Application of Zeolite, A Biomaterial Agent, in Dental Science: A Review Article

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Introduction: Zeolite is an aluminosilicate biomaterial which has been used widely in medicine, tissue engineering, drug delivery systems, wound dressing, as an antibacterial agent and also it has been taken into consideration in dental sciences. So the aim of this study is reviewing the application of this amazing substance in dental sciences. **Materials and Methods**: In recent years there are many investigations on application of Zeolite. This review has been done on the application of this agent in dentistry. According to investigations from 1980, zeolites applications in dentistry were classified to the application in tissue engineering, root canal therapy, prosthodontics, periodontics and implant, restorative dentistry and oral medicine. **Results**: zeolite is a porous, biocompatible and antibacterial agent and according to its suitable properties it has been used as tissue engineering scaffold, wound dressing and so on. Zeolite is an antibacterial agent that can be used in root canal disinfection and in soft liner dentures. It can inhibit pathogens of dental caries and periodontal disease. According to biocompatibility of Zeolite, it also can be used as implant coating to improve osteointegration. It has also been used to detect squamous cell carcinoma. **Conclusion**: It seems that Zeolite can be considered as an amazing substance in dental sciences.

Keywords: Zeolite; Tissue engineering; Wound dressing; Dentistry

Introduction

Zeolite is a porous aluminosilicate agent with pore size between 3 to 10 Å in diameter. These pores can trap cations (Ag, Zn), water, and organic molecules and exchange them by other cations. By this way zeolite can display appealing features such as antimicrobial effect (1, 2). Its main constituents are phosphorus, aluminum, oxygen, silicon, etc., which they are repeated in the structure (3). Zeolites are divided into synthetic and natural groups. Zeolites are widely used in various sciences. zeolite has been used in industry (4), agriculture (5), Animal feed and poultry (6, 7), Water pollution treatment (8, 9), biochemistry (10) and so on. Recently it was taken into consideration in medicine. They are widely used in medicine such as wound dressing (11, 12), drug delivery (13, 14), as an antibacterial agent (15, 16), anticancer agent (17-20), for osteoporosis treatment (21, 22) treatment of various diseases (23, 24), tissue engineering (25) and so on. Zeolite has been also used in dentistry especially for antibacterial properties. The aim of this study is reviewing the application of the zeolite in dentistry.

Materials and Methods

Search has been done by the keywords of zeolite, tissue engineering, wound dressing and dentistry in PubMed and Google scholar search engines for finding all of the available evidence from 1980.

Results

In addition to the diverse and extensive applications of zeolite in various sciences, there is a great attention in dental sciences as well. The applications of this agent were classified in regenerative dentistry, tissue engineering and wound healing, root canal therapy, prosthodontics, oral medicine, restorative dentistry, periodontics and implant and so on as further discussed below.

Regenerative dentistry

Today tissue engineering is very much considered in various medical fields, as well as in the soft and hard tissue engineering of the oral cavity. Zeolite is one of the materials used as a scaffold in bone tissue engineering due to its chemical and porous structure and the possibility of implantation of cells in these pores. Pazarçeviren *et al.* investigate the clinoptilolite/poly (ε-caprolactone)-poly (ethylene glycol)-poly (ε-caprolactone) composite scaffolds as bone tissue engineering scaffold. Clinoptilolite improve the mechanical properties of the scaffold. The scaffold showed higher osteoinductivity in vitro (26). According to Costa *et al.* α-PVDF / NaY-32, which contains Zeolite NaY as filler, increases osteoblast and fibroblast proliferation. In addition, this scaffold did not show a significant pro-inflammatory effect. Therefore, zeolite has favourable properties for use as a tissue engineering scaffold (27). Schutze *et al.* indicated that zeolite-A reduces the number of pits per osteoclast and also reduces the activity of the cathepsin B enzyme by 3 times. So it seems that zeolite can inhibit bone resorption (22). Keeting *et al.* indicated that Zeolite increases mRNA of growth factor beta 1 levels and induces proliferation and differentiation of osteoblast (28). According to Chen *et al.* nano zeolitic imidazolate framework-8 Loaded onto titanium surface, in addition to the anti-bacterial property against Streptococcus mutans, increased the activity of alkaline phosphatase, extracellular matrix mineralization and osteogenic genes expression in MG63 cells (29).

