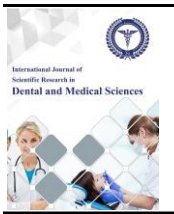

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Evaluation of the Effect of Zirconium Dioxide Nanoparticles on the Flexural Properties of Polymerized Acrylic Resin for Interim Fixed Restorations: A Systematic Review and Meta-analysis

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ABSTRACT

Background and aim: Interim restorations are one of the important steps in placing fixed dental prostheses. Their mechanical and biological properties should be checked, and they should also be checked in terms of aesthetics. The current investigation aims to ascertain the impact of ZrO_2 nanoparticle addition on the flexural strength of acrylic resins when utilized for interim fixed restorations.

Material and methods: Using search terms associated with the study's goals, all worldwide databases, including PubMed, Science Direct, Scopus, ISI, and Embase, as well as Web of Knowledge, were investigated till May 2023. The fixed effect model and inverse-variance methodology have been utilized to get a confidence interval of 95% for mean differences. The meta-analysis has been carried out with Stata/MP v.17 software.

Results: The original review, which also examined the abstracts of 95 papers, was cleaned up of duplicate research. Two writers carefully assessed sixteen papers, and four studies were ultimately chosen. The mean difference in flexural strength between 0.5-ZrO_2 and the control group was 24.07 (MD; 95 CI (20.72, 27.42), $p<0.05$). The 5-ZrO_2 group had the lowest value of flexural strength, which was 0.14 (MD=0.14; 95 CI (-2.51, 2.80), $p>0.05$). The PMMA pristine interim restorative material's flexural strength values were dramatically enhanced by the addition of ZrO_2 (2.5 wt%) (MD=5.03; 95 CI (2.65, 7.14), $p<0.05$).

Conclusions: The highest flexural strength value was related to specimens reinforced with 0.5, 1, and 2.5-wt% ZrO_2 nanoparticles.

1. Introduction

Interim restorations are one of the important steps in placing fixed dental prostheses, and their mechanical and biological properties should be checked. They should also be checked in terms of aesthetics.[1] Auto-polymerized polymethyl methacrylate (PMMA) resin is generally used to make interim restorations, and its advantages are low cost, ease of use, and ease of repair. PMMA's mechanical qualities are less than optimal, and investigations have shown substantial failure rates.[2] For temporary restorations, using computer-aided design (CAD-CAM) PMMAs substances has become prevalent, as these PMMAs have higher fracture resistance than conventional PMMAs.[3] It should be noted that using CAD-CAM technology is difficult for reasons such as the lack of accuracy of materials and the high equipment cost.[4] Studies have reported that adding reinforcing materials (fibers) can improve the mechanical properties of acrylic resins.[5] Other studies have suggested using nanoparticles, metal oxide macroparticles, and microparticles.[6, 7] The findings of the studies indicate that incorporating nanoparticles in polymer matrices can enhance the characteristics of acrylic resins.[8, 9] Numerous metal oxide nanoparticles, including aluminum and titanium, have been the subject of studies; more recently, SiO_2 nanoparticles and nanodiamonds5 have also been examined.[9] Despite having encouraging results, the findings of the studies are contradictory, and one of the disadvantages is a color change. Zirconium dioxide (ZrO_2) can be an option due to its high melting point, biocompatibility, favorable color, and hardness.[2] Also, because of the weak solubility of ZrO_2 nanoparticles within water, they are expected to have minimal absorption in the gastrointestinal tract. Previous studies have investigated the flexural strength of heat-polymerized acrylic resin integrated with ZrO_2 nanoparticles in different concentrations.[10-12] The findings have shown that the concentration of nanoparticles, the size of nanoparticles, and the acrylic resin type affect the study results, and the flexural strength has

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increased with the addition of nanoparticles and has not had a significant effect.[13, 14] This investigation aims to determine the impact of adding ZrO2 nanoparticles upon acrylic resins' flexural strength utilized throughout interim fixed restorations.

