Effect of Incorporation of Boron Nitride Nanoparticles on Impact Strength and Surface Roughness of Heat Cure Poly Methyl Methacrylate Resin: An In Vitro Study

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Abstract

Background: The objective of this research was to explore how the addition of boron nitride (BN) nanoparticles in the concentrations of 1% and 1.5% w/w affect the impact strength and surface roughness of heat-cured poly methyl methacrylate resin (PMMA). **Methods:** Sixty specimens were made from heat-cured acrylic resin and then divided into control, 1%, and 1.5% w/w BN groups. The impact strength and surface roughness were investigated. One-way ANOVA and Tukey's post hoc test were used for data analysis. **Results:** Statistically significant difference is found among the three study groups regarding impact strength ($P = 0.011$) and surface roughness test ($P < 0.001$). The post hoc test showed significant differences for all multiple comparisons for the surface roughness test ($P < 0.001$). Yet, multiple comparisons for the impact strength test revealed only a significant difference between the 1.5% BN and control groups ($P = 0.005$). **Conclusion**: The addition of boron BN into PMMA improves impact strength with 1.5% concentration; while adversely increase the surface roughness.

Keywords: Boron nitride, denture base, heat cure acrylic resin, impact strength, nanoparticle, poly methyl methacrylate, surface roughness

Introduction

Polymethyl methacrylate (PMMA) is a popular polymer because of its optical properties, biocompatibility, and attractive look. Acrylic resin, however, is not an ideal biomaterial because of its inadequate impact strength and fatigue resistance. Biting forces, temperature variations, exposure to saliva, water, acidic foods, and mechanical impacts are just some of the factors that can cause damage to the denture base over time.[1,2] One of the most commonly used denture base materials is PMMA, but an optimal material has yet to be discovered.[3]

The denture can break in two ways: either by impact, as when it is dropped on a hard surface, or by fatigue, as when the denture base deforms repeatedly because of occlusal forces.

Nowadays, more focus is being placed on the inclusion of various components, such as rubber, fibers, or nanosilver into PMMA in order to enhance its physical properties.[4-6]

Boron nitride (BN) is a refractory material that exhibits notable thermal and chemical resistance. Its chemical structure is comparable to that of graphene (carbon 2D material).

BN is wildly used in dental science, for instance reinforcement of dental ceramics,[7] filler of resin-based dental sealants,[8] to increase properties of dental adhesives,[9,10] as a coating for dental implants,[11] as fillers for dental resin composite.[12]

However, the objective of this research was to explore how the addition of BN nanoparticles in the concentration of 1%

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and 1.5% w/w affects the impact strength and surface roughness of heat-cured PMMA.

Materials and Methods

Study protocol approved by the local ethical committee of College of Dentistry, University of Baghdad (approval number (13) on March 01, 2022). Sixty specimens were prepared from heat-cured resin (Rodex, Bagcilar, Turkey). And impact strength test and a surface roughness test were carried out among the study groups: the control group (PMMA without BN) ($n = 10$), PMMA specimens containing 1% ($n = 10$), and 1.5% w/w BN ($n = 10$). (BN, hexagonal, 99.99%, 3–4 um) (SkySpring Nanomaterials, Inc., Houston, USA) was mixed with the monomer liquid to make the acrylic dough for the experimental groups. The BN was thoroughly dispersed using a probe sonicator apparatus (Soniprep-150, Imgen Technologies LLC, Alexandria, USA) for 3 minutes to ensure good BN dispersion and prevent agglomeration within the monomer. Imgen Technologies LLC.

Impact strength test

The acrylic samples for the impact strength test were fabricated with dimensions of $80 \times 10 \times 4$ mm in length, width, and thickness respectively and were maintained in distilled water at 37 °C for 2 days before being tested according to ADA specification No.12.[13] *Charpy* impact testing instrument (TMI, Testing Machine Inc., New York, USA) used in accordance with the guidelines laid out in ISO 179-1.

Surface roughness test

The acrylic samples of the impact strength test were fabricated with dimensions of $65 \times 10 \times 2.5$ mm in length, width, and thickness, respectively, and were stored in distilled water at 37 °C for 2 days before being tested in accordance.[13] The profilometer apparatus (TEREN, DaLian, China) was used to examine the microstructure geometry of the test specimens.

Statistical methods

Data were analyzed using one-way ANOVA and Tukey's post hoc test using R software (R Foundation for Statistical Computing, Vienna, Austria).