Zeolite is also used as wound dressing to improve healing process. Salehi *et al.* evaluated the nanozeolite / starch thermoplastic hydrogels that were loaded by chamomile extract. The release of drug in the wound containing zeolite was more sustained. The MTT test indicated the biocompatibility of this wound for fibroblast mouse cells (L929). Histological assessment on the rats revealed that the wound dressing leads to improved epithelialization, collagen formation, and angiogenesis and also reduces inflammation. In addition the pilot study of five patients with chronic ulcers by car accident, bed sore, pressure ulcer, burn trauma and burn ulcer indicate improvement in wound healing without any hypersensitivity or other complications (11). Neidrauer *et al.* evaluate a topical ointment containing nitric-oxide-loaded zeolites. This agent showed antibacterial properties against Gram-negative bacteria (Escherichia coli and Acinetobacter baumannii), Gram-positive bacteria (Staphylococcus epidermidis and methicillin-resistant Staphylococcus aureus) and fungus (Candida albicans). In addition, it was biocompatible for 3T3 fibroblast cells. It also accelerated wound healing in rats (30). Ninan *et al.* investigated pectin / copper exchange faujasite hybrid membrane. The membrane indicated thermal stability, antibacterial activity, biocompatibility for NIH3T3 fibroblast and improvement in wound healing and re-epithelialisation in rats (31). According to Ninan *et al.* gelatin/copper activated faujasites was biocompatible for NIH 3T3 fibroblast cells. It also improves wound healing in rats (32). Ninan *et al.* also investigate gelatin/hyaluronic acid (HA)/faujasite porous scaffolds. It was biocompatible for NIH 3T3 fibroblast cell lines and promotes wound healing in rats (33). Seifu *et al.* indicate that Loading fluorinated-zeolite (FZ) particles on polyurethane scaffolds increase oxygen delivery to Human coronary artery smooth muscle cell, improve cell proliferation and infiltration depth in scaffold (34). According to zeolite appropriate properties it seems that it can be considered as suitable mucosal wound dressing as well.

Root canal therapy

Recently, zeolite solution has been considered as an agent for canal irrigation due to its antibacterial properties. In the study of Ghivari *et al.* the antibacterial properties of silver-zeolite on bacteria E. faecalis, Staphylococcus aureus, C. albicans, which lead to failure of root cultures, at intervals of 1 s, 5 s, 10 s, 30 s, and 60 s, were evaluated by simulating the biofilm model. In this study Silver-zeolite 2% indicated the least antibacterial property against E. faecalis, S. aureus, and C. albicans compared to NaOCl (5.25%), 2% CHX, OCT (0.10%) (35). Probably the anti-bacterial property of silver-zeolite is related to silver to release or oxygen Increase (36). Since zeolite can trap cations such as silver in its pores of crystalline structure, it can release them gradually. Perhaps because of the fact that zeolite-silver has been investigated as irrigant in this study and therefore its crystalline structure is clogged, it has shown little antibacterial property. Odabas *et al.* evaluated the effect of adding 0.2% and 2% silver-zeolite to the mineral trioxide aggregate (MTA) in antibacterial properties against Staphylococcus aureus, Enterococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Candida albicans, Porphyromonas gingivalis, Actinomyces israelii, and Prevotella intermedia on agar plates at 24, 48, and 72 h time points. MTA incorporated silver-zeolite 0.2% and 2%, showed antibacterial properties on all microorganisms except P. intermedia and A. israelii, at all time intervals. While MTA without silver-zeolite showed antibacterial effect only against C. albicans, E. coli, and P. intermedia. Therefore, the addition of zeolite-silver increased the antibacterial properties of MTA (37). Torabinejad *et al.* reported that MTA has no effect on E. faecalis and S. aureus (38). Estrela *et al.* also observed that MTA has no effect on E. faecalis (39). Considering that some studies have shown the antibacterial properties of MTA in relation to high PH (40-43), It has been shown that PH score increases by adding zeolite-silver up to 11 and the antibacterial properties of MTA will enhance subsequently (37). Ghatole *et al.* In 2016 evaluate the anti-bacterial property of 2% silver zeolite added to calcium hydroxide mixed with sterile water and calcium hydroxide mixed with 2% chlorhexidine against Enterococcus Faecalis in brain-heart infusion (BHI) broth by spectrophotometer on day 1 , 3 and 7. They reported that in all three time intervals, 2% silver zeolite added to calcium hydroxide mixed with sterile water had the highest inhibitory effect (44). In another study, Ghatole *et al.* evaluated the antibacterial properties of MTA, MTA + Silver-Zeolite, MTA + Chlorhexidine by spectrophotometrically using an ELISA-reader in the suspension of Enterococcus faecalis on the test materials. The results indicated that all three materials had antibacterial properties at 1, 3 and 7 time intervals. MTA with silver zeolite showed the highest antibacterial properties, While MTA showed the least antibacterial properties (45). Other studies also found that MTA was ineffective on E. faecalis (46, 47). Others also report the effect of MTA on E. faecalis (41). Cinar *et al.* added Silver zeolite (SZ) at 0.2 and 2% to glass ionomer cement. 2% SZ containing GIC had the highest inhibitory effect on all groups including Streptococcus milleri, Staphylococcus aureus, and Enterococcus faecalis after 24 and 48 h (48). Patel *et al.* showed that zeolites can increase the antibacterial properties of glass ionomer cement, which was observed in vitro for up to 90 days (49). Thom *et al.* compare various sealers including ZUT, Ketac-Cem (GIC component of ZUT), Ketac-Endo and AH 26 sealer for cytotoxicity. In terms of hemolytic and cytotoxic, ZUT was similar to GIC and better than AH26 (50). ZUT is a GIC combined with an antimicrobial zeolite that is made at the University of Toronto's Faculty of Dentistry (49). In the other hand physical properties of zeolite has been considered. In the evaluation of compressive strength by ISO 9917-1, this value was lower for MTA + 2% Ze-Ag-Zn than MTA at day 4 and 21, but MTA + 2% Ze-Ag-Zn did not show cytotoxicity for pulmonary adenocarcinoma cells by MTT test. Therefore, the use of MTA + Ze-Ag-Zn is appropriate in cases where compressive strength is not high (51). In another study comparing MTA and MTA with 0.2% or 2% silver zeolite, it was shown that 2% SZ MTA released the highest calcium value at 24 h and the setting time was decreased compared to MTA .Also, 2% SZ MTA had a higher solubility than MTA and 0.2% SZ MTA at day 7 (52). Lead zeolite and zinc zeolite shorten the setting time of Portland cement. (53) In the Lalh *et al.* study, ZUT also showed good dentin bonding (54). Zinc Zeolite improved the dentin shear bond strength (55).

