Antimicrobial and Mechanical Effects of Zeolite Use in Dental Materials: A Systematic Review

Antimikrobni i mehanički učinci upotrebe zeolita u dentalnim materijalima: sistematizirani pregledni rad

Abstract

Objective: Ion-incorporated zeolite is a widely used antimicrobial material studied for various dental applications. At present, there is no other systematic review that evaluates the effectiveness of zeolite in all dental materials. The purpose of this study was to review all available literature that analyzed the antimicrobial effects and/or mechanical properties of zeolite as a restorative material in dentistry. Material and methods: Following PRISMA guidelines, an exhaustive search of PubMed, Ovid Medline, Scopus, Embase, and the Dentistry & Oral Sciences Source was conducted. No language or time restrictions were used and the study was conducted from June 1, 2020 to August 17, 2020. Only full text articles were selected that pertained to the usage of zeolite in dental materials including composite resin, bonding agents, cements, restorative root material, cavity base material, prosthesis, implants, and endodontics. Results: At the beginning of the study, 1534 studies were identified, of which 687 duplicate records were excluded. After screening for the title, abstract, and full texts, 35 articles remained and were included in the qualitative synthesis. An Inter-Rater Reliability (IRR) test, which included a percent user agreement and reliability percent, was conducted for each of the 35 articles chosen. Conclusion: Although ion-incorporated zeolite may enhance the antimicrobial properties of dental materials, the mechanical properties of some materials, such as MTA and acrylic resin, may be compromised. Therefore, since the decrease in mechanical properties depends on zeolite concentration in the restorative material, it is generally recommended to add 0.2-2% zeolite by weight.

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Introduction

Zeolite, an aluminosilicate with a tetrahedral crystalline structure, has extensive ranging from ecology to dentistry (1, 2). Zeolite is particularly useful to these fields due to its unique porous structure, which creates negatively charged channels and cavities that can hold cations, hydroxyl groups, and water molecules (1). Recently, zeolite’s ability to uptake and release ions, combined with its superior biocompatibility and long-lasting effects, has increased the attention on the compound in dental research (2).

In addition to solely adding zeolite to materials, many studies in dentistry have attempted to combine zeolite with inorganic antimicrobial ions, such as silver and zinc, for controlled release (2). Particularly, most of the studies focus on silver-incorporated zeolite (AgZ) since zeolite has a strong affinity for silver ions. In addition, silver ions are less toxic to bacterial properties of dental materials, the mechanical properties of some materials, such as MTA and acrylic resin, may be compromised. Therefore, since the decrease in mechanical properties depends on zeolite concentration in the restorative material, it is generally recommended to add 0.2-2% zeolite by weight.

Zeolit, alumosilikat s tetraedrskom kristalnom strukturom ima široku primjenu – od ekologije do stomatologije (1, 2). Zeolit je posebno koristan za ta područja zbog jedinstvene porozne strukture koja stvara negativno nabijene kanale i šupljine u kojima se mogu naći kationi, hidroksilne skupine i molekule vode (1). Odnedavno se, zbog svojstva zeolita da apsorbira i oslobađa ione, u kombinaciji s njegovom odličnom biokompatibilnošću i dugotrajnim učincima, poveća zanimanje za taj sop u stomatološkim istraživanjima (2).

Už dodavanje samo zeolita u materijale, u mnogim ga se istraživanjima pokušalo kombinirati s anorganskim antimikrobnim ionima poput srebra i cinka za kontrolirano otpuštanje (2). Autori većine istraživanja posebno se usredotočuju na zeolit sa srebrom (AgZ) jer zeolit ima jak afinity prema ionima srebra. Uz to, ioni srebra manje su toksični za ljudska

Uvod

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human tissues than other metallic ions, such as copper and mercury (3,4). When cations become available in the surrounding oral environment, zeolite exchanges the environmental cation with its embedded silver ions. This, in turn, only occurs with the presence of moisture and until the silver concentration meets the local equilibrium value. Therefore, AgZ may offer targeted and controlled release of antimicrobial ions in the oral microbiome (5).

Furthermore, ion-embedded zeolite may serve as a potential antimicrobial agent towards pathogenic oral microorganisms. When ions released from zeolite encounter specific oral microbes, it may hinder their development by causing the inactivation of key enzymes, interruption of RNA replication, and blockage of microbial respiration (5). Therefore, incorporation of cations into zeolite may potentially decrease oral bacterial growth when added to dental materials.

When zeolite is incorporated into dental materials for antimicrobial effect, it is also important to consider the effect on the mechanical properties of the material. Common activities such as mastication and speech exert forces on teeth and materials incorporated into dentition. Thus, it is critical to the efficacy of dental operations if the materials used can withstand these forces without compromising their strength. Properties imperative to the success of long-term dental operations include flexural strength, bond strength to tooth structure, compressive strength, setting time, and surface microhardness (6). If zeolite can be incorporated into dental materials without hindering their mechanical properties, there can be a potential reduction in oral infections while reducing failures of dental restorations.

In this systematic review, the antimicrobial and mechanical properties of zeolite in different branches of dentistry such as endodontics, prosthetics, implantology, and restorative dentistry are analyzed. Specifically, the available literature was reviewed to determine if adding silver (or zinc) zeolite to dental materials would increase the antimicrobial effectiveness without inhibiting the strength and hardness of materials. The aim of this systematic study was to review both in vitro and in vivo studies that evaluated the antimicrobial effects and mechanical properties of zeolite as a material in dentistry.

Material and Methods

Literature search strategy

An exhaustive search of PubMed, Ovid Medline, Scopus, Embase, and the Dentistry & Oral Sciences Source was conducted between June 1, 2020 and August 17, 2020. All published studies within the databases were screened for eligibility. There were no limitations set on the year or language of the publication. A controlled vocabulary was used (MeSH terms in Pubmed, Subject Headings in Ovid Medline, Emtree terms in Embase) across all databases as well as a search for free terms in the titles and abstracts. The grey literature search was conducted through ProQuest Dissertations & Theses Global and Trip Database. The searches through the electronic databases were separately completed by two authors (J.H. and S.L.). The following search terms were used: MeSH terms: “zeolites”, “biomedical and dental materials”, tkiva od ostalih metalnih iona poput bakra i žive (3, 4). Kad kationi postanu dostupni u okolnom oralnom okružju, zeolit mijenja te katione za ugrađene ione srebra. To se, pak, događa samo uz prisutnost vlage i sve dok koncentracija srebra ne dostigne lokalnu vrijednost ravnoteže. Zato AgZ može osigurati ciljano i kontroliрано oslobađanje antimikrobičkih iona u oralnom mikrobiomu (5).

Nadalje, zeolit s ugrađenim ionima može poslužiti kao antimikrobrovo sredstvo za patogene oralne mikroorganizme. Kada ioni oslobodeni iz zeolita nađu na određene mikroorganizme iz oralnoga mikrobiomu, mogu utezati njihov razvoj i prouzročiti inaktivaciju ključnih enzima, prekid replikacije RNK i blokadu mikrobrovog disanja (5). Zato ugradnja katio na u zeolit može smanjiti rast oralnih bakterija ako se dodaju u dentalne materijale.

Kada se zeolit dodaje u dentalne materijale radi antimikrobrovnog učinka, također je važno uzeti u obzir učinak na mehanička svojstva materijala. Uobičajene aktivnosti, poput žvakanja i govora, čine silu na zube i oralne materijale. Za to je prestudialo da upotrijebljeni materijali mogu podnijeti tu silu bez ugrožavanja integriteta. Svojstva nužna za dugo ročni uspjeh nadomjestaka uključuju savojnu čvrstoću, veznu čvrstoću sa zubnom strukturu, tačnu čvrstoću, vrijeme stvrdnjava i mikrotvrdoću površine (6). Ako se zeolit može ugraditi u dentalne materijale, a da se pritom ne poreme te njihova mehanička svojstva, mogu se potencijalno smanjiti oralne infekcije, uz istodobno smanjenje oštećenja na zubnim nadomjestcima.

