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EVALUATION OF FLEXURAL STRENGTH FOR COMPLETE REMOVABLE DENTURES MADE OF ZIRCONIA-IMPREGNATED PMMA NANOCOMPOSITES: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Abstract

Background and aim: present study investigated the mechanical properties (flexural strength) with different concentrations of Zirconia-Impregnated PMMA Nanocomposites.

Method: In present systematic review and meta-analysis, all articles published until the end of July 2023 through searching in databases PubMed, Scopus, Science Direct, ISI, Web of Knowledge, Elsevier, Wiley, and Embase and Google Scholar search engine were extracted using keywords and their combinations by two trained researchers independently. Data analysis was done using the fixed effects model in meta-analysis, by STATA (version 17); P-value less than 0.05 was considered significant.

Result: A total of five studies were included in the meta-analysis process. mean differences of flexural strength between 1.5% nano-ZrO_2 and control group was 17.14 MPa (MD:17.14 95% CI; 15.83 to 18.45; $p<0.001$). There was no statistically significant difference ($p>0.05$) between the flexural strength of the specimens reinforced with 7% nano-ZrO_2 nanoparticles groups and those in control group (MD: -0.42 MPa 95%CI; -4.77 to 3.93; p=0.85) (Fig.5).

Conclusion: The optimal filler concentrations for reinforcing PMMA denture base resins from the flexural strength perspective were 1.5%, 3 and 5 wt.% ZrO_2.

Keywords: Flexural Strength, ZrO_2 nanoparticles, PMMA, nanoparticle

Introduction

Polymethyl methacrylate (PMMA), a synthetic resin produced from the polymerization of methyl methacrylate(1). PMMA is commonly used for prosthetic dental applications, including the fabrication of artificial teeth, denture bases, dentures, obturators, orthodontic retainers, temporary or provisional crowns, and for the repair of dental prostheses(2). In maxillofacial surgery, they are generally used in conservative treatment of fractures, temporomandibular joint dysfunctions and orthognathic procedures(3). Studies have shown that artificial prostheses made of PMMA can be used in maxillofacial surgery, and their other uses are facial skeleton repair(4). Different types of splints are usually used in osteosynthesis of mandibular and maxillary fractures(5). Although PMMA is widely used, it has poor mechanical properties and can easily be damaged(6). Therefore, many efforts have been made to increase the mechanical properties and improve the polymerization conditions of PMMA(7). Studies have shown that the addition of nanoparticles has a positive effect on improving the mechanical properties of PMMA(3, 8). One of the nanoparticles whose effect on increasing flexural strength has been investigated is zirconium dioxide nanoparticles (nano-ZrO2), which has antioxidant and anticarcinogenic effects

based on the results of studies, and its use seems optimistic(9). Therefore, according to the results of studies and providing strong evidence in this field, the present study was conducted with the aim of Evaluation of Flexural Strength for Complete Removable Dentures Made of Zirconia-Impregnated PMMA Nanocomposites.

Method

Search strategy

In this study, in order to obtain scientific documents about Evaluation of Flexural Strength for Complete Removable Dentures Made of Zirconia-Impregnated PMMA Nanocomposites, articles published in international databases such as PubMed, Web of Science, Scopus, Science Direct, Web of Knowledge, EBSCO, Wiley, ISI, Elsevier, Embase and Google Scholar search engine were used. The search process until July 2023 in PubMed database was done using MeSH keywords: ((((((("Polymethyl Methacrylate"[Mesh]) AND "Splints"[Mesh]) AND ("Prostheses and Implants"[Mesh] OR "Dental Prosthesis"[Mesh])) OR ("Dentures"[Mesh] OR "Denture, Partial, Fixed, Resin-Bonded"[Mesh])) AND ("Zirconium"[Mesh] OR "zirconium oxide" [Supplementary Concept])) AND "Nanoparticles"[Mesh]) AND "Flexural Strength"[Mesh]) AND "Tensile Strength"[Mesh]. In addition, the reference list of the obtained articles was checked to identify the used articles that were not obtained using the above methods. Databases were searched with high sensitivity. To avoid bias, the search was done by two researchers independently.

Study selection criteria

Inclusion criteria: use of the PICO (Problem, Intervention, Comparison and Outcome) strategy to construct the research question is specified in Table 1; in-vitro studies, ZrO2 nanoparticles, English language. studies with incomplete results; animal studies, case reports, editorial and review articles were excluded.

Table1. PECO strategy.

PECO strategy	Description
P	Problem: PMMA with nano-ZrO2 additive
I	Intervention: Flexural strength
C	Comparison: PMMA without additives
O	Outcome: Flexural strength

Data collection

a checklist was designed based on the objectives, and information from the selected articles was entered into the checklist (Table 2).

