Physicochemical and Biocompatibility Characteristic Features of 54SP Bioglass

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**Abstract:** 54SP bioglass is a bioactive material that has garnered significant interest in the field of biomaterials and tissue engineering. It belongs to the family of bioactive glasses, which are designed to interact with biological systems and promote tissue regeneration. The physicochemical and biocompatibility characteristic features of 54SP bioglass make it a promising material for various biomedical applications.To study the physicochemical and biocompatibility characteristic features of 54SP bioglass Generally in bio active glasses, sodium calcium silicate phases were absorbed in which we found NaCaPO4 and calcium carbonate crystalline patterns. Dominated silicate vibrations were absorbed at 1067cm-1, similarly the 950° small arm showed the phosphate vibration. The silica peak was absorbed to 1067 cm-1 and the phosphate peak was 957cm-1. Integrated sheet-like morphology was observed in bio active glasses, similarly calcium sodium silicate phosphate elemental composition was observed through EDS. Blood compatibility authenticates the compatible features of material with interaction of RBCs in which we found a maximum amount of 1.3 % lysis I.E, highly compatible. We analyzed the cell line compatibility with fibroblast cell line in which we found a maximum of more than 80% compatibility cell viability making it also compatible for cellular components. In conclusion, the physicochemical and biocompatibility characteristic features of 54SP bioglass demonstrate its potential as a promising biomaterial for various biomedical applications.

# INTRODUCTION

By establishing bonded connections with biological tissues the medical-grade bioactive glass substance known as Bioglass demonstrates its distinct ability. The medical applications gain significant benefits from this trait because Bioglass shows suitability for implant development and health solutions creation.[(Harsha & Subramanian, 2022; Krishnan & Lakshmi, 2013)](https://paperpile.com/c/4A1dx9/hGRp+6LXl) Bioglass achieves outstanding biocompatibility by showing its ability to be well-accepted by human bodies. The medical importance of this quality exceeds acceptance for implanted materials because it reduces tissue reaction and enables better tissue integration.[(Deepika et al., 2022; Jones et al., 2016)](https://paperpile.com/c/4A1dx9/OiYP+6r5d) Bioglass engages in quick biological tissue reactions and it demonstrates fast bioactivity upon insertion into living tissue. The chemical structure of this substance permits binding to bone tissue. The research and development of bioactive glasses remains extremely active while involving many research groups around the world. Traditional scientific research on bioactive glasses has exceeded a vast thousand count due to active investigations concerning their properties.[(Y.-C. Hu & Zhong, 2009; Solanki et al., 2022)](https://paperpile.com/c/4A1dx9/9N0A+KQ7Z)

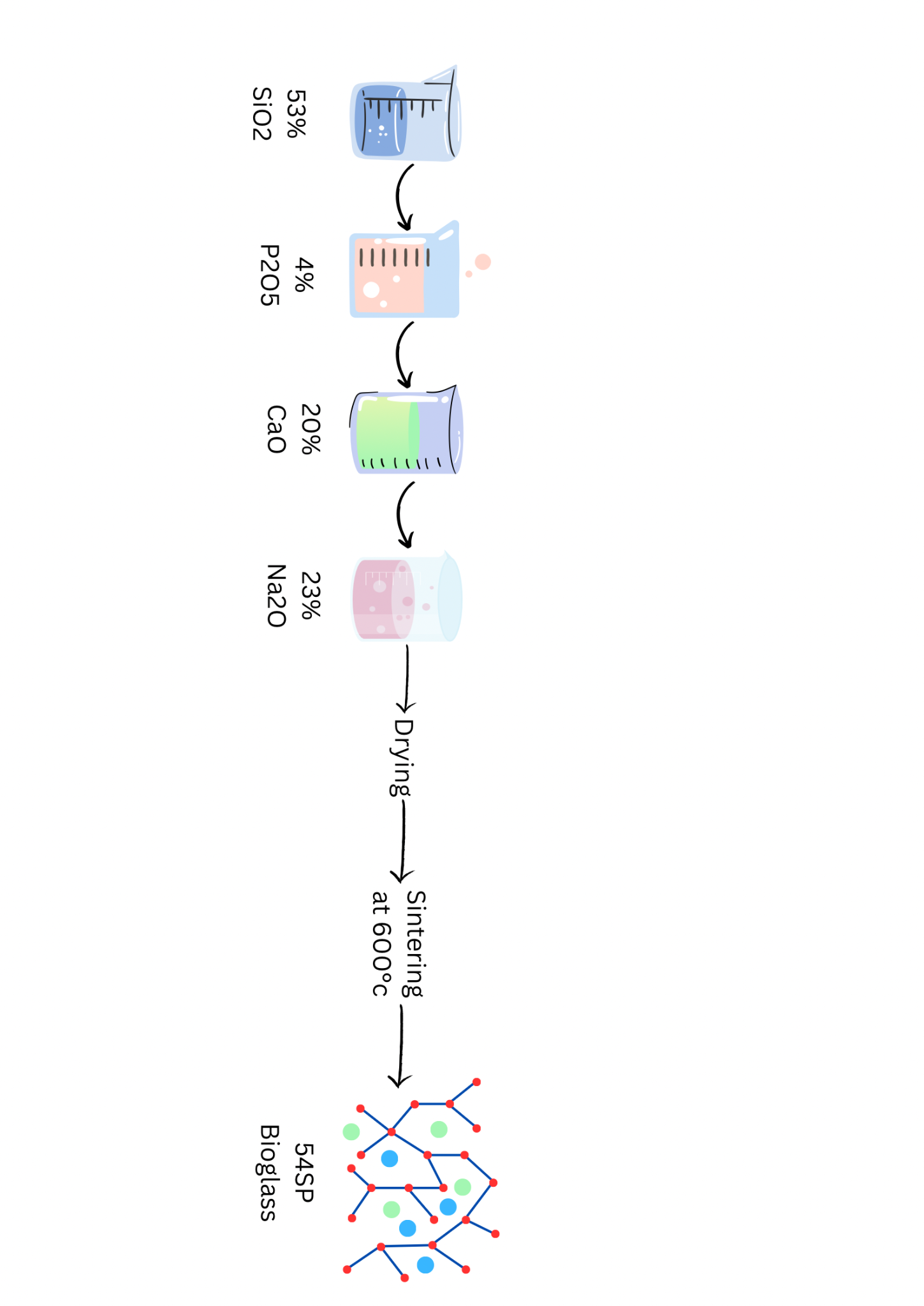
Due to recent research interest the biomaterials field now directs its focus toward studying materials with specific biomedical-oriented physicochemical characteristics. Bioactive glasses show antibacterial behavior against typical bacteria because bioactive glass dissolution leads to an elevated aqueous pH.[(Chidambaram et al., 2022; S. Hu et al., 2008)](https://paperpile.com/c/4A1dx9/E3pX+erjA) Bioglasses continue to receive extensive research interest because they unite bioactivity features together with mechanical properties and biocompatibility benefits.[(Ajay, Rakshagan, et al., 2022; Ajay, Sasikala, et al., 2022; Wilson et al., 1981)](https://paperpile.com/c/4A1dx9/aIGK+nZ6D+tNiR) The 54SP Bioglass composition stands out as a leading material because researchers have extensively examined and used it in multiple medical applications and tissue engineering solutions.[(Ajay, Suma, et al., 2022; “Bioglass 45S5: Structural Characterization of Short Range Order and Analysis of Biocompatibility with Adipose-Derived Mesenchymal Stromal Cells in Vitro and in Vivo,” 2019)](https://paperpile.com/c/4A1dx9/QwcR+HCg7) Research investigators have studied unique compositions which enhance the versatility and performance quality of bioglasses.