Prosthodontics

Nikawa incorporated silver zeolite for the first time in a tissue conditioner which led to proper plaque control and also an inhibitory effect on Candida albicans (1). Tissue conditioners containing silver zeolite were able to inhibit Candida albicans as well as Staphylococcus aureus and Pseudomonas aeruginosa bacteria in saliva immersed media for four weeks. Also it has been shown that tissue conditioners containing silver zeolite can inhibit Candida albicans and Staphylococcus aureus, methicillin-resistant S. aureus (MRSA) over a period of 28 days, and this property did not change with immersion in saliva (56). Saravanan *et al.* evaluated the viscoelastic properties of soft liner containing zeolite after 28 days application by patients. Silver- zeolite could inhibit candida albicans, besides did not change the viscoelasticity in comparison to control group (57). Although PMMA is strictly used in the manufacture of dental prostheses, the probability of bacterial growth is high (58-60). Silver zeolite can have antibacterial properties as Biocide-releasing polymers, while no tissue irritations have been reported (37). Silver zeolite has been inhibited in C. albicans by in vitro, but in the presence of saliva coat, its inhibitory effect was reduced (1). Casemiro *et al.* evaluated the effect of adding silver zinc zeolite in denture base resins at 2.5%, 5.0%, 7.5%, and 10%. It has been concluded that there is antimicrobial activity against C. albicans and S. mutans, but adding high concentrations of zeolite has a negative effect on mechanical properties (61). Silver zeolite can be further evaluated as a substance for optimization of the PMMA-antimicrobial formulation (62). Self-cured acrylic resins are used in the prosthesis temporary crowns or repairing fractured prosthesis. Self-cured acrylic resins can become contaminated and create a very bad smell, if it remain for long time. Also, bacteria found in periodontal diseases have been found in culture of the temporary crowns. It has been also seen that by addition of a resin sample to the Candida albicans culture, it could grow over a short period of time (63). Casemiro *et al.* assessed the antibacterial effect of acrylic resins containing different percentages of silver and zinc zeolite. It indicated that the addition of silver-zinc zeolite could inhibit Candida albicans and Streptococcus mutans, but concentrations of 2.5% and higher silver-zinc zeolite resulted in reducing flexural strength. (61) Kuroki *et al.* evaluated antibacterial properties as well as the amount of residual monomer by adding antibacterial agents to UNIFAST III as self-cured acrylic resins. For this purpose, Zeomic (Carrier: A type zeolite), NOVARON (Carrier: Zirconium phosphate), Bactekiller (Carrier: Zirconium phosphate) were added to UNIFAST III as an inorganic antibacterial agent and their impact on Streptococcus mutans were examined. S. mutans attachment was significantly lower in all three groups than in the control group. Residual viable count of S. mutans (CFU) was significantly decreased in all three groups compared to controls. Residual monomer content was similar to control group. Therefore, by adding an inorganic antibacterial agent, antibacterial properties can be improved in self-cured acrylic resins (64). Adding silver zeolite does not affect the inherent dynamic viscoelastic properties of tissue conditioner's (65).

