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Impact of Cerium Oxide Nanoparticles Incorporation on Water Sorption and Solubility of Acrylic-Based Denture Soft Lining Material

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Abstract

Denture soft liners are specifically engineered to enhance patient performance by altering the surfaces of prosthetics that come into touch with the soft tissues within the oral cavity. Acrylic resin polymethyl methacrylate (PMMA) and silicone elastomer-based are the two main types of denture soft liners. Nanotechnology was employed as a means to enhance the mechanical qualities of dentures. The primary objective of this investigation was to examine the impact of cerium oxide (CeO_2) nanoparticles (NPs) on the water sorption and solubility characteristics of acrylic-based soft liners. The data was subjected to analysis of variance (ANOVA). The surface characteristics were determined using scanning electron microscopy (SEM). This in vitro study demonstrates that including CeO_2 NPs at 2% and 3% concentrations does not impact acrylic-based soft lining materials' water sorption and solubility. The solubility of CeO_2 is well-recognized to be very low. The results indicated that there were no statistically significant differences between the groups.

Article Info.

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CeO_2, Nanoparticles, Soft Liner, Sorption, Solubility.

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1. Introduction

Dentures refer to removable prosthetic dental devices that replace missing teeth and gums. Dentures can be constructed to replace either a solitary absent tooth or a whole dental arch. Complete dentures are utilised in cases where an individual requires the replacement of all their teeth, whereas partial dentures are employed when some of the patient's original teeth are still intact [1, 2]. Polymethyl methacrylate (PMMA) polymer is frequently used as the denture base material. This choice is significant as it contributes to the durability and support of dentures by facilitating a close fit against the oral mucosa [3, 4]. The redistribution of forces generated by functional and parafunctional motions over the denture's bearing surfaces can be mitigated by achieving a well-balanced occlusion [5, 6]. Establishing individual recall intervals is necessary to ensure adequate maintenance, as changes in the prosthesis base are inevitable due to the progressive resorption of alveolar bone after tooth extraction [7]. Regrettably, poorly fitting dentures may arise due to chronic ridge resorption, leading to discomfort or distress for the patient, despite the critical role of retention in facilitating the functionality of the denture [8].

The term "denture relining" pertains to restoring the tissue-facing surface of a denture that lacks proper fit [9]. Resilient denture liners possess the capacity to effectively mitigate the problem of discomfort by providing a cushioning effect, hence aiding the dispersion and alleviation of functional forces. In addition, they can potentially accelerate tissue regeneration after trauma and enhance the perception of calmness and ease for individuals using dentures [10-13]. The initial implementation of soft lining materials for dentures was observed in 1943. Subsequently, soft liners have experienced a significant surge in popularity as a means of alleviating denture-related discomfort for a substantial number of individuals [14]. Resilient materials can be classified into two distinct categories: materials formed from acrylic resin and materials composed of silicone elastomer [15]. Most dentures undergo relining procedures utilising a heat-cured soft denture lining material composed of acrylic [16]. The clinical application of these materials is often associated with several problems, including loss of resilience, hardening, water absorption and solubility, susceptibility to microbial adhesion, colour change, and separation from the denture base resin [17, 18]. Hence, it is imperative to inspect and replace soft liners regularly [19]. Various agents or fillers, such as nanoparticles, have been included in these materials, and their properties have been investigated to assess their potential to mitigate the adverse effects of soft lining materials [20-22]. Soft denture liners' physical and mechanical properties experience significant enhancement with the incorporation of inorganic nanoparticles, even when used in small quantities [23, 24]. Silane coupling agents can facilitate robust interconnections between organic and inorganic materials. Nanoparticles possess significant surface areas, rendering them suitable for interface enhancement due to their notable surface reactivity, surface energy, and chemical reactivity [25].

Nanotechnology primarily centres on utilising techniques to modify matter at the atomic and molecular scales. The field of nanotechnology seeks to explore and harness the beneficial characteristics inherent in the nanoscale by examining materials at this level. All nanomaterials' constituents possess dimensions equal to or less than 100 nm [26].