The innovative composition 54SP Bioglass represents a worthy adaptation which incorporates specific changes to the standard 45S5 composition. The designation "54SP" describes deliberate alterations of SiO2 (silica) and P2O5 (phosphorus pentoxide) amounts in a BYN-formulation which serves to optimize performance parameters. These modifications prove essential because they affect the biological tissue interactions of glass surfaces which determines both biocompatibility and tissue-supporing capacity.

# MATERIALS AND METHODS

## Synthesis of 54 SP Bioglass

Every analytical-grade chemical and reagent requires no additional purification before use in this study. TEOS (tetraethyl orthosilicate; 98% pure) was obtained from Alfa Aesar and sodium hydroxide (98% pure) came from Sisco Research Laboratory while Spectrum Reagents and Chemicals Pvt. Ltd. provided orthophosphoric acid (88% pure) and calcium nitrate (99% pure) together with nitric acid (70% pure). These chemicals served to produce bioglass through the sol-gel synthesis procedure. The mixture of double distilled water, nitric acid and ethanol and 45% TEOS (tetraethyl orthosilicates) was used to promote silica hydrolysis. Agitation of the solution took an entire hour to form a gel. The silica matrix received addition of 23% sodium hydroxide and 53% silicon dioxide and 4% phosphorus pentoxide and 20% calcium oxide. For 45 minutes each reagent solution underwent individual dissolution process. White sol gelation proceeded under agitation and stirring for twelve hours before placing it in the hot air oven for twenty-four-hour drying at 120 degrees Celsius to obtain a stable gel matrix. The heat-treatment process for speciment phase formation included three-hour exposure at 600°C to 700°C and 800°C temperature levels under ambient air in a box furnace. The team will then supply the samples with designation BG600, BG700, and BG800.



**Figure 1:** Schematic diagram of material synthesis

## Material Characterization

The temperature data for the produced bioglass was obtained through an analysis using SII Nanotechnology-TG/DTA-6300 (Japan) for thermal properties assessment. The PANalytical Instruments XRD instrument based in The Netherlands used Cu-Kα1 radiation (λ = 0.154nm) for studying the structural and phase characteristics during a 2θ = 3°/min scan. The FESEM HI-TACHI SU-6600 (Japan) operated at 15 keV measured the surface alterations of BG before and after immersion through its scanning electron microscope visualization method. The study employed Raman (Nanophoton Raman 11i, Japan and Perkin Elmer Spectrum-1) together with Fourier transform infrared spectroscopy to validate the molecular vibrations. The Vickers hardness test for this study followed ASTM C 1327-03 standard protocol using a 0.98 N machine from Vickers microhardness tester Wilson Wolpert based in Germany. The biocompatibility properties were measured through MG-63 (osteosarcoma) cell line testing and erythrocytes-based hemolytic assay.

## Hemocompatibility studies

The assessment of erythrocyte material compatibility relies heavily on the evaluation method named hemocompatibility. In order to prevent coagulation EDTA was used to manage blood collected from a voluntary donor. Using 4 °C for 10 minutes blood underwent centrifugation which allowed the researcher to extract the plasma by performing phosphate buffer saline (PBS) washes on the sample twice or thrice. A mixture of 50 μl blood specimen and 950 μl PBS plus Bioglass samples was placed inside Eppendorf tubes. Multiple analyses (n = 3) took place at three different concentrations (0.5 mg/ml, 1 mg/ml, and 2.5 mg/ml) of bioglass before all samples received 37°C incubation for an hour. Archimedean centrifugation occurred at 4 °C for 10 minutes before measuring the samples at a wavelength of 540 nm. The formula determined the amount of hemolysis (H).

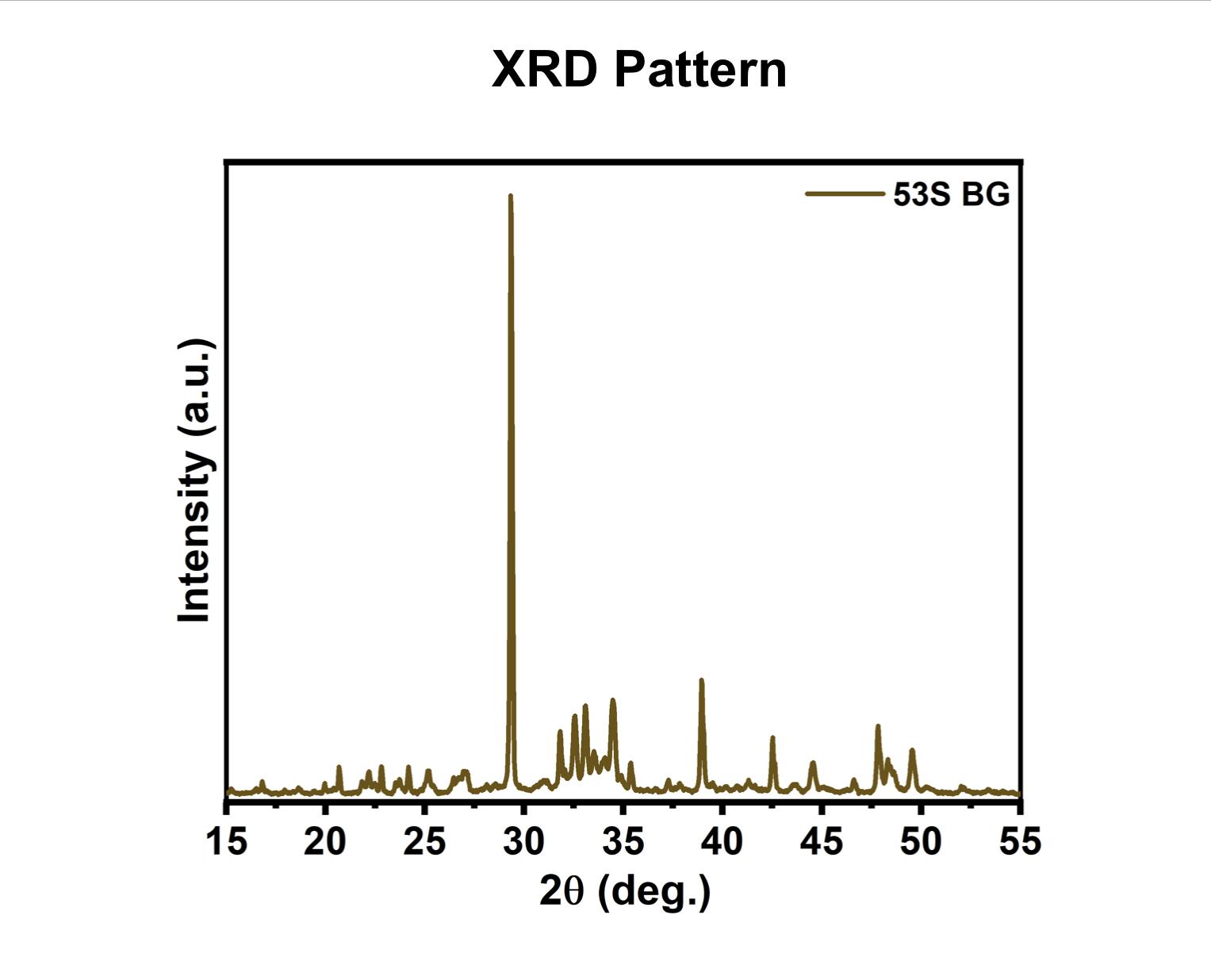
## H = S A − NC/ PC − NC \*100

where S A is sample absorbance, NC is negative control and PC is positive control.

