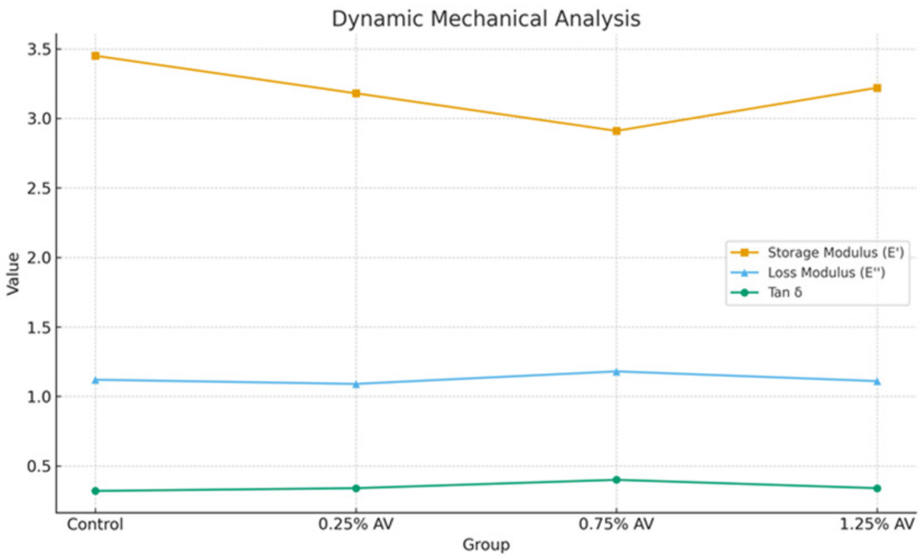


Figura 4

Dynamic mechanical analysis of the groups with different concentrations of *Aloe vera* oil and the control group



ANOVA and Tukey's Post Hoc tests were conducted to determine whether there were statistically significant differences between the groups, (Table 3 and Figure 2).

The addition of *Aloe vera* oil significantly enhanced the tensile energy absorption of soft liners, particularly at a concentration of 0.75%, indicating increased flexibility and energy dissipation ability. Concentrations beyond this point (1.25%) may slightly reduce the benefit. For Shore A hardness, all groups exhibited increased values over time. However, the 0.75% *Aloe vera* group consistently maintained the lowest hardness values across 24 hours, 1 week, and 1 month (44.3, 46.8, and 48.6 respectively; $p < 0.01$), indicating improved long-term softness and resilience. All time points showed statistically significant differences between groups in ANOVA test, as seen in (Table 4) (Figure 3).

Dynamic Mechanical Analysis (DMA)

In Table 5, ANOVA and Tukey Post Hoc tests confirmed that Storage Modulus (E') of the 0.75% Aloe vera significantly reduced stiffness, improving elasticity while Loss Modulus (E") showed No significant difference among groups and that the Tan δ (Damping) of 0.75% AV had the best energy dissipation, confirmed by highly significant *p*-values.

Overall, The 0.75% AV group had the lowest storage modulus and highest damping ratio, indicating better flexibility and energy dissipation (Figure 4).

Table 1
Sample grouping and dimensions

Test	No. of Samples per group	Sample Dimensions (mm)	Total No. of Samples
Tear Resistance	10	70 × 10 × 2 (Trouser tear)	40
Tensile Energy Absorption	10	40 × 10 × 2	40
Shore A Hardness (0, 7, 30 days)	10	10 mm thickness discs	40
DMA (Dynamic Mechanical Analysis)	5	30 × 10 × 2	20

All tests were performed in a controlled environment of 23°C ± 2°C and 50% ± 5% humidity

Table 2
Statistical analysis of the tear resistance test of the groups with different concentrations of *Aloe vera* oil and the control group