U ovom sistemiziranom preglednom radu analiziraju se antimikrobrona i mehanička svojstva zeolita u različitim granama stomatologije, poput endodontskih zahvata, protetike, implantologije i restaurativne stomatologije. Točnije, pregledana je objavljena literatura kako bi se utvrdilo hoće li dodavanje zeolita sa srebrom (ili cinkom) dentalnim materijalima povećati antimikrobrovu učinkovitost bez inhibiranja čvrstoće i tvrdoće materijala. Cilj ovog istraživanja bio je pregledati istraživanja in vitro i in vivo u kojima su autori procjenjivali antimikrobrovnu učinku i mehanička svojstva zeolita kao materijal u stomatologiji.

Materijali i metode

Strategije pretraživanja literature

Ovaj sustavni pregled proveden je u skladu sa smjernicama PRISMA-e (Preferred Reporting Items for Systematic Reviews and Meta-Analyses – Preferirane stavke izvještavanja za sustavne pregledne radove i metaanalize), tablica 1.

Obavljena je iscrpna pretraga baza PubMed, Ovid Medline, Scopus, Embase te Dentistry i Oral Sciences Source između 1. lipnja i 17. kolovoza 2020. Sva objavljena istraživanja u bazama podataka provjerena su kako bi se utvrdilo ispunjavaju li uvjete za uključivanje. Nisu postavljena ograničenja za godinu ili jezik izdavanja. U svim bazama podataka koji su korišteni za istraživanje su sastavnički uključeni u MeSH-u u PubMedu, Subject Headings u Ovid Medlineu, Emtree u Embaseu i slovobodni pojmovi u naslovima i sažetcima. Pretraživanje sive literature provedeno je u bazama ProQuest Dissertations and Theses.
Eligibility Criteria

Studies that pertained to the usage of zeolite in dental materials such as composite resin, bonding agents, cements, restorative root material, cavity base material, prosthesis, implants, and endodontics were included in this systematic review. In addition, only full texts were selected for inclusion. Zeolite used in oral rinses or oral medicaments was excluded as well as those studies pertaining to tissue conditioners. Literature reviews and abstracts were excluded to meet the full-text-only eligibility criteria.

Screening and Selection

The studies that were collected were screened independently by two researchers (J.H. and S.L.) for titles and abstracts that met the identified inclusion criteria. Differences in opinions were discussed between the two researchers until a consensus was reached. Following the discussion, the two reviewers separately screened the selected full texts for eligibility. Disagreements were discussed until a consensus was reached. Due to the COVID-19 pandemic, the numbers of active libraries were smaller than normal. Therefore, with all resources exhausted, the full texts of 3 chosen articles were still unable to be procured and included in the analysis portion of the systematic review. At last, the references of the selected articles were reviewed, and eligibility was determined based on the inclusion criteria. Disagreements were resolved between the two reviewers and discussions with a mentor (F.O.).

Data Extraction

Prior to data extraction, a protocol was agreed upon by two of the authors (J.H. and S.L.). Data were then extracted from the selected full text articles and organized on an excel sheet. The two authors extracted the data including authors, publication year, type of study, antimicrobial/mechanical properties, sample size, materials used, results, microbes tested, and risk of bias, Table 1, Table 2.

Assessment of Risk of Bias of Reviewed Papers

For in vitro studies and randomized control trials, the risk of bias assessment was considered based on a previous study Global and Trip Database. Pretrage elektroničkih baza podataka odvojeno su provela dva autora (J. H. i S. L.). Korišteni su sljedeći pojmovi za pretraživanje: MeSH pojmovi: zeolit, biomedicinski i dentalni materijali, kavitetne podloge, smolasti cementi, zubni cementi, zubna restauracija – trajna, zubna restauracija – privremena, kompozitne smole, keramika, dentalna keramika, zubne ljuske, proteze, akrilatna smola; Subject Heading: zubni cementi, kavitetne podloge, smolasti cementi, zubna restauracija – trajna; kompozitna smola, keramika, dentalna keramika, zubne ljuske, proteze, akrilatna smola; Emtree Terms: dental materials, “resin cement”, “dental cavity lining”, “dental cements”, “dental restoration, permanent”, “dental restoration, temporary”, “composite resin”, “ceramics”, “dental porcelain”, “dental veneers”, “dentes”, “acrylic resin”; Free Terms: “dental cavity lining”, “resin cements”, “dental cements”, “dental cavity lining”, “resin cements”, “dental restoration, permanent”; “composite resin”, “ceramics”, “dental porcelain”, “dental veneers”, “dentes”, “acrylic resin”;

Kriteriji prihvatljivosti

Istraživanja koja su se odnosila na upotrebu zeolita u dentalnim materijalima kao što su kompozitne smole, adheziv, cementi, korijenski materijali, kavitetne podloge, materijali za protetiku, implantologiju i endodonciju uključena su u ovaj sistematizirani pregled. Odabrani su samo cjeloviti tekstovi. Izuzeti su zeoliti koji se u potrebnim situacijama koriste za ispiranje ili za oralne lijekove te oni koji se primjenjuju u regeneraciji tkiva. Recenzije literature i sažeti su izuzeti.

Pregled i odabir

Dva istraživača (J. H. i S. L.) neovisno su pregledala prikupljena istraživanja prema naslovima i sažetcima koji su zadovoljavali utvrđene kriterije za uključivanje. U slučaju neslaganja razgovarali su o razlikama u mišljenju dok nisu postigli konsenzus. Nakon završene rasprave dva recenzenta odvojeno su pregledala odabrane cjelovite tekstove kako bi ustanovili ispunjavaju li uvjete. O nesuglasnicima su raspravljali dok nije postignut konsenzus. Zbog pandemije virusa COVID-19 broj knjižnica koje rade bio je manji od uobičajenog. Stoga, nakon što su svi resursi iscrpljeni, cjeloviti tekstovi triju odabranih radova nisu bili dostupni te se nisu mogli uključiti u dio analizi ovoga sustavnoga preglednog rada. Na kraju je pregledana literatura odabranih radova i utvrđena je prihvatljivost na temelju kriterija za uključivanje. Riješene su nesuglasnice između dvaju recenzenta i obavljen je razgovor s mentorom (F.O.).

Vraćenje podataka

Prije vraćenja podataka, dva autora (J. H. i S. L.) dogovorila su protokol. Podatci su zatim izvučeni iz odabranih radova s cjelovitim tekstom i organizirani na Excel tablici. Zatim su izdvojeni podatci, uključujući autore, godinu izdanja, vrstu istraživanja, antimikrobna/mehanička svojstva, veličinu uzorka, upotrijebljene materijale, rezultate, testirane mikrobe i rizik od pristranosti, tablica 1, tablica 2.

Procjena rizika od pristranosti pregledanih radova

Za randomizirana kontrolirana istraživanja in vitro provedena je procjena rizika od pristranosti na temelju prethodnog
For each parameter I-IV, a score of 0 was given to an article if the criteria were reported clearly, a score of 1 was given to an article if the criteria were vague or insufficiently reported, and a score of 2 was given to an article if the information was not present. For parameter V, a score of 0 was given to an article if there was one operator, a score of 1 was given to an article if there were more operators, and a score of 2 was given to an article if the information was not present.

The five parameter scores for each article were then added for a cumulative score. Articles that were at low risk of bias were scored between 0-3, moderate risk of bias scored between 4-7, and high risk of bias scored between 8-10. Two authors (J.H. and S.L.) independently assessed the risk of bias criteria for each article in duplicate, and any disagreements during the evaluation were later discussed and a consensus was reached.

Inter-Rater Reliability (IRR)

An Inter-Rater Reliability (IRR) test within the risk of bias test was conducted using a kappa calculator. Percent user agreement was calculated by taking the number of studies given the same risk of bias scores by both authors and dividing it by the total number of studies. The same risks of bias were considered in order to use the Cohen’s Kappa test (8), and the resulting kappa values are reported, Table 2. To obtain the percent data that are reliable, the kappa values were squared. From these percentages, a level of agreement was described for each parameter (8).

Results

Search and Selection

The selection process is summarized in the Prisma Flow Chart shown in Figure 1 following Moher et al. (9). A database, grey literature, and reference search yielded 1534 studies, of which 687 duplicate records were excluded. The remaining 847 records were screened for title and abstract, and 801 were removed since they did not meet the eligibility criteria. 46 remaining articles were assessed for eligibility by examining the full-texts, and 11 articles did not meet the eligibility criteria and were therefore excluded. Of the remaining 35 articles included in the qualitative synthesis, 17 studied antimicrobial effects, 12 studied mechanical properties, and 6 studied both properties, Table 1.