Oral medicine

Oral cancer is the sixth most common cancer in the world, most of which is oral squamous cell carcinoma. Recently, volatile organic compounds (VOCs) discharged from human body have been considered as a way of detecting pathologies. Many studies have shown that VOCs, as molecular cancer markers, are produced by in vitro cancer cell lines.(66-70) Shigeyama *et al.* in 2018, evaluated VOCs in patients with oral squamous cell carcinoma by a method of combining thin-film microextraction based on a ZSM-5 / polydimethylsiloxane hybrid film coupled with gas chromatography-mass spectrometry. 35 VOCs were similar between the patient and the control group. In addition, 7 VOCs in the healthy group and 38 VOCs were seen in the affected group and the release pattern of these VOCs was evaluated in two groups. This study showed that ZSM-5 / polydimethylsiloxane hybrid film can be used to identify tumor-specific candidate biomarkers (71). According to the release of VOCs into the saliva through simple diffusion of blood (72), and the fact that saliva collection is easier, less invasive and more cost effective than getting blood sample (73-75), it seems that zeolite can be considered as a tumour marker in early detection of cancer.

Restorative dentistry

Silver zeolite can inhibit bacteria responsible for dental caries including Streptococcus mutans, Streptococcus sanguis and Actinomyces viscosus (76). Can-Karabulut *et al.* investigated the in vitro dentin bond strength of a composite resin after the removal of zeolite as temporary cement after 7 days. Shear bond strength for the composite material was significantly lower in the group that used zeolite as temporary cement in comparison to the control group which no cement was used (77).

Periodontics and implant

Kawahara *et al.* Showed that silver-zeolite can inhibit Porphyromonas gingivalis, Prevotella intermedia and Actinobacillus actinomycetemcomitans as major periodontopathogens in anaerobic condition. Therefore It can be used in anaerobic conditions, including periodontal packets (76). It has also been shown in other studies that Silver zeolite has antibacterial effect on oral pathogens responsible for periodontal diseases and caries, including S. mutans, S. mitis, C. albicans, S. aureus and P. aeruginosa in aerobic conditions in vitro (2, 78). Also, silver zeolite suspended in PBS as mouth rinse was shown to reduce supra-gingival plaque formation (79). Silver-zeolite has antibacterial effect on Streptococcus mutans, Lactobacillus casei, Candida albicans and Staphylococcus aureus in vitro. So it can be considered as way of Oral hygiene control (80). silver-zeolite inhibit P. gingivalis and this effect was stronger in comparison with silver alone. silver-zeolite and a polyphenol-rich extract of A. nodosum (ASCOP) has antibacterial effect on P. gingivalis, reduce TNFα and IL-6 secretion and it has antioxidant properties. Therefore it can be effective against periodontal disease (81). The silver-and zinc-containing zeolite matrix (AgION) was used as a coating for stainless steel and was shown to be antibacterial against Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, and Listeria monocytogenes (82). In the study by Li *et al.* ZSM-5 zeolite was used as a coating on titanium components. In an animal study on rabbits, more bones were formed on zeolite-coated implants (83). Coating the MFI zeolite on a titanium alloy surface improves biocompatibility, corrosion resistance, osteoconductivity and osteoinductivity in vitro (84).

Discussion

Zeolites are biocompatible and high-quality materials for carrying various agents, including drugs and antibacterial agents and release them gradually. In addition to vast applications in medical and other sciences, it also has high potential of use in the field of dentistry. Zeolite is a potential wound dressing and tissue engineering scaffold in oral cavity. Zeolite is used in dentistry with silver for antimicrobial applications inside the root canal and in soft liner dentures and so on. Zeolite can inhibit pathogens of dental caries and periodontal disease. In addition zeolite indicated good biocompatibility properties for osteoblasts as implant surface coating. It has also been used to detect squamous cell carcinoma.

Conclusion

According to the attractive properties of zeolite, it can be concluded that Zeolite has the potential of variety application in dental sciences, especially in combination with antibacterial agents.

Conflict of Interest: 'None declared'.