Data analysis

Meta-analysis was performed using effect size with 95% confidence interval. To estimate the heterogeneity of the studies, the index I^2 (<25%: weak heterogeneity, 25-75%: moderate heterogeneity, and more than 75%: high heterogeneity) was used. The results were combined using the fixed effect model (Inverse–variance method) in meta-analysis. The publication bias was checked by Egger test, data analysis was done using STATA/MP. v17 software. A p-value of less than 0.05 was considered significant.

Result

After searching with related keywords, 414 studies were obtained. Endnote.X8 software was used to organize the studies. By using the mentioned software and reviewing the title and abstract of the articles, 81 duplicate studies were eliminated. Then the abstracts of 319 articles were examined by the researchers. 289 studies that did not meet the inclusion criteria or were excluded due to weak or unrelated relevance to the study objective (if after reading the title and abstract, it was not possible to make a decision about the article, the full text was referred to). The full text of 30 articles was carefully reviewed by two independent researchers, and 25 studies were excluded due to the inconsistency of study objectives; Finally, five articles were selected (Figure 1).

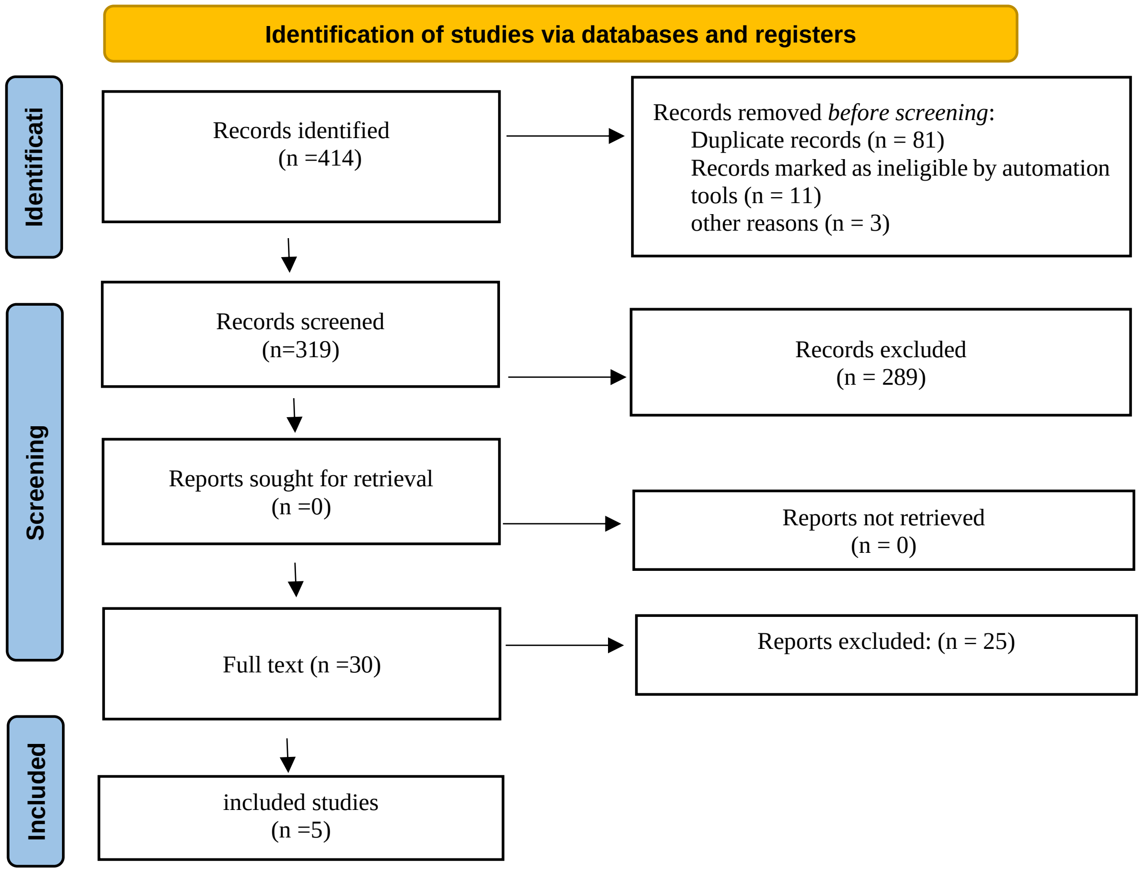

Figure 1. PRISMA 2020 Checklist.

