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BIOACTIVE GLASS – A VERSATILE BIOMATERIAL

[1]Dr. Sandeep Rudranaik, [2]Dr. Sahadev Chickmagaravalli Krishnegowda, [3]Dr. Bharath Makonahalli Jaganath, [4]*Dr. Rakshith Jayanna

[1,3]Professor, Department of Conservative and Endodontics, Sri Hasanamba Dental College and Hospital, Hassan, Karnataka.
[2]Professor and HOD, Department of Conservative and Endodontics, Sri Hasanamba Dental College and Hospital, Hassan, Karnataka.
[4]Post Graduate Student, Department of Conservative and Endodontics, Sri Hasanamba Dental College and Hospital, Hassan, Karnataka.

***Corresponding Author: Rakshith J.**
Post Graduate Student, Department of Conservative and Endodontics, Sri Hasanamba Dental College and Hospital, Hassan, Karnataka.

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ABSTRACT
Regeneration of lost dental hard tissue is a significant contributing factors to long term success of the hard tissue treatment. Several bioceramic materials are now available with high degree of biocompatibility and bioinductive abilities. Bioactive Glass (BAG) is a novel biomaterial with primary components consisting of Silica, Calcium oxide and Phosphate. BAG was initially used as a bone regenerating material & is also found to promote new hydroxyapatite formation. The primary antimicrobial action of BAG is through its alkalinity and is effective against S.aureus and E.coli. In conservative dentistry BAG is used as a pulp capping material due to its ability to stimulate dentin bridge formation and deposition of secondary dentin. It is also capable of enamel remineralization and is used as dental adhesive. In endodontics BAG is used as an effective root canal sealer , perforation repair agent, retrograde filling material, pulp capping agent, repair of resorptive defects, apexification procedures and for pulpotomy procedure in due to its adhesive properties with tooth structure. BAG is used as a component in bioactive obturation materials such as the thermoplastic polymer based Resilon sealer. Bio Gutta, a gutta percha mixed with bioglass is a new alternative to classical GP cones as it does not require the use of a sealer and bonds to the dentin wall. The chemistry of BAG mimics the natural hard tissue composition and along with its bio inductive properties presents as an excellent biomaterial in the field of conservative and endodontics.

KEYWORDS: Bioactive glass, bone regeneration, biomimetic, biogutta, resilon, bioinductive.

INTRODUCTION
One of the biomaterials that has transformed contemporary biomaterial-driven regenerative medicine is bioactive glass, which has developed novel uses in biomedicine including soft tissue healing and drug delivery.[1] Bioactive glasses is applied in orthopaedic and dental applications. By eliciting a potent response after being implanted into the human body (i.e bone, teeth), these glasses transformed the properties and capacities of biomaterials from bioinert to bioactive since 45 years.[2]

Hench was the first to develop bioactive glasses (1969) and these glasses were able to bond to tissues. Wilson et al (1981) reviewed these studies and proposed that bioactive glasses are safefor clinical use.

Composition of Bioactive Glass
BAG was commercially trademarked as Bioglass® 45S5 composed ofSilicon dioxide (SiO2 -45 %), Sodium oxide (Na2O- 24.5%) Calcium oxide (CaO-24.5%) And Phosphorous pentoxide (P2O5-6%).[3]

BAG may also consist of known biocompatible and bioactive minerals,such as fluorapatite (FAP), wollastonite, diopside, and tricalcium phosphate.[4]

The mechanism of hydroxyapetite (HAP) layer formation on bio active glasses
In vitro and in vivo research on the mechanism of HAP layer generation on bioactive glasses has been extensively conducted. This process happens in stages as a silica-rich interlayer develops onthe glass surfaces and calcium ions dissolve from the bioactive glass into the bodily fluid. The surrounding fluid is now supersaturated with HAP due to the dissolution of the calcium ions, making the nucleation of HAP feasible. Moreover, silica-rich interlayer offers ideal locations for the nucleation and dissolves a significant quantity of silicate ion. The reaction between the ions of calcium, phosphate, and

hydroxide continue to cause the HAP layer to form and expand.[5]