References

1. Nikawa H, Yamamoto T, Hamada T, Rahardjo MB, Murata H, Nakanoda S. Antifungal effect of zeolite-incorporated tissue conditioner against Candida albicans growth and/or acid production. J Oral Rehabil. 1997;24(5):350-7.
2. Hotta M, Nakajima H, Yamamoto K, Aono M. Antibacterial temporary filling materials: the effect of adding various ratios of Ag-Zn-Zeolite. J Oral Rehabil. 1998;25(7):485-9.
3. van Koningsveld H, Jansen JC, van Bekkum H. The monoclinic framework structure of zeolite H-ZSM-5. Comparison with the orthorhombic framework of as-synthesized ZSM-5. Zeolites. 1990;10(4):235-42.
4. Bilim C. Properties of cement mortars containing clinoptilolite as a supplementary cementitious material. Construction and Building Materials. 2011;25(8):3175-80.
5. Aziz Y, Shah GA, Rashid MI. ZnO nanoparticles and zeolite influence soil nutrient availability but do not affect herbage nitrogen uptake from biogas slurry. Chemosphere. 2019;216:564-75.
6. Svihus B, Itani K, Borg K, Larsson EC, Ao R, Sudubilige A, et al. Performance and digestive function of broiler chickens given grit in the diet. Br Poult Sci. 2017;58(5):530-5.
7. Hcini E, Ben Slima A, Kallel I, Zormati S, Traore AI, Gdoura R. Does supplemental zeolite (clinoptilolite) affect growth performance, meat texture, oxidative stress and production of polyunsaturated fatty acid of Turkey poults? Lipids Health Dis. 2018;17(1):177.
8. Han Z, Dong J, Shen Z, Mou R, Zhou Y, Chen X, et al. Nitrogen removal of anaerobically digested swine wastewater by pilot-scale tidal flow constructed wetland based on in-situ biological regeneration of zeolite. Chemosphere. 2018;217:364-73.
9. Liu Y, Liu X, Li K, Lu S, Guo X, Zhang J, et al. Removal of nitrogen from low pollution water by long-term operation of an integrated vertical-flow constructed wetland: Performance and mechanism. Sci Total Environ. 2018;652:977-88.
10. Jayaramulu K, Masa J, Morales DM, Tomanec O, Ranc V, Petr M, et al. Ultrathin 2D Cobalt Zeolite-Imidazole Framework Nanosheets for Electrocatalytic Oxygen Evolution. 2018;5(11):1801029.
11. Salehi H, Mehrasa M, Nasri-Nasrabadi B, Doostmohammadi M, Seyedebrahimi R, Davari N, et al. Effects of nanozeolite/starch thermoplastic hydrogels on wound healing. J Res Med Sci. 2017;22:110.
12. Neidrauer M, Ercan UK, Bhattacharyya A, Samuels J, Sedlak J, Trikha R, et al. Antimicrobial efficacy and wound-healing property of a topical ointment containing nitric-oxide-loaded zeolites. J Med Microbiol. 2014;63(Pt 2):203-9.
13. Yang K, Yang K, Chao S, Wen J, Pei Y, Pei Z. A supramolecular hybrid material constructed from pillar[6]arene-based host-guest complexation and ZIF-8 for targeted drug delivery. Chem Commun (Camb). 2018;54(70):9817-20.
14. Wang L, Guan H, Wang Z, Xing Y, Zhang J. Hybrid Mesoporous-Microporous Nanocarriers for Overcoming Multidrug Resistance by Sequential Drug Delivery. 2018;15(7):2503-12.
15. Yao G, Lei J, Zhang W, Yu C, Sun Z, Zheng S, et al. Antimicrobial activity of X zeolite exchanged with Cu(2+) and Zn(2+) on Escherichia coli and Staphylococcus aureus. 2018.
16. Beisl S, Monteiro S, Santos R, Figueiredo AS, Sanchez-Loredo MG, Lemos MA, et al. Synthesis and bactericide activity of nanofiltration composite membranes - Cellulose acetate/silver nanoparticles and cellulose acetate/silver ion exchanged zeolites. Water Res. 2018;149:225-31.
17. Tavolaro P, Catalano S, Tavolaro A. Anticancer activity modulation of an innovative solid formulation of extra virgin olive oil by cultured zeolite scaffolds. Food Chem Toxicol. 2018.
18. Abasian P, Radmansouri M, Habibi Jouybari M, Ghasemi MV, Mohammadi A, Irani M, et al. Incorporation of magnetic NaX zeolite/DOX into the PLA/chitosan nanofibers for sustained release of doxorubicin against carcinoma cells death in vitro. Int J Biol Macromol. 2019;121:398-406.
19. Hu D, Chen Z, Sheng Z, Gao D, Yan F, Ma T, et al. A catalase-loaded hierarchical zeolite as an implantable nanocapsule for ultrasound-guided oxygen self-sufficient photodynamic therapy against pancreatic cancer. Nanoscale. 2018;10(36):17283-92.
20. Vilaça N, Amorim R, Machado AF, Parpot P, Pereira MFR, Sardo M, et al. Potentiation of 5-fluorouracil encapsulated in zeolites as drug delivery systems for in vitro models of colorectal carcinoma. Colloids and Surfaces B: Biointerfaces. 2013;112:237-44.
21. Banu J, Varela E, Guerra JM, Halade G, Williams PJ, Bahadur AN, et al. Dietary coral calcium and zeolite protects bone in a mouse model for postmenopausal bone loss. Nutr Res. 2012;32(12):965-75.
22. Schutze N, Oursler MJ, Nolan J, Riggs BL, Spelsberg TC. Zeolite A inhibits osteoclast-mediated bone resorption in vitro. J Cell Biochem. 1995;58(1):39-46.
23. Cutovic M, Lazovic M, Vukovic-Dejanovic V, Nikolic D, Petronic-Markovic I, Cirovic D. Clinoptilolite for Treatment of Dyslipidemia: Preliminary Efficacy Study. J Altern Complement Med. 2017;23(9):738-44.
24. Karaca G, Aydin O, Pehlivanli F, Altunkaya C, Uzun H, Guler O. Effectiveness of thymoquinone, zeolite, and platelet-rich plasma in model of corrosive oesophagitis induced in rats. Ann Surg Treat Res. 2017;92(6):396-401.
25. Pazarceviren E, Erdemli O, Keskin D, Tezcaner A. Clinoptilolite/PCL-PEG-PCL composite scaffolds for bone tissue engineering applications. J Biomater Appl. 2017;31(8):1148-68.
26. Pazarçeviren E, Erdemli Ö, Keskin D, Tezcaner A. Clinoptilolite/PCL–PEG–PCL composite scaffolds for bone tissue engineering applications. J Biomater Appl. 2016;31(8):1148-68.