2. Material and methods

Search strategy

Searches were conducted on all worldwide databases, including PubMed, Science Direct, Scopus, ISI, Embase, and Web of Knowledge, up to May 2023, Using keywords associated with the study's goals. The PRISMA 2020 checklist (15) was used as the basis for the current study, and relevant papers were also found using the Google Scholar search engine. Keywords and MeSH terms:

("Interim fixed restorations"[Mesh]) AND ("Polymethyl methacrylate"[Mesh] OR "Autopolymerized polymethyl methacrylate"[Mesh])) AND " flexural strength]) AND " zirconium dioxide"[Mesh]) AND (" Nanoparticles"[Mesh]).

Data items, Data collection, and Selection process

Based on a checklist with nine criteria, the details of the samples of the chosen studies were retrieved; the things were the name of the author, year of the publication, size of the sample, study design, nanoparticles Size (nm), specimens dimension, intervention group, control group, standard and flexural strength assessment. Additionally, the information needed for the meta-analysis, such as flexural strength, was taken from the research findings. Two reviewers examined Each record separately, and every report was downloaded. In accordance with inclusion and exclusion criteria, every study was chosen.

Eligibility criteria

Inclusion criteria: Scholarly works written in English, in-vitro studies, research that evaluated flexural strength, only interim fixed restorations, and PMMA resin.

***Exclusion criteria*:** Case studies and review articles as well as case reports. Studies that do not have full-text access.

Critical appraisal

The quality of research was assessed using modified CONSORT Criteria (Rules for reporting pre-clinical in vitro dental material investigations)[16] ;14 items from each research were assessed, and the parameters were given a yes/no response. These things have been:

A detailed synopsis of the procedures, outcomes, and conclusions of the trial; a background along with the justification from the scientific community; certain goals or hypotheses; adequate details about the intervention in each group, such as when and how it has been delivered, to allow replication; a thoroughly specified primary and secondary outcome measure, predetermined, and contains details on how and when it was examined how the sample size was chosen, how it was put into practice, who was in charge of making the random allocation, and who was made blind following the intervention assignment. The statistical procedures utilized in comparing the groups, the outcomes for all groups, the correctness of the effect's predicted size and magnitude, the trial's restrictions, discussing potential causes of bias and imprecision, if any, the diversity of analysis, funding, and other sources of support, as well as where to locate the whole study protocol, are all available. The Cochrane risk of bias instrument was updated, and the risk of bias instrument was employed. Each question in this instrument received a score of 0, 1, or 2; the total of scores between 0 and 3 demonstrates a weak risk of bias, 4 to 7 suggests a moderate risk of bias, and scores between 8 and 10 demonstrate a strong risk of bias. This instrument has a maximum score of 10 and a minimum value of 0.[17]

Data analysis

The I^2 coefficient was used to measure any potential heterogeneity between trials. Values lower than 50% demonstrate low heterogeneity, 50%, and 75% suggest moderate heterogeneity and more than 75% indicate significant heterogeneity. The 95% confidence range for mean differences was computed using the fixed effect model and inverse-variance approach. Software called STATA/MP V17 has been utilized to carry out the meta-analysis.

3. Results

Study selection

The initial keyword search discovered one hundred-three articles; all references were put into the EndNote X8 program. Four of these articles were duplicates, two were due to records being flagged as ineligible by automated programs, and two were deleted for other reasons. Ninety-five papers' abstracts were finally examined, and 79 articles that did not match the inclusion requirements were eliminated. Sixteen papers were thoroughly read and reviewed by two blindfolded observers. Four publications were ultimately chosen (Fig. 1) after eliminating 12 incomplete articles that lacked data or were inconsistent with the study's goals.