# RESULTS

## XRD Pattern of 54S Bioglass

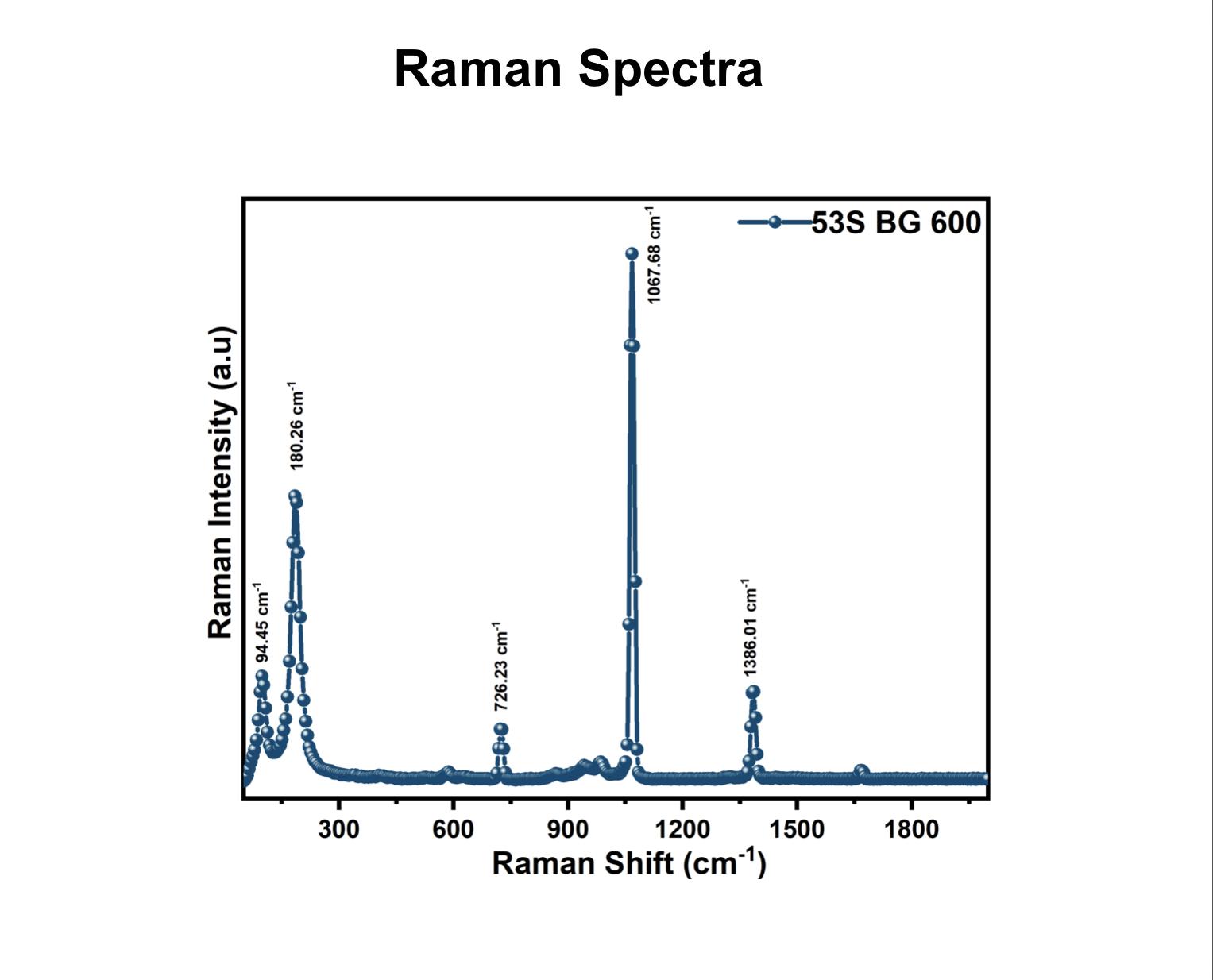
X-ray diffraction (XRD) is performed for the analysis of crystalline materials. XRD is utilized to discern the crystal structure of a substance by examining the way X-rays are scattered during their interaction with the crystal lattice. This process aids in recognizing the specific crystalline phases within a sample, comprehending their organization, and acquiring insights into the crystallographic features of the material. XRD patterns of these 45S5 bioglasses typically display a wide peak, signifying either a fully amorphous or partially amorphous configuration.[(“The Effect of Crystallization of Bioactive Bioglass 45S5 on Apatite Formation and Degradation,” 2013)](https://paperpile.com/c/4A1dx9/mMKHE) in the above done study, Sodium calcium silicate phases were assimilated, revealing the presence of crystalline patterns for NaCaPO4 and calcium carbonate. The Raman spectra results for 45S5 Bioglass indicated the examination of the spectral range from 200 to 1200 cm−1, as this interval encompasses the principal peaks for both silicate glasses and hydroxyapatite.[(“In Situ Raman Spectroscopy Investigation of Bioactive Glass Reactivity: Simulated Body Fluid Solution vs TRIS-Buffered Solution,” 2011)](https://paperpile.com/c/4A1dx9/kanMK) For 54SP bioglass the raman spectra results can be observed in the range from 950 to 1100 cm-1, this interval includes the phosphate and silicate vibrations respectively.



**Figure 2:** XRD pattern of 54S Bioglass

## Raman Spectra of 54S Bioglass

Analyzing material-based molecular vibrations is the main use of Raman spectroscopy techniques. Raman spectroscopy lets users determine chemical substances along with detecting bond structures and elemental compositions. Results indicate that silicate vibrations control the spectrum at 1067 cm-1 yet phosphate vibrations occur at 957cm-1. Abir et al. (1999) established that PO34-peak intensities at 964 cm-1 grew stronger with prolonged immersion times when studying 45S5 bioglass in a previous analysis because hydroxyapatite layers appeared progressively. After two days of observation the PO34- peak displayed its highest peak count while at the same time FTIR analysis detected crystalline HA formation. The mechanism of HA layer maturation was confirmed by new peaks developing at 460 cm-1 and 610 cm-1 during days four and ten respectively. [(“In Situ Raman Spectroscopy Investigation of Bioactive Glass Reactivity: Simulated Body Fluid Solution vs TRIS-Buffered Solution,” 2011)](https://paperpile.com/c/4A1dx9/kanMK) . The phosphate peak reached 957 cm-1 in the present 54SP research while unique silicate vibrations occurred at 1067 cm-1.

