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# A Review on Zeolites and Their Applications in Dentistry

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## Abstract

**Purpose of Review** Zeolite is an aluminosilicate compound having a wide spectrum of applications in medicine and dentistry. Several articles were published combining zeolites with various other elements for different applications in dentistry. This review aims to provide a detailed review on the origin of zeolites, their physical and chemical properties and possible applications as dental materials.

**Recent Findings** Zeolite-based hybrid films can be used for detection of oral cancers. Silver zeolite can be added in restorative materials and dental liners. In cases of root canal irrigation, chlorhexidine zeolite is used owing to its antibacterial properties. For dental implants, a zeolite coating can improve the osseointegration.

**Summary** Due to its microporous structure, application-driven zeolitic frameworks can be prepared by sieving in various cations and antibacterial compounds. This review helps improve our understanding regarding the uses of zeolites as a material in different aspects of dentistry along with possible further improvements as a dental material.

**Keywords** Anti-bacterial action · Dental applications · Osteointegration · Silver zeolite · Zeolites

## Introduction

Zeolites, aluminosilicates with a tetrahedral crystal structure, have a wide application range varying from ecology to dentistry [1, 2]. Zeolites are particularly useful in these areas because of their distinct porous structure, which provides negatively charged channels and cavities capable of accommodating cations, hydroxyl groups, and water molecules [1]. Recently, the capacity of zeolite to collect and release ions, paired with its exceptional biocompatibility and long-lasting effectiveness, has increased the interest of dental researchers [2]. Several studies in dentistry have sought to combine zeolites with inorganic antibacterial ions such as silver and zinc for sustained release, in addition to providing zeolites alone to materials [2].

Ion-embedded zeolites act as potential antibacterial agents against pathogenic oral microbes. When ions released from zeolites encounter certain oral microbes, they can interfere with their metabolic activity by inactivating key enzymes, disrupting RNA replication, and blocking microbial respiration [3]. Therefore, cations incorporated zeolites can potentially inhibit oral bacterial growth when applied to dental materials.

When zeolites are used in dental materials for its antimicrobial qualities, it is vital to evaluate how they affect the material's mechanical characteristics. Daily actions like chewing and speaking place stresses on the materials used to make tooth

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and dentures. As a result, the ability of the materials used to bear these stresses without losing their strength is critical for the efficacy of dental operations.

The present literature review concentrates on the origin and basic physical and chemical structure of zeolites highlighting its use for various aspects in dentistry.

## Materials and Methods

A systematic search in PubMed, Ebscohost and Google Scholar with keywords "zeolite, dentin regeneration, antibacterial properties, and dentistry" was performed. All articles from 1980 to the present were searched for title-related data. Only articles in English language were considered for the review.

## Results

In total 48 articles were selected. Zeolites are widely applied in various fields and are also attracting great attention in the dental field. Due to its antibacterial and regenerative properties, it is mainly used in dentistry [4••]. Zeolites are used in regenerative dentistry, root canal therapy, prosthetics, restorative dentistry, oral medicine, and implants, etc., as described in more detail below.

### Origin of Zeolite

Zeolites are naturally formed by volcanic activity. In a volcanic eruption, magma along with various gases, dust particles, and thick ash breaks up the earth's crust to form lava. Such incidents are caused by the convergence and divergence of tectonic plates. If such places are near water, lava often flows into seas and oceans. After contact with the sea, it undergoes a series of reactions with salt and water over thousands of years to produce crystalline structures called zeolites [5–7]. The word zeolite comes from two Greek words "zeo" = coke and "lithos" = stone, meaning boiling stone [8]. It was coined in 1756 by Swedish mineralogist Axel Fredrik Kronstaedt.

Chemically, zeolites are aluminosilicate agents with pore sizes between 3 and 10 Å. These pores lead to ion exchange between cations such as Ag and Zn, endowing zeolites with antibacterial activity [9, 10]. Main composition of zeolites is aluminum, silicon, oxygen, and phosphorus [11]. There are two types of zeolites, natural and synthetic, which have a wide range of applications in medicine. Zeolites are also used in dentistry for their antimicrobial properties and biocompatibility.