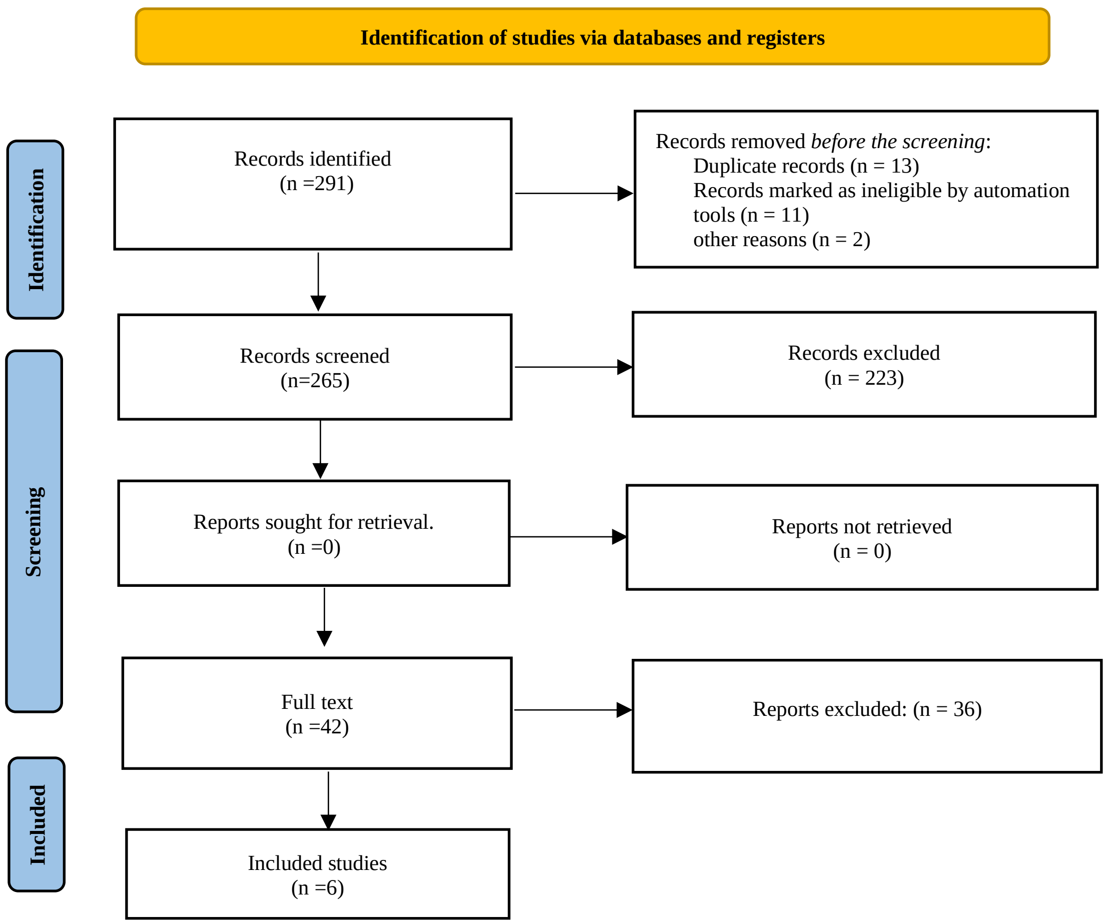

Fig. 1. PRISMA 2020 Checklist.

Study characteristics

In the present study, 300 samples were split into two groups: the intervention group based on the concentration of ZrO2 nanoparticles and the control group without adding ZrO2 nanoparticles. Different concentrations of ZrO2 nanoparticles (0.5, 1, 2.5, 3, and 5 wt% ZrO2 nanoparticles) were used in the studies. The International Organization for Standardization (ISO) 20795-1:2008.40[6, 13] and (ISO) 10477:2018[18] were followed for creating the specimens, which called for the usage of specialized 60×10×3.3-mm[6, 13] 2.5×2×2 mm,[18] and 2×3×20 mm[19] split press metal molds. A 3-point bend test evaluated all studies that included the flexural strength of the samples. Table 1 reports the extracted data.

