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Evaluation of the Flexural Strength Values of Acrylic Resin Denture Bases Reinforced with Silicon Dioxide Nanoparticles: A Systematic Review and Meta-analysis

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ABSTRACT

Background and aim: In the present study, differences in the effects of adding SiNPs at different concentrations (1wt%, 3wt%, 5wt%, and 7wt%) on the flexural strength of the heat-polymerized PMMA were investigated.

Material and methods: Based on the PRISMA 2020 Checklist, the current study is a systematic review and meta-analysis. Databases from Scopus, Science Direct, PubMed, ISI, Web of Knowledge, and Embase were searched until 12 December 2022 to find systematic literature. The 95% confidence interval for mean differences was calculated using the fixed effect model and inverse-variance method. Stata/MP. v.17 software was used to conduct the meta-analysis.

Results: Duplicate studies were removed from the initial review, which also reviewed 97 studies' abstracts. Two authors thoroughly reviewed 39 studies, and six studies were finally selected. Mean differences of flexural strength between the addition of 1%, 3%, 5%, and 7% SiNPs reinforcement and control group was 12.99 (MD, 12.99 95% CI 9.92, 16.05; p>0.05), 5.94 (MD, 5.94 95% CI 4.98, 6.91; p>0.05), 8.28 (MD, 8.28 95% CI 7.14, 9.43; p>0.05) and -2.97 (MD, -2.97 95% CI -3.87, -2.07; p>0.05), respectively.

Conclusions: Based on the present meta-analysis, no statistically significant difference was observed between the effects of adding SiO2 nanoparticles at different concentrations (1wt%, 3wt%, 5wt%, and 7wt%) on flexural strength of the heat-polymerized acrylic compared to the control group. No specific concentration of SiO2 nanoparticles is suitable for strengthening acrylic resin.

1. Introduction

Today, the most common base materials for dental prostheses are heat-polymerized acrylic resin.[1] Their biocompatibility studies have confirmed and reported that their appearance characteristics are similar to those inside the mouth.[2] Based on the findings of recent studies, their flexural strength is considered weak, and prosthesis failure may occur due to repeated chewing forces.[3, 4] Various materials and techniques are used to increase and strengthen flexural strength, and with the introduction of nanoparticles, their use in acrylic resin has been controversial.[5] Among the factors that can effectively reinforce acrylic resin using nanoparticles are the size of nanoparticles, the dispersion level of particles, and silanization.[6] Silica nanoparticles (SiNPs) are the most widely used nanoparticles usually added to polymers and dental composites.[7, 8] SiNPs are mesopores (2-50 nm pores) of silica that exhibit unique physicochemical properties.[9] A study has shown that adding SiNPs in low concentrations to the repaired resins can improve flexural strength.[10] Recently, more experimental studies have investigated the mechanical properties of acrylic resin reinforced with SiNPs.[11-13] In vitro studies can check the preparation of SiNPs, working method, and evaluation of samples. Therefore these studies can provide good results. In the present study, with the consensus of the results of in vitro studies, an attempt has been made to investigate the flexural strength of heat-polymerized acrylic with the addition of SiNPs.

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2. Material and methods

Search strategy

The current study is a systematic review and meta-analysis based on the PRISMA 2020 Checklist(14). Until 12 December 2022, keywords related to the study's objectives were searched in all international databases, including Scopus, Science Direct, PubMed, ISI, Web of Knowledge, and Embase. Additionally, the Google Scholar search engine was used to find relevant articles. MeSH keywords:

(((((("Silicon"[Mesh]) OR "Silicon Dioxide"[Mesh]) AND "Nanoparticles"[Mesh]) OR ("Nanoparticles/administration and dosage"[Mesh] OR "Nanoparticles/adverse effects"[Mesh] OR "Nanoparticles/classification"[Mesh] OR "Nanoparticles/statistics and numerical data"[Mesh])) AND "Flexural Strength"[Mesh]) AND ("Dentures"[Mesh] OR "Denture, Partial, Fixed, Resin-Bonded"[Mesh] OR "Denture Bases"[Mesh])) OR "Prostheses and Implants"[Mesh].

