Investigating the Impact of Neodymium Bioglass Towards Regeneration

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**Abstract:**  Bioactive glass, is a specialised type of glass which can interact with living tissues and can be used for bone regeneration. The aim of this study is to investigate the impact of neodymium important e in structural change of bioglass towards regeneration. The bioglass is prepared by incorporation of compounds like TEOS ,P2O2and CaNO3 in a specific composition ; Neodymium is added to increase the structural stability. .Characterization is done using XRD, Raman Spectra ,Field-Emission Scanning electron microscopy (FE-SEM). The SEM analysis interpreted that the obtained compound was crystalline and while analysing certain peaks in raman spectra 578 cm-1, 838 cm-1, 941 cm-1 etc aids and promotes bone regeneration.In FE-SEM we were able to appreciate a spherical porous surface and in XRD there was Na₂Ca₂Si₃O₉ and NaCaPO₄ stretch vibration ,the EDS depicts the presence of Neodymium along with Na,P, and Ca. The combination of neodymium-doped bioglass shows potential in regenerative medicine because it maintains bioactive qualities and produces distinct neodymium ion effects for improving tissue regeneration potential. Medical experts have found that adding neodymium to bioglass scaffold structures leads to better osteogenesis and angiogenesis together with essential cellular functions necessary for healing and tissue regeneration.

**Keywords:** Neodymium; Bioglass; Tissue regeneration; Scaffolds; Compatibility.

# INTRODUCTION

Regeneration refers to the natural process by which living organisms replace or restore damaged or lost tissues, organs, or body parts [(Harsha & Subramanian, 2022)](https://paperpile.com/c/qI6sLO/MjcUp)[(Deepika et al., 2022)](https://paperpile.com/c/qI6sLO/OLOWg)[(Solanki et al., 2022)](https://paperpile.com/c/qI6sLO/WcmfD). It is a remarkable ability exhibited by certain animals and plants, allowing them to repair injuries, recover from damage, and sometimes even regrow entire body parts[(Chidambaram et al., 2022)](https://paperpile.com/c/qI6sLO/dU41q).[(Ajay, Sasikala, et al., 2022)](https://paperpile.com/c/qI6sLO/kW5mP).There are different types of regeneration such as bone regeneration which is a complex physiological process of bone formation and can be seen during fracture healing, involves continuous bone remodelling[(Ajay, Rakshagan, et al., 2022)](https://paperpile.com/c/qI6sLO/O7wEW) .They are needed during skeletal abnormalities ,trauma or in the case where the regeneration is compromised and other regeneration include tissue , complex regeneration [(Dimitriou et al., 2011)](https://paperpile.com/c/qI6sLO/g29Y1). There are many bone regenerative materials like nano-hydroxyapatite, biodegradable polymers, calcium phosphate cement, bioactive glass, 3D printed, 3D printed scaffold, polylactic acid, beta-tricalcium phosphate[(Anbu et al., 2019)](https://paperpile.com/c/qI6sLO/N0DnE)[(Ben Amara et al., 2017)](https://paperpile.com/c/qI6sLO/UvqdF).

Bioglass is a type of specialised glass that has the ability to bond with living bone and tissues [(Ajay, Suma, et al., 2022)](https://paperpile.com/c/qI6sLO/MicVk) [(Katyal et al., 2021)](https://paperpile.com/c/qI6sLO/TLUQB). Bioglass is composed of various oxides, such as silicon, calcium, sodium, and phosphorus, which are similar to the components found in the mineral structure of bone[(Jabin et al., 2021)](https://paperpile.com/c/qI6sLO/bwjF2)[(Balaji Ganesh S & Sugumar, 2021)](https://paperpile.com/c/qI6sLO/flCEj) [(Govindaraj & Dinesh, 2021)](https://paperpile.com/c/qI6sLO/0auNa) . The key characteristic of bioglass is its bioactivity. When bioglass comes into contact with bodily fluids or living tissues, it forms a strong bond with the surrounding bone. This bond is due to the formation of a layer of hydroxyapatite, a mineral that is also a major component of natural bone [(Tiwari & Jain, 2023)](https://paperpile.com/c/qI6sLO/Ng27d)[(Graf et al., 2023)](https://paperpile.com/c/qI6sLO/cqDQf). The formation of this hydroxyapatite layer allows the bioglass to integrate with the surrounding tissue, promoting bone growth and facilitating the healing process [(Tiskaya et al., 2021)](https://paperpile.com/c/qI6sLO/ULLK4).