Preparations of Bioactive Glass

Melt quenching has been used to make glasses, such as Bioglass® 45S5.[6] Powdered substances are heated to high temperatures typically above 1300 °C during the melt quenching process, and then they are quickly cooled to cause the atomic structure to freeze. However, this method has drawbacks such the difficulty to create porous scaffolds and decreased bioactivity at higher sintering temperatures.[7] The glass is frequently treated with heat to ease thermomechanical strains brought on by rapid cooling. As is the case with the thermal treatment of Bioglass® 45S5, heat treatment may, at particular temperature ranges, lead to the production of various crystalline phases that may adversely influence the elastic modulus and strength, predisposing for mechanical failure. Stresses are released from the glass during heat treatment of silicate-based BAG because there is a chance that residual glassy phases will combine with crystalline phases to form, which could damage the mechanical characteristics.[8] Compared to melt-quenched glasses, sol-gel glasses have larger porosity, apatite-forming capacity, and surface area, which has the advantage of higher mechanical characteristics.

Antimicrobial Properties

BAGS, specifically BAG-S53P4, have shown to possess broad-spectrum antimicrobial properties[9] S. aureus is a significant biofilm contributor and one of the most frequent bacterial strains linked to prosthetic joint infections(PJI). Moreover, it has been noted that numerous multi-drug resistant strains isolated from PJIs are impacted by the antibiofilm action. The addition of antimicrobial compounds to the BAG such as SiO2 and CaO glass also results in an enhanced antibiofilm action. Osteomyelitis has been effectively treated with S53P4 in the past. Bioactive glasses have antimicrobial and antibiofilm properties because, once inside the body, they raise the local pH and osmolarity, which inhibits local bacterial growth and adherence.[10]

Clinical Application of bioactive glasses in dentistry

Due to their numerous benefits, such as their capacity to support the structure of biological tissues, their effectiveness as scavengers, and their ability to inhibit the growth of bacteria, bioactive glasses have proven very helpful in a variety of dental specialties.[11] Bioactive glasses have been used in various dental products especially toothpaste.[12] Because they can release antibacterial agents, promote remineralization, and lessen hypersensitization.[13]

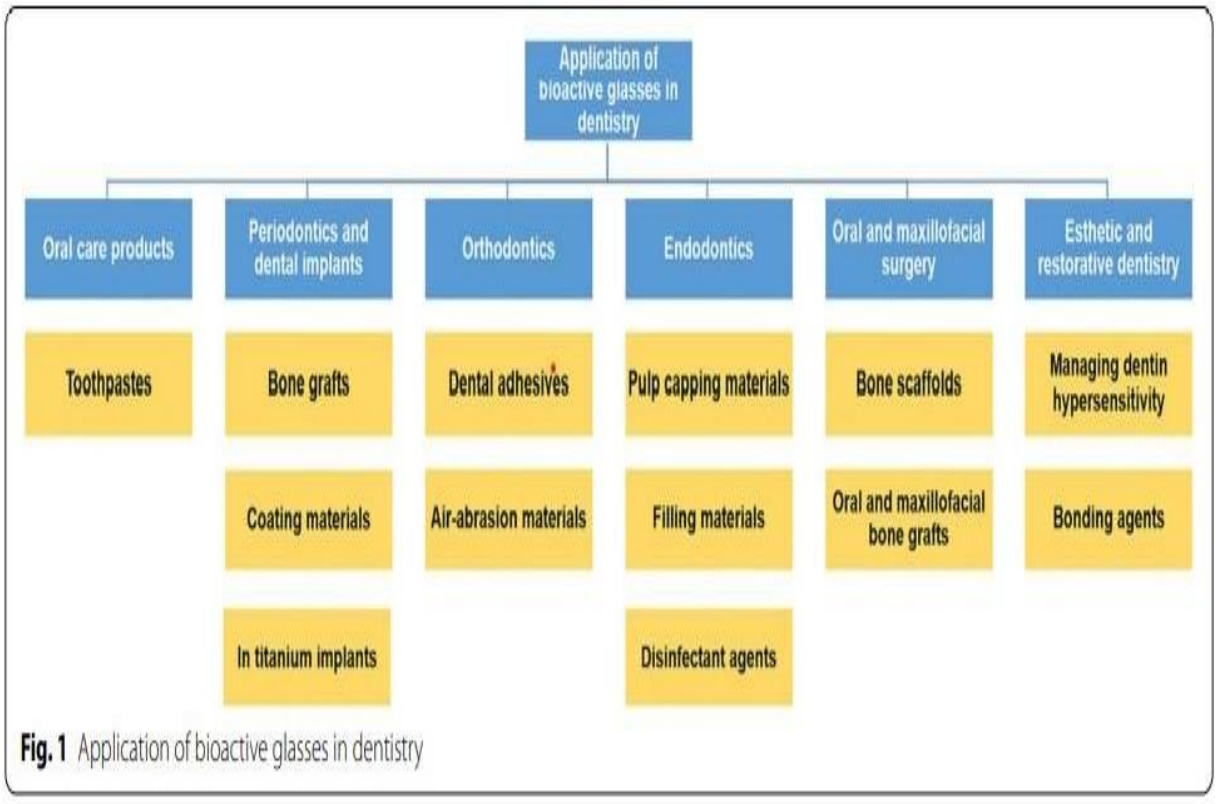
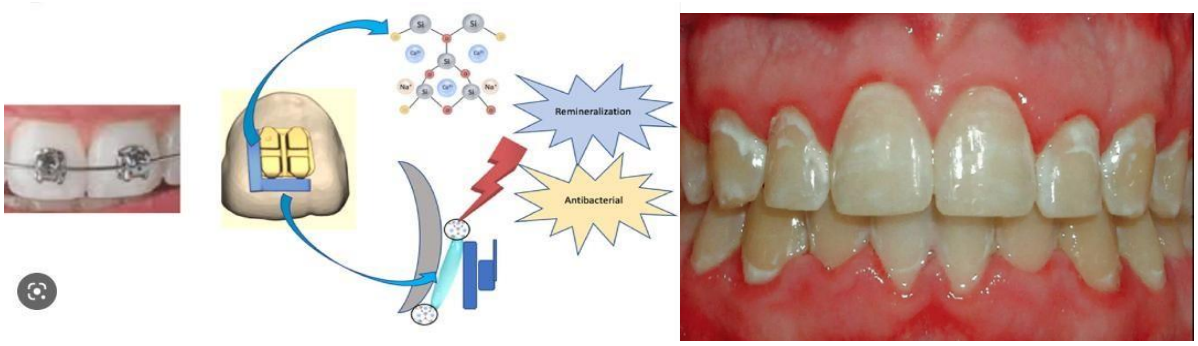