Data items, Data collection, and Selection procedure

Using a checklist that included the author's name, year of publication, sample size, study design, Nanoparticles Size, Silanization, specimen dimension, Testing type, and the standard was extracted and reported in Table 2. Additionally, data about flexural strength required for meta-analysis were extracted from the studies. Following the inclusion criteria-based selection of all articles, two reviewers independently reviewed each record, and each report was retrieved.

Eligibility criteria

Inclusion criteria: According to Table 1, inclusion criteria responded to PICO. Articles published in English, in-vitro studies, and studies that assessed the effect of SiNPs on flexural strength.

Exclusion criteria: Case reports, case studies, and review papers. Studies without access to the full text.

Table1. PICO strategy.

PICO Strategy	Description
P	Population: denture base material
I	Intervention: SiNPs
C	Comparison: without SiO2 nanoparticles
O	Outcome: flexural strength

Study risk of bias assessment

Modified CONSORT Criteria (Guidelines for reporting pre-clinical in vitro studies on dental materials) were used to evaluate the quality of studies;[15] Each study was reviewed with 14 items, and the parameters were reported as yes or no. These items were:

A structured summary of the trial's methods, results, and conclusions. A scientific context and explanation; specific objectives or hypotheses; sufficient information about each group's intervention, including when and how it was administered, to permit replication; a fully defined, predetermined primary and secondary outcome measure, including how and when it was evaluated, how the sample size was determined, how the random allocation sequence was generated, how it was implemented, and who was responsible for creating the random allocation, who after intervention assignment become blind, The statistical methods used to compare the groups, the results for each group, the estimated size of the effect and its precision, the trial limitations, addressing potential sources of bias, imprecision, and, if the relevant multiplicity of analysis, sources of funding and other support, where to find the full trial protocol can all be found. The risk of bias tool (adapted and modified from the Cochrane risk of bias tool) was used. In this tool, each item was given a score of 2, 1, or 0; the sum of scores from 0 to 3 indicates a low risk of bias, 4 to 7 indicates a moderate risk of bias, and scores of 8 to 10 indicate a high risk of bias. In this tool, the lowest score was 0, and the highest score was 10.[16]

Data analysis

STATA/MP. V17 software was used to analyze the data. The 95% confidence interval for mean differences was calculated using the fixed effect model and inverse-variance method. I^2 demonstrated heterogeneity, and random effects were employed to address potential heterogeneity. I^2 values indicate low heterogeneity under 50%, and I^2 values over 50% indicate moderate to high heterogeneity.

3. Results

Study selection

The initial search found one hundred nineteen articles related to the keywords. Of these, 11 articles were records removed for other reasons, five articles were records marked as ineligible by automation tools, and six studies were duplicate records. After reviewing the abstracts of 97 articles, the remaining 58 articles were ultimately excluded from the study in accordance with the exclusion criteria. After reviewing the full texts of 39 articles, 33 studies were excluded based on the inclusion criteria, and six studies were selected (Fig. 1).

Study characteristics

There were 53 sample sizes analyzed, and the data collected from the studies is shown in Table 2.

Risk of bias in studies

Four studies had a moderate risk of bias, one had a low risk of bias, and one had a high risk of bias, using the risk of bias assessment tool (Tables 3 and 4).