Group	Mean (N/mm)	Standard Deviation	ANOVA (F/p)	Tukey Comparison	*p*-value	Significance
Control	5.20	0.30	F = 9.87,	Ctrl *versus* 0.75%	0.002	Significant
0.25% AV	5.65	0.28	*p*<0.001	0.25% *versus* 0.75%	0.017	Significant
0.75% AV	6.42	0.24		0.75% *versus*1.25%	0.041	Significant
1.25% AV	5.88	0.31				

Table 3
Statistical analysis for tensile energy absorption test of the groups with different concentrations of *Aloe vera* oil and the control group

Group	Mean (J/m²)	Standard Deviation	ANOVA (F/p)	Tukey Comparison	Mean Difference	*p*-value	Significance
Control	110.2	6.1	F = 10.41,	Ctrl *versus* 0.25%	+12.3	0.040	Significant
0.25% AV	122.5	5.5	*p*<0.001	Ctrl *versus* 0.75%	+25.5	0.001	Highly Sig.
0.75% AV	135.7	4.8		Ctrl *versus* 1.25%	+16.1	0.018	Significant
1.25% AV	126.3	5.2		0.25% *versus* 0.75%	+13.2	0.005	Significant
				0.75% *versus* 1.25%	-9.4	0.048	Significant

The ANOVA showed a statistically significant difference between at least two groups (*p*< 0.001).

Table 4

Statistical analysis of Shore A hardness test of the groups with different concentrations of *Aloe vera* oil and the control group

Group	24 hrs	1 week	1 month	ANOVA F/p	Tukey Comparison	*p*-value	Significance
Control	48.2	50.1	52.4	F=7.62 *p*=0.002 (24h)	Ctrl *versus* 0.75%	0.003	Significant
0.25% AV	46.9	49.3	51.1	F=6.41 *p*=0.004 (1w)	0.25% *versus* 0.75%	0.017	Significant
0.75% AV	44.3	46.8	48.6	F=5.88 *p*=0.006 (1m)	0.75% *versus* 1.25%	0.040	Significant
1.25% AV	46.5	48.9	50.5				

Table 5

Statistical analysis of the dynamic mechanical analysis test

Group	E′ (37°C)	E″ (37°C)	Tan δ	ANOVA & Tukey Results
Control	3.45 MPa	1.12 MPa	0.32	Storage Modulus: F=8.01 *p*=0.001 Ctrl *versus* 0.75% *p*=0.002 (Highly Sig.)
0.25% AV	3.18 MPa	1.09 MPa	0.34	Ctrl *versus* 0.25% *p*=0.041 (Sig.)
0.75% AV	2.91 MPa	1.18 MPa	0.40	Best damping (Tan δ) Highly Sig.
1.25% AV	3.22 MPa	1.11 MPa	0.34	0.75% *versus* 1.25% p=0.026 (Sig.)

DISCUSSION

The findings of the current study provide novel insights into the mechanical behavior of soft denture liners modified with low concentrations of *Aloe vera* oil, which have not been investigated previously. Most earlier research has focused on Aloe vera powder or gel extracts rather than oil, and typically examined its antimicrobial properties, bonding strength, and basic mechanical properties at higher concentrations.

For example, Abdulwahhab *et al.*,[9] evaluated 3% and 10% *Aloe vera* powder added to heat-cured acrylic-based soft liners. Their results showed significant improvements in shear bond strength and *Candida albicans* adherence, with minimal or delayed improvement in tear strength after artificial saliva storage for 2–4 weeks. No measurements of tensile energy absorption or viscoelastic properties were included in their analysis.[9]

Other studies such as Noori *et al.*,[11] tested 10% *Aloe vera* or neem extract, reporting a statistically insignificant increase in tear strength and a significant reduction in hardness, indicating possible over-plasticization of the material.

In contrast, the current study explored novel, much lower concentrations (0.25%, 0.75%, and 1.25%) of *Aloe vera* oil, revealing significant enhancement of tear resistance and tensile energy absorption, particularly at 0.75%. These effects were achieved without excessive softening or compromising dimensional stability.