Fig. 1 Application of bioactive glasses in dentistry

Dental Adhesives

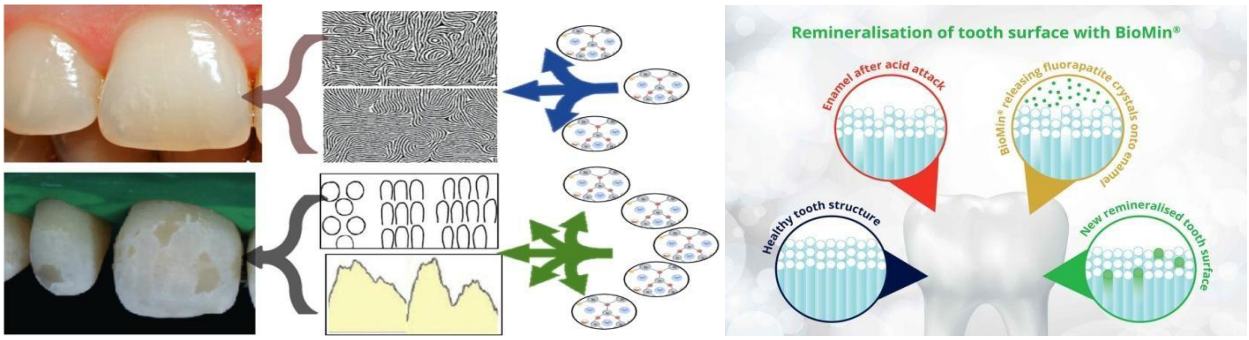
Dental adhesives enable a substance or material, such as dental composite or orthodontic brackets, to adhere to or attach to the tissue of a tooth. Orthodontic bracket adhesion creates conditions that are suitable for bacterial colonization, which may cause white spot lesions (WSLs).[14] BAG-containing bonding systems reduced micro-permeability by remineralization of mineral-deficient areas as well as showing an increase in modulus of elasticity and hardness along with the dentine interface. The commercial glue containing niobophosphate BAG fillers produced higher

microhardness and radiopacity. Fluoride-containing glue may play a clinical role in remineralization and the prevention of WSLs around orthodontic brackets by encouragingthe formation of apatite in neutral and acidic environments.