Bias assessment

All studies received a score of 3, indicating a weak risk of bias. The parts on blinding and evaluation methodologies in every study were of low quality. Blinding and assessment methods sections (Tables 2 and 3).

Flexural strength

The mean difference of flexural strength between 0.5-ZrO2 and the control group was 24.07 (MD; 95 CI (20.72, 27.42), $p<0.05$) ($I2=0.00\%$). Fig. 2 shows a substantial difference between the control group and the 0.5-ZrO2 ($p=0.00$). Including a small amount of ZrO2 (0.5 wt%) substantially raised the PMMA pristine interim restorative material's flexural strength values.

Table 1. Extracting important data from selected studies for meta-analysis.

Study. Years	Study Design	Sample Size	Nanoparticles Size (nm)	Specimens Dimension (mm)	Intervention Group	Control Group	Standard	Flexural Strength Assessment
Jehan et al., 2022[18]	In-vitro	160	30-50	2.5×2×2	2.5% ZrO2, 2.5% TiO2,2.5% Al2O3 nanoparticles	Without added nanoparticles	(ISO) 10477:2018	Three-point bending test
Alrahlah et al., 2022[19]	In-vitro	60	<100 nm	2×3×20	0.5, 1.5, and 3.0 wt% ZrO2 and TiO2	Without added nanoparticles	NR	Three-point bending test
Alshahrani et al., 2021[13]	In-vitro	40	40	60×10×3.3	1, 2.5, and 5 wt% ZrO2 nanoparticles	Without added ZrO2 nanoparticles	(ISO) 20795-1:2008.40	Three-point bending test
Alhavaz et al., 2017[6]	In-vitro	40	15	60×10×3.3	1, 2.5, and 5 wt% ZrO2 nanoparticles	Without added ZrO2 nanoparticles	(ISO) 20795-1:2008	Three-point bending test

ZrO2: zirconium dioxide; TiO2: Titanium; Al2O3: Aluminum oxide.

Table 2. Quality of the studies that were included.

Study. Years	Item Grade													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jehan et al., 2022[18]	√	√	√	√	×	√	√	×	×	√	×	√	×	×
Alrahlah et al., 2022[19]	√	√	√	√	√	√	√	×	×	√	√	√	×	×
Alshahrani et al., 2021[13]	√	√	√	√	×	√	×	×	×	√	√	√	×	×
Alhavaz et al., 2017[6]	√	√	√	√	√	√	√	×	×	√	√	√	×	×

Table 3. Risk assessment.

Study. Years	Allocation Concealment	Sample Size	Blinding	Assessment Methods	Selective Outcome Reporting	Score	Risk of Bias
Jehan et al., 2022[18]	1	0	2	0	0	3	Low
Alrahlah et al., 2022[19]	1	0	2	0	0	3	Low
Alshahrani et al., 2021[13]	1	0	2	0	0	3	Low
Alhavaz et al., 2017[6]	1	0	2	0	0	3	Low

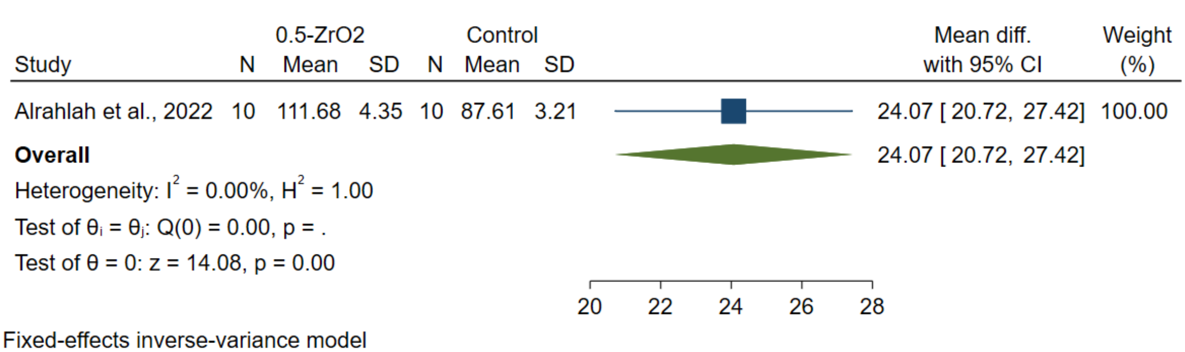

Fig. 2. The forest plot showed Mean differences in deviation flexural strength of pure PMMA (control) and 0.5-ZrO2.