Physical Characteristics of Particles

The average size of the ZrO2 nanoparticles ranged between 30 nm and 100 nm. Table 2 showed characteristics of particles.

Table 2. Characteristics of selected studies.

No.	Study. Years	Sample size	Number of specimens		Control group	Experimental group	Nanoparticle size (nm)	wt% concentrations
			Experimental	control				
1	Gad et al., 2022 (10)	20	10	10	unaltered acrylic resin in 1 step	ZrO2 nanoparticles	40	0.5,1,1.5
2	Alhotan et al., 2021 (11)	20	10	10	pure, heat-cured PMMA	ZrO2 nanoparticles	<100	1.5,3,5,7
3	Zidan et al., 2020 (12)	30	20	10	0% of ZrO2 nanoparticles	ZrO2 nanoparticles	30-60	3,5
4	Zidan et al., 2019 (13)	50	40	10	0% of ZrO2 nanoparticles	ZrO2 nanoparticles	30–100	1.5,3,5,7, 10
5	Ergun et al., 2018 (14)	40	30	10	PMMA without nano-ZrO2.	ZrO2 nanoparticles	<100	5,10,20

Flexural Strength

mean differences of flexural strength between 1.5% nano-ZrO2 and control group was 17.14 MPa (MD:17.14 95% CI; 15.83 to 18.45; $p<0.001$). The outputs of the meta-analysis revealed that there was a statistically significant difference in the flexural strength of the specimens in the 1.5% nano-ZrO2 groups when compared to the specimens in control group ($p<0.001$) (Fig.2). According to the coefficient I^2, high heterogeneity between studies was observed (I^2=93.95%; $p<0.001$).

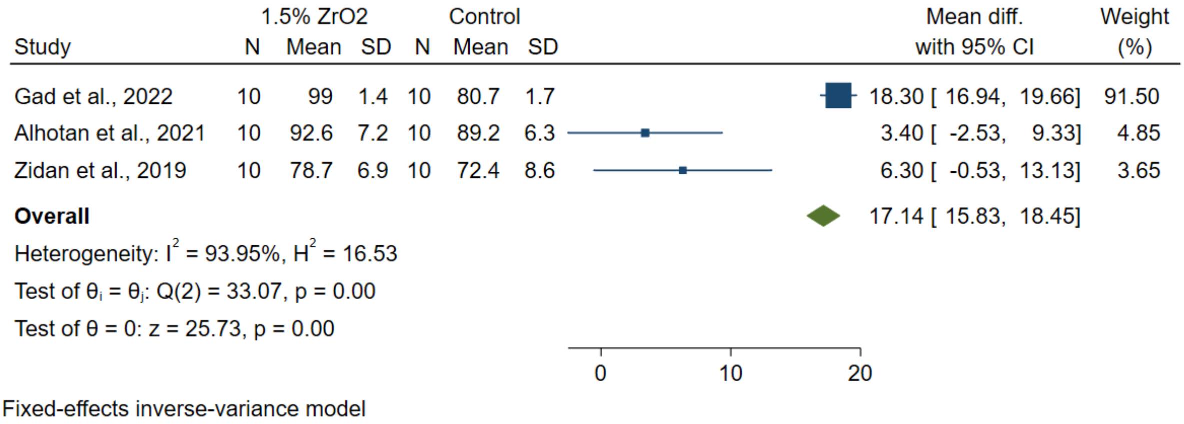

Figure 2. forest plot showed effect of nano-1.5% ZrO2 additive concentration on the flexural strength of PMMA composites.

However, there was statistically significant difference ($p<0.001$) between the flexural strength of the specimens reinforced with 3% nano-ZrO2 nanoparticles and those in control group. The mean difference was 11.22 MPa (MD:11.22 95% CI; 6.85 to 15.58; $p<0.001$) (Fig.3). According to the coefficient I^2, low heterogeneity between studies was observed (I^2=11.52%; p=0.32).