Cerium, a rare earth element classified within the lanthanide series, has garnered significant attention across various academic disciplines encompassing physics, chemistry, biology, and materials science [27]. Because of their vast surface area, fast interconversion between Ce^{+3} and Ce^{+4}, outstanding stability, biocompatibility, cost-effectiveness, and outstanding surface chemistry, cerium oxide (CeO_2) nanoparticles (NPs) have attracted much interest and have been widely used in several industries [28, 29]. Against both gram-positive and gram-negative bacteria, as well as Candida albicans, the CeO_2 nanoparticles demonstrate exceptional antibacterial and antifungal capabilities [30]. Evidence from both in vitro and in vivo studies indicates that CeO_2 nanoparticles are a safe and biocompatible substance; moreover, they have proven to be highly effective agents for several biological applications [31, 32]. Despite extensive research on denture liners, there is a notable absence of studies investigating the incorporation of CeO_2 nanofiller into denture soft lining materials.

Water sorption and solubility are essential characteristics closely linked to the durability and longevity of prosthetic devices, such as dentures, over extended periods. Excessive water absorption can result in the plasticisation of polymers, causing a decrease in internal stress thresholds and alterations in dimensional stability. These effects can ultimately contribute to the occurrence of early fracture. The significance of solubility lies in its ability to provide information regarding the quantity of a dissolved chemical within a polymer [33]. The water sorption characteristics of dental materials are influenced by their degree of hydrophobicity and porous structure [34]. Liners composed of acrylic materials with elevated water sorption and solubility characteristics have various effects, including swelling, deformation, hardening, absorption of odours, and alterations in colour [35].

The objective of this in vitro study was to include CeO_2 NPs in the acrylic-based denture soft liner material at concentrations of 2% and 3%, followed by evaluating the extent of water sorption and solubility.

2. Experimental Work

2.1. Specimen Design and Sample Preparation

Disk-shaped aluminium models were produced using computer numerically controlled machining (CNC) in compliance with the specifications stated in ISO 10139-2:2016 [36]. These models had a diameter of 50 ± 1mm and a thickness of 0.5 ± 0.05mm. The goal behind creating these models was to generate moulds that could be utilised in the production of test specimens, as shown in Fig. 1.

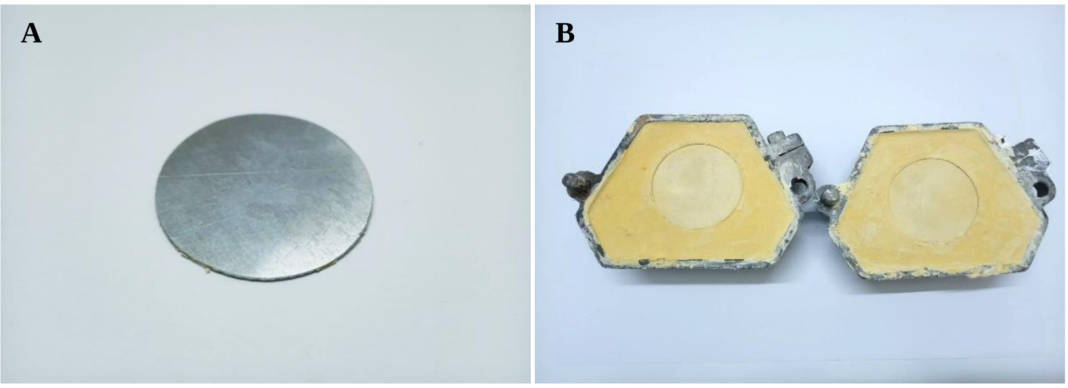

Figure 1: (A) Aluminium model, (B) Stone mould for water sorption and solubility test.