The mean difference in flexural strength between 1-ZrO2 as well as the control group has been 4.89 (MD; 95 CI (2.65, 7.14), p<0.05) (I^2=92.16 %; high heterogeneity). Fig. 3 shows a substantial difference between the 1-ZrO2 (p=0.00) and control group. Including ZrO2 (1 wt%) substantially raised the PMMA pristine interim restorative material's flexural strength values. The 1-ZrO2 group exhibited high flexural strength.

The mean difference of flexural strength between 2.5-ZrO2 and the control group has been 5.03 (MD; 95 CI (2.65, 7.14), p<0.05) (I^2=95.28 %; high heterogeneity). Fig. 4 shows a substantial difference between the control group and the 2.5-ZrO2 (p=0.00). Including ZrO2 (2.5 wt%) substantially raised the PMMA pristine interim restorative material's flexural strength values. Flexural strength had a high value of 2.5%.

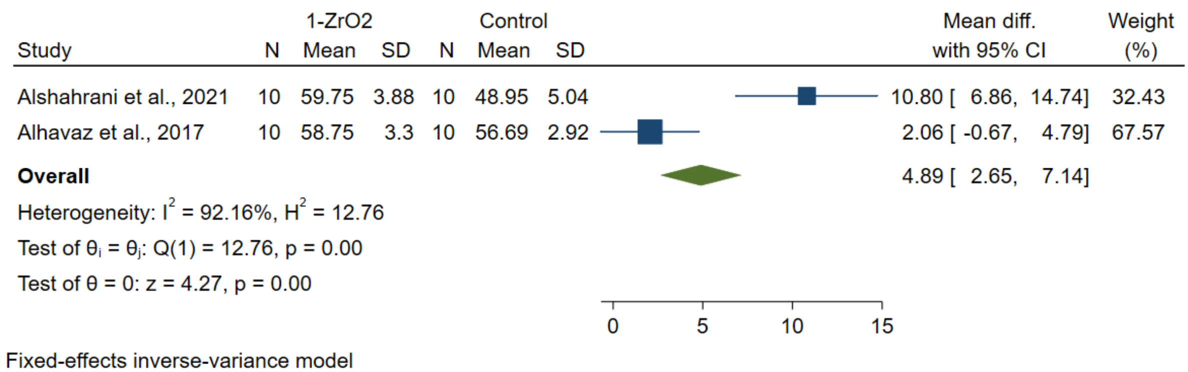

Fig. 3. The forest plot showed Mean differences in deviation flexural strength of pure PMMA (control) and 1-ZrO2.