Results

The statistically significant difference was found among the three study groups regarding impact strength ($P = 0.011$) and surface roughness test ($P < 0.001$). The Post hoc test showed significant differences for all multiple comparisons for the surface roughness test ($P < 0.001$). Yet, multiple comparisons for the impact strength test revealed a significant difference between the 1.5% BN and control (0% BN) group ($P = 0.005$) and a non-significant difference between the 1% BN versus control group ($P = 0.020$) and 1% BN versus 1.5% BN group ($P = 0.023$) [Figure 1].

Discussion

The resistance of an acrylic denture base to cracking when faced with an unexpected, intense force, such as when dropped, is a crucial quality. For this research, we utilized the Charpy impact testing equipment, which is well recognized as one of the most popular techniques for determining the relative toughness of a material in a time- and cost-efficient manner. In this study, the addition of 1% and 1.5% BN reduced the mean value of impact strength in comparison with the control group. This reduction was statistically insignificant for the 1.5% BN group.

The research of Gaffari *et al.*, reported a similar finding, discovering a decrease in strength with the addition of silver nanoparticles.[14] Ihab *et al.*, assessed the effect of addition of the ZrO_2 nanoparticles into PMMA and found a significant rise in impact and transverse strength at concentration of 5%, but a non-significant increase was observed at 7%.[15] This reduction may be caused by a rise in the number of particles, each of which serves as a focal point for a localized region of high stress. As a result of their influence on the interface area

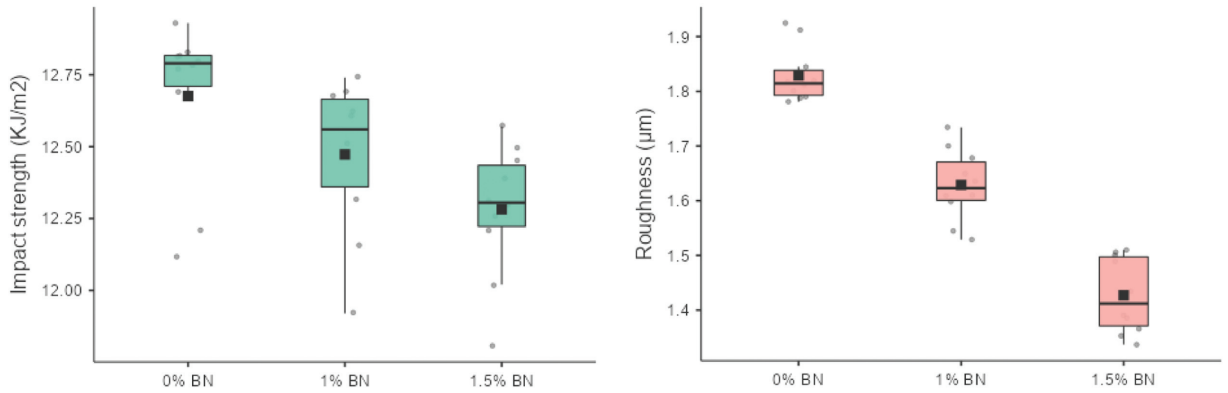

Figure 1: Box and whisker plot depicted summary statistics related to impact strength and roughness test.

at high concentrations, reinforcing materials help to minimize the loss of energy during testing.[16] In contrast, Alqahtani reported that the addition of 5% BN increased the flexural strength, Vickers hardness and the modulus of elasticity.[17,18] Kamil and Al-Judy examined the addition of silicon carbide nanoparticles to PMMA and reported a non-significant decrease in impact strength.[19] Also, Alwan and Alameer reported a significant increase in impact and transverse strength with the addition of TiO2 nanoparticles to PMMA.[20]

However, increased surface roughness allows the development of bacterial plaque and stains on the denture, which has a negative effect on the hygiene and esthetics of dentures. The esthetic features and biofilm adhesion are both affected by the initial surface roughness.[21]

This study used a profilometer device, which has been recognized as a high-quality device for the assessment of surface roughness. The present study's findings showed that the addition of BN reduced surface roughness. Our findings are in accordance with the outcomes of Mangal *et al.*, who revealed that the addition of diamond filler resulted in a reduction in surface roughness.[22] In contrast, Ahmed *et al.* showed the incorporation of silanized SiO_2 nanoparticles and oxygen plasma-treated polypropylene fiber to heat cure PMMA and increase surface roughness of acrylic resin.[23] Kamil and Al-Judy reported a significant increase in surface roughness after the addition of silicon carbide nanoparticles.[19] Alwan and Alameer showed a significant increase in surface roughness with the incorporation of TiO2 nanoparticles into PMMA.[20] Inconsistency aside, Ihab *et al.* reported non-significant increases in surface roughness following the addition of ZrO_2 nanoparticles.[15]

The limitations of this study must be noted. In vitro studies could not exactly act out like oral environs. Other limitation of this study is a limited sample size.