27. Costa R, Ribeiro C, Lopes AC, Martins P, Sencadas V, Soares R, et al. Osteoblast, fibroblast and in vivo biological response to poly(vinylidene fluoride) based composite materials. Journal of Materials Science: Materials in Medicine. 2013;24(2):395-403.
28. Keeting PE, Oursler MJ, Wiegand KE, Bonde SK, Spelsberg TC, Riggs BL. Zeolite A increases proliferation, differentiation, and transforming growth factor beta production in normal adult human osteoblast-like cells in vitro. J Bone Miner Res. 1992;7(11):1281-9.
29. Chen J, Zhang X, Huang C, Cai H, Hu S, Wan Q, et al. Osteogenic activity and antibacterial effect of porous titanium modified with metal-organic framework films. J Biomed Mater Res A. 2017;105(3):834-46.
30. Neidrauer M, Ercan UK, Bhattacharyya A, Samuels J, Sedlak J, Trikha R, et al. Antimicrobial efficacy and wound-healing property of a topical ointment containing nitric-oxide-loaded zeolites. J Med Microbiol. 2014;63(Pt 2):203-9.
31. Ninan N, Muthiah M, Park IK, Elain A, Wong TW, Thomas S, et al. In Vitro and In Vivo Evaluation of Pectin/Copper Exchanged Faujasite Composite Membranes. J Biomed Nanotechnol. 2015;11(9):1550-67.
32. Ninan N, Muthiah M, Bt Yahaya NA, Park IK, Elain A, Wong TW, et al. Antibacterial and wound healing analysis of gelatin/zeolite scaffolds. Colloids Surf B Biointerfaces. 2014;115:244-52.
33. Ninan N, Muthiah M, Park IK, Elain A, Wong TW, Thomas S, et al. Faujasites incorporated tissue engineering scaffolds for wound healing: in vitro and in vivo analysis. ACS Appl Mater Interfaces. 2013;5(21):11194-206.
34. Seifu DG, Isimjan TT, Mequanint K. Tissue engineering scaffolds containing embedded fluorinated-zeolite oxygen vectors. Acta Biomater. 2011;7(10):3670-8.
35. Ghivari SB, Bhattacharya H, Bhat KG, Pujar MA. Antimicrobial activity of root canal irrigants against biofilm forming pathogens- An in vitro study. J Conserv Dent. 2017;20(3):147-51.
36. Matsumura Y, Yoshikata K, Kunisaki S, Tsuchido T. Mode of bactericidal action of silver zeolite and its comparison with that of silver nitrate. Appl Environ Microbiol. 2003;69(7):4278-81.
37. Odabas ME, Cinar C, Akca G, Araz I, Ulusu T, Yucel H. Short-term antimicrobial properties of mineral trioxide aggregate with incorporated silver-zeolite. Dent Traumatol. 2011;27(3):189-94.
38. Torabinejad M, Hong CU, Pitt Ford TR, Kettering JD. Antibacterial effects of some root end filling materials. J Endod. 1995;21(8):403-6.
39. Estrela C, Bammann LL, Estrela CR, Silva RS, Pecora JD. Antimicrobial and chemical study of MTA, Portland cement, calcium hydroxide paste, Sealapex and Dycal. Braz Dent J. 2000;11(1):3-9.
40. Al-Hezaimi K, Al-Shalan TA, Naghshbandi J, Oglesby S, Simon JH, Rotstein I. Antibacterial effect of two mineral trioxide aggregate (MTA) preparations against Enterococcus faecalis and Streptococcus sanguis in vitro. J Endod. 2006;32(11):1053-6.
41. Al-Hezaimi K, Al-Hamdan K, Naghshbandi J, Oglesby S, Simon JH, Rotstein I. Effect of white-colored mineral trioxide aggregate in different concentrations on Candida albicans in vitro. J Endod. 2005;31(9):684-6.
42. Al-Nazhan S, Al-Judai A. Evaluation of antifungal activity of mineral trioxide aggregate. J Endod. 2003;29(12):826-7.
43. McHugh CP, Zhang P, Michalek S, Eleazer PD. pH required to kill Enterococcus faecalis in vitro. J Endod. 2004;30(4):218-9.
44. Ghatole K, Gowdra RHG, Azher S, Sabharwal S, Singh VT, Sundararajan BV. Enhancing the antibacterial activity of the gold standard intracanal medicament with incorporation of silver zeolite: An in vitro study. Journal of International Society of Preventive & Community Dentistry. 2016;6(1):75-9.