Risk of Bias Test of the Studies in the Systematic Review

Supplementary [S3 Table] shows the risk of bias data of the 35 articles analyzed following the methods outlined by Astudillo-Rubio et al. (7). As shown in the table, the majority of papers were given a score of 2 by both authors in the “blinding operator” and “single operator” parameters for failing to provide any pertinent information. All studies had a moderate risk of bias except three studies with low, and one study with high risk of bias (9-15). The study with a high risk of bias score failed to use a control and did not reveal any
Inter-rater Reliability Results

The results of IRR tests for each risk of bias parameter are shown in Table 2. All parameters showed at least 74% or higher in percent user agreement and the average percent user agreement across all five parameters was 89.06%. The average percent of data that are reliable, as determined by Cohen’s Kappa Test, is 46.6%, indicating an overall moderate level of reliability. Because the risk of bias test included 3 different possible scores, the discrepancies between authors were due to whether the parameters in question were clearly specified in the studies. Therefore, most of the score differences were due to one author judging an article as clearly reporting the parameter, while the other author judged the article

Rezultati pouzdanosti između ocjenjivača

Rezultati IRR testova za svaki parametar rizika od pristranosti prikazani su u tablici 2. U svim je parametrima postignut postotak od najmanje 74 % ili podudarnost među ocjenjivačima, a prosječni postotak podudarnosti u svih pet parametara bio je 89,06 %. Prosječni postotak pouzdnih podataka, kako je utvrđeno Cohenovim Kappa testom, iznosio je 46,6 %, što upućuje na ukupno umjerenu razinu pouzdanosti. Budući da je test pristranosti obuhvaćao tri različita moguća rezultata, neslaganja između ocjenjivača nastala su uvisno o tomu jesu li parametri jasno navedeni u istraživanjima. Zato je većina razlika nastala zato što je jedan autor ocijenio da se u radu jasno navodi traženi parametar, a drugi je
| Author, Year | Type of Study | Material Used | Results | Microbes Tested |
|--------------|---------------|---------------|---------|-----------------|
| Saengmee-Anupharb et al [10] (2013) | In vitro | AgZ, AgZrPSi, AgZrP | All inorganic materials with silver had antimicrobial effects. | S. mutans, L. casei, C. albicans, S. aureus |
| Cinar et al [14] (2008) | In vitro | GIC (Endion), AgZ | AgZ increased the antimicrobial effects. | S. milleri, S. aureus, E. faecalis |
| Can-Karabulut et al [21] (2010) | In vitro | GIC, zeolite, bone hydroxyapatite, provisional cement | Bond strength decreased with zeolite in cement. | N/A |
| Chung et al [20] (2001) | RCT | Ketac-Endo, KT-308, ZUT | ZUT and KT-308 showed highest bond strength. | N/A |
| Ghatole et al [28] (2016) | In vitro | MTA, AgZ, CHX | MTA with AgZ showed the greatest efficacy against E. faecalis. | E. faecalis, S. aureus, C. albicans |
| Ghivari et al [25] (2017) | In vitro | Na Hypochlorite, Octenidine, AgZ | AgZ showed the least antimicrobial effectiveness. | E. faecalis, S. aureus, C. albicans |
| Horta et al [3] (1998) | In vitro | Ag-Zn-Zeolite, SiO2 filler and urethane acrylate paste | Ag-Zn-Ze inhibited S. mutans and S. mitis but not S. salivarius or S. sanguis. | S. mutans, S. mitis, S. salivarius, S. sanguis |
| Kawahara et al [4] (2000) | In vitro | Zeomic, AgZ | AgZ inhibited microbial growth under anaerobic conditions. | P. gingivalis, actinomycetemcomitans, S. mutans, A. viscosus, S. aureus |
| Kiro et al [16] (2016) | In vitro | CHX-loaded zeolite nanoparticles, GIC | GIC + CHX/Zeolite inhibited S. mutans. No decrease in compressive or bond strength | S. mutans |
| Kuroki et al [37] (2010) | In vitro | self-cured acrylic resin (UNIFAST III), zeomic, bactekiller, novaron | Adding zeomic decreased S. mutans | S. mutans |
| Lee et al [13] (2007) | In vitro | Zeomic, GIC | Zeomic improved antimicrobial properties. Below 3% wt retained compressive strength. | S. mutans |
| Li et al [23] (2020) | RCT | EMT nano-zeolites, silver ions, dental adhesive (ASRB2) | Inhibited biofilm growth/attachment. | S. mutans, S. gordonii, S. sanguinis |
| Mabrouk et al [15] (2013) | In vitro | MTA powder, 2% Ag-Zn-Ze composite | MTA with 2% Ag-Zn-Ze decreased push-out bond strength. | N/A |
| Padachey et al [18] (2000) | In vitro | GIC, gutta percha, ZUT | ZUT was not more effective than GIC. But gutta percha improved the resistance to bacterial ingress. | E. faecalis |
| Partozar et al [11] (2019) | In vitro | nano-ZnO zeolite, ZnO zeolite | NanoZnO/zeolite was effective in inhibiting E. faecalis biofilm | E. faecalis |
| Cinar et al [29] (2013) | In vitro | MTA powder, AgZ | Adding AgZ to MTA didn't decrease physio-chemical properties. | N/A |
| El-Guindy et al [24] (2010) | In vitro | Rely X Unicem, G bond, ZnZ | Pretreatment of dentin with G bond and ZnZ increased bond strength between dentin/alloy. | N/A |
| Ghasemi et al [30] (2019) | In vitro | MTA powder, 2% Ag-Zn-Ze composite | MTA with 2% Ag-Zn-Ze decreased push-out bond strength. | N/A |
| Ghatole et al [26] (2016) | In vitro | Calcium hydroxide, AgZ, 2% CHX | AgZ in calcium hydroxide increased antimicrobial activity | E. faecalis |
| Casemiro et al [40] (2008) | In vitro | Microwave-polymerized acrylic resin, Heat-polymerized resins, AgZ | Acrylic resin with Ag-Zn-Ze increased antimicrobial effects. | C. albicans and S. mutans |
| Malic et al [38] (2019) | In vitro | Dental acrylics, AgZ, Na-zeolite | Adding zeolite to dental acrylics increased antimicrobial effect. | S. mutans, E. nucleatum, C. albicans |
| Authors                    | Type          | Group                        | Material                          | Effect                                                                                           | Ref.          |
|----------------------------|---------------|------------------------------|-----------------------------------|--------------------------------------------------------------------------------------------------|---------------|
| Odabas et al [27] (2011)   | In vitro A    | 5 per group                  | AgZ, MTA                          | MTA with zeolite increased antimicrobial effects except against P. intermedia and A. israelii.   |               |
| Patel et al [17] (2000)    | In vitro A    | 108 per group                | KT-308, Zeomic                    | Regardless of concentration, all ZUT inhibited E. faecalis at 15 hours.                          | E. Faecalis   |
| Sandomierski et al [22] (2019) | In vitro M  | 10 per material              | Zeolite filler, diazonium cation methacrylic resin-based composite | Diazonium-modified zeolite fillers improved compressive and flexural strength.             | N/A           |
| Saravanav et al [32] (2015) | In vitro A    | 30 patients                  | AgZ, soft liners                  | Soft liner with AgZ inhibited bacterial growth.                                                   | c. albicans, gram negative bacteria |
| Tamanai-Shacoor et al [12] (2014) | In vitro B  | 3 per group                  | AgZ, ASCOP                        | AgZ with ASCOP inhibited P. gingivalis but not S. gordonii growth.                               | P. gingivalis, S. gordonii |
| Naji et al [34] (2017)     | In vitro M    | 10 per group                 | Sodalite, alumina, ZTA, glass     | Sodalite-infiltrated ceramics had higher shear bond strength than glass-infiltrated.           | N/A           |
| Naji et al [35] (2018)     | In vitro M    | 20 per group                 | KBr-Sodalite, porous alumina, ZTA | Increasing sintering temp of SOD-ZTA/A increased hardness and bond strength.                  | N/A           |
| Naji et al [33] (2016)     | In vitro M    | 10 per group                 | sodalite, zeolite-infiltrated alumina (IA-SOD), ZTA, glass | Sodalite-infiltrated ZTA had increased fracture toughness.                                     | N/A           |
| Naji et al [36] (2016)     | In vitro M    | 10 per group                 | Sodalite, alumina, ZTA, glass     | Sodalite infiltrated alumina and ZTA were in the acceptable range of hardness and flexural strength. | N/A           |
| Yadav et al [41] (2015)    | In vitro M    | 10 per group                 | Fluconazole, CHX Gluconate, Ag-Zn-Ze, PMMA | Flexural strength decreased significantly                                                     | N/A           |
| Nakanoda et al [39] (1995) | In vitro B    | 4 per group                  | Zeomic, acrylic resin             | Tensile and bending strength decreased in zeolite containing resin,                           | C. albicans   |
| Samiei et al [31] (2017)   | In vitro M    | 15 per group                 | MTA, 2% Ag-Zn-Ze                  | Mixing MTA with 2% Ze-Ag-Zn decreased compressive strength.                                     | N/A           |
| Wang et al [42] (2011)     | In vitro A    | 3 per material               | Titanium alloy, AgZ, ZTA, AgZ titanium alloy | Zeolite coating on implant reduced bacterial growth.                                              | S. aureus     |
| McDougall et al [19] (1999) | In vitro A    | 10 per group                 | ZUT, Kerr scaler, KT-308, gutta percha | E. faecalis penetration increased in canals filled with ZUT                                      | E. faecalis   |