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Conflicts of interest

There are no conflicts of interest.

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Clinical evaluation of the pain predictors among temporomandibular joint disorders patients with full dentition and free-end extensions: An Analytical Cross-Sectional Study

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Abstract

Introduction: We aimed to evaluate the possible role of the age, occlusion type, type of dentition (full dentition or free-end extensions), and type of temporomandibular disorders (TMD) to predict the presence of pain. **Methods:** Subjects were selected from volunteer male TMD patients with one partially edentulous jaw from the Baghdad city in 2022. Pain was assessed via the Visual Analogue Scale (VAS). Angle's and Kennedy's classifications were employed to assess occlusion and partially edentulous jaw conditions. TMD was assessed using Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications. Relationship between pain as ordinal dependent variable and other predictor variables was assessed via ordinal logistic regression using SPSS 26. **Results:** 240 subjects were assessed for eligibility and 180 TMD patients (mean age 41.1 ± 0.46) were included in the study. The omnibus test showed that the model outperforms the null model ($p < 0.001$). Disc displacement with reduction (odds ratio: 0.09) and Kennedy's Class I (odds ratio: 0.42) were statistically significant inverse predictors for pain ($p < 0.05$). Age ($p = 0.66$) and Angle's occlusion type ($p = 0.91$) were not significant predictors for pain. **Conclusion:** Probability of pain decreased in disc displacement with reduction and Kennedy's Class I.

Keywords: logistic regression, occlusion, orofacial pain, pain, temporomandibular disorders, temporomandibular joint

Introduction

Temporomandibular joint (TMJ) is a bilateral synovial dynamic articulation act between the squamous region of the temporal bone of the skull above and condylar process of the mandible below; from these bones the name of TMJ is derived, the articular disc is located in the space between those two bones. This joint is unique in its shape, structural characteristics, and that it is a bilateral joint that functions as one piece.

Temporomandibular joint disorder (TMD) is a complex disease process caused by various factors, including muscle dysfunction or overactivity genetic, and traumatic injuries. Additionally, hormonal changes, as well as articular alterations, can contribute to the development of TMD. TMD affects 5% to 12% of the US population and costs American businesses an estimated $4 billion annually.[1] Several treatments are suggested in the literature for TMD including cognitive behavior therapy, physical therapy, occlusal devices, nonsteroidal anti-inflammatory drugs, benzodiazepines or antidepressants (for chronic cases), and injection of hyaluronic acid and platelet-rich plasma.[2,3,4,5]

A review of 2419 articles stated that there is still much debate surrounding the interaction between occlusion and TMD.[6]

A recent meta-analysis reported the overall prevalence for TMD: 31.1% and disk displacements: 19.1% among adults and elderlies.[7] Pain is one of the main overwhelming symptoms for which patients with TMD seek treatment. Alkhubaizi Q and Khalaf ME reported the prevalence of TMD-associated pain was 26.8%.[8] Al-Khotani A *et al.* showed prevalence of pain among TMD patients was 15%.[9]

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However, the aim of this study was to evaluate the possible role of the age, occlusion type, type of dentition (full dentition or free-end extensions), and type of TMD to predict the presence of pain.

Materials and Methods

Study protocol was approved by research ethics committee of the college of dentistry, University of Baghdad on December 27, 2021 (Ref. number 432).

