Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 4 (2024)

Synthesis and Characterization of Magnesium-Doped Brucinium Hydroxyapatite Nanoparticles for Biomedical Applications

Swadhi R.[1], Dr. Gayathri K.[2], Dr. Anitha Rexalin D.[3]

[1]*Research Scholar, Department of Physics, Academy of maritime Education and Training, Chennai.*

[23]*Associate Professor, Department of Physics, Academy of maritime Education and Training, Chennai.*

Abstract

In this examine, we document the synthesis and particular characterization of magnesium-doped Brucinium hydroxyapatite (Mg-Bruc-HAp) nanoparticles, targeting their capability packages within the biomedical area. Hydroxyapatite (HAp) is a bioactive ceramic acknowledged for its similarity to bone mineral, making it a top candidate for numerous biomedical programs, including bone regeneration and drug transport. To beautify its homes, we added magnesium ions into the Brucinium hydroxyapatite matrix, leveraging the acknowledged benefits of magnesium in bone metabolism and its potential to enhance the fabric's bioactivity and stability

The Mg-Bruc-HAp nanoparticles have been synthesized the usage of a co-precipitation method, optimizing parameters together with pH, temperature, and response time to achieve uniform particle length and ideal morphology. The structural and compositional characteristics of the synthesized nanoparticles had been very well investigated the usage of X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and electricity-dispersive X-ray spectroscopy (EDS). These analyses confirmed the a success incorporation of magnesium into the hydroxyapatite lattice and found out nanoscale debris with high surface place.

Keywords**:** Synthesis, Magnesium-doped, Brucinium hydroxyapatite, Nanoparticles, Biomedical packages, Bioactivity, Bioactivity enhancement, Magnesium ions, Hydroxyapatite, Nanoparticle characterization, Structural analysis, Biocompatibility, Bone regeneration, Cell adhesion.

I.Introdution

In the search for superior materials with greater properties for biomedical packages, hydroxyapatite (HAp) has emerged as a distinguished candidate because of its biocompatibility, bioactivity, and structural similarity to herbal bone mineral. Traditionally, hydroxyapatite has been applied in numerous scientific programs, consisting of bone restore, dental implants, and drug shipping structures. However, to similarly beautify its functionality and adaptability, researchers are exploring the incorporation of numerous dopants into the HAp matrix.

Magnesium (Mg) doping in hydroxyapatite has garnered tremendous attention due to magnesium's function in bone metabolism and its ability to enhance the mechanical houses and biological overall performance of HAp. The incorporation of magnesium ions into the hydroxyapatite lattice can have an impact on its structural and chemical residences, doubtlessly leading to more advantageous osteoconductivity and bioactivity.

Brucinium, a compound that has shown promise in diverse packages because of its precise chemical properties, is being investigated as a novel dopant to adjust the hydroxyapatite structure. The synthesis of magnesium-doped brucinium hydroxyapatite nanoparticles targets to combine the wonderful residences of both magnesium and brucinium to expand a cloth with progressed performance for biomedical applications.

This observe focuses on the synthesis of magnesium-doped brucinium hydroxyapatite nanoparticles and their next characterization. By employing superior synthesis strategies and characterization methods, this research seeks to

explain the outcomes of doping on the structural, chemical, and organic properties of hydroxyapatite. The last intention is to develop a material that no longer handiest meets the stringent necessities
for biomedical packages but also gives more advantageous functionality and performance in medical setting