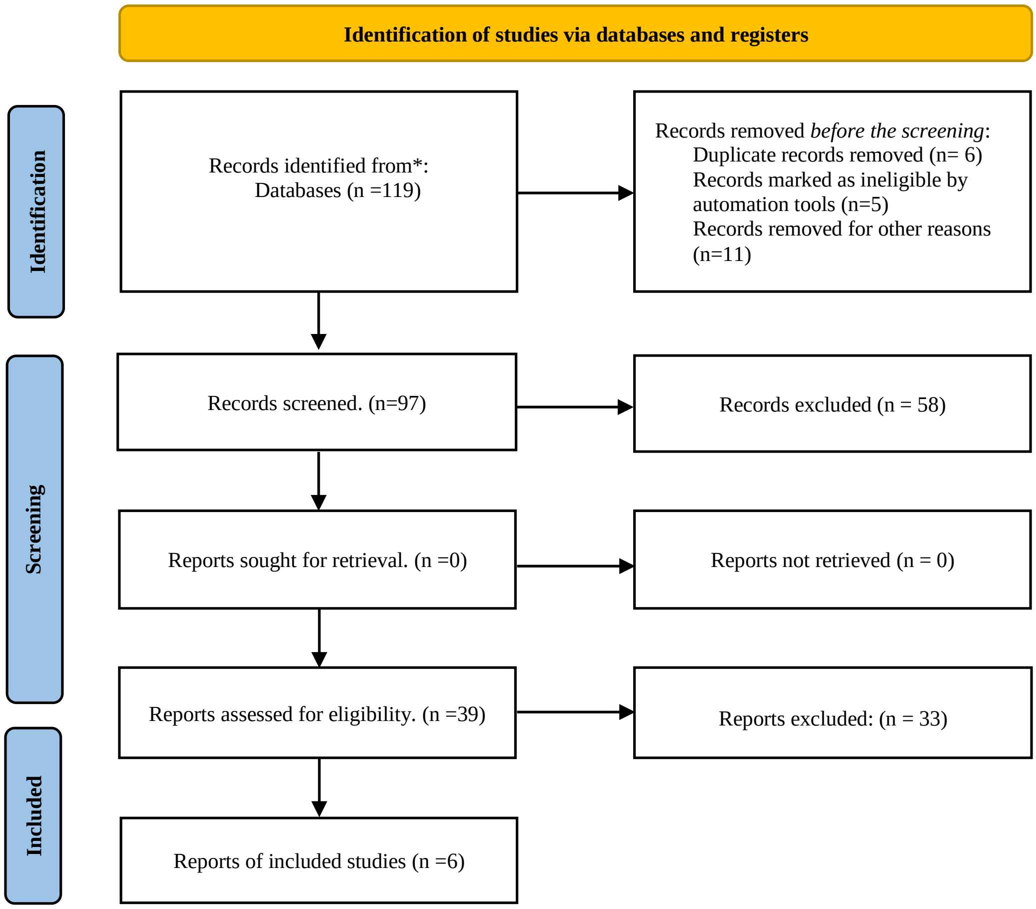

Figure 1. PRISMA 2020 Checklist.

Table 2. Summary of data.

No	Study. Years	Study Design	Sample size	Nanoparticles Size (nm)	Silanization	Specimens Dimension (mm^3)	Testing type	Standard
1	Azmy et al., 2022[17]	In-vitro	10	16	NR	8 × 10 × 20	-----	ISO 1567: 1999
2	Karci et al., 2019[13]	In-vitro	7	15	NR	65 × 10 × 3	3-point bending test cross-speed of 5 mm	ISO 1567
3	Jiangkongkho et al., 2018[12]	In-vitro	8	36	γ-MPS	64×10×3.3	3-point bending test cross-head speed of 5 mm	ISO 20795-1:201319
4	Cevik et al., 2018[11]	In-vitro	8	12	γ-MPS	65 × 10 ×3	3-point bending test cross-head Speed 1 mm	ISO 20795
5	Salman et al., 2017[18]	In-vitro	10	50	γ-MPS	NR	3-point bending test	ISO (20795 1:2008.32)
6	Alnamel et al., 2014[19]	In-vitro	10	100	Epoxy Coupling agent	65x 10 x 2.5	3-point bending test cross-head speed of 1mm	ADA, 1999

NR: not reported; γ-MPS: γ-methacryloxypropyltrimethoxysilane.

Table 3. Quality of the included studies.

Study. Years	Item Grade													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Krishnan et al., 2022[1]	√	√	×	×	×	×	×	×	×	√	×	×	×	×
Karci et al., 2019[13]	√	√	√	√	√	√	√	×	×	√	√	√	×	×
Jiangkongkho et al., 2018[12]	√	√	√	√	×	√	×	×	×	√	√	√	×	×
Cevik et al., 2018[11]	√	√	√	√	√	√	√	×	×	√	√	√	×	×
Salman et al., 2017[18]	√	√	×	√	×	×	×	×	×	√	√	√	×	×
Alnamel et al., 2014[19]	√	√	×	×	×	×	×	×	×	√	×	√	×	×

Yes: √; No: ×

Table 4. Risk assessment.