Abbreviations: N/S: Not Stated; N/A: Not Applicable; A: Antimicrobial; M: Mechanical; B: Both Antimicrobial and Mechanical; PMMA: Polymethylmethacrylate; ZTA: Zirconium Toughened Alumina; AgZ: Silver-Incorporated Zeolite; ZnZ: Zinc-Incorporated Zeolite; Ag-Zn-Ze: Silver-Zinc-Incorporated Zeolite; MTA: Mineral Trioxide Aggregate; GIC: Glass Ionomer Cement; CHX: chlorhexidine; ZUT: AgZ with KT-308 GIC; Zeomic: a synthetic AgZ; ASCOP: polyphenol-rich extract of A. nodosum
as vaguely or insufficiently reporting the parameter. This was highlighted with the sample size parameter, in which the authors initially disagreed on whether the details surrounding the sample size were elaborated sufficiently. Another parameter with a low level of agreement was the standardized sample preparation. The disagreements among the authors regarding this parameter were explained by the variability in extent to which each article specifically stated that they conducted a standardized procedure. All disagreements were resolved after discussion among the authors.

Discussion

Thirty-five in vitro studies and randomized control trials were evaluated to assess the effects of zeolite on the antimicrobial and/or mechanical properties of dental materials. Generally, zeolite itself had little to no effect on antimicrobial properties unless there was an incorporation of ions such as silver or zinc. In addition, ion-incorporated zeolite exhibited prolonged ion release and can serve as a long-term antimicrobial material (4, 10-12). The present systematic review evaluates such properties by grouping the literature into four major categories based on the type of dental material tested: dental restorations, endodontics, prosthetics, and implants.

Dental Restorations

Regarding dental restorative materials, zeolite was generally combined with glass ionomer cements (GIC), resin cements, or bonding agents (3, 13-23).

Glass Ionomer Cement

When an ion-incorporated zeolite was combined with GIC, the antimicrobial effects were usually measured by an in vitro ion release profile or an agar diffusion test. As the ratio of AgZ by weight was increased, the inhibitory effect towards oral bacteria such as S. mutans would also increase (13). Similarly, 2% AgZ had the greatest antimicrobial properties against S. milleri, S. aureus, and E. faecalis compared to 0.2% and 0% AgZ (14). It is important to note that while GIC alone can only provide a rapid release of fluoride for two days, AgZ GIC can provide sustained release of silver ions for long periods of time (13). Similar antimicrobial results to AgZ can also be found in zinc-incorporated zeolite (ZnZ) against E. coli, S. aureus, P. aeruginosa, B. subtilis, and C. albicans (15). In addition, zeolite in GIC can also have effective antimicrobial properties against S. mutans when it is loaded with chlorhexidine (16). For GIC used as root canal sealers, KT-308, inhibited E. faecalis growth significantly more than KT-308 alone, regardless of concentration and time (17). On the other hand, Padachey et al. and McDougall et al. both concluded that ZUT was not more effective than the other GIC (18, 19). The present results show that depending on the concentration of zeolite incorporated, GIC can have enhanced and sustained antimicrobial properties. However, the results may be affected by the use and type of GIC, and this could be a topic of further research.

smatrao da je parametar nejasno ili nedovoljno naveden. To je istaknuto kod parametra veličine uzorka u kojem se autori na početku nisu složili o tome jesu li detalji o veličini uzorka dovoljno razrađeni. Sljedeći parametar s niskom razinom slaganja bio je standardizirana priprema uzorka. Nesuglasnice između autora u vezi s tim parametrom objašnjavaju se variabilnošću u mjeri u kojoj je u svakomu radu posebno istaknuto da se provodio standardizirani postupak. Autori su sve nesuglasice riješili raspravom.

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Although the antimicrobial properties of GIC tended to have a direct relationship with the concentration of zeolite, the amount of zeolite that GIC can successfully uptake is limited by its resulting mechanical properties. The change in shear bond strength of zeolite-incorporated GIC depended on the type and use of the GIC (20, 21). ZUT presented higher shear bond strength than GIC Ketac-Endo alone and was not affected when it was conditioned by media such as calcium hydroxide, chlorhexidine, formocresol, and deionized water (20). However, adding zeolite to provisional cements may decrease the shear bond strength between the dentin and composite resin. Zeolite provisional cement was compared against bone hydroxyapatite provisional cement and showed an inferior bonding strength. A possible explanation for the decrease is that zeolite-incorporated provisional cement may contain more calcium hydroxide than the bone hydroxyapatite-incorporated cement (21). The compressive strength of zeolite-GIC also had varying results depending on the type and use of zeolite (13, 16). Lee et al. reported that although AgZ GIC showed higher compressive strength at 1% wt, it decreased when the concentration was higher than 3% (13). However, Kim et al. concluded that there was no significant difference in compressive or bond strength when small amounts of chlorhexidine-loaded zeolite nanoparticles (around 1% wt) were added to GIC (16).

Resin Cements

When zeolite was incorporated into resins, antimicrobial properties were improved against some microorganisms. Various ratios of AgZ and ZnZ inhibited S. mutans and S. mitis growth but did not inhibit S. salivarius or S. sanguinis colonies. In contrast to what was observed with GIC, greater amounts of Ag-Zn-zeolite did not lead to greater amounts of antimicrobial activity in resins (3). After zeolite was modified with active diazonium, the compressive strength and flexural strength of the modified resin-based composite was either improved or remained the same (22). However, further research may be needed in this aspect of modifying zeolite because there is limited research on this topic.

Bonding Agents

Although zeolite alone did not improve the antimicrobial properties of bonding agents, the incorporation of AgZ did. Increasing the exchange time between AgZ and environmental ions can decrease biofilm formation of S. mutans, S. gordonii, and S. sanguinis on dental adhesives. Despite the linear relationship, increasing the amount of silver ions loaded into the zeolite so that the release time is greater than 40 minutes can result in damages to zeolite pore channels and uncontrollable silver ion release (23). Pretreating dentin with zinc zeolite may also enhance the shear bond strength between dentin and alloys using dental adhesives. This increase in shear bond strength was especially significant in the self-etch adhesive approach (24).

Endodontics

Zeolite in endodontics was generally added to calcium hydroxide and mineral trioxide aggregate (MTA) and used as root canal irrigants (25-31).