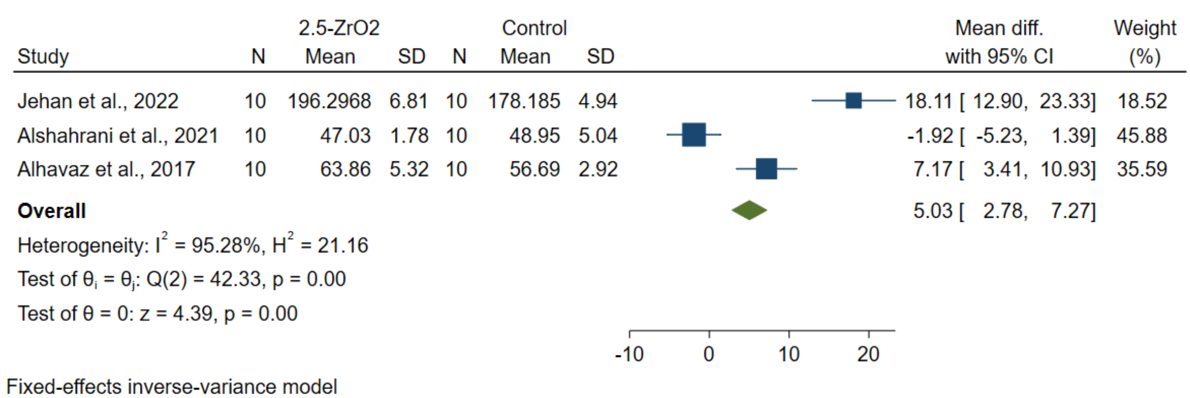

Fig. 4. The forest plot showed Mean differences in deviation flexural strength of pure PMMA (control) and 2.5-ZrO2.

The mean difference of flexural strength between 3-ZrO2 and the control group was 3763.67 (MD; 95 CI (3694.22, 3833.12), p<0.05) (I^2=0.00%). Fig. 5 shows a substantial difference between the 3-ZrO2 (p=0.00) and the control group. Flexural strength significantly dropped when the ZrO2 filler content was increased to 3.0 wt%.

The mean difference in flexural strength between 5-ZrO2 and the control group has been 0.14 (MD; 95 CI (-2.51, 2.80), p>0.05) (I^2=86.20%; high heterogeneity). Fig. 6 (p=0.92) demonstrates no discernible difference between the control and 5-ZrO2 groups. Flexural strength has been lowest in the 5-ZrO2 group.

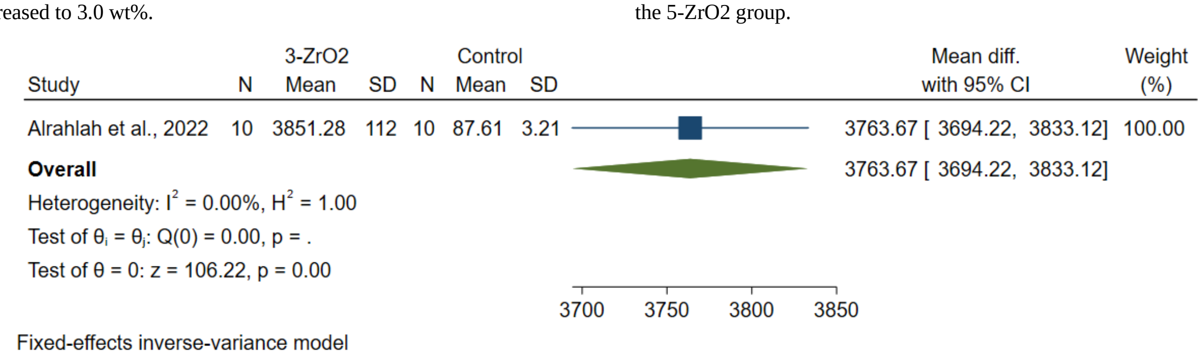

Fig. 5. The forest plot showed Mean differences of deviation flexural strength of pure PMMA (control) and 3-ZrO2.