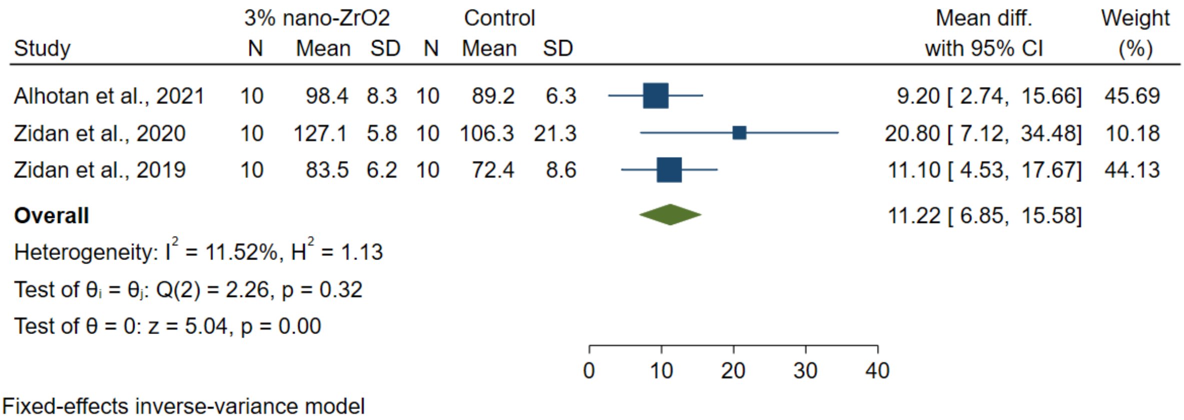

Figure 3. forest plot showed effect of nano-3% ZrO2 additive concentration on the flexural strength of PMMA composites.

The meta-analysis revealed that the significant differences ($p<0.001$) in flexural strength was observed in the specimen groups 5% nano-ZrO2 (MD: 7.91 MPa 95% CI; 3.56 to 12.27) compared to those in control group (Fig.4). According to the coefficient I^2, moderate heterogeneity between studies was observed (I^2=65.77%; p=0.03).

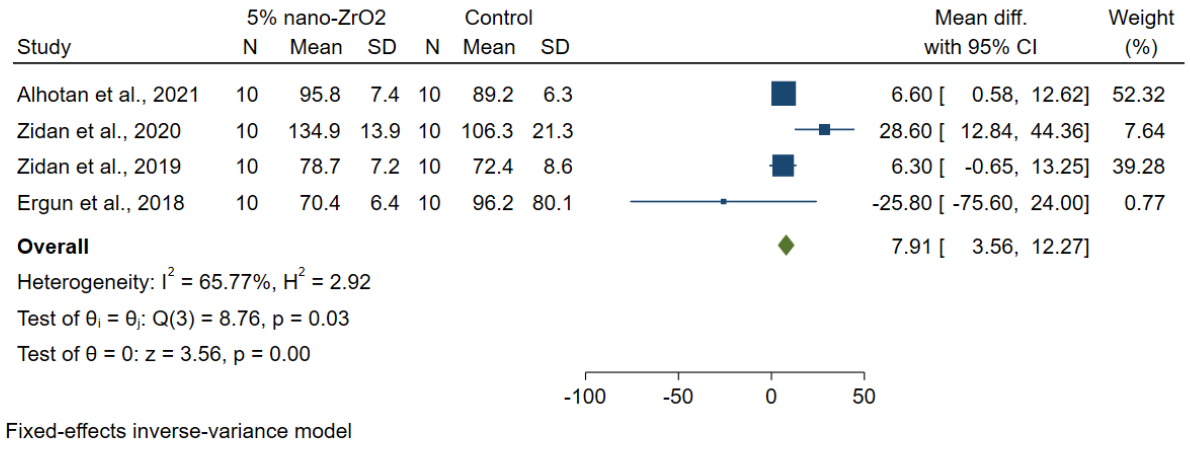

Figure 4. forest plot showed effect of nano-5% ZrO2 additive concentration on the flexural strength of PMMA composites.

There was no statistically significant difference (p>0.05) between the flexural strength of the specimens reinforced with 7% nano-ZrO2 nanoparticles groups and those in control group (MD: -0.42 MPa 95%CI; -4.77 to 3.93; p=0.85) (Fig.5). According to the coefficient I^2, low heterogeneity between studies was observed (I^2=0%; p=0.79).