Iako su antimikrobna svojstva SIC-a bila u izravnom odnosu s koncentracijom zeolita, količina zeolita koju SIC može uspješno prihvatiti ograničena je mehaničkim svojstvima koja iz toga proizlaze. Promjena posmične čvrstoće veze SIC-a s ugrađenim zeolitom ovisila je o vrsti i upotrebi SIC-a (20, 21). ZUT je imao veću posmičnu čvrstoću od samoga SIC-a Ketac-Endo i nije bio pogoden medijima kao što su kalcij hidroksid, klorheksidin, formokresol i deionizirana voda (20). Međutim, dodavanje zeolita privremenim cementima može smanjiti posmičnu veznu čvrstoću izmedju dentina i kompozitne smole. Privremeni cement sa zeolitom uspoređen je s privremenim cementom s koštanim hidroksiapatitom i imao je manju veznu čvrstoću. Moguće objašnjenje za smanjenje jest da privremeni cement s ugrađenim zeolitom može sadržavati više kalcijeva hidroksida od cementa s ugrađenim koštanim hidroksiapatitom (21). Za vlačnu čvrstoću SIC-a sa zeolitom također su dobiveni različiti rezultati, ovisno o vrsti i upotrebi zeolita (13, 16). Lee i suradnici izvijestili su da, iako je AgZ GIC imao veću vlačnu čvrstoću uz sadržaj od 1%, ona se smanjila kada je koncentracija bila veća od 3% (13). No Kim i suradnici zaključili su da nema značajne razlike u tlačnoj ili veznoj čvrstoći kada su u SIC dodane male količine nanočestica zeolita napunjenih klorheksidinom (oko 1%) (16).

Kompozitni cementi

Kada se zeolit ugradi u smole, poboljšana su antimikrobnob va svojstva protiv nekih mikroorganizama. Razni omjeri AgZ-a i ZnZ-a inhibiraju rast S. mutans i S. mitis, ali ne s prose skaju količine S. salivarius ili S. sanguinis. Za razliku od odnosa što je zapaženo kod SIC-a, veće količine Ag-Zn-zeolita nisu rezultirale boljim antimikrobnim djelovanjem u smolama (3). Nakon što je zeolit modificiran aktivnim diazonijem, tlačna i savojna čvrstoća preinačenog kompozita na bazi smole ili su poboljšane ili su ostale iste (22). No o tom aspektu modificiranja zeolita potrebna su daljnja istraživanja jer su dosadašnja o toj temi ograničena.

Adheziva

Iako sam zeolit nije poboljšao antimikrobnou svojstva adheziva, ugradnja AgZ-a jest. Povećanje vremena razmjene između AgZ-a i iona iz okoline može smanjiti stvaranje bioživaca S. mutans, S. gordonii i S. sanguinis na dentalnim adhezivima. Unatoč linearnom odnosu, povećanje količine srebrobih iona u zeolitu tako da vrijeme oslobađanja traje dulje od 40 minuta može rezultirati oštećenjima kamenja pora zeolita i nekontroliranim oslobađanjem srebrenih iona (23). Prethodna obrada dentina cinkovim zeolitom također može poboljšati posmičnu veznu čvrstoću izmedju dentina i legura primjenom dentalnih adheziva. To povećanje posmične vezne čvrstoće bilo je posebno značajno kod samojekstirajućih adheziva (24).

Endodontija

Zeolit u endodondiji općenito se dodaje kalcijevu hidroksidu i mineralnom trioksidnom agregatu (MTA) te se upotrebljava kao irigans korijskoga kanala (25 – 31).
Root Canal Irrigants

Although 2% AgZ did show statistically significant antimicrobial effectiveness as a root canal irrigant compared to the saline control, it did not exhibit as much effectiveness compared to common root canal irrigants such as 5% Sodium hypochlorite, 2% Chlorhexidine, and 0.10% Octenidine (OCT) (25). A possible reason why AgZ was not as effective as the other root canal irrigants against E. faecalis, C. albicans, and S. aureus growth is that it was not as effective at breaking down the biofilm of these microorganisms (25). When further studies on the mechanical properties of AgZ are published, a better conclusion can be drawn on whether it is worth using AgZ as a root canal irrigant.

Calcium hydroxide

Calcium hydroxide is considered an ideal intracanal medication in endodontics due to its unique ability to increase surrounding pH by dissociating in water to produce hydroxyl ions. Although the high pH denatures bacterial protein and breaks down cell walls, calcium hydroxide was not effective on all types of microorganisms that cause endodontic infections. Ghatole et al. showed that when AgZ was added to calcium hydroxide, antimicrobial property against E. faecalis is enhanced compared to the control or when chlorhexidine is added (26). Therefore, AgZ can potentially be added to intracanal medications, such as calcium hydroxide, to improve antimicrobial effectiveness.

MTA

When AgZ was added to MTA, it exhibited significant antimicrobial properties toward selected oral microflora. AgZ in MTA was effective against most oral microorganisms, such as E. faecalis, S. aureus, and C. albicans. However, it was not effective against P. intermedia and A. israelii (27-28). No big differences were found in the types of microbes inhibited by 0.2% and 2% AgZ MTA, but 2% AgZ MTA demonstrated significantly higher inhibitory effects than 0.2% AgZ MTA throughout a 72-hour period. Specifically, 2% AgZ demonstrated the highest amount of silver ion release at 24 hours (27). In addition, 2% AgZ was found to have greater antimicrobial properties compared to MTA with 2% chlorhexidine (28). Therefore, 2% AgZ could serve as a potential additive in MTA to enhance its antimicrobial properties.

Although zeolite significantly increased the antimicrobial properties of MTA, it did negatively affect physical properties such as setting time, water absorption, push-out bond strength and compressive strength (29-31). Setting time decreased as the ratio of 2% AgZ increased, and water absorption was the lowest when 2% AgZ was incorporated into MTA compared to the MTA-only control (29). In addition, adding Ag-Zn-Ze composite had a negative effect on the push-out bond strength and compressive strength of MTA (30-31). A possible reason for the decrease in push-out bond strength is that zeolite is very porous in its structure. When water molecules reside in the pores, they can disturb the hydration and crystallization processes of MTA (30). In conclusion, although zeolite may enhance the antimicrobial proper-

Irigansi korijenskih kanala

Iako je 2% AgZ-a imalo statistički značajnu antimikrobi- nu učinkovitost kao sredstvo za ispiranje korijenskih kanala u odnosu prema fiziološkoj otopini, nije pokazao toliku učin- kovitost u usporedbi s uobičajenim sredstvima za ispiranje kanala kao što su 5-postotni natrij hipoklorit, 2-postotni klorheksidin i 0,10-postotni oktenidin (OCT) (25). Mogući razlog zašto AgZ nije bio toliko učinkovit kao druga sredstva za ispiranje korijenskoga kanala kad je riječ o rastu E. faecalis, C. albicans i S. aureus jest taj što nije bio toliko učinkovit u razgradnji biofilma tih mikroorganizma (25). Kada se obja- ve daljna istraživanja o mehaničkim svojstvima AgZ-a, moći se dati bolji zaključak o tome treba li upotrebljavati AgZ kao sredstvo za ispiranje korijenskog kanala.

Kalcijev hidroksid

Kalcijev hidroksid smatra se idealnim intrakanalnim li- jekom u endodonciji zbog svojeg jedinstvenog svojstva da poveća okolin pH razdvajanjem u vodi stvarajući hidroksil- ne ione. Iako visoki pH denaturira bakterijski protein i razbi- ja stanične stijenke, kalcijev hidroksid nije učinkovito djelo- vao na sve vrste mikroorganizama koji uzrokuju endodontske infekcije. Ghatole i suradnici pokazali su da se dodavanjem AgZ-a doziraju za pojačavanju antimikrobna svojstva protiv E. faecalis u usporedbi s kontrolom ili dodavanjem klorheksidina (26). Zato se AgZ može dodati intrakanalnim lijekovima, kao što je kalcijev hidroksid, radi poboljšanja an- timikrobne učinkovitosti.

MTA

Kad je AgZ dodan MTA-i, imao je izražena antimikrobi- nu svojstva prema odabranim oralnim mikrobroma. AgZ u MTA- i učinkovito je djelovao na većinu oralnih mikroorganizama, kao što su E. faecalis, S. aureus i C. albicans. No nije bio učin- kovito kad je riječ o P. intermedia i A. israelii [27 – 28]. Nisu pronađene velike razlike u vrstama mikroba koje su inhibirali 0.2 % i 2 % AgZ MTA-a, ali 2 % AgZ MTA-e imao je zna- čajno veći inhibitorni učinak od 0.2 % AgZ MTA-e tijekom razdoblja od 72 sata. Točnije, 2 % AgZ-a pokazalo je najve- ţu količinu oksidacijska ione stvorena u 24 sata (27). Uz to, utvrđeno je da 2 % AgZ-a ima bolja antimikrobna svojstva u usporedbi s MTA-om s 2 % klorheksidinom (28). Zato bi 2 % AgZ-a moglo poslužiti kao aditiv u MTA-i za poboljšanje njezinih antimikrobnih svojstava.