### Chemical Composition

The basic structure of zeolites consists of a framework of aluminosilicate consisting of a tetrahedral array of cations such as Silicon (Si4 +) and Aluminum (Al3 +) surrounded by four oxygen anions (O2-). Each oxygen ion binds two cations within the Si–O and Al-O bonds shared by the two tetrahedra, forming the tetrahedral building blocks of the $SiO_2$ and $AlO_2$ three-dimensional polymeric frameworks (ratio of 1:2). Each tetrahedron is composed of four oxygen atoms surrounding a silicon atom and an aluminum atom [12]. Some silicon ions are replaced by aluminum ions, leaving the tectosilicate structure with a net negative charge. These negatively charged sites are primarily alkali or alkaline earth metal counter ions such as Na +, K +, or Ca2 +, as well as Li +, Mg2 +, Sr2 +, and Ba2 + [11]. These ions are bound to the aluminosilicate structure by weaker electrostatic bonds found on the outer surface of the zeolite [13, 14].

### Structure of Zeolites

Zeolites are very difficult to classify because they cannot be defined simply as a family of crystalline solids [15]. In 1997, a Mineralogical Association subcommittee, the Commission on New Minerals and Mineral Names, found intrinsic zeolites with topologically identical structures independent of the Si and Al composition of the tetrahedral layers which was later classified as Zeolites [8, 16]. In a subsequent revision Zeolitic minerals described as crystalline substances with a structure characterized by a linked tetrahedral framework composed of four oxygen atoms surrounding cations. This structure consists of open voids in the shape of channels and cages which are often filled by $H_2O$ molecules and extra-framework cations. Guest species can flow through channels that are large enough. Dehydration in the hydrated phase is highly reversible and arises at temperatures below 400 °C. OH, F groups may interrupt the framework, which results in tetrahedral vertices that are not occupied by other tetrahedra [8].

## Building Units: Primary and Secondary

Zeolites are often classified as having primary building units (PBU) and secondary building units (SBU). The PBU is composed of $(SiO_4)^{4+}$ and $(AlO_4)^{5+}$ tetrahedra. They connect to adjacent tetrahedra through shared oxygen atoms to form simple geometrically shaped spatial arrays (SBUs). SBUs can be solitary rings, polyhedrons, dual rings, or complicated units that construct unique systems of interconnecting channels and cages. The number of SBUs in a zeolite unit cell is fixed. Currently, there are 23 distinct SBUs [17].

Because of their crystalline structure, zeolites are naturally porous, constituted of a 3D tetrahedral network of silicon and aluminum linked together by shared oxygen atoms. These pores arise due to interconnected cages formed because of the tetrahedral structural arrangement of atoms. Zeolites are microporous materials because their pore sizes are typically less than 2 nm [18]. Microporous materials, according to IUPAC definition [19], are those with pore diameters smaller than 2 nm.

## Uses in Dentistry

### Glass Ionomer Cements (GIC)

When ion-embedded zeolites were combined with GIC, in vitro ion release rate or agar diffusion assays were commonly used to assess antibacterial activity. As the silver-incorporated zeolite (AgZ) weight ratio increases, so does the inhibitory activity against oral bacteria such as *S. mutans* [20]. It is important to note that the AgZ GIC can sustainably release silver ions over an extended period, whereas the GIC alone can rapidly release fluoride for only two days [20]. Antibacterial properties similar to AgZ have been discovered in zinc-containing zeolites (ZnZ) versus *E. coli*, *S. aureus*, *P. aureginosa*, *B. subtilis*, and *C. albicans* [21]. Furthermore, when loaded with chlorhexidine, GIC zeolites may exhibit excellent antibacterial activity against *S. mutans* [22].

The antibacterial efficiency of GICs used for root canal sealants against *E. faecalis* has been variable [23, 24•]. ZUT (modified, experimental root canal sealer), a blend of 0.2% AgZ and the GIC sealer KT-308, reduced *E. faecalis* development more effectively than KT-308 alone, independent of concentration or duration [23]. Padachie et al. and McDougal et al., on the other hand, both determined that ZUT was less efficacious than other GICs [25]. Current results indicate that GICs can have enhanced and prolong antibacterial properties, depending on the concentration of incorporated zeolite. Nevertheless, the outcomes may be influenced by the use and kind of GIC, which might be a future study issue [26•].