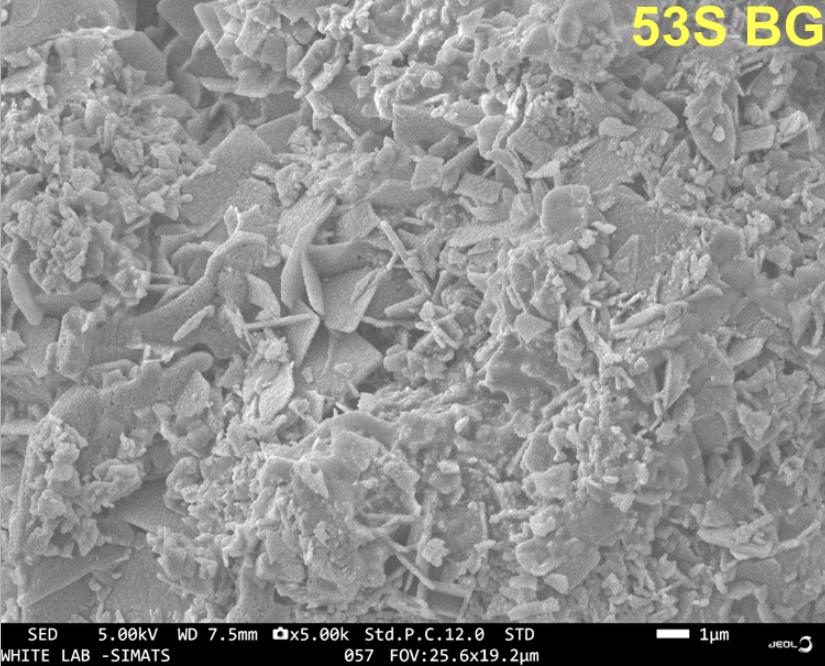


**Figure 3:** Raman spectra of 54S Bioglass.

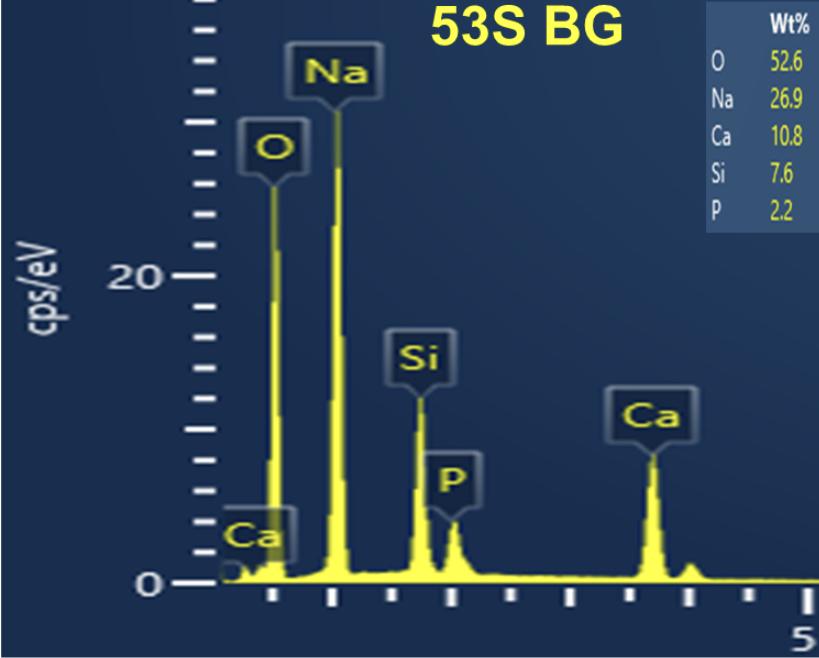
## FE-SEM and EDS Analysis of 54S Bioglass

In contrast, the previous work on 45S5 bioglass showed a peak increase after two days, showing the presence of crystalline HA, while the study on 54SP showed unique silicate vibrations at 1067 cm-1, revealing that these two glass compositions have different vibrational characteristics.

SEM analysis is performed to investigate the surface morphology and intricate structures of materials on a micro- to nanoscale level. SEM analysis takes place with 1 micrometer as the main focus point. The surface of 45S5 grains developed only small apatite layers after a 24 and 48-hour immersion in simulated bodily fluid (SBF) according to previous SEM observations.[(“An Elucidating Study on Physical and Structural Properties of 45S5 Glass at Different Sintering Temperatures,” 2015)](https://paperpile.com/c/4A1dx9/JulPD) The current work relies on SEM analysis to study 54SP bioglass on a 1 micrometer scale.