Iako je zeolit značajno poveća antimikrobna svojstva MTA-e, negativno je utjecao na fizička svojstva kao što su vrijeme stvrdnjavanja, apsorpcija vode, vlačna i tlačna čvrstoća (29 – 31). Vrijeme stvrdnjavanja smanjilo se u odnosu prema fiziološkoj otopini, nije pokazalo toliku učin- kovitost u usporedbi s uobičajenim sredstvima za ispiranje kanala kod kojih je riječ o rastu E. faecalis, C. albicans i S. aureus (26). Mogući razlog zašto AgZ nije bio toliko učinkovit u razradnji biofilma tih mikroorganizma (25). Kada se obja- ve daljna istraživanja o mehaničkim svojstvima AgZ-a, moći se dati bolji zaključak o tome treba li upotrebljavati AgZ kao sredstvo za ispiranje korijenskog kanala.

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ties of MTA, it does reduce the mechanical properties. Thus, further research is needed to determine the proper concentration of zeolite that may be incorporated into MTA, if any, to improve its antimicrobial properties without compromising its mechanical properties.

Prosthesis

Zeolite in prosthesis was added to both acrylic resin and non-acrylic materials, such as ceramic (32-38).

Non-Acrylic Resins

The non-acrylic materials that were tested with zeolite ranged from soft prosthetic liners to all-ceramic prosthesis. Adding AgZ to soft liners improved its antimicrobial properties against C. albicans and gram-negative bacteria while also retaining its viscoelastic properties (32). Regarding the mechanical properties, the applications of zeolite into ceramic prosthesis generally focused on sodalite zeolite (33-36), a subtype of zeolite that can easily infiltrate other material due to its selectivity and strong catalytic activity (33). In alumina and zirconium toughened alumina (ZTA) ceramic prostheses, sodalite zeolite-infiltrated samples had higher bond strength than the commercial glass-infiltrated samples between ceramic core and porcelain (34). In addition, all soda-lite zeolite-infiltrated samples showed flexural strength above the acceptable ranges considered by the ISO (35-36). Furthermore, some studies have shown that the zeolite-infiltrated samples had a significantly higher flexural strength and hardness in comparison with glass-infiltrated control, especially when heated to 1600°C (35). Finally, sodalite zeolite-infiltrated ZTA has one of the highest fracture toughness and elastic modulus values compared to its glass-infiltrated counterparts (33). Therefore, sodalite zeolite infiltrated samples can serve as a potential alternative to the glass infiltrated ZTA due to superior properties in bond strength, flexural strength, Vickers hardness, fracture toughness, and elastic modulus (33-36).

Acrylic Resin

AgZ increased the antimicrobial properties of acrylic resin against oral microbes such as S. mutans, F. nucleatum, and C. albicans. Self-cured acrylic resins tend to absorb copious amounts of water and do not easily polymerize, resulting in the accumulation of periodontal disease-causing bacteria. AgZ-incorporated acrylic resin may potentially resolve this issue since it effectively diminished the attachment of S. mutans, F. nucleatum, and C. albicans to polymethylmethacrylate (PMMA) and lasted for up to 45-60 days (37-39). Similarly, 2.5% Ag-Zn-Ze was effective at inhibiting C. albicans and S. mutans when added to PMMA (40). Therefore, both AgZ and Ag-Zn-Ze may be potentially viable options to improve the antimicrobial properties of PMMA.

However, depending on the percentage added, AgZ may negatively affect the mechanical properties of acrylic resin (38-41). Adding AgZ with concentrations of 2.5% and higher, depending on the type of acrylic resin, will significantly reduce the impact and flexural strength (38, 40-41). However, some types of heat-cured acrylic resin, such as QC20 and Lucitone 550, may still satisfy the standard for denture

živanja kako bi se utvrdila odgovarajuća koncentracija zeolita koji se može ugraditi u MTA-u, ako postoji, kako bi se poboljšala njegova antimikrobnova svojstva, a da se pritom ne naruše ona mehanička.

Protetika

Zeolit u protezi dodaje se akrilatnoj smoli i neakrilatnim materijalima poput keramike (32 – 38).

Neakrilatne smole

Neakrilatni materijali koji su ispitivani sa zeolitom kretali su se od materijala za mekano podlaganje proteza do potpuno keramičkih proteza. Dodavanjem AgZ-a materijalima za mekano podlaganje poboljšala su se njegova antimikrobnova svojstva protiv C. albicans i gram-negativnih bakterija, a istodobno su se zadržala viskoelastična svojstva (32). Kad je riječ o mehaničkim svojstvima, primjena zeolita u keramičkim proteza ma uglavnom se fokusirala na sodalitni zeolit (33 – 36), podvrsu proteza koji se lako može infiltrirati u drugi materijal zbog selectivnosti i jakih katalitičkih aktivnosti (33). U keramičkim protezama od ojačane gline i cirkonijske okside (ZTA), uzorci infiltrirani u zeolit sodalitom imali su veću veznu čvrstoću od komercijalnih uzoraka infiltriranih staklom između keramičke jezgre i obložne keramike (34). Uz to, svi uzorci infiltrirani zeolit sodalitom imali su savojnu čvrstoću iznad prihvatljivih granica prema ISO standardu (35 – 36). Nadalje, u nekim istraživanjima autorii su pokazali da su uzorci infiltrirani zeolitom imali znatno veću savojnu čvrstoću i tvrdoću u usporedbi s kontrolom infiltriranim staklom, posebno kada su zagrijani na 1600 °C (35). Konačno, ZTA sa zeolit sodalitom ima jednu od najvećih vrijednosti žilavosti i modula elastičnosti u usporedbi s materijalima infiltriranima staklom (33). Zato uzorci infiltrirani zeolit sodalitom mogu poslužiti kao potencijalna alternativa staklom infiltriranom ZTA-u zbog superiornih svojstava kad je riječ o veznoj i savojnoj čvrstoći, tvrdoći prema Vickersu, žilavosti i modulu elastičnosti (33 – 36).

Akrilatne smole

AgZ je povećao antimikrobna svojstva akrilatnih smola kad je riječ o oralnim mikrobima kao što su S. mutans, F. nucleatum i C. albicans. Autopolymerizirajuće akrilatne smole imaju tendenciju upijanja obilnih količina vode i ne mogu se lako polymerizirati, što rezultira nakupljanjem parodontopa
togenih bakterija. Akrilatna smola ugrađena u AgZ može riješiti taj problem jer učinkovito smanjuje vezanje S. mutans, F. nucleatum i C. albicans za polymethylmethacrylate (PMMA) u trajanju od 45 do 60 dana (37 – 39). Slično tomu, 2,5% Ag-Zn-Ze-a bilo je učinkovito u inhibiciji C. albicans i S. mutans kada se doda u PMMA (40). Zato i AgZ i Ag-Zn-Ze mogu biti dobre opcije za poboljšanje antimikrobnih svojstava PMMA-e.

No ovisno o dodanom postotku, AgZ može negativno utjecati na mehanička svojstva akrilatne smole (38 – 41). Dodavanje AgZ-a u koncentracijama od 2,5 % i više, ovisno o vrsti akrilatne smole, značajno će smanjiti savojnu čvrstoću (38, 40 – 41). No neke vrste toplinski polymeriziranih akrilatnih smola, poput QC20 i Lucitone 550, još uvijek mogu zadovoljiti standard za akrilatne proteze koji zahtijeva savoj-
acrylics, which requires flexural strength to be higher than 65 MPa (38, 40). Depending on the concentration of zeolite added, both mean tensile strength and bending strength decreased. It was recommended to add less than 4% zeolite wt to keep adequate mechanical strength, and 2% when factoring in both mechanical and fungicidal effects (39). Therefore, low percentages of silver-zinc antimicrobial zeolites added to polymethylmethacrylate can be a valuable alternative for antimicrobial effects, which could help prevent common oral infections such as denture stomatitis (38).