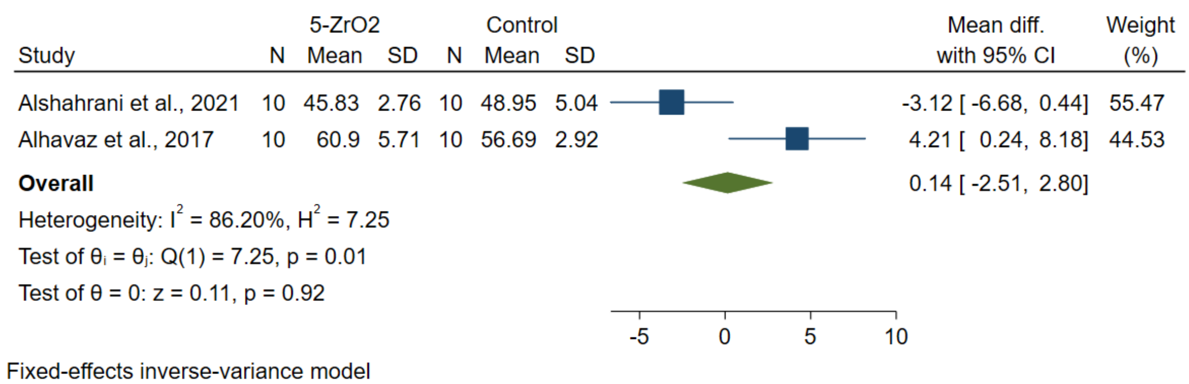

Fig. 6. The forest plot showed Mean differences in deviation flexural strength of pure PMMA (control) and 5-ZrO2.

4. Discussion

This work is the very first systematic review and meta-analysis research that, to our knowledge, has looked at how ZrO2 nanoparticles affect PMMA's flexural strength for interim fixed restorations. Fixed interims are very important in complete oral rehabilitation. A fixed interim helps protect periodontal and pulpal tissues, prevents primary teeth migration, and maintains adequate occlusal plan and mandibular relationships.[20] The most often used substances of interim restorations are PMMA, 2-polymethyl methacrylate (PEMA) resin, 5-visible light-cured urethane dimethacrylate, and 3-polyvinyl methacrylate resin.[21] Zirconium oxide nanoparticles were widely used as a nanofiller to strengthen dental materials. Studies have shown that different concentrations of zirconium oxide, the type of acrylic resins, and the size of nanoparticles can improve the mechanical properties or have no significant effect.[22, 23] Surface-modified or unmodified nanoparticles can be added to resins; studies have shown that both nanoparticles (modified and unmodified) can significantly enhance the characteristics of acrylic resins.[23] Based on the study's findings, combining nanoZrO2 and fibers can improve the flexural strength of PMMA.[24] According to the current meta-analysis, an intermediate restorative material based on PMMA that was filled with a tiny amount of ZrO2 (0.5, 1, 2.5 wt%) considerably increased flexural strength. Flexural strength reduced when ZrO2 nanoparticle concentration rose, even though the greater concentration of these fillers (ZrO2 (3.5 wt%)) did not improve flexural strength. According to the research outcomes, integrating nanoparticles in dental biomaterials can show promising results in improving flexural strength.[7, 11, 25, 26] The utilization of ZrO2 nanoparticles gives helpful insights for therapeutic applications, in accordance with the results of this study; ZrO2 nanoparticles in low concentrations can strengthen the flexural strength of interim fixed restoration. This same effect can facilitate long-lasting temporary restorations. These encouraging outcomes are anticipated to influence individuals needing long-term interim restorations majorly. Among the limitations of the current work, one can mention the following: The results of the current study should be regarded cautiously because of the significant heterogeneity among trials. Although reinforcing with low ZrO2 nanoparticle concentrations was successful, care should be taken when interpreting the findings. This heterogeneity can be associated with the method of the study. Also, Since all of the chosen research was conducted in vitro, it is important to consider intra-oral factors that may impact the outcomes, such as salivary flow, temperature variations, occlusal function, and oral hygiene practices. Liquids in the testing environment might cause the acrylic resin to absorb them, changing the material's mechanical characteristics. Also, the age of the patients can affect the final results. Therefore, it is suggested that in future studies, the comparison of different materials and techniques used to make temporary materials should be considered.

5. Conclusion

The current meta-analysis shows that flexural strength may be statistically substantially boosted by mixing ZrO2 nanoparticles into PMMA at low concentrations. The highest flexural strength value was related to specimens reinforced with 0.5, 1, and 2.5-wt% ZrO2 nanoparticles. In accordance with the results of this investigation, strengthening PMMA with ZrO2 nanoparticles in low concentrations can increase the overall performance of temporary fixed restorations.

Conflict of Interest

The authors declared that there is no conflict of interest.

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