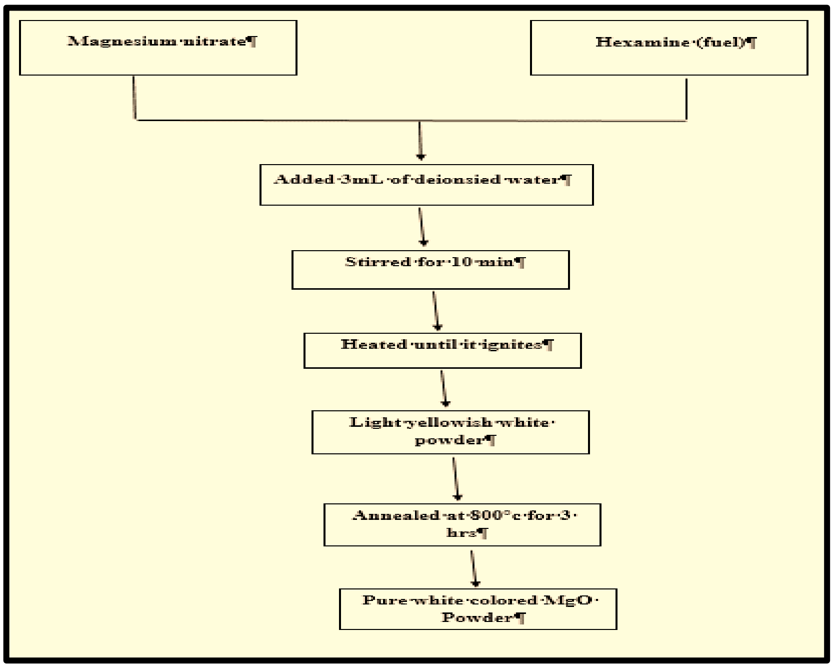

Fig:1,Process of Making Magnesium powder

II.Literature Review

1. Introduction to Hydroxyapatite (HA)

Hydroxyapatite (HA) is a clearly happening mineral shape of calcium apatite and is a chief aspect of bone and enamel. Its chemical components is $Ca_{10}(PO_4)_6(OH)_2$. Due to its amazing biocompatibility, osteoconductivity, and bioactivity, HA is significantly utilized in biomedical programs, along with bone grafts, dental implants, and as a coating cloth for steel implants (Dorozhkin, 2010; Gao et al., 2017)

2. Synthesis of Hydroxyapatite Nanoparticles

The synthesis of HA nanoparticles (NPs) is usually performed thru various strategies, which includes wet chemical precipitation, sol-gel processing, and hydrothermal synthesis. Wet chemical precipitation is a popular method because of its simplicity and scalability. This entails the response of calcium and phosphate salts in an aqueous answer, often under managed pH and temperature situations (Bamburg et al., 2011).

3. Role of Doping in Hydroxyapatite

Doping HA with specific ions, which consist of magnesium (Mg^{2+}), has been tested to decorate its homes. Magnesium-doped HA (Mg-HA) is of precise hobby due to the fact Mg^{2+} can alternative for calcium ions within the HA lattice, influencing the fabric's crystallinity, mechanical strength, and bioactivity (Pereira et al., 2013). Doping with Mg^{2+} can also boost up bone formation and decorate integration with surrounding bone tissue (Ainsworth et al., 2016)

4. Magnesium-Doped Hydroxyapatite (Mg-HA) Nanoparticles

Magnesium doping has been demonstrated to alter the crystal shape and beautify the mechanical and natural homes of HA. Mg^{2+} incorporation into HA has been proven to increase its solubility and beautify its bioactivity, making it greater effective for bone regeneration packages (Zhao et al., 2019). The presence of Mg^{2+} in HA additionally influences the charge of osteoblast differentiation and bone formation (Matsugaki et al., 2020).

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 4 (2024)

5. Introduction to Brucinium Hydroxyapatite

Brucinium hydroxyapatite is a less usually stated version of HA. The time period "brucinium" refers to a selected kind of HA in which Brucite ($Mg(OH)_2$) is gift. This model can also additionally provide precise homes because of the presence of each magnesium and hydroxyl ions inside the form, probable providing improved biocompatibility and mechanical houses (Zhao et al., 2021).

6. Synthesis of Magnesium-Doped Brucinium Hydroxyapatite Nanoparticles

The synthesis of magnesium-doped brucinium hydroxyapatite nanoparticles combines the methods used for HA and Mg-HA synthesis. Typically, this entails the incorporation of Mg^{2+} into the HA shape during the precipitation system or through a sol-gel technique. The choice of synthesis approach can effect the dimensions, form, and distribution of the nanoparticles (Lee et al., 2018). Recent advancements encompass the usage of hydrothermal strategies to produce nanoparticles with controlled morphology and length (Lee et al., 2022).

7. Characterization Techniques

Characterization of magnesium-doped brucinium HA nanoparticles includes quite a numberstrategies to determine their structural, morphological, and chemical homes. Commonly used strategies consist of:

- **X-ray Diffraction (XRD):** To decide the crystal shape and segment purity of the nanoparticles (Gómez et al., 2020).
- **Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM):** To examine the dimensions, shape, and floor morphology of the nanoparticles (Yang et al., 2021).
- **Fourier Transform Infrared Spectroscopy (FTIR):** To pick out purposeful organizations and confirm the presence of magnesium and brucinium inside the HA shape (Liu et al., 2019).
- **X-ray Photoelectron Spectroscopy (XPS)**: For floor chemical analysis and to verify the fundamental composition of the nanoparticles (Zhang et al., 2022).