Previous studies have been done by doping bioglass with magnesium using sol-gel method to analyse their drug delivery and a cellular in-vitro bioactivity, which illustrated that apatite formation was hindered with the increase in magnesium concentration and also the kinetics of the drug release was improved, this was due to the porosity and increased surface area [(Tabia et al., 2019)](https://paperpile.com/c/qI6sLO/3nuNI). Another research was done by doping strontium and bioglass to study the mineralisation, and results revealed that it assists the patients with osteoporosis, which is skeletal disorder characterised by low bone density and microarchitectural deterioration of bone tissue and ultimately increase the risk of fracture.The results interpreted that mineralisation is not that prominent [(Kargozar et al., 2019)](https://paperpile.com/c/qI6sLO/MAPK4)[(Jia et al., 2023)](https://paperpile.com/c/qI6sLO/HxfQi) and so there is need for a new study to promote efficient bone mineralisation.

Neodymium is a rare earth element with the symbol Nd and belongs to the group lanthanoid . They are refined for general use and have been mined in the USA, Brazil, India, Australia, Sri Lanka, and mostly in China[(Sabarathinam & Madhulaxmi, 2021)](https://paperpile.com/c/qI6sLO/QNDfY)[(Sushanthi et al., 2021)](https://paperpile.com/c/qI6sLO/WZPGJ)[(Harsha et al., 2022)](https://paperpile.com/c/qI6sLO/WEDOy). Neodymium does not exist in metallic or mixed forms with other lanthanide they are used in various applications cause of their ability to generate a static magnetic field, neodymium magnets are used in medical devices such as magnetic resonance imaging devices to diagnose and treat chronic pain syndrome, arthritis, wound healing, in- somnia, headache, and a variety of other disorders [(Yuksel et al., 2018)](https://paperpile.com/c/qI6sLO/szh6N). Using a wet chemical precipitation process, hydroxyapatite was cationically replaced with neodymium and magnesium to form the comparable inorganic phase of bone and make their structure therapeutically fight infections[(Neha et al., 2021)](https://paperpile.com/c/qI6sLO/g049W)[(Maliael et al., 2021)](https://paperpile.com/c/qI6sLO/kUJ2H)[(Lakshmi, 2021)](https://paperpile.com/c/qI6sLO/Brma0). The morphological and compositional properties of the generated nanomaterial were examined, which confirmed the presence of the HA phase with high compositional purity and an evident change in crystallinity, lattice properties, morphology, and particle shape[(Dharman et al., 2021)](https://paperpile.com/c/qI6sLO/Bhwgy). Due to their positive effect on osteoblastic activity, they can be used for bone regeneration [(Website, n.d.-a)](https://paperpile.com/c/qI6sLO/B4gv2) .By incorporating neodymium with bioglass the osteoblastic activity can be enhanced and improvised. The aim of this study is to synthesise Nd infused and analyse the structural changes of Nd-bioglass toward bone regeneration.