45. Ghatole K, Patil A, Giriyappa RH, Singh TV, Jyotsna SV, Rairam S. Evaluation of Antibacterial Efficacy of MTA with and without Additives Like Silver Zeolite and Chlorhexidine. J Clin Diagn Res. 2016;10(6):Zc11-4.
46. Eldeniz AU, Hadimli HH, Ataoglu H, Orstavik D. Antibacterial effect of selected root-end filling materials. J Endod. 2006;32(4):345-9.
47. Hasan Zarrabi M, Javidi M, Naderinasab M, Gharechahi M. Comparative evaluation of antimicrobial activity of three cements: new endodontic cement (NEC), mineral trioxide aggregate (MTA) and Portland. J Oral Sci. 2009;51(3):437-42.
48. Cinar C, Ulusu T, Ozcelik B, Karamuftuoglu N, Yucel H. Antibacterial effect of silver-zeolite containing root-canal filling material. J Biomed Mater Res B Appl Biomater. 2009;90(2):592-5.
49. Patel V, Paul Santerre J, Friedman S. Suppression of Bacterial Adherence by Experimental Root Canal Sealers. J Endod. 2000;26(1):20-4.
50. Thom DC, Davies JE, Santerre JP, Friedman S. The hemolytic and cytotoxic properties of a zeolite-containing root filling material in vitro. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003;95(1):101-8.
51. 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;9(3):e356-e60.
52. Cinar C, Odabas M, Gurel MA, Baldag I. The effects of incorporation of silver-zeolite on selected properties of mineral trioxide aggregate. Dent Mater J. 2013;32(6):872-6.
53. Gervais C, Ouki SK. Performance study of cementitious systems containing zeolite and silica fume: effects of four metal nitrates on the setting time, strength and leaching characteristics. Journal of Hazardous Materials. 2002;93(2):187-200.
54. Lalh MS, Titley K, Torneck CD, Friedman S. The shear bond strength of glass ionomer cement sealers to bovine dentine conditioned with common endodontic irrigants. Int Endod J. 1999;32(6):430-5.
55. 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;19(3):205-11.
56. Abe Y, Ishii M, Takeuchi M, Ueshige M, Tanaka S, Akagawa Y. Effect of saliva on an antimicrobial tissue conditioner containing silver-zeolite. J Oral Rehabil. 2004;31(6):568-73.
57. Saravanan M, Kumar A, Padmanabhan TV, 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. 2015;28(3):265-9.
58. Minagi S, Miyake Y, Inagaki K, Tsuru H, Suginaka H. Hydrophobic interaction in Candida albicans and Candida tropicalis adherence to various denture base resin materials. Infect Immun. 1985;47(1):11-4.
59. Gerson DF, Scheer D. Cell surface energy, contact angles and phase partition III. Adhesion of bacterial cells to hydrophobic surfaces. Biochimica et Biophysica Acta (BBA) - Biomembranes. 1980;602(3):506-10.
60. Edgerton M, Raj PA, Levine MJ. Surface-modified poly(methyl methacrylate) enhances adsorption and retains anticandidal activities of salivary histatin 5. J Biomed Mater Res. 1995;29(10):1277-86.
61. Casemiro LA, Gomes Martins CH, Pires-de-Souza Fde C, Panzeri H. Antimicrobial and mechanical properties of acrylic resins with incorporated silver-zinc zeolite - part I. Gerodontology. 2008;25(3):187-94.
62. Sivakumar I, Arunachalam KS, Sajjan S, Ramaraju AV, Rao B, Kamaraj B. Incorporation of antimicrobial macromolecules in acrylic denture base resins: a research composition and update. J Prosthodont. 2014;23(4):284-90.
63. Wendt S, Glass RT. The infected denture: how long does it take? Quintessence Int. 1987;18(12):855-8.
64. 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.
65. Ueshige M, Abe Y, Sato Y, Tsuga K, Akagawa Y, Ishii M. Dynamic viscoelastic properties of antimicrobial tissue conditioners containing silver-zeolite. J Dent. 1999;27(7):517-22.
66. Filipiak W, Sponring A, Mikoviny T, Ager C, Schubert J, Miekisch W, et al. Release of volatile organic compounds (VOCs) from the lung cancer cell line CALU-1 in vitro. Cancer Cell International. 2008;8(1):17.