**Implants**

Numerous applications of zeolite also extend to antibacterial coatings on implants. Although there is not a great amount of literature on this topic, coating titanium implants with AgZ was effective in inhibiting methicillin-resistant *S. aureus* (MRSA) growth (42). This positive outcome, combined with zeolite’s superior biocompatibility, may render zeolite a possible new material to be used in orthopedic implants.

**Limitations of the study**

Since most of the literature covered in the present review consisted of *in vitro* studies, it is important to note that there is a lack of widely accepted and clear criteria for assessing the risk of bias and quality of *in vitro* studies. To address this problem, a risk of bias test used in a previous study was adapted and used in this review (7). In the future, there should be more *in vivo* studies performed in order to better understand the effects of zeolite on the oral environment.

**Conclusion**

The available evidence collected through the present systematic review showed that ion-incorporated zeolite demonstrated enhanced antimicrobial properties when incorporated into dental materials. When ion-zeolite was incorporated into non-acrylic prosthetic materials, the mechanical as well as the antimicrobial properties were enhanced. GIC demonstrated the greatest antimicrobial effectiveness with 2% zeolite wt while maintaining mechanical properties between 1-3% zeolite wt. Therefore, it was recommended to use a concentration of 2% zeolite wt with GIC to optimize both factors. Lower concentrations such as 0.2-2% wt were recommended for MTA and acrylic prosthetic materials, which showed the greatest decrease in mechanical properties when combined with zeolite.

**Conflict of interest**

The authors report no conflict of interest.

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nu čvrstoću veću od 65 MPa (38, 40). Ovisno o koncentraciji dodanoga zeolita, smanjile su se i srednja vlačna čvrstoća i savojna čvrstoća. Preporučeno je dodavanje manje od 4% zeolita kako bi se zadržala odgovarajuća mehanička svojstva, a 2% kada se uzimaju u obzir i mehanički i fungicidični učinci (39). Zato nizak postotak antimikrobog srebno-cinkovog zeolita dodanoga polimetilmetakrilatu može biti vrijedna alternativa za postizanje antimikrobog učinka, što bi moglo pomoći u prevenciji uobičajenih oralnih infekcija poput protečkog stomatitisa (38).

**Implantati**

Brojne primjene zeolita također se proteže na antibakterijske obloge na implantatima. Iako o toj temi nema mnogo radova, oblaganje titaonijskih implantata AgZ-om učinkovito je inhibiralo rast bakterije *S. aureus* otporne na meticilin (MRSA) (42). Taj pozitivni ishod, u kombinaciji s vrhunskom biokompatibilnošću, zeolit može učiniti mogućim novim materijalom koji će se upotrebljavati u ortopedskim implantatima.

**Ograničenja istraživanja**

Budući da su večina radova obrađenih u ovom pregledu istraživanja *in vitro*, važno je napomenuti da nedostaju široko prihvaćeni i jasni kriteriji za procjenu rizika od pristranosti i kvalitete istraživanja *in vitro*. Kako bi se riješio taj problem, u ovom je pregledu prilagođen i korišten test rizika od pristranosti iz prethodnoga istraživanja (7). U budućnosti bi trebalo provesti više istraživaњa *in vivo* da bi se bolje shvatili učinci zeolita u intraoralnom okružju.

**Zaključak**

Dokazi prikupljeni u ovomu sistematiziranom pregledu pokazali su da zeolit s ugrađenim ionima ima pojačana antimikrobna svojstva kada se uključuje u dentalne materijale. Kada se zeolit s ugrađenim ionima inkorporira u protetičke materijale koji nisu na bazi akrilata, poboljšana su mehanička i antimikrobna svojstva. SIC je imao najveću antimikrobnu učinkovitost s 2% masnoga udjela zeolita, zadržavajući mehanička svojstva između 1 i 3% udjela zeolita. Zato je preporučena koncentracija od 2% zeolita u SIC-u za optimizaciju obaju čimbenika. Niže koncentracije poput 0,2 do 2% preporučene su za MTA i akrilatne protetičke materijale koji su pokazali najveće narušavanje mehaničkih svojstava u kombinaciji sa zeolitom.

**Sukob interesa**

Autori ne navode sukob interesa.

**Zahvala**

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Zeolite Use in Dental Materials: A Systematic Review

Hao i sur.

Sazetak

Svrha istraživanja: Zeolit s ugrađenim ionima često je korišten antimikrobijski materijal koji se proučava za različite primjene u stomatologiji. Trenutačno ne postoji ni jedan drugi sistemizirani pregledni rad u kojem bi se ocijenjivala učinkovitost zeolita u svim dentalnim materijalima. Svrha ovoga istraživanja bila je pregledati svu objavljenu literaturu u kojoj su analizirani antimikrobički učinci i/ili mehanička svojstva zeolita kao restaurativnog materijala u stomatologiji.

Materijal i metode:

Slijedeći smjernice PRISMA-e, od 1. lipnja do 17. kolovozu 2020. provedeno je iscrpno pretraživanje baza PubMed, Ovid MEDLINE, Scopus, Embase te Dental and Oral Sciences Source. Nisu korištena jezična ili vremenska ograničenja. Odabrani su samo cijevlji članci kojima je tema bila upotrebna zeolita u dentalnim materijalima, uključujući kompozitne materijale, adhezive, cemente, restaurativne intrakorijenske materijale, podloge te materijale u protekti, implantologiji i endodonciji. Rezultati: Na početku su pronađena 1534 istraživanja, od kojih je isključeno 652 duplih zapisa. Nakon pregleda naslova, sažetka i cijevljivih tekstova, ostalo je 35 radova koji su uključeni u kvalitativnu sintezu. Za svaki od njih proveden je test pouzdanosti medu ocjenjivačima (IRR) koji je obuhvaćao postotak sličnosti, postotak pouzdanosti i postotak pouzdanosti.

Zaključak: Iako zeolit s ugrađenim ionima može pojačati antimikrobijsku svojstva dentalnih materijala, mehanička svojstva nekih mogu biti ugrožena, poput MTA i akralatne smole. Stoga, s obzirom na to da pogoršanje mehaničkih svojstava ovisi o koncentraciji zeolita u restaurativnom materijalu, općenito se preporučuje dodavanje 0,2 do 2 mas.% zeolita.

