

Original Article

Effect of Adding Titanium Dioxide Nanoparticles on Some Mechanical Properties of Dental Alginate

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Abstract

Objective: This study aimed to evaluate the effect of adding titanium dioxide nanoparticles (TiO₂NPs) on Shore A hardness, Young's modulus, and tear strength of alginate impression material.

Methods: Each test consists of one control group (alginate without TiO₂NPs), and three test groups (2%, 3%, and 5%) of TiO₂NPs were added, respectively. For each group, seven samples were constructed. For Shore A hardness, the samples were prepared according to ISO standards (7619-1:2010); Young's modulus was calculated from the obtained Shore A hardness value according to a special standard equation. In contrast, for tear strength, the samples were prepared according to ASTM D 624-00.

Results: The Control group exhibited a significantly less Shore A hardness value than all the other groups except the group that contained 2% TiO₂NPs, where the increase in the hardness value was non-significant. A similar result was observed for Young's modulus test, where the addition of TiO₂NPs significantly increased Young's modulus compared to the control group. Although, on the contrary, the tear strength was significantly improved by adding 3% TiO₂NPs compared to control and other groups, there was a significant drop in the value of tear strength when 5% TiO₂NPs were added to alginate.

Conclusions: The addition of 3% TiO₂NPs to dental alginate increased Shore A hardness, Young's modulus, and significantly improved tear strength.

Keywords: Alginate, Hardness, Nanoparticles, Tear strength, Young's modulus.

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Introduction

Many materials have been used for dental impressions, but the most commonly used material is alginate, an irreversible hydrocolloid material due to its elasticity. Impression material will be placed in the patient mouth to make negative reproduction of teeth and oral tissue. The impression is then poured with gypsum product to obtain a working model^(1,2).

The major advantages of this material are its elastic property, easy manipulation, comfort for patients, and relatively low cost because it does not require any special equipment⁽³⁾. At the same time, the main shortcoming of this material is the dimensional instability due to syneresis or imbibition phenomenon⁽⁴⁾. Disinfection of impression is an integral and necessary procedure in dentistry to prevent cross-infection among patients, dentists, and dental technicians, a variety of methods have been employed for this purpose, such as immersion and spraying methods, but they are associated with the unwanted dimensional changes in the alginate impression due to its hydrophilic nature^(5,6).

Recently, studies have reported that metallic oxide nanoparticles, such as silver and magnesium oxide nanoparticles, were very effective against many bacteria and fungi^(7,8). As a result, many researchers have experimented with incorporating silver nanoparticles into alginate impression materials, and they found evidence of antimicrobial activity^(9,10) without any significant change in its physical properties⁽¹¹⁾.

The effect of adding TiO₂NPs has been studied in dentistry, and its role was proven to improve some mechanical properties^(12,13) alongside effective antimicrobial activity⁽¹³⁾.

No previous study has been conducted on the efficacy of incorporating TiO₂NPs into dental alginate impression material. Therefore, this study was performed to evaluate the effect of adding TiO₂NPs on Shore A hardness, Young's modulus, and tear strength of the alginate.

Materials and methods

A total of 56 samples were prepared (28 samples) for the Shore A hardness test and (28 samples) for the Tear strength test. The study design for each test consists of four major groups, one control group, and three

modified groups to which TiO₂NPs (20 nm size, 99% purity) at (2%, 3%, and 5%) respectively by using an electronic balance (OHAUS Europe GmbH-Switzerland) with 0.0001 mg of precision were added to (Alginplus) extra high precision alginate ISO 21563 (Major- Italy), the alginate and the TiO₂NPs powder was dispensed in a container and mixed⁽¹¹⁾ in a circular motion manually for 90 seconds to ensure a uniform distribution of the TiO₂NPs within the alginate powder. The powder/water mixing ratio was done according to the manufacturer's recommendation. The exact weight of the powder was mixed with distilled water using an electronic automatic alginate mixer machine (Cavex-Netherlands) for ten seconds. The impression procedures were performed in a controlled temperature (25°C) room. The samples were removed after alginate gelation.

Shore A hardness test

Sample preparation and measurement for Shore A hardness were done according to the ISO standards 7619⁽¹⁴⁾. Seven samples for each group were constructed from a plastic mold with a diameter of 50 mm and a thickness of 6 mm; the mold was placed on a glass slab, filled with the alginate, and covered by the second slab. The pressure was applied manually until the two glass slabs were in contact with the mold to ensure even alginate thickness during gelation, then 5 kilograms of weight was placed over the slab until the setting was complete. After 10 min, the alginate discs were carefully removed. Each sample was divided into six equal zones; one measurement was made for each zone. Digital Shore A Hardness Durometer tester kit (Yueqing ABE model LX-A-4. China), as shown in Figure 1, was used to measure the hardness of the samples that were loaded with 10 N for 15 seconds, the mean of the six measurements was considered as the value of the Shore A hardness.



Figure 1: Shore A hardness durometer testing kit.