To generate the samples, we adhered to the guidelines provided by the manufacturer. This involved combining the powder of the acrylic-based soft lining material known as Moonstar (made in Turkey) with liquid monomer in a dry and sterile glass jar. The prescribed ratio for this mixture to the liquid is 1.2 g of powder per 1 mL of liquid monomer. The mass of CeO_2 NPs (procured from US Research Nanomaterials, Inc. United States) of a particle size ranging from 10 to 30 nm was determined using an electronic scale. CeO_2 NPs of different weight percentages were introduced into the soft-liner monomer. The combination underwent probe sonication with a power of 120W and a frequency of 60 kHz for 3 minutes [36]. This sonication procedure aimed to induce fragmentation of the nanoparticles into discrete particles by vibrational energy [37, 38]. To prevent the agglomeration of particles, the suspension of CeO_2 - soft liner monomer was promptly mixed with soft liner powder. To achieve the desired powder to liquid ratio, it was necessary to decrease the weight of the soft-liner powder by the quantity of nanomaterial present in the monomer [39, 40]. The soft liner was added at the dough stage, and placed in a sealed flask. A hydraulic press was utilised to gradually exert pressure on the flask to achieve consistent material flow. The soft lining material was cured in a digital water bath at 100 °C for 20 minutes, adhering to the guidelines provided by the makers. Following that, the flask was subjected to a cooling process for 30 minutes until it attained the ambient temperature; the flask was cooled again for a further 15 minutes using tap water, after which it was unsealed, and specimens were taken out, as shown in Fig. 2.

Thirty samples were generated by incorporating CeO_2 NPs (0, 2, and 3wt%) into the soft-liner monomer. Ten control specimens were made without the addition of CeO_2 NPs. Furthermore, ten specimens were created for each weight percentage of 2% and 3% of CeO_2 NPs.

2.2. Testing Procedure

After the preparation stage, all disc-shaped specimens were dried in a desiccator containing pre-dried silica gel. The desiccator was positioned in an incubator that was adjusted to 37ºC ± 1ºC for 23 ± 1 hours. After that, the specimens were relocated to a chamber maintained at room temperature for one hour. Following that, the specimens were weighted utilising a digital electronic scale possessing a precision of 0.0001g, as shown in Fig. 3. The procedure above was repeated until a state of equilibrium was reached, when the weight loss of each disc was limited to a maximum of 0.5 mg within a 24-hour period. The initial weight (W1) was used as the baseline.

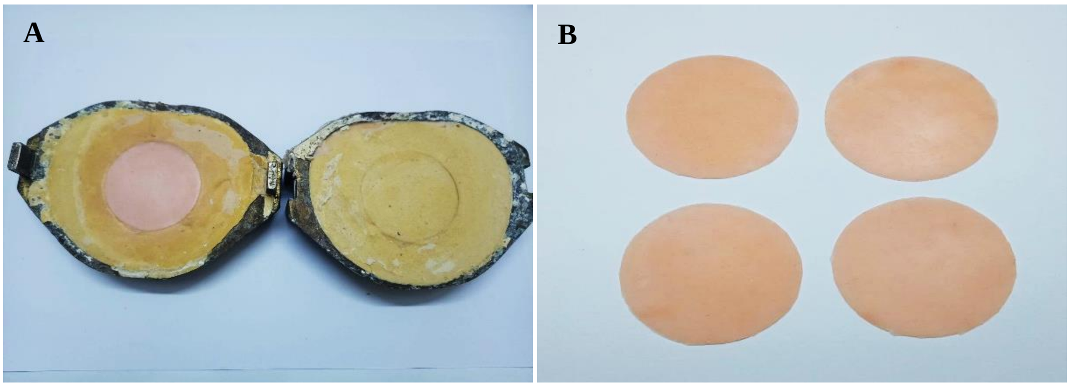

Figure 2: Water sorption and solubility specimens (A) immediately after unsealing the flask, (B) finished specimens.