# MATERIALS AND METHOD

## MATERIALS

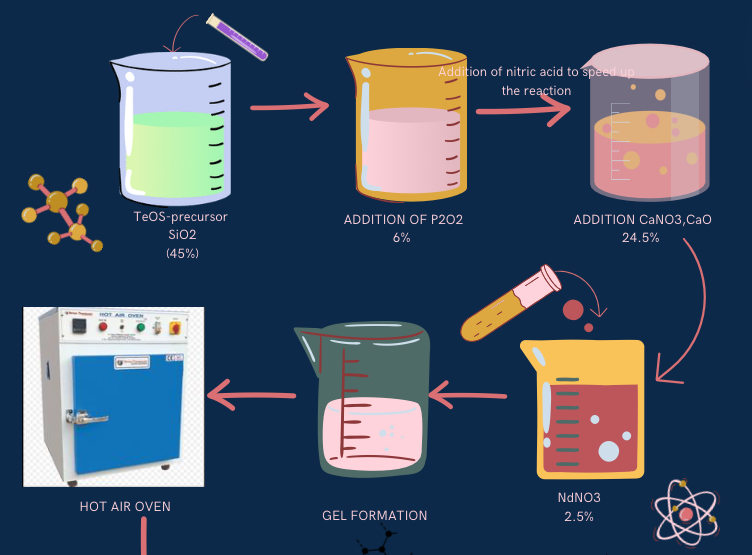
Tetraethylorthosilicate (TEOS), Ca(NO₃)₂·4H₂O, H₃PO₄, NaNO₃ and Nd(NO₃) was used as a source material for preparation of bioglass.

## PREPARATION OF BIOGLASS

The preparation of bioactive materials through sol-gel method involved tetraethyl orthosilicate (TEOS) at 45% weight while using orthophosphoric acid [OPA] at 6% weight and calcium nitrate at 24.5% weight and finally Nd(NO₃) at 24.5% weight. The TEOS solution is prepared through the combination of double distilled water and ethanol containing nitric acid (70%). A gel-like matrix forms through sol-gel process by using nitric acid at a TEOS: HNO₃: C₂H₅OH concentration rate of 3.5:1:0.5. The solution then gets the addition of orthophosphoric acid which needs full dissolution. Separate dissolution of calcium and sodium precursors occurs one after the other during a 1-hour interval in the existing hydrogel solution while it receives continuous agitation. The bioactive materials Nd(NO₃)-BG and NaOH-BG derived from 24.5% sodium nitrate and sodium hydroxide sources retained the 45S5 bioglass composition throughout the synthesis process (24.5% of each element in the composition). The complete gelation process requires conducting the entire experiment at room temperature. The drying process occurs in a stirrer hot plate at 80 ◦C for overnight. The research team subjected the samples to 100 ◦C heat in a hot air oven over 24 h to completely evaporate all moisture content inside. Afterward the bioactive materials undergo thermal treatment at 600 ◦C for a duration of 3 hrs [(S. & S., 2021)](https://paperpile.com/c/qI6sLO/sYdB) .

## CHARACTERISATION

Using X-ray Diffraction (XRD) available from PANalytical Instruments in The Netherlands researchers characterized fabricated bioactive powders to detect their crystalline phases. Cu-Kα1 radiation served as the source while the rate stood at 10 ◦C/min. The software program XRDA 3.1 generated the computational calculation for lattice parameter assessment. The FESEM (JEOL, JSM-IT 800) was used to image the prepared bioactive materials (powders) in their morphological state. The energy dispersive X-ray analysis (EDAX- Oxward instrumentation) evaluated subsequent elemental composition of the materials. The Micro Raman spectral data was obtained through a confocal Raman microscope (RAMAN 11i - Nano- photon) by using 532 nm wavelength excitation light.