Young's Modulus test

The Young's Modulus value was calculated from the Shore A hardness value according to an equation by (Gent 1958)⁽¹⁵⁾, who found that there is a very close correlation between Durometer Shore A hardness and Young's Modulus using this equation:

$$E = \frac{0.0981(56+7.62336s)}{0.137505(254-2.45s)}$$

Where E = Young's modulus in MPa, S = Shore A Hardness.

Tear strength test

Sample parameters and testing were done according to ASTM D624-00⁽¹⁶⁾; 28 samples were divided into four groups, and each group (n=7) was prepared from a V-shaped mold of 3mm thickness (Figure 2 A). First, the mold was placed on a glass slab, filled with the alginate, and covered by the second slab in the same manner as described previously for Shore A hardness sample preparation to ensure uniform alginate thickness, then 5 kilograms of weight was placed over the second slab until the setting was complete after 10 minutes. Then, the V-shaped alginate specimens were removed from the mold and immediately subjected to the tear strength test. The testing procedure was done using a computer programmed universal testing machine (DRK101SA, China), with a 50 mm/min crosshead speed, as seen in Figure 2 B. The ultimate tear strength calculation was done according to this equation.

$$T = F/A$$

Where T is tear strength (N/mm), F is the force at the rupture (N), and A is the initial cross-sectional area (mm²).

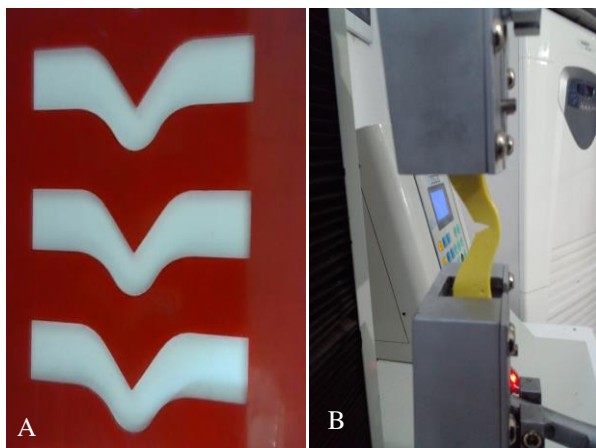


Figure 2: (A) Tear strength mold, (B) Universal testing machine.

Statistical analysis

The obtained data post hoc test (multiple comparisons with LSD) was done using SPSS software version 22, and the P. Value for the level of significance was 0.05 ($\alpha = 0.05$).

Results

Shore A hardness test

The Durometer Shore A hardness results showed that the control group (0% TiO₂NPs) had the optimum and least Shore A hardness of 10.485, while the group to which 5% TiO₂NPs were added showed the highest Shore A hardness of 13.128, as shown in Table 1.

As mentioned earlier, Young's modulus value was extracted from the Shore A hardness value and calculated according to the early mentioned Gent (1958) equation. The control group presented with the least Young's Modulus value (0.426MPa) compared to other groups, followed by the group to which 2% TiO₂NPs were added, having Young's modulus mean value (0.4268MPa). In comparison, the highest Young's Modulus (0.503 MPa) was found in the group modified by adding 5% TiO₂NPs. The results of all groups are presented in Table 1.

As shown from the LSD test result in the table.2, the addition of up to 2% of TiO₂NPs to the alginate doesn't significantly affect the mean Shore hardness. In comparison, the other added concentrations significantly increased the Shore hardness from (10.485) for the control group to (11.142) for the group to which 3% of TiO₂NPs were added and (13.128) to the alginate impregnated with 5% of the nanoparticle. Fortunately, the increased mean of hardness remains within the acceptable range for the elastomeric materials since it is below the scale of 70⁽²⁾.

The Young's modulus for the control group was (0.4260 MPa), although adding 2% of TiO₂NPs increased the alginate's stiffness (0.4268 MPa), but this effect was statistically non-significant. However, increasing the added concentration to 3% and 5% significantly increased Young's modulus of the material compared to the control group (LSD test), as shown in Table 3.

Tear strength

As observed in Table 4, the tear strength increased by increasing the percentage of added TiO₂NPs to the alginate. The control group value was (0.5205 N/mm), while the highest was for the 3% TiO₂NPs group (0.5337 N/mm).

At 5% TiO₂NPs to the alginate, the value of tear strength dropped significantly (LSD test) compared to the 3% TiO₂NPs group, but still greater than the control and 2%

group values. Table.5 shows the post hoc test (multiple comparisons-LSD) for all the tested groups.

Table 1: Mean and Standard deviation of Shore A hardness and Young's modulus (MPa).

	N	Shore A hardness Mean (SD)	Young's modulus Mean MPa (SD)
Control	7	10.485 (0.134)	0.4260 (0.0036)
2 % TiO ₂ NPs	7	10.614 (0.069)	0.4268 (0.0028)
3 % TiO ₂ NPs	7	11.142 (0.139)	0.4452 (0.0041)
5 % TiO ₂ NPs	7	13.128 (0.138)	0.5038 (0.0041)

Table 2: Post hoc tests (Multiple comparisons- LSD) for shore A hardness.