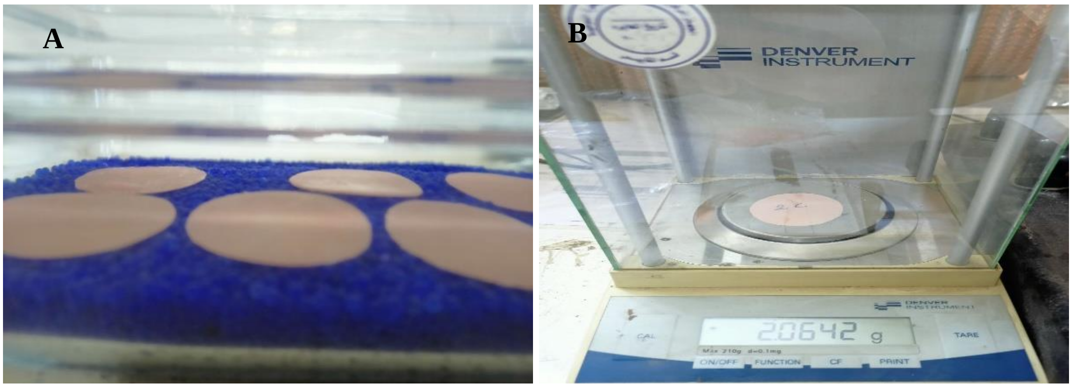

Figure 3: (A) Sorption and solubility specimens in the desiccator, which contain silica gel, (B) weighing specimen in digital electronic balance.

Following this, the specimens were immersed in distilled water for seven days, with a permissible deviation of ± 2 hours, at a temperature of 37ºC, with a permissible deviation of ± 1ºC. After the prescribed time interval, each disk was retrieved from the water using a pair of tweezers. Afterwards, every disc was carefully dried using a clean, dry hand towel until all observable moisture was removed. After a 15-second interval of air exposure, the discs were precisely weighted one minute after their removal from the water. This weight was designated as (W2). Following this, the samples underwent desiccation in a desiccator, and their masses were recorded every 24 hours until a consistent mass (designated as W3) (± 0.5mg) was attained.

Water sorption and solubility were quantified using relative sorption and solubility measurements according to ISO 10139-2:2016 [36], represented in micrograms per cubic millimetre ($\mu g/mm^3$). The computations were executed using the following formulas:

Sorption ($\mu g / mm^3$) = (W2-W1) / Volume of the specimen

Solubility ($\mu g / mm^3$) = (W1-W3) / Volume of the specimen

3. Results and Discussion

In a polymeric matrix, it is hypothesised that nano-fillers will exhibit a more uniform scattering pattern than larger micro-fillers. This interaction is expected to have an impact on the properties of the composite materials [41]. Nevertheless, the dispersion of nanoparticles may pose challenges as a result of the Van der Waals interactions that exist between them [42].

The dispersion of CeO_2 NPs within the matrix was investigated using high-resolution field emission scanning electron microscopy (SEM). The SEM images of the control and experimental samples revealed that CeO_2 NPs were evenly dispersed throughout the matrix, as shown in Fig. 4.

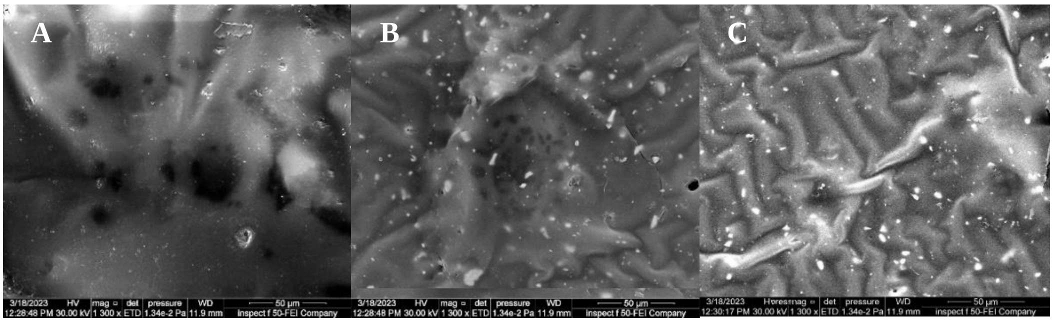

Figure 4: SEM images at 1300x (A) control samples, (B) soft liner with 2% CeO_2, (C) soft liner with 3% CeO_2.