Considering alpha error probability of 0.05, power of 0.90, effect size of 0.3, and difference of 4, a sample size of 174 was needed. Subjects were selected from volunteer male TMD patients with one partially edentulous jaw from the Baghdad city in 2022. All subjects signed informed consent. The inclusion criteria were: 1) Healthy subjects without history or signs and symptoms of any systemic disorders.[10,11] 2) Subjects with pain in mastication muscles and/or pain with clicking with/or without limitation of mouth opening. 3) Subjects not taking any analgesic or anti-inflammatory medications. Exclusion criteria were: 1) Female patients (to avoid bias related to changes of the estrogen levels during menstrual cycle and its effect on pain).[12] 2) Patients with bridges, partial dentures, and mobile teeth. 3) Patients with neoplastic disease, parathyroid gland disease, endocrine disorders, rheumatoid arthritis, and developmental disorders of the TMJ, such as condylar aplasia, hypoplasia, or hyperplasia.

Pain was assessed via the Visual Analogue Scale (VAS). Angle's and Kennedy's classifications were employed to assess occlusion and partially edentulous jaw conditions.[11] TMD was assessed using Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications[13] and classified as: 1) Disc displacement (DD) with reduction. 2) DD with reduction with intermittent locking. 3) DD without reduction with limited opening. 4) DD without reduction without limited opening. 5) Myofascial pain dysfunction syndrome.

Relationship between pain as ordinal dependent variable and other predictor variables was assessed via ordinal logistic regression using SPSS 26 (IBM Corp., Armonk, NY). Sample size was determined using Gpower (http://www.gpower.hhu.de/).

Results

Two hundred and forty subjects were assessed for eligibility and 180 TMD patients were included in the study. All 180 participants (mean age 41.1 ± 0.46) completed the study and were included in the analysis. The omnibus test showed that the model outperforms the null model ($p < 0.001$). DD with reduction and Kennedy's Class I were statistically significant inverse predictors for pain [Table 1].

Discussion

Results of this study showed DD with reduction and Kennedy's Class I were significant inverse predictors for pain. Age and Angle's occlusion type were not significant predictors for pain.

PubMed search with the query *}*temporomandibular joint disorders*}* AND *}*pain*}* on Jan 25,2023 showed the number of articles is growing fast ($y = 5.3659x - 10527$, $R^2 = 0.8598$, y: article number, x: year). Yet, to our knowledge assessment of pain predictors among TMD patients was rarely reported in the literatures.

Alkhubaizi Q and Khalaf ME reported that the TMD patients with pain were varied remarkably on the depression scale and Bodily pain scores in compression with control group.[8] Osiewicz M *et al*. showed a significant relationship between TMD ache and depression (odds ratio: 2.9) and nonsignificant relationship with gender, age, bruxism, somatization, and chronic pain-related impairment.[14] Choi YS *et al*. reported experience of injury in TMJ was found to be associated with pain in the joint region.[15] Jordani PC *et al*. reported obesity and sedentarism were not connected with the presence of pain in TMD adult patients.[16] Al-Khotani A

Table 1: Results of Ordinal Logistic Regression Evaluating Pain Predictor Parameters

Parameter	Percent	Regression Coefficient	*P* Value	Odds Ratio	95% CI for Odds Ratio
Kennedy's Class I	31.1%	−0.862	0.010	0.422	0.220 to 0.811
Kennedy's Class II	18.9%	−0.210	0.588	0.811	0.379 to 1.733
Full dentition	50.0%	0		1	
DD with reduction	33.3%	−2.355	0.000	0.095	0.043 to 0.210
DD with reduction with intermittent locking	2.2%	−1.384	0.242	0.251	0.025 to 2.549
DD without reduction with limited opening	8.3%	−0.286	0.588	0.752	0.268 to 2.111
DD without reduction without limited opening	22.8%	−0.478	0.202	0.620	0.297 to 1.293
Myofascial pain dysfunction syndrome	33.3%	0		1	
Angle's Class I	66.1%	0.034	0.911	1.035	0.571 to 1.875
Angle's Class II	33.9%	0		1	
Age	–	0.010	0.668	1.010	0.966 to 1.056

DD: disc displacement.

et al. showed in children and adolescents, the TMD-related pain appears to have an association with emotional, behavioral and somatic functions, with higher frequencies of anguish, depression, somatic issues, aggressive behavior, and thought complications.[17]

However, readers must be noted to inherent limitations of cross-sectional study, such as the inability to make a causal inference and lack of follow-up. Study sample in this study is limited to a city. Large-scale, multicentral studies are needed to reach a more reliable conclusion.

As a suggestion for future researches, conduction of systematic review and meta-analysis to summarize results of studies regarding prevalence of pain among TMD patients is encouraged.

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Conflict of Interest

The authors declare that there was no conflict of interest regarding this research.

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