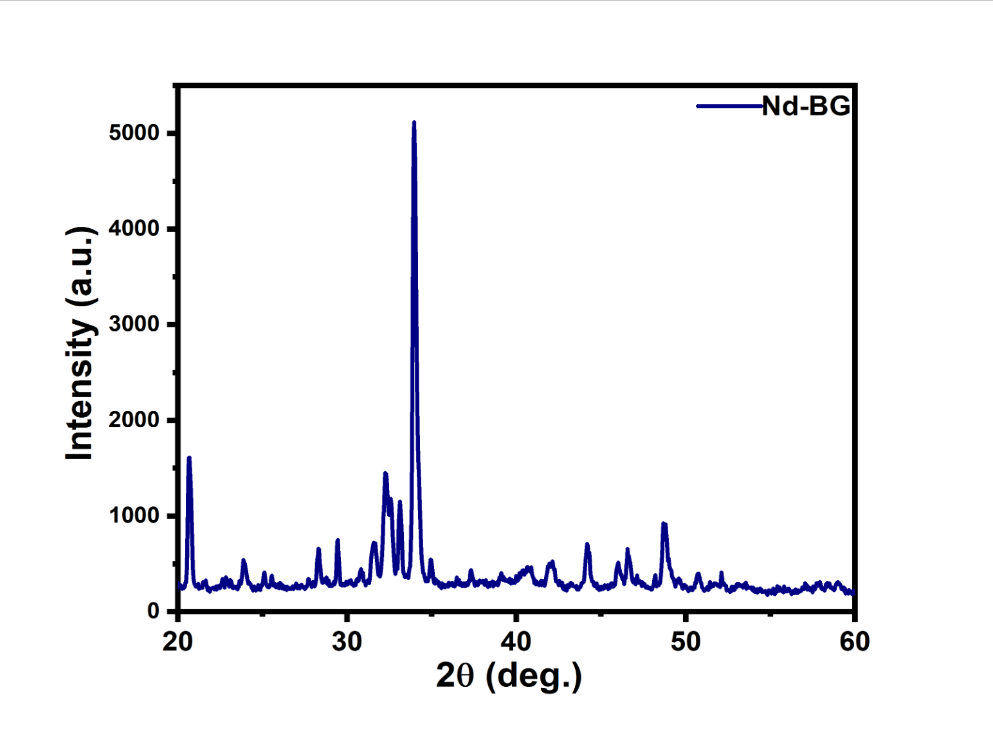


**Fig 1:** Represents the methodology of formation of Neodymium doped bioglass (ND-BG)

# RESULT AND DISCUSSION

## XRD ANALYSIS

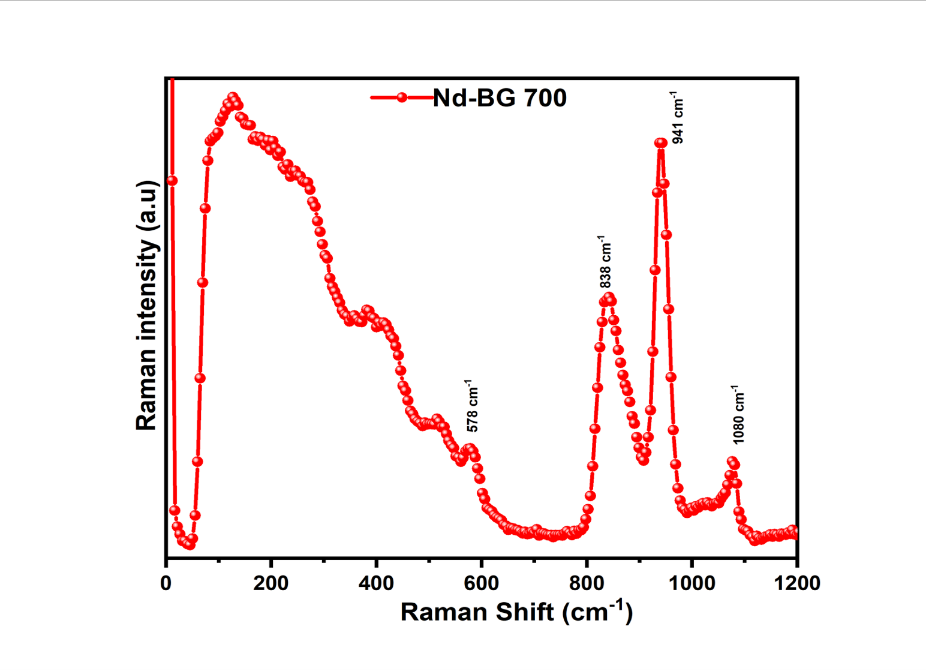
X Ray Diffraction pattern used to access the crystalline phase. The 2θ value corresponds to the angle between the incident X-rays and the detector. The range shown here is from 20 ° to 60 °. Different peaks in this range correspond to different crystallographic planes in the material being analysed. The XRD pattern has a prominent peak around 34 ° that indicates the NaCaPO₄ crystalline phase. This suggests the crystalline nature of the sample; several smaller peaks are also observed across the range, indicating the presence of Na₂Ca₂Si₃O₉ contributions from the diffraction patterns. The introduction of Nd into the bioactive glass matrix could result in the enhancement of NaCaPO₄ crystalline phase [(Shivalingam et al., 2020)](https://paperpile.com/c/qI6sLO/rH0T).



