Summary and conclusions

Throughout life, the human body’s muscular-skeleton system is constantly being formed and resorbed; with increasing age this leads to a reduction in bone mass and density and need to replace or repair the degenerated bone and restore its biologic function. Techniques to combat this serious problem have now become a major clinical need. Bioceramics are a class of advanced ceramics, which are defined as “the substance that confirm completely to the human body’s environment are those manufactured by the body itself (autogenous) and any other substance that is recognized as foreign, and initiates some type of reaction”. With the increase in clinical demands for dental and orthopaedic implant surgery, different types of bioceramic based materials are developed during the past decades. Nowadays, bioceramics and tissue engineering science aim to develop materials which can be implanted in the human body to replace damaged tissues. It is known that the reactivity of solids begins on their surface. This general statement is of particular importance in the field of bioceramics, since they will be in contact with an aqueous medium and in presence of cells and proteins.

Currently, there has been a great deal of interest in synthesis of different types of bioceramic materials for biomedical applications. Hydroxyapatite (HAP) of the chemical formula \( \text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2 \) has received much attention in tissue engineering. In fact, it is used as a bioceramic because of its bioactivity and osteoconductive properties. Compared to other bioceramics as bioglass, the advantage of HAP use as a bioceramic or biomaterial is its chemical similarity to the inorganic component of bone and tooth. It also exhibits no cytotoxic effects and shows excellent biocompatibility with hard tissues, skin and muscle tissues. Therefore, HAP has been applied clinically not only as a dense, sintered material but also as a coating on metallic implants. Moreover, an enormous number of substitutions, especially the composites resulting from the cationic substitution are of potential application in the fields of dental and bone substitution, luminescence, drug delivery, and catalysis because of the high stability and flexibility of the apatitic structure. However, use of HAP in biomedical fields is limited by its relatively slow rate of biological interaction, and there is also a requirement to improve the success rate of HAP implants, an approach to improve the osseointegration is to modify chemically the HAP by doping with low levels of beneficial elements which are found in human
bone. These doped elements can modify the surface structure of HAP, with potential influence on the material in biological environment. Among the elements that have been substituted, Zn and Fe are considered to have great potential. Also the nanoparticles of calcium silicate (CaSiO$_3$) ceramics have been investigated as new bioceramics for bone regeneration. The metal ion distribution and physical properties of the materials also depend upon the preparative method. Although conventional methods for the synthesis of bioceramics, have not received importance because of the use of expensive raw materials and many processing steps. Therefore in this work we have focused on the synthesis, characterization and applications of calcium silicate and hydroxyapatite based bioceramic materials.

Chapter – 1:

This chapter includes information about the bioceramics in brief. Types and applications of bioceramics are also discussed. Biocompatibility, biodegradation, drug delivery and clinical uses of bioceramics are also included. Literature survey regarding the applications and preparation methods such as auto-combustion and wet chemical precipitation of bioceramics are also included.

Chapter – 2:

This chapter deals with the details of characterization techniques such as TGA/DTA, X-ray analysis, SEM, EDAX, TEM, FTIR, Wettability measurement and UV-visible spectroscopy are included with instrumentation and working. Determination of lattice parameter and crystallite size by using XRD study also discussed.

Chapter – 3:

This chapter consists of wet chemical technique for the preparation of CaSiO$_3$ nanoparticles followed by fabrication of pellets. The X-ray diffraction analysis shows single phase hexagonal structure. The average crystallite size obtained for CaSiO$_3$ sample calcined at 1250°C was found to be ~ 34 nm. Spherical shape morphology and microstructure of the synthesized sample was studied by TEM and SEM analysis. EDAX and FTIR analysis of the synthesized nanomaterial corroborates that the material is composed of Ca, Si and O without any impurity. In vitro wetting experiment revealed that the CaSiO$_3$ material was superhydrophilic in nature. Cell culture, MTT assay and cell adhesion assay showed that the nanosized CaSiO$_3$ powder provided a more adequate environment for cell adhesion and proliferation and was characterized by good biocompatibility. The degradability in vitro was evaluated
by weight loss in the SBF and it shows that the CaSiO$_3$ nanoparticles exhibit a higher degradation rate. CaSiO$_3$ could efficiently adsorb and controlled release of norfloxacin, which suggested its extended applications for other antibiotics.

**Chapter – 4:**

It consists of synthesis of hydroxyapatite (HAP) bioceramics by auto-combustion technique by using citric acid as a fuel. Crystallite size obtained from XRD was found to be 30 nm. The porous microstructure of synthesized HAP material which is beneficial for cell growth was examined by SEM analysis. EDAX and FTIR analysis of the synthesized nanomaterial corroborates that the material is composed of Ca, P and O without any impurity. TEM analysis was found to be good agreement with the value obtained form XRD pattern. Wetting experiment revealed that the HAP material was superhydrophilic in nature. Cell culture, MTT and cell adhesion assay showed good biocompatibility of HAP nanoparticles. The degradability in vitro was evaluated by weight loss in the SBF and it shows that the HAP sample exhibit a higher degradation rate. Drug loading and drug release behavior of HAP nanoparticles show good uptake and release capacity.

**Chapter – 5:**

In this chapter we have employed the simple auto-combustion technique using citric acid to synthesize zinc doped hydroxyapatite (Ca$_{10-x}$Znx(PO$_4$)$_6$(OH)$_2$) nanoparticles. Crystallite size obtained from XRD was found to be 30 to 40 nm. EDAX analysis confirms that the material is composed of Ca, P, O and Zn. Formations of nanorod like structure by increasing zinc concentration in pure HAP were studied by SEM and TEM analysis. The results reveal that there is a strong correlation between zinc concentration and the product morphology. Effect of zinc concentration on in vitro biocompatibility, in vitro biodegradation and in vitro drug delivery were also observed.

**Chapter – 6:**

This chapter deals with synthesis of Ca$_{10-2x}$Fe$_{2x}$(PO$_4$)$_6$(OH)$_2$ by using auto-combustion method and its characterization. From the XRD result, it is confirmed that the synthesized material forms single hexagonal phase with average crystallite size 30 to 25 nm. The FTIR result shows distinct differences between the spectra of the HAP and Fe doped HAP due to the addition of Fe. Cell adhesion studies shows that no negative influence of Ca$_{10-2x}$Fe$_{2x}$(PO$_4$)$_6$(OH)$_2$ system up to x=0.4 which indicate
Summary and conclusions

...good biocompatibility. In vitro drug delivery was also investigated by using norfloxacin drug.

**Future Scope**

While the past 40 years has seen a major move forward both in the quantity of bioceramics used in clinical application and also the quality of bone repair that they offer, there is still potential for major advances to be made in the field. These include a requirement for the

- Evaluation of in vivo performance and clinical trials of newly prepared nanostructured bioceramics materials.
- Improvement in their performance in terms of their stability and ability to deliver biological agents.
- Development of smart nanomaterials capable of combining sensing with bioactivity.
- Development of improved biomimetic composites.

However, there is still need to be better understanding of the biological system. If we were able to fully understand the fundamentals of bone response to specific ions and the signals they activate, then we would be able to design better bioceramics for the future.