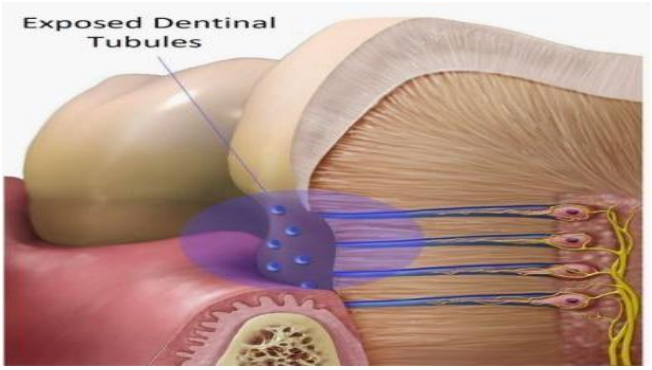
Enamel Remineralization

Re-mineralization of the dental hard tissue is a challenging problem faced by dentists across the globe on a daily basis.[15,16] Bioactive glass may enhance enamel remineralization more effectively and at a faster rate with the combination of fluoride and high phosphate content, commercially known as BiominF®. This combination resulted in the formation of Fluorapatite(FAP)rather than fluorite, CaF2. The high phosphate content serves as a source of delivery of all the necessary ions of FAP, Ca5(PO4)3F .The remineralization efficacy of BiominF® is better compared to a BAG-containing dentifrice and Novamin® using micro-CT study.[15,17]



Dentin Hypersensitivity

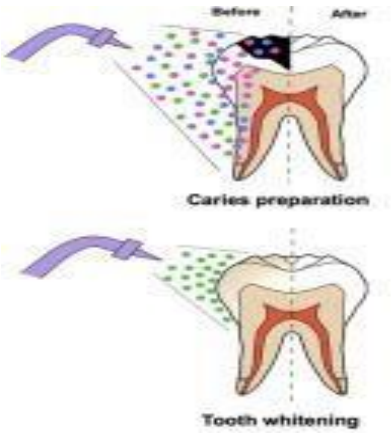
One of the most prevalent clinical disorders that is frequently linked to exposed dentinal surfaces is dentin hypersensitivity (DH). The dentinal tubule is exposed, which leads to dentin hypersensitivity. When the tubule's width increases, acidic food or oral microorganisms can demineralize dentin as it becomes more exposed. Thus, the key point of DH treatment is to desensitize dentin through the re-mineralization of the exposed dentin by obstructing the exposed dentinal tubules. Bio-silicate (P_2O_5–Na_2O–CaO–SiO_2), A fully crystallized bioactive glass- ceramic has been proposed to treat DH by depositing hydroxyl carbonate apatite in open dentinal tubules.[18]

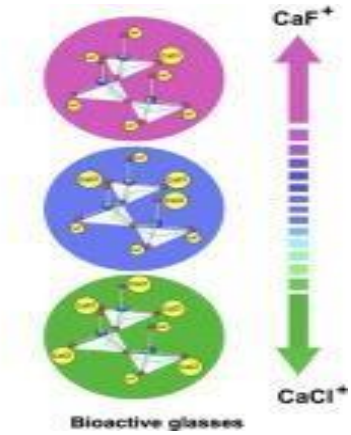


Air Abrasion

Novamin®, or BAG in general, exhibits a hardness (Moh) of 7 GPa, which is higher than that of enamel (3.5 GPa).[19] More rounded glass particles are less abrasive. With the increase in particle size, the abrasiveness increases. The cementoenamel junction is prone to DH due to the wear of enamel. Therefore, the use of less abrasive dentifrices is advised on the outer enamel layer