**Fig 2:** XRD pattern of Nd-bioactive glass.

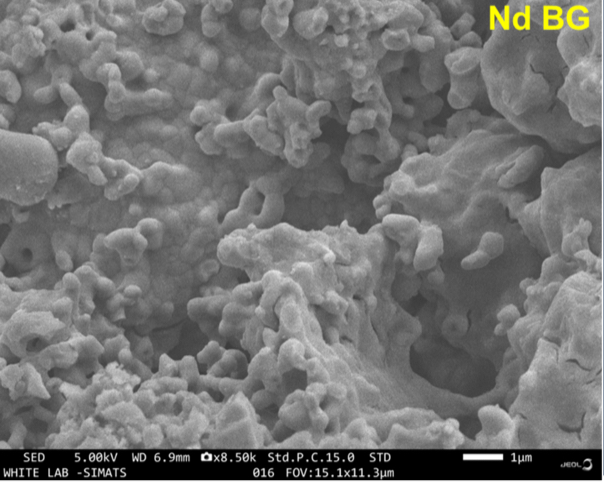
## RAMAN SPECTROSCOPY

The Raman shift represents vibrational modes of the molecules of the material. The range here spans from 0 to 1200 cm⁻¹, this is the typical range for assess vibrational modes in inorganic materials like ceramics. 578 cm⁻¹ peak correspond to the stretching vibrations of P-O-P bending modes. A peak evolved at 838 cm⁻¹ is typically associated with symmetric stretching modes of Si-O-Si in silica-based networks. A peak centered at 941 cm⁻¹ corresponds to Si-O asymmetric stretching modes, specifically in SiO₄ tetrahedra. A band at 1080 cm⁻¹ is usually related to asymmetric stretching of non-bridging oxygen vibrations in the glass network. The maximum peaks are correspond to various vibrational modes of the silica glass matrix, including bending and stretching modes of Si-O bonds and that are common in silicate as well as phosphate glasses.This respective material subjected to a heat treatment at 700°C, which influence the network connectivity. These specific changes can be reflected in the Raman spectrum [(S et al., 2022)](https://paperpile.com/c/qI6sLO/uEml)

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**Fig 3:** the Raman spectral analysis to understand the functional group properties.

# FE-SEM ANALYSIS

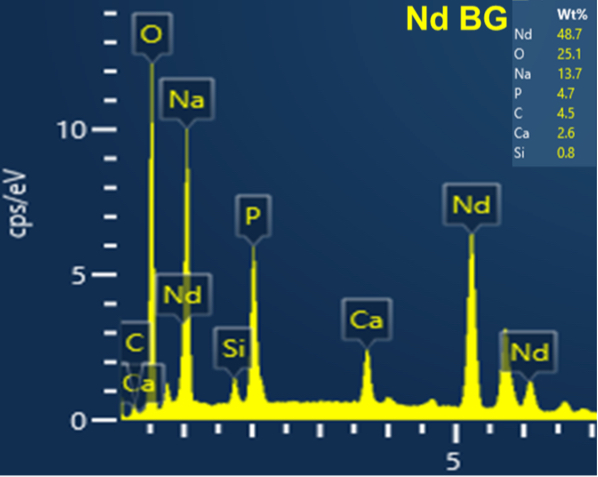


**Fig 4:** The SEM image indicates the presence of crystalline nature of the Nd doped bioglass.

This FE-SEM analysis of Nd BG shows the surface morphology of a neodymium- incorporated bioactive glass (BG) (Chehelgerdi et al., 2023). The morphology reveals a porous and rough surface with interconnected granular structures, which indicates the porous nature of bioactive glasses. Such porous structures are beneficial in biomedical applications; since, they promote cell attachment as well as proliferation, and also allow for better integration with the biological environment. The porosity may also facilitate the material’s bioactivity by promoting ion exchange with surrounding biological tissues that is critical for bone regeneration and other dental as well as orthopaedic applications [(Chitra et al., 2020)](https://paperpile.com/c/qI6sLO/9yf5).