The samples containing CeO_2 NPs with a weight percentage of 3% demonstrated the highest water sorption value, with an average of 29.225 µg/mm^3; the 2% weight CeO_2 NPs samples had an average water sorption of 27.512 µg/mm^3. In contrast, the control samples exhibited a mean value of 25.095 µg/mm^3, as shown in Fig. 5(A). In the solubility test, the control samples exhibited the highest value of 3.958 µg/mm^3, followed by the 2% wt. samples with a value of 3.889 µg/mm^3, and the 3% wt. samples with a mean value of 3.688 µg/mm^3, as shown in Fig. 5 (B).

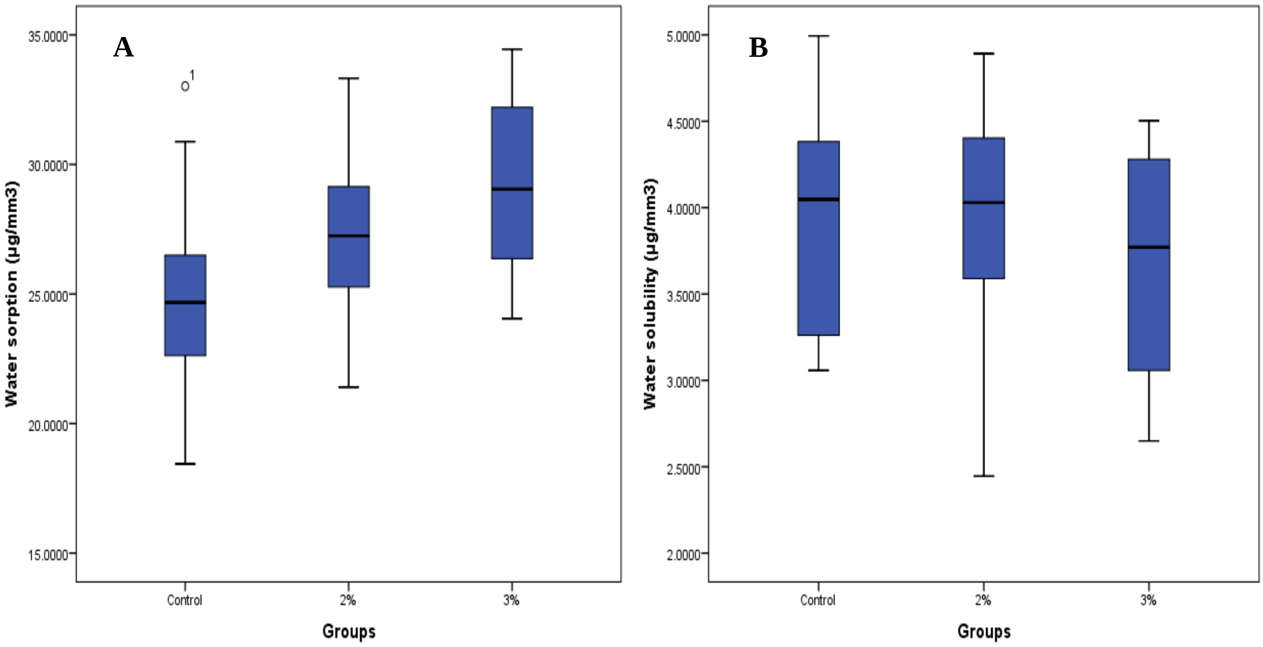

Figure 5: (A) Box plot for water sorption mean values, (B) Box plot for water solubility mean values.

The results indicated that the water absorption of the soft liner exhibited a modest rise as the concentration of CeO_2 NPs increased compared to the control samples. However, no statistically significant differences were observed, as shown in Table 1.

Table 1: ANOVA-test for comparing average values of water sorption among all samples.

	Sum of Squares	**df**	**Mean Square**	**F**	**P value**
Between Groups	86.123	2	43.061	3.107	0.061 NS
Within Groups	374.213	27	13.860		
Total	460.336	29			

The observed phenomenon can be ascribed to the clustering of nanoparticles at elevated concentrations, resulting in a greater prevalence of filler-filler interactions compared to filler-matrix interactions, which leads to a decrease in the uniformity within the matrix and has a detrimental impact on the polymerised material's ability to absorb and dissolve water [43]. Furthermore, non-reactant interfacial surfaces between the polymer matrix and the nanoparticles may provide a favourable environment for water molecules to accumulate, increasing water sorption [44].