**Figure 4:** SEM analysis of 54S Bioglass.

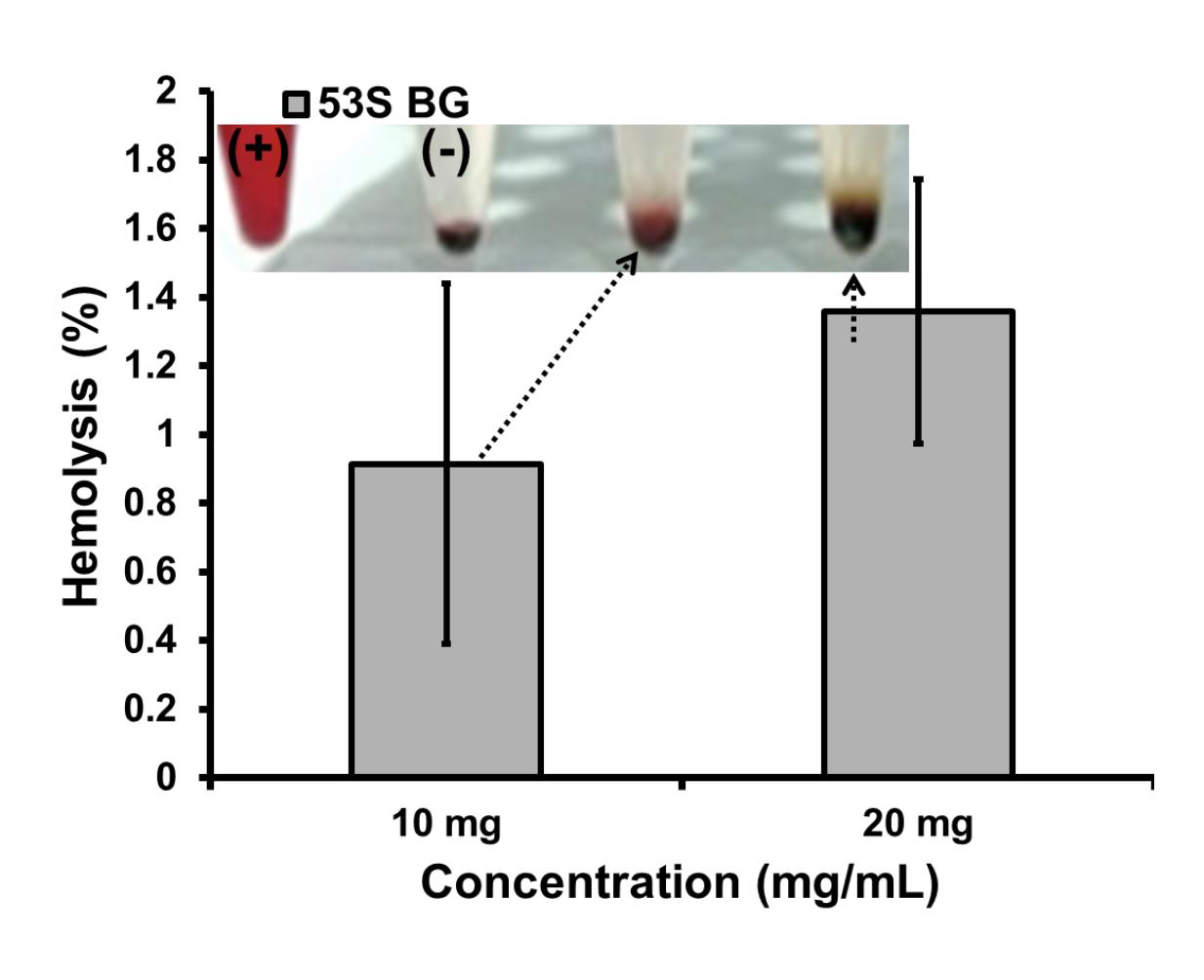


**Figure 5:** EDS spectra of 54S Bioglass.

A sheet-like morphology was identified in bioactive glasses, and likewise, the elemental composition of calcium sodium silicate phosphate was detected using Energy-Dispersive X-ray Spectroscopy (EDS). The composition of 45S5 Bioglass typically includes essential elements such as 45 wt.% SiO2, 24.5 wt.% Na2O, 24.5 wt.% CaO and 6 wt.% P2O5. . The precise ratios of these constituents play a pivotal role in determining its bioactive properties. [(“Development and Characterization of Self-Etching Adhesives Doped with 45S5 and Niobophosphate Bioactive Glasses: Physicochemical, Mechanical, Bioactivity and Interface Properties,” 2021)](https://paperpile.com/c/4A1dx9/cE0Ew) In this study the composition of 54SP bioglass was found to be 53% of silicon dioxide, 4% phosphorus pentoxide, 20% calcium oxide and 23% sodium oxide.

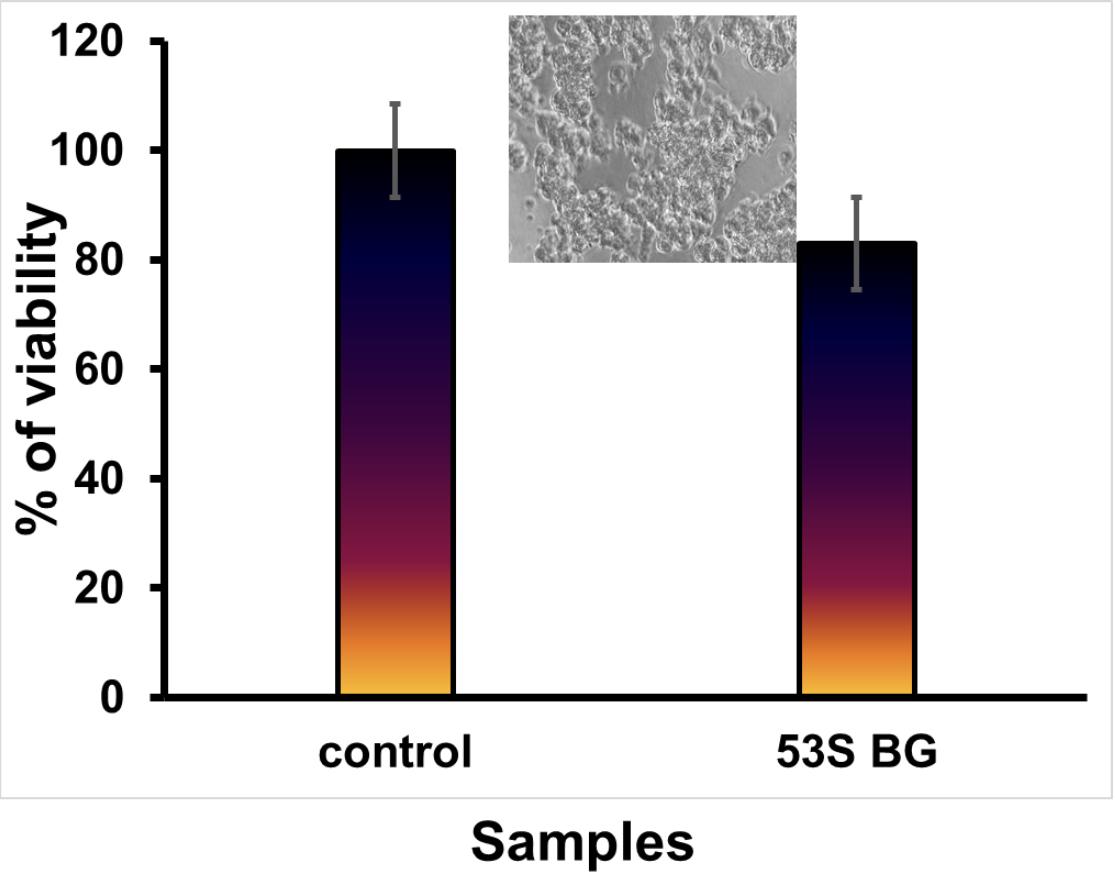
## Biocompatibility Assay

Blood compatibility verifies the harmonious characteristics of a material in its interaction with red blood cells (RBCs), wherein we observed a maximum lysis of 1.3 mm, indicating a high level of compatibility. Blood compatibility denotes a material's capacity to engage with blood components without inducing unfavorable reactions or clotting. The surface features of 45S5 Bioglass have been engineered for minimizing contacts with red blood cells to stop the rupture of blood cells known as hemolysis while reducing other detrimental effects.[(Sugumaran et al., 2022)](https://paperpile.com/c/4A1dx9/gk4AN) The observed lysis measurement reached 1.3 millimeters which demonstrates good compatibility between materials. The test results demonstrate that the material suffered minimal destructive forces thus showing positive effects of environmental interaction with biological components. The low lysis measurement indicates that the material excellently maintains its structural integrity while delivering effective results within its designated application thus increasing overall compatibility.



**Figure 6:** Blood compatibility of 54S Bioglass

Laboratory tests revealed that the material exhibited more than 80% maximum cell viability with fibroblast cells which proves its suitability for cellular applications. Laboratory tests of fibroblast cell viability show that 45S5 bioglass typically enhances cell growth as well as cell health. The material shows excellent potential in tissue engineering as well as wound healing applications for regenerative medicine since it can promote vital cellular operations including cell adhesion and spreading together with cell multiplication.[(Malavasi et al., 2019)](https://paperpile.com/c/4A1dx9/iYa1k) The independent research tested the material on a fibroblast cell line and established it provides cell survival rates exceeding 80%. Research findings validate increased cellular compatibility of the material thus strengthening previous beneficial observations in the initial statements.