Group	Group	Mean Difference	Sig. (p < 0.05)
Control	2% TiO ₂ NPs	0.12857	0.064 NS
	3% TiO ₂ NPs	0.65714*	0.000 HS
	5% TiO ₂ NPs	2.64286*	0.000 HS
2% TiO ₂ NPs	3% TiO ₂ NPs	0.52857*	0.000 HS
	5% TiO ₂ NPs	2.51429*	0.000 HS
3% TiO ₂ NPs	5% TiO ₂ NPs	1.98571*	0.000 HS

NS= Non-significant, HS= highly-significant

Table 3: Post hoc tests (Multiple comparisons- LSD) for Young's modulus.

Group	Group	Mean Difference	Sig. (p < 0.05)
Control	2% TiO ₂ NPs	0.000857	0.672 NS
	3% TiO ₂ NPs	0.019286*	0.000 HS
	5% TiO ₂ NPs	0.077857*	0.000 HS
2% TiO ₂ NPs	3% TiO ₂ NPs	0.018429*	0.000 HS
	5% TiO ₂ NPs	0.077000*	0.000 HS
3% TiO ₂ NPs	5% TiO ₂ NPs	0.058571*	0.000 HS

NS= Non-significant, HS= highly-significant

Table 4: Mean and Standard deviation of Tear strength (N/mm).

	N	Mean N/mm (SD)
Control	7	0.5205 (0.007)
2 % TiO ₂ NPs	7	0.5215 (0.0017)
3 % TiO ₂ NPs	7	0.5337 (0.0011)
5 % TiO ₂ NPs	7	0.5242 (0.0007)

Table 5: Post hoc tests (Multiple comparisons- LSD) for tear strength.

Group	Group	Mean Difference	Sig. (p < 0.05)
Control	2% TiO ₂ NPs	0.001000	0.120 NS
	3% TiO ₂ NPs	0.013143*	0.000 HS
	5% TiO ₂ NPs	0.004714*	0.000 HS
2% TiO ₂ NPs			
	3% TiO ₂ NPs	0.012143*	0.000 HS
	5% TiO ₂ NPs	0.003714*	0.000 HS
3% TiO ₂ NPs			
	5% TiO ₂ NPs	0.008429*	0.000 HS

Discussion

Shore hardness is defined as resistance to indentation. It is expressed in terms of a Hardness Number calculated from an indentation test⁽¹⁷⁾.

The elasticity is considered an essential criterion that should be available in the elastic dental impression materials, especially when recording the undercut areas, the presence of viscoelastic properties in these materials allows it possesses some degree of deformation during the removal of impression from the undercut areas then undergoing elastic recovery⁽¹⁸⁾.

In this study, The Shore A hardness increased significantly when increasing the addition of TiO₂NPs above 2% to the alginate. From the literature, no previous studies had been done to evaluate the effect of adding nanoparticles on the Shore A hardness for irreversible hydrocolloid impression materials (alginate). Still, the results of several studies^(19,20) on some elastic impression materials showed that the nanoparticles increased the hardness of the material; this may be due to more crosslinking of the polymer since there is no additives that affect the polymerization of the alginate. Therefore there is more polymer crosslink chain mobility, and after the modification, by adding TiO₂NPs, these crosslinks become stronger^(6,7,21) so that there was a resistance to penetration by the durometer indenter⁽²⁰⁾.

The elastic modulus property is considered an important factor because it gives an idea of the force that this material could withstand when the impression is removed from the oral cavity⁽²²⁾.

The control group exhibited the maximum elastic property compared to the other groups, the increase of

Young's modulus was inversely related to the concentration of the added TiO₂NPs. This finding may be because inert small-sized TiO₂NPs (20nm) were well dispersed in the polymer matrix. Thus, the intermolecular gaps were occupied by such nano-sized particles, causing an alteration in crosslinking density or changing the crosslinks' geometry, which may have led to decreasing the elasticity⁽²⁰⁾.

Tear strength is the ability of the impression material to resist tear while removed from the oral cavity or during the cast removal from the impression; tear strength depends on the water powder ratio of the used material; the higher powder/water ratio shows higher tear strength than a material mixed with a lower powder/water ratio. The addition of TiO₂NPs up to 3% to alginate increased the tear strength compared to the control group; this may be due to the surface energy of this nanoparticle that caused a reinforcement of the crosslinked matrix while adding 5% TiO₂NPs to alginate impression material decreases the tear strength significantly compared to the previous group, the possible reason for this is the agglomeration of the TiO₂NPs within the matrix so that the polymeric crosslink chains detached or weakened⁽²³⁾.

Conclusions

Within the limitation of this study, adding TiO₂NPs improves the tear strength of alginate impression material, but the shore hardness and Young's modulus significantly increased when increasing the concentration of TiO₂NPs; this increase is within the acceptable range.

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