67. Filipiak W, Sponring A, Filipiak A, Ager C, Schubert J, Miekisch W, et al. TD-GC-MS analysis of volatile metabolites of human lung cancer and normal cells in vitro. Cancer Epidemiol Biomarkers Prev. 2010;19(1):182-95.
68. Sponring A, Filipiak W, Ager C, Schubert J, Miekisch W, Amann A, et al. Analysis of volatile organic compounds (VOCs) in the headspace of NCI-H1666 lung cancer cells. Cancer Biomark. 2010;7(3):153-61.
69. Mochalski P, Sponring A, King J, Unterkofler K, Troppmair J, Amann A. Release and uptake of volatile organic compounds by human hepatocellular carcinoma cells (HepG2) in vitro. Cancer Cell International. 2013;13(1):72.
70. Nozoe T, Goda S, Selyanchyn R, Wang T, Nakazawa K, Hirano T, et al. In vitro detection of small molecule metabolites excreted from cancer cells using a Tenax TA thin-film microextraction device. J Chromatogr B Analyt Technol Biomed Life Sci. 2015;991:99-107.
71. Shigeyama H, Wang T, Ichinose M, Ansai T, Lee S-W. Identification of volatile metabolites in human saliva from patients with oral squamous cell carcinoma via zeolite-based thin-film microextraction coupled with GC–MS. Journal of Chromatography B. 2019;1104:49-58.
72. Amann A, Costello Bde L, Miekisch W, Schubert J, Buszewski B, Pleil J, et al. The human volatilome: volatile organic compounds (VOCs) in exhaled breath, skin emanations, urine, feces and saliva. J Breath Res. 2014;8(3):034001.
73. Radhika T, Jeddy N, Nithya S, Muthumeenakshi RM. Salivary biomarkers in oral squamous cell carcinoma – An insight. Journal of Oral Biology and Craniofacial Research. 2016;6:S51-S4.
74. Ishikawa S, Sugimoto M, Kitabatake K, Tu M, Sugano A, Yamamori I, et al. Effect of timing of collection of salivary metabolomic biomarkers on oral cancer detection. Amino Acids. 2017;49(4):761-70.
75. Pfaffe T, Cooper-White J, Beyerlein P, Kostner K, Punyadeera C. Diagnostic potential of saliva: current state and future applications. Clin Chem. 2011;57(5):675-87.
76. Kawahara K, Tsuruda K, Morishita M, Uchida M. Antibacterial effect of silver-zeolite on oral bacteria under anaerobic conditions. Dent Mater. 2000;16(6):452-5.
77. Can-Karabulut DC, Akincioglu A, Ozyegin SL, 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;12(6):469-75.
78. Matsuura T, Abe Y, Sato Y, Okamoto K, Ueshige M, Akagawa Y. Prolonged antimicrobial effect of tissue conditioners containing silver-zeolite. J Dent. 1997;25(5):373-7.
79. Morishita M, Miyagi M, Yamasaki Y, Tsuruda K, Kawahara K, Iwamoto Y. Pilot study on the effect of a mouthrinse containing silver zeolite on plaque formation. J Clin Dent. 1998;9(4):94-6.
80. Saengmee-Anupharb S, Srikhirin T, Thaweboon B, Thaweboon S, Amornsakchai T, Dechkunakorn S, et al. Antimicrobial effects of silver zeolite, silver zirconium phosphate silicate and silver zirconium phosphate against oral microorganisms. Asian Pac J Trop Biomed. 2013;3(1):47-52.
81. Tamanai-Shacoori Z, Chandad F, Rebillard A, Cillard J, Bonnaure-Mallet M. Silver-zeolite combined to polyphenol-rich extracts of Ascophyllum nodosum: potential active role in prevention of periodontal diseases. PLoS One. 2014;9(10):e105475.
82. Cowan MM, Abshire KZ, Houk SL, Evans SM. Antimicrobial efficacy of a silver-zeolite matrix coating on stainless steel. J Ind Microbiol Biotechnol. 2003;30(2):102-6.
83. Li Y, Jiao Y, Li X, Guo Z. Improving the osteointegration of Ti6Al4V by zeolite MFI coating. Biochem Biophys Res Commun. 2015;460(2):151-6.
84. Bedi RS, Beving DE, Zanello LP, Yan Y. Biocompatibility of corrosion-resistant zeolite coatings for titanium alloy biomedical implants. Acta Biomater. 2009;5(8):3265-71.

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