Study. Years	Allocation Concealment	Sample Size	Blinding	Assessment Methods	Selective Outcome Reporting	Score	Risk of Bias
Krishnan et al., 2022[1]	1	2	2	0	0	5	Moderate
Karci et al., 2019[13]	1	0	2	0	0	3	Low
Jiangkongkho et al., 2018[12]	1	2	2	0	0	5	Moderate
Cevik et al., 2018[11]	1	2	2	0	0	5	Moderate
Salman et al., 2017[18]	1	2	2	0	0	5	Moderate
Alnamel et al., 2014[19]	1	2	2	2	1	8	High

Flexural strength

Subgroup meta-analysis

The mean differences in flexural strength between the addition of 1% SiNPs reinforcement and the control group was 12.99 (MD, 12.99 95% CI 9.92, 16.05; $p>0.05$) with high heterogeneity (I^2=98.98%; p=0.00). According to meta-analysis, no statistically significant difference was observed between groups (Fig. 2).

The mean differences in flexural strength between the addition of 3% SiNPs reinforcement and the control group was 5.94 (MD, 5.94 95% CI 4.98, 6.91; $p>0.05$) with high heterogeneity (I^2=93.09%; p=0.00). According to meta-analysis, no statistically significant difference was observed between groups (Fig. 2).

The mean differences in flexural strength between the addition of 5% SiNPs reinforcement and the control group was 8.28 (MD, 8.28 95% CI 7.14, 9.43; $p>0.05$) with high heterogeneity (I^2=98.62%; p=0.00). According to meta-analysis, no statistically significant difference was observed between groups (Fig. 2).

The mean differences in flexural strength between the addition of 7% SiNPs reinforcement and the control group was -2.97 (MD, -2.97 95% CI -3.87, -2.07; $p>0.05$) with high heterogeneity (I^2=86.12%; p=0.00). According to meta-analysis, no statistically significant difference was observed between groups (Fig. 2).