**Figure 7:** Cytocompatibility of of 54S Bioglass using MG-63 cell line

# DISCUSSION

The medical and dental branch utilizes a manufactured type of bioactive glass called Bioglass. The unique characteristic of bioglass involves its potential to bond with living tissues which promotes the integration process and tissue regeneration.[(“Characterization of Some Bioglass–ceramics,” 2003; Jabin et al., 2021; Katyal et al., 2021; Maiti, 2021)](https://paperpile.com/c/4A1dx9/IY71+lBPs+kat2+T1FQ) Dental use of composites extends to dental implant procedures and tooth repair work that ensures strong bonding with organic tooth components.. Additionally, in wound care products, bioglass aids in healing by stimulating tissue regeneration and warding off infections. Bioglass demonstrates flexibility in applications because it bonds favorably with biological tissues thus making it essential for multiple medical and dental applications. The key attribute of 45S5 Bioglass is its power to establish biologically active tissue bonds with living organs (Rafi et al., 2024). 45S5 Bioglass develops bioactive qualities which enable strong lasting bonds to natural tooth structures [(“Antibacterial Activity of Nanostructured Ti–45S5 bioglass–Ag Composite against Streptococcus Mutans and Staphylococcus Aureus,” 2016; Balaji Ganesh S & Sugumar, 2021; Sushanthi, 2021)](https://paperpile.com/c/4A1dx9/YrN0+GXCM+nO0V). This material shares key bioactive properties with 45S5 bioglasses allowing it to activate positively with living tissues through hydroxyapatite formation on its surface.

​​Outstanding bioactivity represents the main defining feature of 54SP Bioglass. This material makes bodily fluids create physiologically active hydroxyapatite layers on its surface. The material suits biological system-interacting medical implants and devices because it participates in integration and renewal processes that occur naturally in bone tissue[(Chitra et al., 2019; Graf et al., 2023; Ramamurthy, 2021; Tiwari & Jain, 2023)](https://paperpile.com/c/4A1dx9/e2N9+7482+azVH+YDni). The safe compatibility of 54SP Bioglass with biological systems extends further than its bioactive properties because it exists without triggering adverse system reactions. Bioactivity serves as an intrinsic quality that makes 54SP Bioglass suitable for many medical applications involving tissue contact thus guaranteeing patient protection and health[(Maiti, 2021; “The Mechanical Characteristics and in Vitro Biocompatibility of Poly(glycerol Sebacate)-Bioglass® Elastomeric Composites,” 2010)](https://paperpile.com/c/4A1dx9/jnLT+ekWu).

Its ability to allow new bone tissue to integrate with its structure makes 54SP Bioglass appropriate for dental and orthopedic uses because of its osteoconductivity properties. The biomaterial works better as an implant solution due to its bone-like properties thus minimizing stress shielding and implant failure risks.[(Chitra et al., 2020; Maliael et al., 2021)](https://paperpile.com/c/4A1dx9/WnP2+ZuUh) The capability of 54SP Bioglass to regulate its degradation rate gives clinicians valuable options to optimize performance for different medical applications (Tuluwengjiang et al., 2024). The controlled breakdown procedure releases vital ions including calcium and phosphorus because of which the implant maintains structural stability while triggering bone growth and tissue remodeling[(Lakshmi, 2021; “Insight into the Impingement of Different Sodium Precursors on Structural, Biocompatible, and Hemostatic Properties of Bioactive Materials,” 2021)](https://paperpile.com/c/4A1dx9/oVmt+86gp).

Some bioglass formulations including the 54SP variant contain integrated antibacterial properties which protect implant sites from bacterial infections. The material's therapeutic value becomes more significant in medical practices because it enhances clinical results while reducing dependency on additional treatments[(Dharman, 2021; Gillam et al., 2002)](https://paperpile.com/c/4A1dx9/ChAv+Ov6j). The biological composition of 54SP Bioglass enables its adoption into diverse shapes such as powders with granules and porous scaffolds which demonstrates its useful application span from tissue engineering to bone grafting. Medical technology and regenerative medicine benefit from 54SP Bioglass due to its adaptable form and broad physical and chemical properties.[(“Impact of Copper on in-Vitro Biomineralization, Drug Release Efficacy and Antimicrobial Properties of Bioactive Glasses,” 2020)](https://paperpile.com/c/4A1dx9/7GqUN)

# CONCLUSION

The comprehensive review of analysis results demonstrates that 54SP Bioglass represents a highly promising biomaterial which has multiple applications in biomedical industry. Scientists have discovered specific properties through extensive biocompatibility testing which positions 54SP Bioglass as an ideal material for different medical applications. Scientific modifications to SiO2 and P2O5 contents in the material led to improved functionality. Bone structure integration strengthens when silicon dioxide is added to glass composition since the material triggers hydroxyapatite layer development upon biological fluid exposure.. The presence of phosphorus pentoxide in the glass enhances the tissue regeneration process and activates cell activity to achieve overall better bioactivity of the material.

Research investigations focused on fundamental biocompatible properties of 54SP Bioglass for human body implementation materials. The new glass structure achieved better results than traditional glass due to its improved bone-to-bone bonding performance in orthopedic implants as well as other medical devices. Smooth tissue regeneration can happen through controlled deterioration resulting in controlled ion releases with no adverse effects detected at the observed levels. The biocompatibility tests performed at multiple SiO2 and P2O5 levels establish 54SP Bioglass as a promising biomedical material for various medical uses.

