

## *International Journal of Scientific Research and Reviews*

### **Nanocomposites For Biomedical Applications**

**Majumder Devipriya Rabin<sup>1\*</sup> and Sayyed Ulfat<sup>2</sup>**

<sup>1,2</sup>Department of Microbiology

<sup>1,2</sup>Abeda Inamdar Senior College, 2390, K.B. Hidayatullah Road, Azam Campus, Pune 411001, India.

#### **ABSTRACT**

Nanotechnologies represent an unprecedented recent advance which is revolutionizing core areas of biology and medicine. In recent years there has been a rapid increase in applications of nanotechnology in medicine in order to prevent and treat diseases in the human body. Biomedical nano - composites have potential to become critically important to the development of biomedical applications, ranging from diagnostic and therapeutic devices, tissue regeneration and drug delivery matrixes to various bio-technologies that are inspired by biology but have only indirect biomedical relation. Nano - diagnostic is the term used for the application of nano - biotechnology in molecular diagnosis, which is important for developing personalized therapy. Nanotechnology is based on pharmaco-genomics, and pharmaco-proteomic information but it also consider environmental factors which influence the therapy response. This article discusses current efforts and focuses on key research challenges in the emerging use of nano - composites for potential biomedical applications.

**KEY WORDS:** Nano - composites, Biomedical Applications, Nanotechnologies

#### **\*Corresponding author**

**Dr. D. R. Majumder**

Department of Microbiology

M.C.E. Society, Pune, Abeda Inamdar Senior College, 2390,

KB Hidayatullah Rd, Azam Campus,

Pune 411001, India.

E-mail:devipriyamajumder@gmail.com

## INTRODUCTION

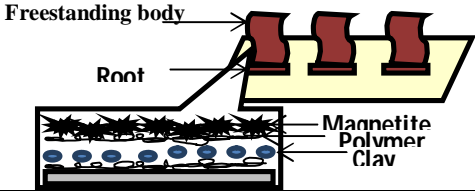
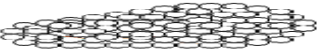
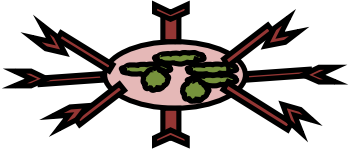
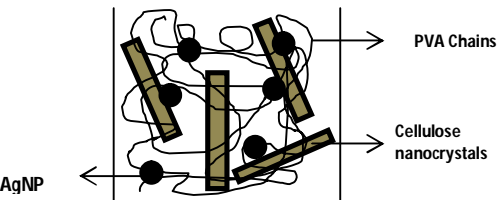
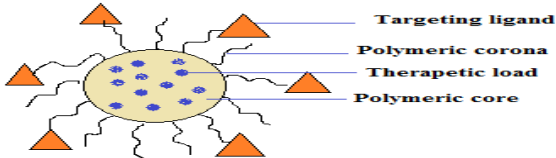
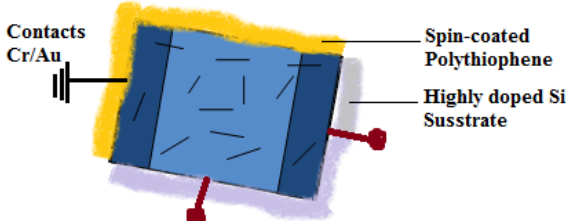
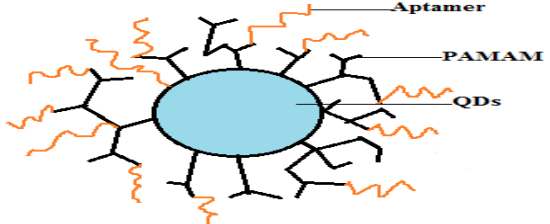
Early nanomaterials were produced without the capacity of controlling their structure and morphology and without a full understanding of what gives nanoparticles their unique properties. The dawn of modern nanotechnology can be traced to Richard Feynman's 1959 Caltech speech, "There's Plenty of Room at the Bottom "Nano-composite" is a multiphase solid material which have one, two or three dimensional phases less than 100 nanometers (nm), or structures having nano-scale repeat distances between the different phases that make up the material".<sup>1</sup>

Bio-nano-composites add a new dimension to the properties of nano-composites, in that they are biocompatible and/or biodegradable materials. Bio-nano-composites forms combinations of multiple areas that brings together biology, materials science, and nanotechnology. New bio-nano-composites are impacting diverse areas, in particular, biomedical science.<sup>2</sup>In this review, biodegradable materials can be described as materials degraded and gradually absorbed and/or eliminated by the body, where degradation is caused mainly by hydrolysis or mediated by metabolic processes. These nanocomposites are extremely useful in diagnostic purposes yielding fast and accurate results.<sup>3</sup> Therefore, these nanocomposites are of immense interest to biomedical technologies such as tissue engineering, bone replacement / repair, dental applications, and controlled drug delivery.<sup>4,5</sup>

### ***Structures of Nan composites:***

The nanocomposites have similar size and structure as most of the biological molecules; therefore, nonmaterial's can be useful for both in vivo and in vitro biomedical research and applications. The integration of nanocomposite with biology has led to the development of diagnostic devices, contrast agents, analytical tools, physical therapy applications, and drug delivery vehicles.<sup>2,3,4</sup>Nanoparticles possess certain size-dependent properties and particularly with respect to optical and magnetic parameters. Now the size and shape of nano particles can be tailor made too.<sup>6</sup>The structure of nanocomposites usually consists of the matrix material containing the nano-sized reinforcement components in the form of particles, whiskers, fibers, nanotubes etc.<sup>1</sup>Table 1 presents the detail list of different Nano-composites.