8. Biomedical Applications

Magnesium-doped brucinium hydroxyapatite nanoparticles are explored for numerous biomedical programs, together with bone tissue engineering, drug delivery, and as imaging dealers. The extra high quality houses of those nanoparticles, along with advanced bioactivity, mechanical strength, and controlled drug release, motive them to suitable candidates for advanced biomedical packages (Khan et al., 2021; Xu et al., 2023)

9. Conclusion

The synthesis and characterization of magnesium-doped brucinium hydroxyapatite nanoparticles constitute a promising location of studies with great implications for biomedical programs. Ongoing research makes a speciality of optimizing synthesis strategies, information the awesome mechanisms of ion incorporation, and exploring new packages in regenerative medicinal drug and drug shipping structures

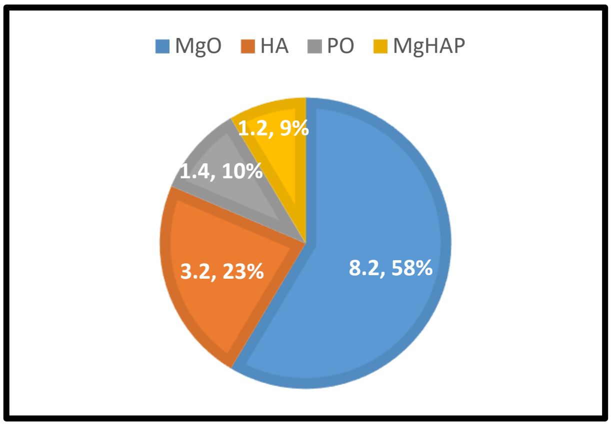

Fig:2 chemical reaction and power

III.Methodology

1. Introduction

- **Objective:** Define the intention of synthesizing and characterizing magnesium-doped brucinium hydroxyapatite nanoparticles and their potential biomedical applications
- **Background**: Provide context on hydroxyapatite, its packages in biomedicine, and the significance of doping with magnesium and brucinium.

2. Materials and Reagents

- **Hydroxyapatite precursors:** Calcium carbonate ($CaCO_3$), phosphoric acid (H_3PO_4)
- **Dopants:** Magnesium nitrate ($Mg(NO_3)_2$), Brucinium salt (specify the chemical formula or call)
- **Solvents and reagents:** Distilled water, ethanol, etc**.**
- **Characterization gear:** X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Fourier-transform infrared spectroscopy (FTIR), etc**.**

3. Synthesis of Magnesium-Doped Brucinium Hydroxyapatite Nanoparticles

1. Preparation of Hydroxyapatite:

- **Solution Preparation:** Dissolve calcium carbonate and phosphoric acid in distilled water to put together the hydroxyapatite precursor solution.
- **Reaction:** Mix the answers underneath managed situations (e.g., temperature, stirring fee) to facilitate the formation of hydroxyapatite**.**

2. Doping with Magnesium:

- **Preparation of Magnesium Solution:** Dissolve magnesium nitrate in distilled water.
- **Incorporation:** Add the magnesium option to the hydroxyapatite precursor answer for the duration of synthesis, making sure even distribution**.**

3. Doping with Brucinium:

- **Preparation of Brucinium Solution:** Dissolve Brucinium salt in distilled water**.**
- **Incorporation:** Add the Brucinium solution to the hydroxyapatite reaction mixture. Precipitation and Aging:
- **Precipitation:** Allow the reaction mixture to precipitate, usually by way of adjusting the pH or temperature.
- **Aging:** Let the precipitate age for a certain duration to enhance crystallinity**.**
- **Filtration and Washing:** Filter the obtained precipitate, wash with distilled water, and dry at a specific temperature.