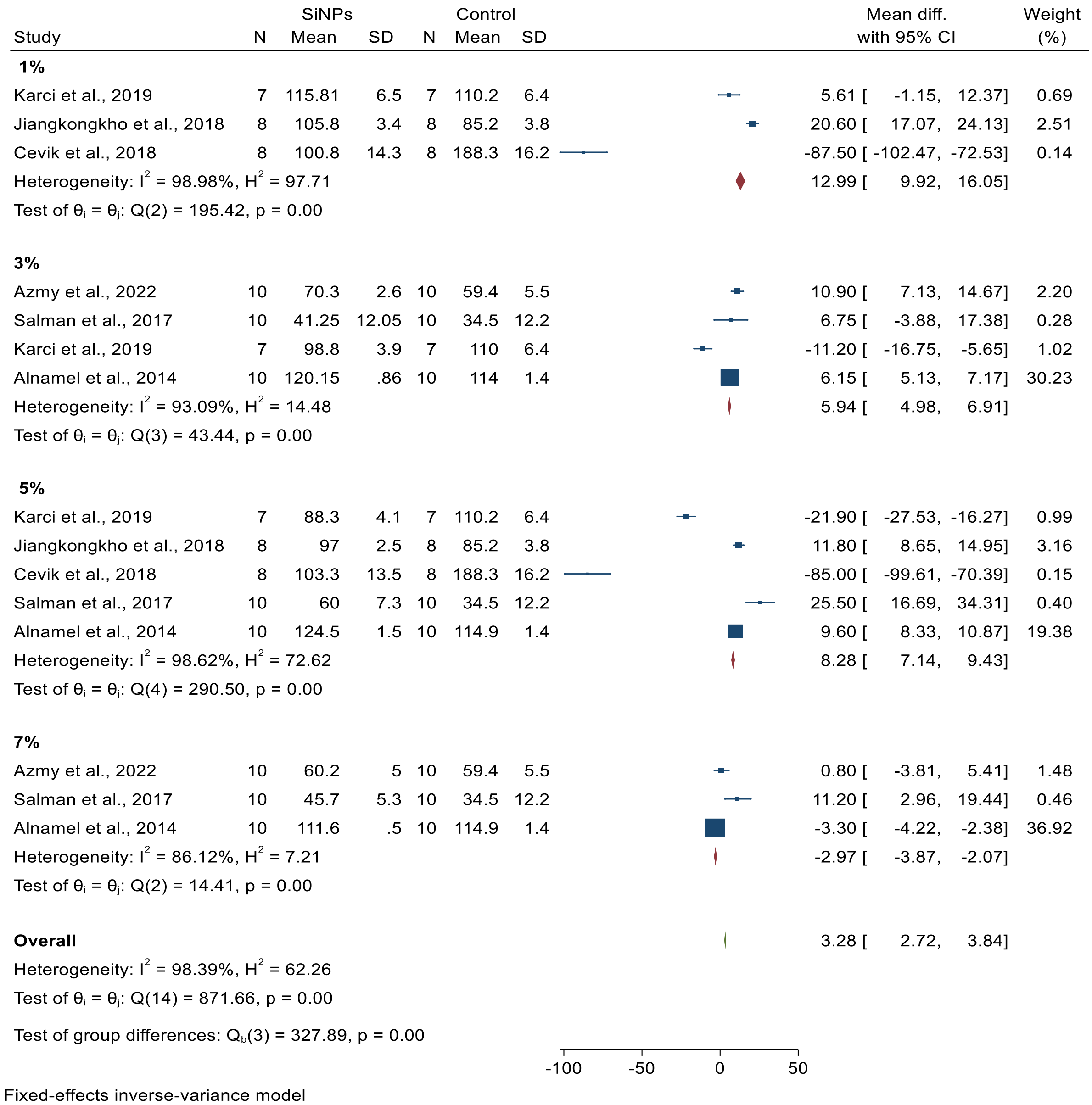

Fig. 2. Forest plots showed that adding 1%, 3%, 5%, and 7% SiNPs significantly affects flexural strength.

4. Discussion

In the present study, differences in the effects of the addition of SiNPs at different concentrations (1wt%, 3wt%, 5wt%, and 7wt%) on the flexural strength of the heat-polymerized PMMA were investigated. The present meta-analysis showed that the addition of SiNPs at different concentrations (1wt%, 3wt%, 5wt%, and 7wt%) had no difference in increasing flexural strength value compared to the control group (without the addition of SiNPs) and the modified and unmodified group had no increase. There was no significant difference in flexural strength. However, adding SiNPs at 3% and 7% concentrations resulted in a slight increase. High heterogeneity was observed between the studies, which could be related to the cognitive methodology of the studies. The findings of the present study should be interpreted with caution. Also, the quality of most of the selected studies was average. Among the reasons for the above heterogeneity, we can mention the use of different sizes of nanoparticles, the type and composition of the resin, and the method of obtaining the samples. Also, the sample size of the studies was very small, so it is necessary to conduct more studies with a larger sample size to confirm the findings of the present study. Based on the findings of studies, increasing the concentration of SiNPs leads to decreased mechanical properties.[12, 18, 19] A systematic review and meta-analysis study conducted by AlSwuailem et al. (2021) showed that the proportion of SiO2 nanoparticles incorporated from 0.25% to 15% and the reported flexural strength values for reinforced acrylic resin from 41.25 MPa to 124.56 MPa was variable.[20] Other studies also showed that adding nanoparticles in low concentrations can improve flexural strength due to forming surface bonds between nanoparticles.[11] The present study had limitations: firstly, only two studies followed ISO standards; Secondly, there was considerable variation in the polymerization cycle used for the samples, which could affect the flexural strength of the acrylic resin. Thirdly, the sample size of the studies was very small, and finally, in the present study, only heat-polymerized acrylic resin was investigated. As a result, it is impossible to compare the findings of the meta-analysis with the results of studies investigating other types of acrylic resins. Future studies of mechanical properties other than flexural strength should be investigated, and the effect of adding other nanoparticles should also be investigated.

5. Conclusion

Based on the present meta-analysis, no statistically significant difference was observed between the effects of adding SiO2 nanoparticles at different concentrations (1wt%, 3wt%, 5wt%, and 7wt%) on flexural strength of the heat polymerized PMMA compared to the control group. Therefore, adding 3% and 7% SiO2 nanoparticles significantly increases the flexural of PMMA acrylic resin. The addition of SiO2 is recommended in low concentrations (3%). Therefore, no specific concentration of SiO2 nanoparticles is suitable for strengthening acrylic resin. However, high heterogeneity between studies was found, which suggests that the results of the present study should be interpreted with caution.

Conflict of Interest

The authors declared that there is no conflict of interest.

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