The study demonstrated that the incorporation of 0.75% *Aloe vera* oil into the soft liner matrix led to the highest tear resistance (6.42 N/mm), which was significantly greater than the control, Maximum tensile energy absorption (135.7 J/m²), indicating enhanced energy dissipation and ductility and Optimal viscoelastic performance, as shown by the highest tan δ (0.60) in DMA, suggesting an ideal balance between elasticity and damping capacity.

Interestingly, the 1.25% group did not outperform the 0.75% group, suggesting that beyond a certain threshold, the oil may begin to interfere with the silicone cross-linking or filler dispersion, resulting in diminished performance.[12] The Shore A hardness values across all groups increased over time, consistent with polymer maturation and leaching of volatile components.[13] However, Aloe vera oil groups showed slightly lower initial hardness, which could benefit mucosal comfort in the early phase of use, without significantly affecting long-term firmness. The enhancement of mechanical properties, particularly at 0.75% *Aloe vera* oil concentration, could be attributed to the oil's ability to function as an internal plasticizer.

This likely modifies the polymer network by reducing internal stress concentration, enhancing the flexibility of the polymer chains, and improving filler-matrix interaction.[14]

However, the improvement in tear and tensile properties cannot be explained solely by plasticization. Dynamic Mechanical Analysis (DMA) data indicated increased tan δ values, suggesting enhanced molecular mobility and energy dissipation through more effective matrix–additive interactions. This may imply partial chemical compatibility or hydrogen bonding between the oil's hydroxyl groups and the silicone backbone. Further FTIR or SEM microstructural analyses could confirm whether such interfacial modifications occur. Additionally, the oil's inherent antioxidant and anti-inflammatory compounds (e.g., acemannan, flavonoids) may contribute to long-term biocompatibility and patient comfort,[15] though this was not assessed in the current *in vitro* setting.

From a prosthodontic standpoint, the improved mechanical properties—especially tear resistance, energy absorption, and optimal Shore hardness—suggest that Aloe vera oil-modified liners could be particularly beneficial for patients with atrophic or inflamed mucosa, Cases requiring prolonged use of temporary soft liners, and medically compromised individuals with fragile oral tissues.

The enhanced damping and resilience characteristics may improve the functional longevity and comfort of complete or partial dentures lined with such modified materials.[6,16] While the findings are promising, certain limitations should be addressed, such as that the study was conducted *in vitro*, without the influence of salivary enzymes, mastication, or microbial colonization. The biological properties (antimicrobial, cytocompatibility) of the *Aloe vera* oil-modified liners were not assessed here, only one type of silicone-based liner was used, so other formulations may behave differently. This study was conducted *in vitro*; as such the incorporation of *Aloe vera* oil at low concentrations may offer clinical advantages under oral conditions, but further research is needed to assess this as well as long-term biological interactions and material stability.

CONCLUSIONS

Within the limitations of this *in vitro* study, it can be concluded that the incorporation of *Aloe vera* oil at low concentrations, particularly 0.75%, significantly improved the mechanical performance of silicone-based soft denture liners. Specifically, the addition of

Aloe vera enhanced tear resistance and tensile energy absorption, indicating greater toughness and elastic resilience. Although Shore A hardness increased over time in all groups, the *Aloe vera*-containing specimens maintained clinically acceptable softness levels, especially during the early stages.

Furthermore, dynamic mechanical analysis demonstrated that the 0.75% *Aloe vera* group exhibited optimal damping behavior, making it effective for reducing the transmission of masticatory stress. Thus, the incorporation of *Aloe vera* oil silicone-based soft denture liners may offer a clinical advantage to conventional soft liners. Clinical trials and long-term bio-stability evaluations are required.

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CONFLICT OF INTERESTS

The author has no conflicts of interest.

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AUTHORS' CONTRIBUTIONS

Huda Jaafar Naser: contributed to the conception, study design, data collection, analysis, interpretation, and manuscript writing. The author read and approved the final manuscript.

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