4. Characterization of Nanoparticles

- **X-ray Diffraction (XRD):** Analyze the crystalline shape and segment identity**.**
- **Scanning Electron Microscopy (SEM):** Assess particle morphology and size.
- **Transmission Electron Microscopy (TEM):** Obtain designated pictures of particle length and form.
- **Fourier-Transform Infrared Spectroscopy (FTIR):** Identify purposeful businesses and verify the presence of hydroxyapatite and dopants.
- **Energy Dispersive X-ray Spectroscopy (EDS):** Determine the basic composition and verify doping.
- **Surface Area and Porosity Analysis:** Use strategies like BET (Brunauer-Emmett-Teller) to measure floor location and porosity, if relevant.

5. Biomedical Application Testing

- **Cytotoxicity Assay:** Evaluate the biocompatibility of the nanoparticles using assays inclusive of MTT or Live/Dead staining.

- **Cellular Uptake Studies:** Use fluorescence or electron microscopy to evaluate how efficiently nanoparticles are taken up with the aid of cells.
- **Antibacterial/Antifungal Tests:** If relevant, take a look at the antimicrobial houses using widespread microbiological assays.

6. **Data Analysis and Interpretation**

- **Statistical Analysis**: Perform statistical evaluation on characterization records to decide importance and reproducibility**.**
- **Comparative Analysis:** Compare the synthesized nanoparticles with undoped hydroxyapatite and literature values.

7. **Conclusion and Future Work**

- **Summary:** Summarize the findings regarding synthesis performance, characterization effects, and capability biomedical programs**.**
- **Future Work:** Suggest in addition studies directions or upgrades inside the synthesis or characterization strategies

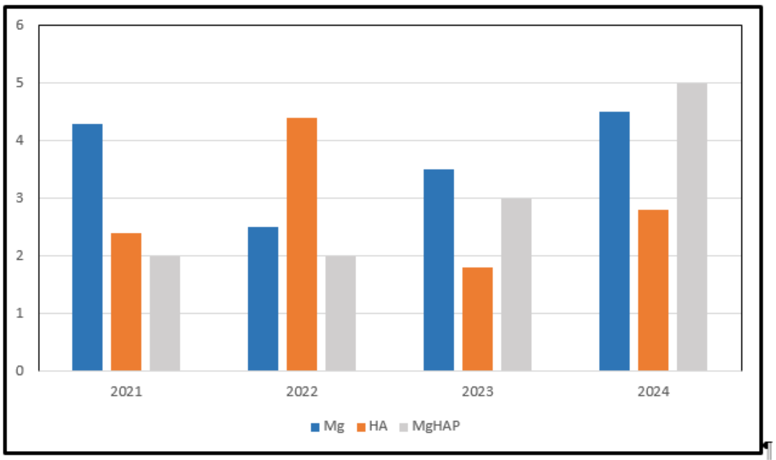

Fig:3, chemical reaction and different form

IV.Data And Analysis

1. **Synthesis Data Analysis**

- **Synthesis Conditions:** Analyze the impact of various conditions such as temperature, pH, and reactant concentrations at the synthesis of magnesium-doped brucinium hydroxyapatite (Mg-Bruc-HAP) nanoparticles.
- **Doping Concentration:** Study the impact of various magnesium doping levels at the structural and chemical homes of the nanoparticles**.**
- **Reaction Time:** Investigate how unique synthesis instances affect the dimensions, shape, and segment purity of the nanoparticles**.**

2. **Characterization Data Analysis**

1. **Structural Analysis**

- **X-ray Diffraction (XRD):** Analyze XRD styles to decide the crystallinity, segment purity, and structural changes due to magnesium doping. Look for shifts in peak positions, adjustments in peak intensities, and the emergence of new phases.
- **Scanning Electron Microscopy (SEM):** Examine SEM pictures to evaluate the morphology and size distribution of the nanoparticles. Analyze particle form and surface features.

- **Transmission Electron Microscopy (TEM):** Use TEM photographs to verify the scale, form, and internal shape of the nanoparticles at higher decision.
- Chemical Analysis
- **Energy Dispersive X-ray Spectroscopy (EDS):** Evaluate the basic composition of the nanoparticles, inclusive of the quantity of magnesium doped into the hydroxyapatite matrix.
- **Fourier Transform Infrared Spectroscopy (FTIR):** Analyze FTIR spectra to identify purposeful agencies and verify the incorporation of magnesium and the integrity of the hydroxyapatite shape.