As shown in Table 2, no statistically significant differences were observed in water solubility between the samples that received the integrated substance and the control samples.

Table 2: ANOVA-test for comparing average water solubility values among all samples.

	Sum of Squares	**df**	**Mean Square**	**F**	**P value**
Between Groups	0.393	2	0.196	0.376	0.690 NS
Within Groups	14.107	27	0.255		
Total	14.499	29			

The solubility of CeO_2 is well-recognised to be very low [45]. The water absorption and solubility characteristics of acrylic resin soft liners are thought to be affected by various factors, including impurities, plasticisers, and ethanol evaporation [46]. Consequently, the primary mechanism of water solubility occurs inside the resin matrix [47]. As a result, an augmentation in the concentration of CeO_2 nanoparticles leads to a reduction in the proportion of the resin matrix present, which could account for the observed drop in solubility as the CeO_2 nanofiller content increases.

These findings contradict those of Issa and Abdul-Fattah (2015), who reported a significant reduction in water sorption and solubility of acrylic-based soft liners with the addition of AgNPs [48]. They also disagree with those of Go et al. (2012), who observed a significant decrease in water sorption and solubility of 3D printing denture base resin with the addition of CeO_2 NPs [49].

4. Conclusions

Several studies have found that acrylic-based softlining materials are the most popular. It is important to note that there is currently no perfect soft lining material that meets all requirements. Based on the research findings, CeO_2 NPs did not significantly impact the water sorption and solubility of acrylic-based denture soft liners. It is crucial to do more research to examine the impact of different concentrations of CeO_2 NPs powder on the mechanical and physical properties of various denture liners.

Further study is needed to enhance materials' physical and chemical properties to align more effectively with human physiological needs. Enhanced mechanical and physical properties will improve the performance of the soft liner, leading to its increased utilisation in dentistry.

Conflict of interest

Authors declare that they have no conflict of interest.

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تأثير دمج جزيئات أوكسيد السيريوم النانوية على امتصاص الماء وقابلية ذوبان مادة البطانة الناعمة لأطقم الأسنان المعتمدة على الأكريليك

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الخلاصة

تم تصميم بطانات الأسنان الناعمة خصيصًا لتعزيز أداء المريض عن طريق تغيير أسطح الأطراف الاصطناعية التي تتلامس مع الأنسجة الرخوة داخل تجويف الفم. يعتبر راتينج الأكريليك والمطاط السيليكوني هما النوعان الرئيسيان من البطانات الناعمة للأسنان. تم استخدام تقنية النانو كوسيلة لتعزيز الصفات الميكانيكية. كان الهدف الأساسي من هذا البحث هو دراسة تأثير الجسيمات النانوية لأكسيد السيريوم على خصائص امتصاص الماء وقابلية البلل للبطانات الناعمة المعتمدة على الأكريليك. تم إنشاء ثلاثين عينة من خلال دمج جسيمات أكسيد السيريوم النانوية في مونومر بطانة ناعمة بنسب وزنية تبلغ 0%، و2%، و3%. تم إجراء عشر عينات مراقبة دون إضافة جسيمات نانوية من أكسيد السيريوم. علاوة على ذلك، تم إنشاء عشر عينات لكل نسبة وزن 2% و3% من الجزيئات النانوية لأكسيد السيريوم. تم إخضاع البيانات لتحليل التباين. تم تحديد خصائص السطح باستخدام المجهر الإلكتروني الماسح. أشارت النتائج إلى عدم وجود فروق ذات دلالة إحصائية بين المجموعتين. توضح هذه الدراسة المختبرية أن تضمين جزيئات أكسيد السيريوم النانوية بتركيزات 2% و3% لا يؤثر على امتصاص الماء وقابلية ذوبان مواد البطانة الناعمة القائمة على الأكريليك.

الكلمات المفتاحيه: أوكسيد السيريوم، الجسيمات النانوية، البطانة الناعمة، الامتصاص، الذوبان.