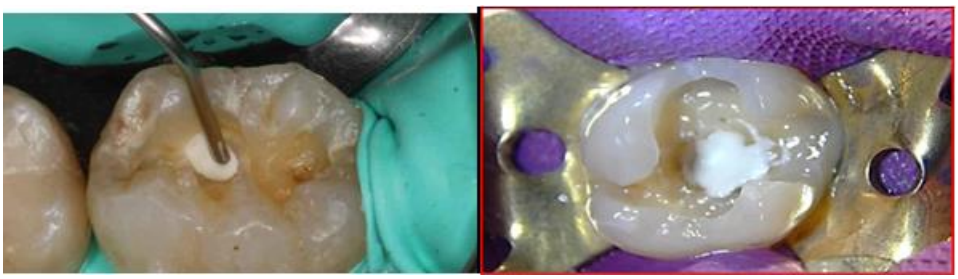
that is susceptible to wear. The addition of fluoride or strontium reduces the hardness of BAG and should be included in dentifrices. Novamin® has been used for teeth whitening owing to its abrasive properties. Surface stains can be removed by the high-pressure airflow of ceramic particles. Patients had subjective reductions of DH and whiter teeth using airflow with Novamin® particles compared to conventional sodium bicarbonate particles.





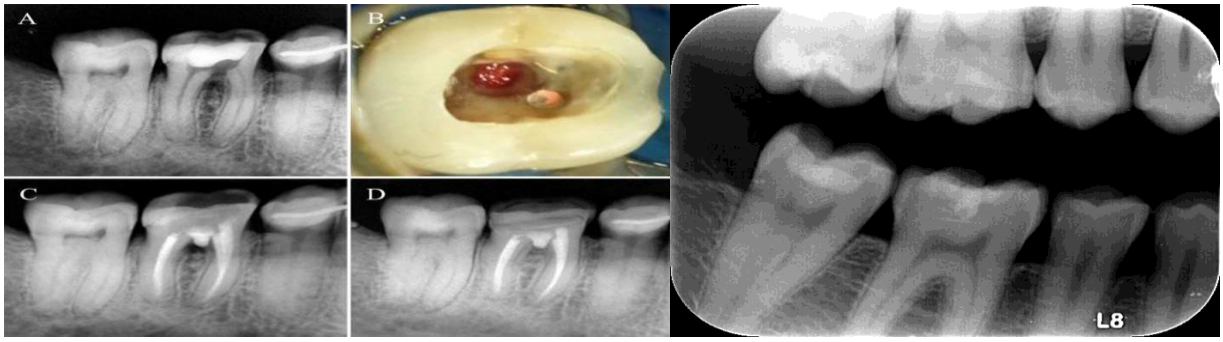
Restorative Materials

One of the fields of dental biomaterial research has been the creation of dental restorative materials capable of remineralizing or repairing demineralized dentin after bacterial invasion. By making a strong bond with the tooth and a hostile environment for germs, dental restorations can be made to last for a long time. Through hydroxyapatite precipitation, bonding agents with bioactive characteristics can create a sealed interface. Dentin remineralization has been proven to be induced by Bioglass® 45S5. Without weakening the binding strength, flowable resin composite materials have been shown to slow the growth of oral microorganisms such S. mutans and E. coli.[20] Resin composites with BAG and fluoride enhanced dentin remineralization and eliminated enzymatic degradation at the dentin interface.



Pulp Capping and Root Canal Therapy

BAG has an interest in endodontic management as well. The selection of a pulp-capping material is crucial when treating an exposed dental pulp that has been recommended for partial pulpotomy or pulp capping, among other treatments.[21] Although tunnel-like defects prevent calcium hydroxide (CH) from completing the dentin bridge, which has been employed in a numerous endodontic procedures, including pulp capping. When utilised for direct pulp capping, BAG formed from sol-gel promoted the development of a thick dentin bridge with inflammatory reactions resembling those caused by mineral trioxide aggregate (MTA), After bacteria had gone into the pulp, root canal therapy is advised. In addition to a tight coronal seal, a strong and dimensionally stable root filling material that resists bacterial leakage is required. BAGs have been implemented in endodontic root filling materials as well. The endodontic obturation thermoplastic polymer commercially known as Resilon™ utilizes BAG as filler particles.



A substitute for traditional gutta-percha (GP) has arisen, which is known as Bio-Gutta since itcan attach to dentin walls and doesn't need sealants.[22] Since GP shrinks when it cools and finds it difficult to adapt to the canal's morphology without heating, a sealer must be used toclose the gap.

An obturating substance with a high level of biocompatibility.[23] equivalent to GP is called bio-gutta. It also raises the pH, offers an effective seal, and has antibacterial properties. According to the theory behind Bio-Gutta, calcium phosphate would build on a material's surface when it was moist, providing self-adhesion and a tight seal. In order to create root canal filling materials with good sealing ability and eliminate the need for a sealer, polyisoprene (PI) and polycaprolactone (PCL) were combined with Bioglass® 45S5 up to 30 weight% separately.[24] Bio-Gutta, PCL, and PI with BAG may therefore be used as clinical substitutes for traditional GP.