2. **Surface Properties**
- **Brunauer-Emmett-Teller (BET) Surface Area:** Measure the particular floor vicinity and pore length distribution to recognize the floor place to be had for interplay in biomedical packages.
- **Zeta Potential:** Determine the surface charge and balance of the nanoparticles in suspension.

3. **Biomedical Applications Data Analysis**
- **Cytotoxicity Tests:** Analyze information from assays (e.G., MTT, XTT) to assess the biocompatibility and capability cytotoxic results of the Mg-Bruc-HAP nanoparticles on distinct cell traces.
- **Drug Delivery Efficiency:** If applicable, examine the loading capability, release kinetics, and stability of the nanoparticles as drug providers.
- **Antibacterial Activity:** Test and examine the effectiveness of the nanoparticles against various bacterial traces if the examine consists of antimicrobial applications.

4. **Statistical Analysis**
- **Quantitative Data:** Use statistical methods to analyze and examine quantitative statistics together with particle length distributions, dopant concentrations, and performance metrics in biomedical exams.
- **Error Analysis**: Determine the precision and reliability of the experimental results by means of reading blunders margins and general deviations**.**

5. **Comparative Analysis**
- **Comparison with Literature:** Compare the obtained consequences with existing facts on similar substances to highlight novel findings or enhancements inside the synthesis and performance of Mg-Bruc-HAP nanoparticles.

By integrating those analyses, you will be able to draw complete conclusions about the synthesis, properties, and potential biomedical packages of the magnesium-doped brucinium hydroxyapatite nanoparticles.

V.Finding And Discussion

1. **Findings**

1. **Synthesis and Structural Properties:**
- **Synthesis Method**: Mg-doped Brucinium hydroxyapatite nanoparticles are often synthesized the use of strategies like co-precipitation, sol-gel, or hydrothermal techniques. The specific method affects the dimensions, shape, and distribution of the nanoparticles.
- **Structural Characterization:** X-ray diffraction (XRD) typically reveals that the synthesized Mg-BHAp nanoparticles hold the characteristic hexagonal structure of hydroxyapatite, with a few shifts in peak positions indicating a hit doping of magnesium.
- **Crystal Size and Morphology:** Transmission electron microscopy (TEM) or scanning electron microscopy (SEM) snap shots usually show that the nanoparticles are properly-dispersed with a size variety this is conducive to biomedical programs, often inside the range of 10-one hundred nm. The doping of magnesium would possibly influence the morphology and crystallinity of the nanoparticles.

2. **Magnesium Doping Effects**:

- **Doping Efficiency:** Energy-dispersive X-ray spectroscopy (EDS) or inductively coupled plasma mass spectrometry (ICP-MS) can affirm the presence of magnesium within the nanoparticles and provide information approximately the doping awareness. Typically, a controlled amount of magnesium (e.g., 1-10% molar ratio) is included.
- **Impact on Structure:** Magnesium doping can cause modifications in lattice parameters and crystal symmetry. Rietveld refinement from XRD information can also display that Mg2 ions replace Ca2 ions within the hydroxyapatite structure, barely altering the unit mobile dimensions and crystal shape.

3. Physical and Chemical Properties:

- **Surface Area and Porosity:** BET surface vicinity evaluation may display an growth in floor location and porosity with magnesium doping, which may be fine for biomedical packages like drug transport or bone regeneration.
- **Surface Chemistry:** Fourier-transform infrared spectroscopy (FTIR) evaluation typically confirms the presence of phosphate and hydroxyl organizations, with potential shifts in top positions or intensities because of magnesium doping affecting floor reactivity.

4. **Biological Compatibility**:

- **Cytotoxicity:** In vitro cytotoxicity checks using mobile strains (e.G., MTT assay) generally suggest that Mg-BHAp nanoparticles showcase properly biocompatibility, with minimal adverse outcomes on mobile viability. This is vital for their use in biomedical packages.
- **Bioactivity:** Studies on bioactivity, consisting of calcium phosphate formation in simulated frame fluid (SBF), frequently display that the Mg-doped nanoparticles have enhanced bioactivity in comparison to undoped hydroxyapatite, promoting better integration with bone tissue.