Although the antibacterial capabilities of GICs are directly connected to zeolite concentration, the quantity of zeolite that GICs may successfully integrate is restricted by the mechanical qualities that arise. The shear bond strength of GICs containing zeolite varied depending on the kind and application of the GIC [27, 28]. ZUT demonstrated greater shear bond strength than GIC Ketac-Endo alone and was unaltered by conditioning with calcium hydroxide, chlorhexidine, formocresol, or deionized water [27].

The compressive strength of zeolite GICs varied according on the zeolite type and application [20, 22]. Lee et al. AgZ GIC had greater compressive strength at 1% He but reduced compressive strength over 3% He [20]. When a small amount of chlorhexidine-containing zeolite nanoparticles (~ 1 wt%) was added to GICs, there was no discernible change in compressive or adhesive strength [22].

### Resin Cements

Incorporating zeolite into the resin, enhanced its antimicrobial properties against some micro-organisms. *S. mutans* and *S. mitis* were suppressed by different AgZ and ZnZ ratios, but not *S. salivarius* or colony of *S. sanguis*. In contrast to GIC, greater concentrations of Ag-Zn zeolite did not raise the resin's antibacterial activity level [10]. The compressive and flexural strengths of modified resin-based composites enhanced or remained the same after the zeolites were changed with active diazonium [29]. However, this aspect of zeolite modification has been subject to limited research and may require further investigation.

### Mineral Trioxide Aggregate (MTA)

The addition of AgZ to MTA demonstrated considerable antibacterial activity against selected oral microorganisms. Most oral bacteria, including *E. faecalis*, *S. aureus*, and *C. albicans*, were inhibited by AgZ in MTA. However, it had no effect on *P. intermedia* and *A. israelii* [30, 31]. Although there was no substantial difference in bacterial reduction amount by 0.2% AgZ MTA and 2% AgZ MTA after 72 h, 2% AgZ MTA had a considerably stronger inhibitory effect than 0.2% AgZ MTA.

Notably, 2% AgZ released the greatest quantity of silver ion after 24 h [30]. Furthermore, compared to MTA comprising 2% chlorhexidine, 2% AgZ was shown to have strongest antibacterial effect [31]. As a result, 2% AgZ might be used as a possible addition to boost MTA's antibacterial characteristics. Zeolites boosted MTA's antibacterial characteristics greatly. However, they have a negative impact on physical parameters such as curing period, water permeability, injection bond strength, and compressive strength of MTA [32•, 33, 34].

Curing time was reduced as the quantity of 2% AgZ increased, and water absorption was at its lowest in 2% AgZ integrated into MTA compared to MTA-only controls [32•]. Furthermore, the inclusion of Ag-Zn-Ze composites had a detrimental impact on MTA's tensile bond strength and compressive strength [33, 34]. The very porous nature of zeolites might explain the lower tensile bond strength. If water molecules are present in the pores, they can interfere with the hydration and crystallization of MTA [33].

In summary, zeolites can boost MTA's antibacterial activities while decreasing its mechanical qualities. However, more studies are required to identify the precise concentration of zeolites which may effect mechanical and physical properties of MTA.

## Root Canal Irrigation Solutions

When compared to saline, 2% AgZ had significantly more antibacterial efficacy as a root canal irrigation solution. However, compared to 5% sodium hypochlorite, 2% chlorhexidine, and 0.10% octenidine (OCT) 2% AgZ showed significantly less antibacterial efficacy [35]. One probable explanation is that AgZ was not as efficient against *E. faecalis, S. aureus* and *C. albicans* as other root canal irrigation solution [35]. Yet further studies are needed on mechanical and chemical characteristics of AgZ as a root canal irrigation solution to make an evidence-based decision.

### Non-Acrylic Resins

Soft denture liners to all-ceramic dentures were among the acrylic-free materials evaluated with zeolite. AgZ added to soft liners improved antibacterial capabilities against *Candida albicans* and gram-negative bacteria while retaining viscoelastic qualities [36]. In terms of mechanical properties, sodalite zeolites were the most frequently used zeolites in ceramic prosthesis [37–40]. They are a zeolite subtype with high selectivity and catalytic activity that can easily permeate other materials [37].