# REFERENCES

1. [Ajay, R., Rakshagan, V., Queenalice, A., Vinothkumar, S., Ravivarman, C., & Saravanadinesh, P. (2022). Effect of triazine comonomer substitution on the structure and glass transition temperature of monomethacrylate-based resin polymer: An in vitro study. The Journal of Contemporary Dental Practice, 23(2), 202–207. https://doi.org/](http://paperpile.com/b/4A1dx9/nZ6D)[10.5005/jp-journals-10024-3260](http://dx.doi.org/10.5005/jp-journals-10024-3260)
2. [Ajay, R., Sasikala, R., Rakshagan, V., Raghunathan, J., LalithaManohari, V., & Baburajan, K. (2022). Evaluation of cytocompatibility of thermopolymerized denture base copolymer containing a novel ring-opening oxaspiro comonomer. World Journal of Dentistry, 13(2), 127–132. https://doi.org/](http://paperpile.com/b/4A1dx9/tNiR)[10.5005/jp-journals-10015-1901](http://dx.doi.org/10.5005/jp-journals-10015-1901)
3. [Ajay, R., Suma, K., Sasikala, R., Rakshagan, V., Baburajan, K., & Kalarani, G. (2022). Evaluation of linear dimensional stability of monomethacrylate-based dental polymer containing a novel tricyclic diacrylate cross-linker using a novel surface-level index technique. World Journal of Dentistry, 13(6), 568–573. https://doi.org/](http://paperpile.com/b/4A1dx9/HCg7)[10.5005/jp-journals-10015-2106](http://dx.doi.org/10.5005/jp-journals-10015-2106)
4. [An elucidating study on physical and structural properties of 45S5 glass at different sintering temperatures. (2015). Journal of Non-Crystalline Solids, 412, 24–29. https://doi.org/](http://paperpile.com/b/4A1dx9/JulPD)[10.1016/j.jnoncrysol.2015.01.005](http://dx.doi.org/10.1016/j.jnoncrysol.2015.01.005)
5. [Antibacterial activity of nanostructured Ti–45S5 bioglass–Ag composite against Streptococcus mutans and Staphylococcus aureus. (2016). Transactions of the Nonferrous Metals Society of China, 26(1), 118–125. https://doi.org/](http://paperpile.com/b/4A1dx9/YrN0)[10.1016/S1003-6326(16)64096-7](http://dx.doi.org/10.1016/S1003-6326(16)64096-7)
6. [Lakshmi, D. (2021). Medicinal value and oral health aspects of acacia catechu - an update. International Journal of Dentistry and Oral Science, 1399–1401. https://doi.org/](http://paperpile.com/b/4A1dx9/86gp)[10.19070/2377-8075-21000277](http://dx.doi.org/10.19070/2377-8075-21000277)
7. [Balaji Ganesh S, & Sugumar, K. (2021). Internet of Things—A novel innovation in dentistry. Journal of Advanced Oral Research, 12(1), 42–48. https://doi.org/](http://paperpile.com/b/4A1dx9/GXCM)[10.1177/2320206820980248](http://dx.doi.org/10.1177/2320206820980248)
8. [Bioglass 45S5: Structural characterization of short range order and analysis of biocompatibility with adipose-derived mesenchymal stromal cells in vitro and in vivo. (2019). Materials Science and Engineering: C, 103, 109781. https://doi.org/](http://paperpile.com/b/4A1dx9/QwcR)[10.1016/j.msec.2019.109781](http://dx.doi.org/10.1016/j.msec.2019.109781)
9. [Characterization of some bioglass–ceramics. (2003). Materials Chemistry and Physics, 80(3), 599–609. https://doi.org/](http://paperpile.com/b/4A1dx9/IY71)[10.1016/S0254-0584(03)00082-8](http://dx.doi.org/10.1016/S0254-0584(03)00082-8)
10. [Chidambaram, S. R., George, A. M., Muralidharan, N. P., Prasanna Arvind, T. R., Subramanian, A., & Rahaman, F. (2022). Current overview for chemical disinfection of dental impressions and models based on its criteria of usage: A microbiological study. Indian Journal of Dental Research: Official Publication of Indian Society for Dental Research, 33(1), 30–36. https://doi.org/](http://paperpile.com/b/4A1dx9/erjA)[10.4103/ijdr.IJDR\_623\_20](http://dx.doi.org/10.4103/ijdr.IJDR_623_20)
11. [Chitra, S., Bargavi, P., & Balakumar, S. (2020). Effect of microwave and probe sonication processes on sol–gel-derived bioactive glass and its structural and biocompatible investigations. Journal of Biomedical Materials Research. Part B, Applied Biomaterials, 108(1), 143–155. https://doi.org/](http://paperpile.com/b/4A1dx9/WnP2)[10.1002/jbm.b.34373](http://dx.doi.org/10.1002/jbm.b.34373)
12. [Chitra, S., Bargavi, P., Durgalakshmi, D., Rajashree, P., & Balakumar, S. (2019). Role of sintering temperature dependent crystallization of bioactive glasses on erythrocyte and cytocompatibility. Processing and Application of Ceramics, 13(1), 12–23.](http://paperpile.com/b/4A1dx9/e2N9) <http://www.doiserbia.nb.rs/ft.aspx?id=1820-61311901012C>
13. [Deepika, B. A., Ramamurthy, J., Girija, S., & Jayakumar, N. D. (2022). Evaluation of the antimicrobial effect of Ocimum sanctum L. oral gel against anaerobic oral microbes: An in vitro study. World Journal of Dentistry, 13(S1), S23–S27. https://doi.org/](http://paperpile.com/b/4A1dx9/6r5d)[10.5005/jp-journals-10015-2140](http://dx.doi.org/10.5005/jp-journals-10015-2140)
14. [Development and characterization of self-etching adhesives doped with 45S5 and niobophosphate bioactive glasses: Physicochemical, mechanical, bioactivity and interface properties. (2021). Dental Materials: Official Publication of the Academy of Dental Materials, 37(6), 1030–1045. https://doi.org/](http://paperpile.com/b/4A1dx9/cE0Ew)[10.1016/j.dental.2021.03.004](http://dx.doi.org/10.1016/j.dental.2021.03.004)
15. [Dharman, S., (2021). Ecofriendly Synthesis, Characterisation and Antibacterial Activity Of Curcumin Mediated Silver Nanoparticles. International Journal of Dentistry and Oral Science, 2314–2318. https://doi.org/](http://paperpile.com/b/4A1dx9/Ov6j)[10.19070/2377-8075-21000457](http://dx.doi.org/10.19070/2377-8075-21000457)
16. [Gillam, D. G., Tang, J. Y., Mordan, N. J., & Newman, H. N. (2002). The effects of a novel Bioglass® dentifrice on dentine sensitivity: a scanning electron microscopy investigation. Journal of Oral Rehabilitation, 29(4), 305–313. https://doi.org/](http://paperpile.com/b/4A1dx9/ChAv)[10.1046/j.1365-2842.2002.00824.x](http://dx.doi.org/10.1046/j.1365-2842.2002.00824.x)
17. [Graf, S., Thakkar, D., Hansa, I., Pandian, S. M., & Adel, S. M. (2023). 3D metal printing in orthodontics current trends, biomaterials, workflows and clinical implications. Seminars in Orthodontics. https://doi.org/](http://paperpile.com/b/4A1dx9/YDni)[10.1053/j.sodo.2023.01.001](http://dx.doi.org/10.1053/j.sodo.2023.01.001)
18. [Harsha, L., & Subramanian, A. K. (2022). Comparative assessment of pH and degree of surface roughness of enamel when etched with five commercially available etchants: An in vitro study. The Journal of Contemporary Dental Practice, 23(2), 181–185. https://doi.org/](http://paperpile.com/b/4A1dx9/6LXl)[10.5005/jp-journals-10024-3252](http://dx.doi.org/10.5005/jp-journals-10024-3252)
19. [Hu, S., Chang, J., Liu, M., & Ning, C. (2008). Study on antibacterial effect of 45S5 Bioglass®. Journal of Materials Science. Materials in Medicine, 20(1), 281–286. https://doi.org/](http://paperpile.com/b/4A1dx9/E3pX)[10.1007/s10856-008-3564-5](http://dx.doi.org/10.1007/s10856-008-3564-5)
20. [Hu, Y.-C., & Zhong, J.-P. (2009). Osteostimulation of bioglass. Chinese Medical Journal, 122(19), 2386. https://doi.org/](http://paperpile.com/b/4A1dx9/9N0A)[10.3760/cma.j.issn.0366-6999.2009.19.035](http://dx.doi.org/10.3760/cma.j.issn.0366-6999.2009.19.035)