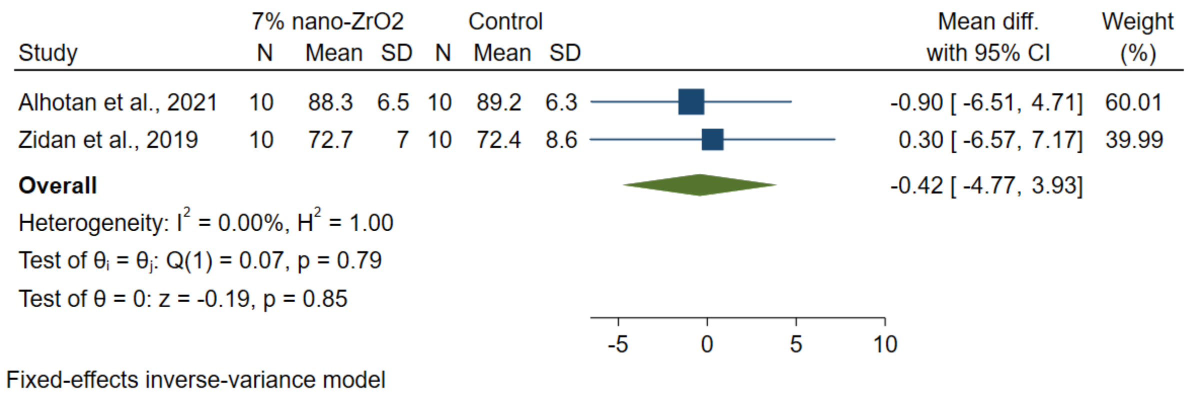

Figure 5. forest plot showed effect of nano-7% ZrO2 additive concentration on the flexural strength of PMMA composites.

The highest flexural strength value was observed in Group E7 (105 ± 10.6 MPa), while Group T7 (83.5 ± 7.2 MPa) had the lowest flexural strength among the reinforced groups.

Discussion

In this study, the effect of adding nano-ZrO2 in concentrations of 1.5%, 3%, 5% and 7% to strengthen the bases of dental prostheses was investigated. Although other concentrations were also examined in the studies, due to the small number of studies, only these four concentrations were examined. The highest flexural strength value was observed in 1.5 % nano-ZrO2 group, while 7 % nano-ZrO2 group had the lowest flexural strength among the reinforced groups. the flexural strength values of the PMMA increased by mean dereferences 17.14 MPa ($p < 0.05$) when 1.5% wt.% ZrO_2 was added to the PMMA resin but it slightly decreased when 7 wt.% ZrO_2 was incorporated (-0.42 MPa).

The outcomes of the current study are consistent with the results of previous studies that assessed the impact nano-ZrO_2 has on the flexural strength of PMMA dentures(13, 15). Nejatian et al., (2020) proved that the inclusion of silanated ZrO_2 into heat-cured PMMA at 10 wt.% reduced the flexural strength of PMMA denture(16). According to Ergun et al., (2018) the addition of various ratios of nano-ZrO_2 to heat-cured PMMA (5 wt.% 10 wt.%, and 20 wt.%) reduced the flexural strength of the material in comparison to the pure PMMA control group(14). In a meta-analysis study, it was reported that the addition of nano-ZrO_2 increases the flexural strength of the composite with the PMMA matrix depending on the size of the ZrO_2 grains administered(3). The general interpretation of the results of the present study is consistent with other evaluations discussing the effect of nanofillers on the properties of PMMA-based composites(17).

Only a few studies on the effect of adding ZrO_2 nanoparticles in HI heat-cured denture base acrylic resin are available in the literature. In contrast, investigators have worked on improving the mechanical properties of conventional heat-cured denture base acrylic resin by incorporating different types of fillers(18). Alhareb et al., 2011 [showed a 16% increase in flexural strength value compared to control samples when PMMA was reinforced with ZrO_2 with a filler concentration of 5 wt%(19). Zhang et al., 2014 investigated the effect of hybrid ZrO_2 nanoparticles and micro-particles of aluminium borate whiskers (ABWS) at concentrations of 1 wt%, 2 wt%, 3 wt%, and 4 wt% on the flexural strength of PMMA denture base resin. They found that 2 wt% nano-ZrO_2 with a ZrO_2/ABWS ratio of 1:2 improved flexural strength by 32% when compared to a control group(20). These previous studies in the literature were in agreement with the results obtained in present study, which revealed that zirconia positively influenced the flexural properties of PMMA with an optimum zirconia concentration between 1.5 wt%, 3 wt% and 5 wt%.

In the present study, high heterogeneity between studies was observed in some variables, therefore, the interpretation of the present results should be done with caution, and more studies are needed to confirm the evidence, because few studies were included in the meta-analysis. Nanoparticles, although promising in terms of material mechanics, may be unsuitable for their intended applications. To determine this, studies using tissue fluid mimics on cell lines and then on tissues and organisms are needed.

Conclusion

The optimal filler concentrations for reinforcing PMMA denture base resins from the flexural strength perspective were 1.5%, 3 and 5 wt.% ZrO_2. According to meta-analysis A significant increase in the hardness of the composites was observed for all the fillers at all concentrations with exception of the 7 wt.% concentration of ZrO_2 nanoparticles. For all zirconia contents, the impact flexural strength of the nanocomposites was significantly higher than that of the control group. However, at 7 wt% zirconia contents, the proportion of reduction in impact strength was not significantly different from that of the control group. Thus, improving the mechanical properties of PMMA denture bases through the use of the fibre and filler can produce dentures that can achieve longer clinical service.

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