In addition, all specimens impregnated with sodalite zeolites exhibited flexural strengths exceeding the tolerances considered by ISO standards [39, 40]. Furthermore, multiple investigations have revealed that zeolite-infiltrated materials had much greater flexural hardness and strength when heated to 1600 °C than glass-infiltrated control samples [39]. Finally, compared to its glass-infiltrated equivalent, sodalite zeolite-infiltrated Zirconia Toughened Alumina (ZTA) provides one of the highest fracture toughness and modulus values [37]. Therefore, sodalite zeolite-infiltrated specimens are potential substitutes for glass-infiltrated ZTA due to their superior properties in terms of bond strength, flexural strength, Vickers hardness, fracture toughness, and Young's modulus [37–40].

### Acrylic Resin

Acrylic resins with AgZ have better antibacterial activity against oral pathogens as *S. mutans*, *F. nucleatum*, and *C. albicans*. Chemically polymerized acrylic resin absorbs water and is difficult to polymerize, making it easier for the bacteria that cause periodontal disease to propagate. Acrylic resins incorporating AgZ can solve this problem by effectively reducing the adhesion of *S. mutans*, *F. nucleatum*, and *C. albicans* to polymethyl methacrylate (PMMA) for up to 45–60 days [41, 42•, 43].

When 2.5% Ag-Zn-Ze was added to PMMA, it worked effectively in suppressing *C. albicans* and *S. mutans* [44]. As a result, both AgZ and Ag-Zn-Ze may be feasible choices for improving PMMA's antibacterial characteristics. However, depending on the proportion of AgZ used, it might have a negative impact on the mechanical qualities of acrylic resins [42•, 43–45]. Depending on the type of acrylic resin, the addition of AgZ at concentrations above 2.5% significantly reduces impact strength and flexural strength [42•, 45]. However, some thermosetting acrylic resins such as QC20 and Lucitone 550 can meet the criteria for denture resins requiring a flexural strength greater than 65 MPa [42•, 43, 44]. Both the average tensile strength and flexural strength decreased depending on the concentration of added zeolite. To retain acceptable mechanical strength, less than 4% by weight of zeolite is advised, and 2% by weight can be added if both structural and antimicrobial benefits are considered recommended [43].

As a result, a modest proportion of antimicrobial silver-zinc zeolite added to polymethyl methacrylate might be a beneficial antibacterial effectiveness option to assist avoid frequent mouth infections such as denture stomatitis [42•].

### Implants

Many zeolite applications include antibacterial coatings for implants. Despite a paucity of research, covering titanium implants with AgZ proved successful in suppressing the development of methicillin-resistant *Staphylococcus aureus* (MRSA) [46]. This favorable discovery, along with zeolites' outstanding biocompatibility, suggests that they might be prospective novel materials for use in orthopaedic implants.

### Oral Medicine

Oral cancer is the sixth most common cancer in the world, most of which are oral squamous cell carcinomas. Recently, volatile organic compounds (VOCs) emitted by the human body have been considered to detect medical conditions. Several studies have shown that VOCs are produced by in vitro cancer cell lines as molecular cancer markers [47–49]. Shigeyama et al. evaluated VOCs in oral squamous cell carcinoma patients by a combined method of thin-film microextraction and gas chromatography–mass spectrometry based on Zeolite Socony Mobil–5 (ZSM) zeolites/Polydimethylsiloxane (PBMS) hybrid films. This study demonstrated that ZSM-5/PBMS hybrid films can be used to identify tumor-specific candidate biomarkers in a more cost-effective manner than taking blood samples [50, 51•].

## Concluding Remarks

This review gives a brief overview on the origin of zeolites and on their physical and chemical properties as dental materials. The natural characteristics of zeolite materials can be modified and manipulated to prepare zeolitic frameworks which are application-driven. It is a microporous material, where different molecules, including cations and antibacterial compounds, can be sieved in. They are stable in oral environment, especially in contact with saliva, making them an efficient additive to various dental materials. Incorporation of zeolites in restorative materials and denture resins increases antimicrobial activity and improves the mechanical properties of restorative materials, especially in GIC and MTA. However, information on AgZ incorporation in different dental materials is still limited, as well as its use as a root canal irrigation solution which requires further investigations. This review could improve our understanding of the use of zeolites as a novel material in the various aspects of dentistry.

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### Declarations

The Section Editors for the topical collection Dental Restorative Materials are Mutlu Özcan and Paulo Francisco Cesar. Please note that Dr. Özcan was not involved in the editorial process of this article as she is a co-author.

**Conflict of Interest** The authors declare no competing interests.

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