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References
1. Pavelić S, Medica J, Gumbarević D, Filošević A, Przulj N, Pavelić K. Critical review on zeolite clinoptilolite safety and medical applications in vivo. Front Pharmacol. 2018 Nov 27;9:1350.
2. Derakhshankhah H, Jafari S, Sarvari S, Barzegari E, Moakedi F, Ghorbani M, et al. Biomedical applications of zeolitic nanoparticles, with an emphasis on medical interventions. Int J Nanomedicine. 2020 Jan 21;15:363-386.
3. Hotta M, Nakajima Y, Yamamoto K, Aono M. Antibacterial temporary filling materials: the effect of adding various ratios of Ag-Zn-Zeolite. J Oral Rehabil. 1998 Jul;25(7):485-9.
4. Kawahara T, Tsuchido K, Morishita M, Mochida M. Antibacterial effect of silver-zeolite on oral bacteria under anaerobic conditions. Dent Mater. 2000 Nov;16(6):452-5.
5. Sivakumar I, Arunachalam K, Sajan S, Ramaraju A, Rao B, Kararaj B. Incorporation of antimicrobial macromolecules in acrylic denture base resins: a research composition and update. J Prosthodont. 2014 Jan;23(4):284-90.
6. Wang L, D’Alpino P, Lopes L, Pereira J. Mechanical properties of dental restorative materials: relative contribution of laboratory data. Journal of Applied Oral Science. 2003; 11:162-167.
7. Astudillo-Rubio D, Delgado-Gaete A, Bellot-Arcis C, Montel-Company J, Pascual-Moscardó A, Almerich-Silla J. Mechanical properties of provisional dental materials: a systematic review and meta-analysis. PLoS One. 2018 Feb 28;13(2):e0193162.
8. McHugh ML. Interrater reliability: the kappa statistic. Biochemistry medica. 2012; 22(3):276-282.
9. Moher D, Liberati A, Tetzlaff J, Altman DG. The PRISMA Group, Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Medicine. 2009; 6(7):e1000097.
10. Saengmee-anupharb S, Srikihirin T, Thawboon B, Thawboon S, Amornsakchai T, Dechunakorn S, Sushashthara T. Antimicrobial effects of silver zeolite, silver zirconium phosphate silicate and silver zirconium phosphate against oral microorganisms. Asian Pac J Trop Biomed. 2013 Jan;3(1):47-52.
11. Partoazar A, Talaei N, Bahador A, Pourhajibagher M, Depour S, Sadati M, Bakhtianari A. Antibiofilm activity of natural zeolite supported NanoZnO: inhibition of Esp gene expression of Enterococcus faecalis. Nanomedicine (Lond). 2019 Mar;14(6):675-687.
12. Tamanai-Shacoori Z, Chandad F, Rébillard A, Cillard J, Bonnare-Mallet M. Silver-zeolite combined to polyphenol-rich extracts of ascophyllum nodosum potential active role in prevention of periodontal diseases. PLoS One. 2014 Oct 1;9(10):e105475.
13. Lee JH, Lee S, Kim KN, Kim KM, Lee YK. Antibacterial effect of silver-zeolites in glass-ionomer cements. J Biomed Mater Res B Appl Biomater. 2009 Aug;90(2):592-5.
14. Cinar C, Ulusu T, Ozcelik B, Karamuftuoğlu N, Yücel H. Antibacterial effect of silver-zeolite containing root-canal filling material. Journal of Biomedical Materials Research, Part B Applied Biomaterials. 2009; 90(2):592-595.
15. Mabrouk M, Selim M, Beheshtian E, El Gohary M. Incorporation effect of silver and zinc-zeolites into commercial glass ionomer cement. International Ceramic Review. 2013;62(1):50-54.
16. Kim HJ, Son JS, Kim KH, Kwon TY. Antimicrobial activity of glass ionomer cement incorporated with chlorhexidine-loaded zeolite nanoparticles. Journal of Nanoscience and Nanotechnology. 2016;16(2):1450-1453.
17. Patel V, Santerre JP, Friedman S. Suppression of bacterial adherence by experimental root canal sealers. J Endod. 2000 Jan;26(1):20-4.
18. Padachey N, Patel V, Santerre P, Cvitkovitch D, Lawrence HP, Friedman S. Resistance of a novel root canal sealer to bacterial ingress in vitro. J Endod. 2000 Nov;26(11):656-9.
19. McDougall I, Patel V, Santerre P, Friedman S. Resistance of experimental glass ionomer cement sealers to bacterial penetration in vitro. Journal of Endodontics. 1999;25(11): 739-742.
20. Chung HA, Tittley K, Torneck CD, Lawrence HP, Friedman S. Adhesion of glass-ionomer cement sealers to bovine dentin conditioned with intracanal medications. Journal of Endodontics. 2001;27(5):85-88.
21. Can-Karabulut D, Akincioğlu A, Özgeyän S, Karabulut B. Influence of experimental provisional cements containing zeolite, bone hydroxyapatite and linoleic acid on bond strength of composite to dentin in vitro. J Adhes Dent. 2010 Dec;12(6):469-75.
22. Sandomierski M, Okulus Z, Voelkel A. Active diazonium-modified zeolite fillers for methacrylate-based composites. Composite Interfaces. 2019;26(7):643-657.
23. Li W, Qi M, Sun X, Chi M, Wan Y, Zheng X, Li C, Wang L, Dong B. Novel dental adhesive containing silver exchanged EMT zeolites against cariogenic biofilms to combat dental caries. Microporous and Mesoporous Materials. 2020;299:110113.
24. El-Guindy J, Selim M, El-Agroudi M. Alternative pretreatment modalities with a self-adhesive system to promote dentin/alloy shear bond strength. J Prosthodont. 2010 Apr;19(3):205-11.

25. Ghivari S, Bhattacharya H, Bhat K, Pujar M. Antimicrobial activity of root canal irrigants against biofilm forming pathogens—An in vitro study. J Conserv Dent. May-Jun 2017;20(3):147-51.

26. Ghatole K, Gowdra R, Azher S, S. Sabharwal S. Enhancing the antibacterial activity of the gold standard intracanal medicament with incorporation of silver zeolite: An in vitro study. J Int Soc Prev Community Dent. Jan-Feb 2016;6(1):75-9.

27. Odabaş M, Çınar Ç, Akça G, Araz I, Ulusu T, Yücel H. Short-term antimicrobial properties of mineral trioxide aggregate with incorporated silver-zeolite. Dent Traumatol. 2011 Jun;27(3):189-94.

28. Ghatole K, Patel A, Giriyappa R, Singh T, Jyotsna S, Rairam S. Evaluation of antibacterial efficacy of MTA with and without additives like silver zeolite and chlorhexidine. J Clin Diagn Res. 2016 Jun;10(6):ZC11-4.

29. Çınar Ç, Odabaş M, Gürel M, Baldağ I. The effects of incorporation of silver-zeolite on selected properties of mineral trioxide aggregate. Dent Mater J. 2013;32(6):872-6.

30. N. Ghasemi N, Rahimi S, M. Samiei M, M. Mohamadi M, Y. Rezaei Y, B. Divband B, N. Farhangi N. Effect of zeolite containing silver-zinc nanoparticles on the push out bond strength of mineral trioxide aggregate in simulated furcation perforation. J Dent (Shiraz). 2019 Jun;20(2):102-106.

31. Samiei M, Ghasemi N, Asl-Aminabadi N, Divband B, Golparvar-Dashti Y, Shirazi S. Zeolite-silver-zinc nanoparticles: Biocompatibility and their effect on the compressive strength of mineral trioxide aggregate. J Clin Exp Dent. 2017 Mar 1;9(3):e356-e360.

32. Saravanan M, Kumar V, Padmanabhan T, Banu F. Viscoelastic properties and antimicrobial effects of soft liners with silver zeolite in complete dental prosthesis wearers: an in vivo study. Int J Prosthodont. May-Jun 2015;28(3):265-9.

33. Naji G, Omar R, Yahya R. The effect of sodalite zeolite infiltrated material on the fracture toughness, elastic modulus and optical properties of all-ceramic dental prostheses. Ceram Int. 2016;42(16):18737-18746.

34. Naji G, Omar R, Yahya R. Influence of sodalite zeolite infiltration on the coefficient of thermal expansion and bond strength of all-ceramic dental prostheses. J Mech Behav Biomed Mater. 2017 Mar;67:135-143.

35. Naji G, Omar R, Dabbagh A, Yahya R. Effect of sintering temperature on the microstructures and mechanical properties of sodalite infiltrate all-ceramic material for dental restorations. Adv Appl Ceram. 2018;117(5):291-302.

36. Naji G, Omar R, Yahya R, Dabbagh A. Sodalite zeolite as an alternative all-ceramic infiltrating material for alumina and zirconia toughened alumina frameworks. Ceram Int. 42(10):12253-12261.

37. Kuroki K, Hayashi T, Sato K, Asai T, Okano M, Kominami Y, et al. Effect of self-cured acrylic resin added with an inorganic antibacterial agent on Streptococcus mutans. Dent Mater J. 2010;29(3):277-85.

38. Malic S, Rai S, Redfern J, Pritchett J, Liauw C, Verran J, Tosheva L. Zeolite-embedded silver ends antimicrobial activity of dental acrylics. Colloids Surf B Biointerfaces. 2019 Jan 1;173:52-57.

39. Nakanoda S, Nikawa H, Hamada T, Yamamoto T, Nakamoto K. The material and antifungal properties of antibiotic zeolite incorporated acrylic resin. Japanese Prosthodontic Society. 1995;39(5):919-926.

40. Casemiro L, Martins C, Pires de Sousa F, Panzeri H. Antimicrobial and mechanical properties of acrylic resins with incorporated silver-zinc zeolite - part I. Gerodontology. 2008 Sep;25(3):187-94.

41. Yadav N, Saraf S, Mishra S, Hazari P. Effects of flucloxacile, chlorhexidine gluconate, and silver-zinc zeolite on flexural strength of heat-cured polymethyl methacrylate resin. J Nat Sci Biol Med. Jul-Dec 2015;6(2):340-2.

42. Wang J, Wang Z, Guo S, Zhang J, Song Y, Dong X, Wang X, Yu J. Antibacterial and anti-adhesive zeolite coatings on titanium alloy surface. Micropor Mesopor Mat. 2011;146(1):216-222.