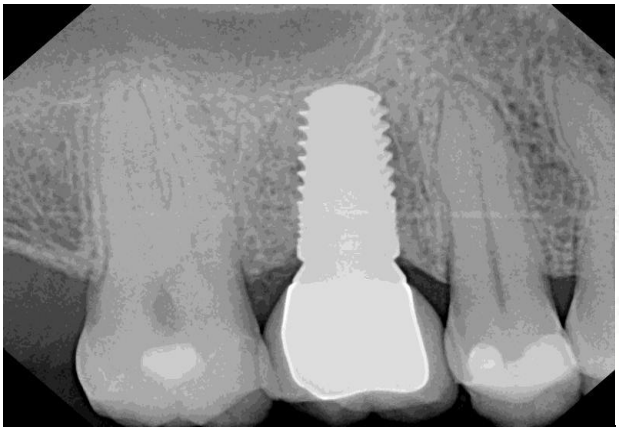
Bone Regeneration

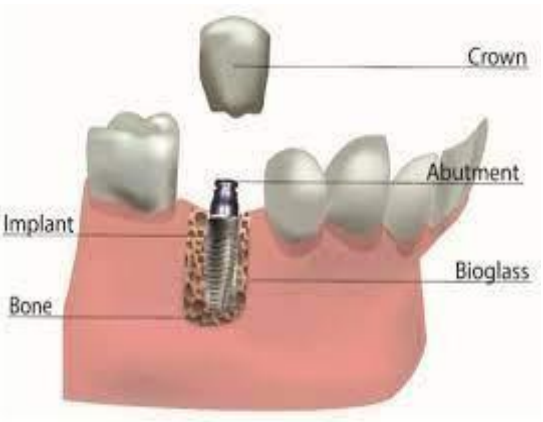
Autologous bone grafts (BGs), allogenic BGs, xenografts, and synthetic BGs are the bone- grafting materials now used. Because it possesses all the elements required for bone regeneration, bears no danger of unfavourable immunological reactions, and is highly osteogenic, autologous BG is regarded as the gold standard.[25]

In Implant Dentistry

Endosseous implants, commonly known as dental implants (DI), are screw-shaped components that are put into the alveolar bone to support prosthodontic constructs that enhance function and esthetics. Osseointegration, or direct contact between the implant surface and bone tissue, is required to promote sufficient retention in bone.[26] bioactive glass coating materials were biocompatible and nontoxic and bioactive glass-coated implants were as equally successful as hydroxyapatite in achieving osseointegration and supporting final restorations. So that glass- coated implants were a viable

alternative coating material for dental implants.





In Maxillofacial Surgery

Oral and maxillofacial surgery(OMFS), has actively explored Bioglass® 45S5 and formulations based on it. BAG stimulates bone formation at a higher quantity and quality and a faster rate as compared to other calcium phosphate-based chemicals used in osseous repair, such as hydroxyapatite and tricalcium phosphate.[26] Biogran® is one of the commercial treatments used mostly to repair flaws in maxillofacial applications.

CONCLUSIONS

The chemistry of BAG is mimicking the natural hard tissues composition, and has a bioactive role in the regeneration. BAGs are usually composed of 40–52% SiO2, 10–50% CaO, 10–35% Na2O, the glass composition may contain 2–8% P2O5, 0–25% CaF2, or 0–10% B2O3. Na-free BAG prevented the disruption of the glass network and showed equal bioactivity. In addition, various elements such as Si, P, Sr, Cu, F, Ag, Zn, and F are added to enhance the bioactivity and antimicrobial properties. Generally, the BAGs are prepared by either quenching or sol-gel technique. The bioactivity is influenced by the structure and composition of the glass, manufacturing techniques, and the rate of ionic dissolution. The most bioactive glasses have superior surface area with higher dissolution rate and thus faster apatite formation. The FDA has approved Bioglass® 45S5 and S53P4 for clinical applications due to desired antimicrobial properties. There is increasing use of bioactive glasses in various aspects of dentistry including dental restorative materials, toothpaste, mineralizing agents, desensitizing agents, pulp capping, root canal treatment, and air abrasion.

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