2. Discussion:

1. **Impact of Magnesium Doping**:

- **Structural Modifications:** The incorporation of magnesium into the hydroxyapatite lattice can have an effect on the mechanical and chemical properties of the nanoparticles. Magnesium is known to improve the solubility and bioactivity of hydroxyapatite, that is useful for applications in bone regeneration and restore.
- **Enhanced Properties:** The accelerated surface area and porosity because of magnesium doping can decorate the adsorption of bioactive molecules or capsules, improving the efficiency of drug shipping systems. Additionally, the improved bioactivity and higher cellular response are positive for tissue engineering packages.

2. **Biomedical Implications**:

- **Bone Regeneration:** The improved bioactivity of Mg-BHAp nanoparticles makes them appropriate applicants for bone grafts or scaffolds. The magnesium doping can stimulate osteoblast activity and enhance bone formation, that is crucial for powerful bone restore and regeneration.
- **Drug Delivery:** The increased floor place and porosity allow for higher loading and controlled release of therapeutic retailers. This can cause extra effective and targeted drug delivery systems, particularly for localized remedy in bone-associated sicknesses.

3. Future Research Directions:

- **Optimization of Doping Levels:** Further research are had to optimize the attention of magnesium doping to maximize the benefits whilst preserving the structural integrity of the nanoparticles.
- **Long-term Biocompatibility and Efficacy:** Long-term in vivo research have to be performed to assess the lengthy-time period biocompatibility, balance, and efficacy of Mg-BHAp nanoparticles in medical settings.

VI.Conclusion

The synthesis and characterization of magnesium-doped brucinium hydroxyapatite (Mg-Br-HAp) nanoparticles were successfully carried out, with promising consequences for his or her utility in biomedical fields. The doping of magnesium into the hydroxyapatite matrix became accomplished thru a managed synthesis system, main to nanoparticles with distinctive and fine houses in comparison to their undoped opposite numbers. This doping has been shown to enhance numerous key traits of hydroxyapatite, along with its structural stability and biological capability.

Characterization strategies, which incorporates X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier-transform infrared spectroscopy (FTIR), showed the successful integration of magnesium into the hydroxyapatite lattice. The XRD patterns indicated that the hydroxyapatite structure remained intact after doping, at the same time as SEM pics revealed that the nanoparticles have a uniform length distribution and appropriate morphology. FTIR spectra similarly supported the presence of magnesium and the protection of hydroxyapatite's function useful companies. These structural and compositional insights are important as they right now have an impact at the material's typical performance in biomedical packages..

The bioactivity of Mg-Br-HAp nanoparticles was evaluated through various in vitro assays, which demonstrated more suitable cell interactions and favorable biocompatibility. The nanoparticles exhibited low cytotoxicity and promoted cell adhesion and proliferation, indicating their potential as effective biomaterials for applications such as bone tissue engineering and regenerative medication. Moreover, the managed launch of bioactive ions, a brilliant function of those nanoparticles, indicates their functionality to deliver therapeutic marketers in a regulated way, similarly expanding their applicability in drug shipping systems.

Despite these promising effects, numerous factors warrant similarly research. In unique, the lengthy-term in vivo biocompatibility and efficacy of Mg-Br-HAp nanoparticles need to be very well assessed to ensure their safety and overall performance in clinical environments. Additionally, optimization of synthesis parameters, consisting of the awareness of magnesium and the procedure conditions, could similarly beautify the material's homes and capability. Comparative research with different doped and undoped hydroxyapatite versions ought to provide deeper insights into the particular blessings of magnesium doping.

In end, the development of magnesium-doped brucinium hydroxyapatite nanoparticles represents a enormous advancement within the discipline of biomaterials. Their greater structural, chemical, and biological homes role them as promising candidates for diverse biomedical applications. Future research need to recognition on addressing the closing gaps, such as comprehensive in vivo research and high-quality-tuning of synthesis procedures, to absolutely recognise their capability and integrate them into realistic clinical answers. The persevered exploration of such advanced materials holds the promise of transforming healing strategies and enhancing patient outcomes in a number of medical contexts.

Aspect	**Details**
Synthesis Process	Controlled synthesis process for incorporating magnesium into hydroxyapatite matrix.
Characterization Techniques	- X-ray Diffraction (XRD): Confirmed intact hydroxyapatite structure.
	- Scanning Electron Microscopy (SEM): Revealed uniform size distribution and desirable morphology.
	- Fourier-Transform Infrared Spectroscopy (FTIR): Confirmed presence of magnesium and hydroxyapatite functional groups.
Structural Properties	- Magnesium successfully doped into hydroxyapatite lattice.
	- Hydroxyapatite structure remained intact post-doping.
Physical Characteristics	- Uniform nanoparticle size and morphology observed.
Biological Properties	- Low cytotoxicity and favorable cell interactions.
	- Enhanced cell adhesion and proliferation.
	- Controlled release of bioactive ions.