# EDS ANALYSIS

The EDS analysis exhibits the elemental composition of Nd BG (neodymium-doped bioactive glass). Major elements include phosphorus (P-4.7%), oxygen (O-25.1 %), carbon (C-4.5 %), sodium (Na-13.7 %), calcium (Ca-2.6 %), and silicon (Si-0.8 %). The highest percentage of neodymium (Nd), which constitutes 48.7% by weight, indicates a significant doping of Nd on the surface of the material (Saadh et al., 2024). These elements represent the composition of bioactive glass, which consists of silica, phosphate, sodium, calcium with neodymium to enhance properties like antibacterial effects, bioactivity, and radiopacity.



**Fig 5:** EDS analysis of Nd doped bioglass.

The impact of neodymium bioglass on regeneration has been extensively investigated in the context of bone and tissue engineering. Previous study was done by incorporating bioglass with methacrylated gelatin cryogel; in which the FT-IR spectrum revealed the Si-O-Si stretching band at 1080 **cm1** and the typical bending vibration of the phosphate group peaks at 561 and 603 cm1 and the ratio of calcium to phosphate on cryogel surfaces was determined to be 1.63 which has been found to be almost our body's composition; the results interpreted that [(Kwon et al., 2018)](https://paperpile.com/c/qI6sLO/RVzpn).

Another research illustrates CT and histological study, the two groups exhibiting the highest levels of new bone formation were the defects receiving Sr-MBG scaffolds and the defects receiving MBG + estrogen replacement therapy. When compared to other modalities, Sr scaffolds showed fewer tartrate-resistant acid phosphatase-positive cells. The present study's findings show that local Sr release from bone scaffolds can improve fracture healing; the present study's findings show that local Sr release from bone scaffolds can improve fracture healing.[(Wei et al., 2014)](https://paperpile.com/c/qI6sLO/1vypb)

A study was conducted regarding the regeneration of defective bone by *in-vivo* evaluation of the composite colloidal gels reveals their capacity to support the regeneration of osteoporotic bone defects [(*Website*, n.d.-b)](https://paperpile.com/c/qI6sLO/IzdG). The activity of osteoblasts and the differentiation of mesenchyme stem cells into osteogenic lineages have been encouraged through use of neodymium-doped bioglass supports. This helps accelerate bone formation while leading to buttressing of the bioglass scaffold with the host tissue. Moreover, neodymium bioglass has also shown usefulness in soft tissue engineering, like in the case of wound healing and skin restoration. The reasons for the actions of neodymium bioglass on regeneration are not yet clear. Interaction of neodymium ions with cells as well as with the surrounding tissue needs to be understood to facilitate the design and manufacture of neodymium-doped bioglass scaffolds. Also, the amount of neodymium along with its release rates should be dealt with carefully to optimize regenerative results without harmful cell lethal effects. More studies are needed to clarify the particular tissues and cellular events of neodymium’s action on tissue regeneration and to formulate customized strategies for a range of regenerative applications.

# CONCLUSION

Silica and phosphate vibrations with small spherical porous morphology were observed in Nd-Bioglass. Spherical integrated porous morphology with respective Si, Ca, P, Na, and Nd elemental compositions were found that authenticate the formation of bioglass. Neodymium-doped bioglass is expected to be useful in regenerative medicine because of its bioactive characteristics and the special role neodymium ions have on tissue regeneration. The addition of neodymium to bioglass scaffolds may improve bone formation, blood vessel formation, and other important cellular activities needed for the repair and regeneration of tissues.

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