21. [Impact of copper on in-vitro biomineralization, drug release efficacy and antimicrobial properties of bioactive glasses. (2020). Materials Science and Engineering: C, 109, 110598. https://doi.org/](http://paperpile.com/b/4A1dx9/7GqUN)[10.1016/j.msec.2019.110598](http://dx.doi.org/10.1016/j.msec.2019.110598)
22. [Insight into the impingement of different sodium precursors on structural, biocompatible, and hemostatic properties of bioactive materials. (2021). Materials Science and Engineering: C, 123, 111959. https://doi.org/](http://paperpile.com/b/4A1dx9/oVmt)[10.1016/j.msec.2021.111959](http://dx.doi.org/10.1016/j.msec.2021.111959)
23. [In situ Raman spectroscopy investigation of bioactive glass reactivity: Simulated body fluid solution vs TRIS-buffered solution. (2011). Materials Characterization, 62(10), 1021–1028. https://doi.org/](http://paperpile.com/b/4A1dx9/kanMK)[10.1016/j.matchar.2011.07.008](http://dx.doi.org/10.1016/j.matchar.2011.07.008)
24. [Jabin, Z., Nasim, I., Vishnu Priya, V., & Agarwal, N. (2021). Quantitative analysis and Effect of SDF, APF, NaF on Demineralized Human Primary Enamel Using SEM, XRD, and FTIR. International Journal of Clinical Pediatric Dentistry, 14(4), 537–541. https://doi.org/](http://paperpile.com/b/4A1dx9/T1FQ)[10.5005/jp-journals-10005-1988](http://dx.doi.org/10.5005/jp-journals-10005-1988)
25. [Jones, J. R., Brauer, D. S., Hupa, L., & Greenspan, D. C. (2016). Bioglass and Bioactive Glasses and Their Impact on Healthcare. International Journal of Applied Glass Science, 7(4), 423–434. https://doi.org/](http://paperpile.com/b/4A1dx9/OiYP)[10.1111/ijag.12252](http://dx.doi.org/10.1111/ijag.12252)
26. [Katyal, D., Subramanian, A. K., Venugopal, A., & Marya, A. (2021). Assessment of wettability and contact angle of bonding agent with enamel surface etched by five commercially available etchants: An in vitro study. International Journal of Dentistry, 2021, 9457553. https://doi.org/](http://paperpile.com/b/4A1dx9/kat2)[10.1155/2021/9457553](http://dx.doi.org/10.1155/2021/9457553)
27. [Krishnan, V., & Lakshmi, T. (2013). Bioglass: A novel biocompatible innovation. Journal of Advanced Pharmaceutical Technology & Research, 4(2), 78. https://doi.org/](http://paperpile.com/b/4A1dx9/hGRp)[10.4103/2231-4040.111523](http://dx.doi.org/10.4103/2231-4040.111523)
28. [Maiti, S.,(2021). Comparative analysis of abrasion resistance in relation to different temporary acrylic crown material using toothbrush simulator- an in vitro study. International Journal of Dentistry and Oral Science, 2153–2157. https://doi.org/](http://paperpile.com/b/4A1dx9/lBPs)[10.19070/2377-8075-21000425](http://dx.doi.org/10.19070/2377-8075-21000425)
29. [Malavasi, G., Salvatori, R., Zambon, A., Lusvardi, G., Rigamonti, L., Chiarini, L., & Anesi, A. (2019). Cytocompatibility of Potential Bioactive Cerium-Doped Glasses based on 45S5. Materials, 12(4), 594. https://doi.org/](http://paperpile.com/b/4A1dx9/iYa1k)[10.3390/ma12040594](http://dx.doi.org/10.3390/ma12040594)
30. [Maliael, M. T., Subramanian, A. K., & Srirengalakshmi. (2021). Effectiveness of a fluoride-releasing orthodontic primer in reducing demineralization around brackets – a systematic review. Orthodontic Waves (English Ed.), 80(4), 218–223. https://doi.org/](http://paperpile.com/b/4A1dx9/ZuUh)[10.1080/13440241.2021.2007678](http://dx.doi.org/10.1080/13440241.2021.2007678)
31. Rafi, D. M., Lakshmi, T. V., Shirley, C. P., Ravivarman, G., & Senthilkumar, G. (2024, April). Improving Prostate Cancer Diagnosis with Weakly Supervised Learning and Radiology-Confirmed Negative MRI Data. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1183-1188). IEEE.
32. [Ramamurthy, J., (2021). Evaluation of antioxidant and anti inflammatory activity of grape seed oil infused with silver nanoparticles an in vitro study. International Journal of Dentistry and Oral Science, 3318–3322. https://doi.org/](http://paperpile.com/b/4A1dx9/7482)[10.19070/2377-8075-21000676](http://dx.doi.org/10.19070/2377-8075-21000676)
33. [Solanki, L., Shantha Sundari, K. K., Muralidharan, N. P., & Jain, R. (2022). Antimicrobial effect of novel gold nanoparticle oral rinse in subjects undergoing orthodontic treatment: An ex-vivo study. Journal of International Oral Health: JIOH, 14(1), 47. https://doi.org/](http://paperpile.com/b/4A1dx9/KQ7Z)[10.4103/jioh.jioh\_155\_21](http://dx.doi.org/10.4103/jioh.jioh_155_21)
34. [Maiti, S. (2021). Adhesion of microflora and the role of denitrifies in colour stability on provisional crowns: An in-vitro study. International Journal of Dentistry and Oral Science, 3805–3809. https://doi.org/](http://paperpile.com/b/4A1dx9/ekWu)[10.19070/2377-8075-21000780](http://dx.doi.org/10.19070/2377-8075-21000780)
35. [Sugumaran, V., Krishnamoorthy, E., Kamalakkannan, A., Ramachandran, R. C., & Subramanian, B. (2022). Unscrambling the Influence of Sodium Cation on the Structure, Bioactivity, and Erythrocyte Compatibility of 45S5 Bioactive Glass. ACS Applied Bio Materials. https://doi.org/](http://paperpile.com/b/4A1dx9/gk4AN)[10.1021/acsabm.1c01322](http://dx.doi.org/10.1021/acsabm.1c01322)
36. [Sushanthi, (2021). Vernonia amygdalina mediated copper nanoparticles and its characterization and antimicrobial activity - an in vitro study. International Journal of Dentistry and Oral Science, 3330–3334. https://doi.org/](http://paperpile.com/b/4A1dx9/nO0V)[10.19070/2377-8075-21000678](http://dx.doi.org/10.19070/2377-8075-21000678)
37. [The effect of crystallization of bioactive bioglass 45S5 on apatite formation and degradation. (2013). Dental Materials: Official Publication of the Academy of Dental Materials, 29(12), 1256–1264. https://doi.org/](http://paperpile.com/b/4A1dx9/mMKHE)[10.1016/j.dental.2013.09.016](http://dx.doi.org/10.1016/j.dental.2013.09.016)
38. [The mechanical characteristics and in vitro biocompatibility of poly(glycerol sebacate)-Bioglass® elastomeric composites. (2010). Biomaterials, 31(33), 8516–8529. https://doi.org/](http://paperpile.com/b/4A1dx9/jnLT)[10.1016/j.biomaterials.2010.07.105](http://dx.doi.org/10.1016/j.biomaterials.2010.07.105)
39. [Tiwari, A., & Jain, R. K. (2023). Comparative evaluation of White Spot lesion incidence between NovaMin, probiotic, and fluoride containing dentifrices during orthodontic treatment using laser fluorescence - A prospective randomized controlled clinical trial. Clinical and Investigative Orthodontics, 1–8. https://doi.org/](http://paperpile.com/b/4A1dx9/azVH)[10.1080/27705781.2023.2190950](http://dx.doi.org/10.1080/27705781.2023.2190950)
40. Tuluwengjiang, G., Rasulova, I., Ahmed, S., Kiasari, B. A., Sârbu, I., Ciongradi, C. I., & Samaniego, S. S. C. (2024). Dendritic cell-derived exosomes (Dex): Underlying the role of exosomes derived from diverse DC subtypes in cancer pathogenesis. Pathology-Research and Practice, 254, 155097.
41. [Wilson, J., Pigott, G. H., Schoen, F. J., & Hench, L. L. (1981). Toxicology and biocompatibility of bioglasses. Journal of Biomedical Materials Research, 15(6), 805–817. https://doi.org/](http://paperpile.com/b/4A1dx9/aIGK)[10.1002/jbm.820150605](http://dx.doi.org/10.1002/jbm.820150605)