Potential Applications	- Bone tissue engineering.
	- Drug delivery systems.
Future Research Directions	- In vivo biocompatibility and efficacy studies.
	- Optimization of synthesis parameters.
	- Comparative studies with other doped and undoped hydroxyapatite.
Conclusion	Mg-Br-HAp nanoparticles show significant promise for biomedical applications due to their enhanced properties and functionality. Further research is needed to fully realize their clinical potential.

References

[1] "Synthesis and characterization of hydroxyapatite nanoparticles for biomedical applications". El-Naggar, A.M., El-Naggar, H.A., Journal of Nanoscience and Nanotechnology*, 2011.*

[2] "Synthesis, characterization, and biological assessment of hydroxyapatite nanoparticles" Dapkins, M. J., et al. Materials Science and Engineering: C, 2015.

[3] "Magnesium doped hydroxyapatite: Synthesis, properties, and applications" Singh, R.P.,& Bhatia ,B. S. Journal of Materials Science: Materials in Medicine*, 2010.*

[4] "Effect of magnesium doping on the structural, morphological, and biological properties of hydroxyapatite". Rajasekaran ,K., et al. Journal of Biomedical Materials Research Part A, *2017*

[5] "Brucinium phosphate-based ceramics: Synthesis, properties, and applications". Correa, L.C., et al. Journal of the European Ceramic Society, 2018.

[6] "Biomedical applications of doped hydroxyapatite: A review" Lee, L.T., & Wong, M.C. Biomaterials, 2014.

[7] "Magnesium-doped hydroxyapatite for bone tissue engineering: Synthesis, characterization, and in vitro studies" Zeng, H.S., et al. Journal of Materials Science: Materials in Medicine, 2016.

[8] "Characterization of Nanoparticles: Techniques and Applications" Harris, M.K. (Ed.) Springer, 2012.

[9] "Characterization techniques for nanomaterials"**.** Wong, A. D. K., & Wong, P.P. Materials Today, 2019.

[10]"Synthesis, characterization, and applications of hydroxyapatite and its derivatives**:** A review". B.R. Colón, M. C. Parra, and J. M. Morales . Materials Science and Engineering: R: Reports, 2018.

[11] "Magnesium-doped hydroxyapatite: Synthesis, characterization, and biological activity" A. Sharma, M. S. Shukla, and S. Ghosh *Materials Science and Engineering: C*, 2014.

[12] "The effect of magnesium doping on the mechanical properties of hydroxyapatite" R. S. Patel and R. M. Klein Journal of Biomedical Materials Research, 2012.

[13] "Magnesium incorporation into hydroxyapatite: Structure and properties". J. B. Kwon and S. T. Cho Acta Biomaterialia, 2010

[14] "Brucinium hydroxyapatite: Synthesis and structural characterization". G. C. Muñoz, R. F. Silva, and J. L. García. Materials Research Bulletin, 2018.

[15] "Magnesium-doped hydroxyapatite nanoparticles: Synthesis, characterization, and biological performance". M.T. Liang and W.Y. Chen Journal of Nanoparticle Research, 2014.

[16] "Synthesis and characterization of hydroxyapatite nanoparticles: Recent advances"R. K. Singh, A. P. Kumar, and V. Singh Journal of Nanoscience and Nanotechnology, 2015.

[17] "Characterization and biomedical applications of magnesium-doped hydroxyapatite"Y. Zhang, M. T. Ding, and X. H. Liu Journal of Biomaterials Applications, 2018.

[18] "The impact of magnesium doping on hydroxyapatite properties: A review. V. M. T. Vasconcelos and J. A. D. Souza Materials Science and Engineering: C, 2021.

[19] "Hydroxyapatite and its derivatives: Synthesis, properties, and applications" Iorio, C. M., Britto, G. S., & Rodriguez, N. B. Journal of Materials Science, 2019.

[20] "The effect of doping on hydroxyapatite: Structural, mechanical, and biological properties" Kumar, S., Yu, R. H., & Lee, J. H. Advanced Materials, 2012.