Table 1: Nano-composites Structure and Applications

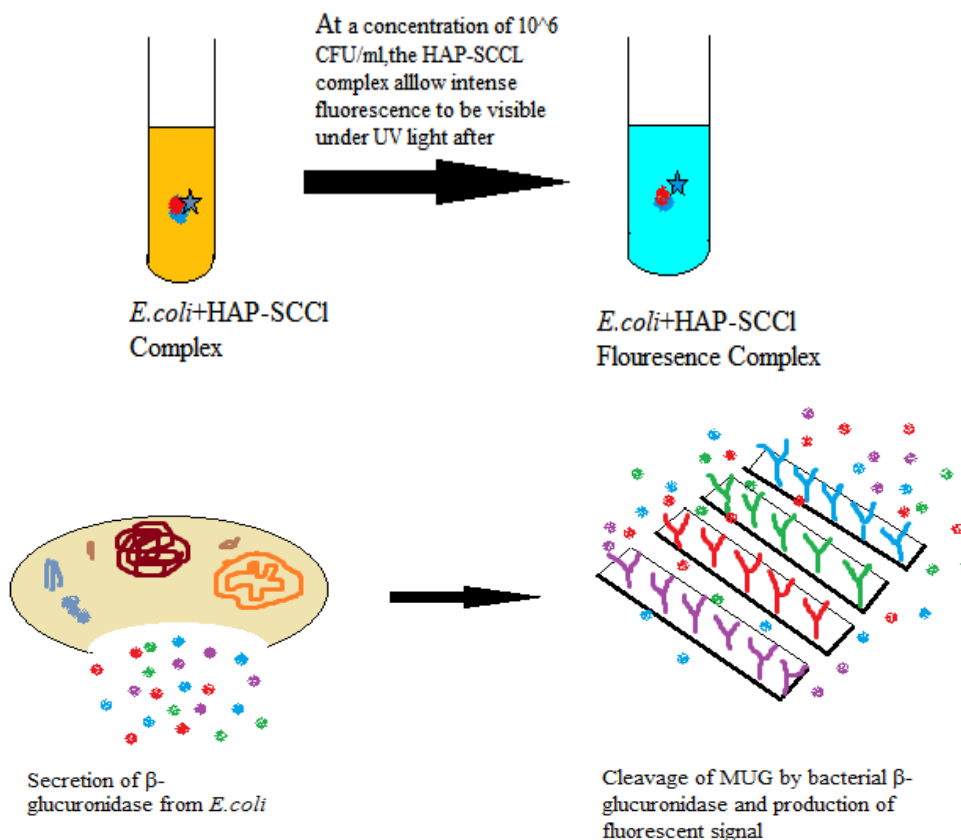
| Nano-composites  | Structures   | Applications   |
|--|--|--|
| Nano composite cantilevers-Ultrathin <sup>7</sup>  |    | <ul style="list-style-type: none"> <li>-High-throughput screening</li> <li>-DNA mutation detection</li> <li>-Diseases protein biomarker detection</li> <li>- provide sensor arrays</li> </ul>                          |
| Nano composite Carbon nanotubes <sup>8</sup>   |     | <ul style="list-style-type: none"> <li>-DNA mutation detection</li> <li>-Disease protein biomarker detection</li> <li>-Tissue engineering</li> <li>-Drug delivery</li> </ul>   |
| Nano composite Dendrimers Eg.cisplatin and PLK-1 siRNA loaded PLGA dendrimer immune nano-composites <sup>9</sup> |     | <ul style="list-style-type: none"> <li>-Image contrast detection</li> <li>- Cancer therapy</li> </ul>  |
| Nano composite crystals Eg.Cellulose nano-crystal with PVA and AgNP <sup>10</sup>                                |    | <ul style="list-style-type: none"> <li>- Increased the modulus and tensile strength of the films</li> <li>- Decreased the brittleness of the films.</li> <li>-Biocompatible materials in tissue engineering</li> </ul> |
| Nano composite Eg.Nano-shells <sup>11</sup>  |  | <ul style="list-style-type: none"> <li>-Tumor-specific imaging</li> <li>- Therapy</li> </ul>   |
| Nano composite Nanowire Eg.nanocomposite of silicon nanowire and polythiophene <sup>12</sup>                     |  | <ul style="list-style-type: none"> <li>-High-throughput screening</li> <li>-Disease protein biomarker detection</li> <li>-DNA mutation detection</li> </ul>  |
| Nano composite Quantum dots- Eg.CdS QDs- PAMAM-Apt). nano-composites <sup>13</sup>                               |  | <ul style="list-style-type: none"> <li>-Optical detection of gene and protein in animal model and bioassay</li> <li>-Tumor and lymph node visualization</li> </ul>   |

## **SCOPE**

The nano-composite plays an important role in biomedical application as drug carriers, wound healing agents due to their high water/solvent holding capacity. Multilevel imaging by advanced nano size fluorophores vindicates the need for the development of these which can be used in all kinds of labelling (cellular and in-vitro labeling for diagnosis and studies concerning metabolic pathways) and imaging techniques, such as PET, SPECT, MRI, CT, TEM and co focal microscopy etc. Fluorescent Nan composites of noble metals and quantum dots find a wide range of applications in multiplex bioimaging, biolabelling and as biosensors. This is possible due to their unique properties such as tunable shape, size, spectral and fluorescence emissions, stability to photo bleaching and biocompatibility, nontoxic nature.<sup>14</sup>

Currently used procedures of detection and identification of bacterial infections are laborious, time-consuming, and require a high workload and well-equipped laboratories. Therefore by using nanotechnology new method was developed based on hydroxyapatite nanoparticles with fluorogenic substrate which is simple, fast, and low cost method of bacterial detection.

For early detection of bacteria by visual and fluorescence spectroscopy techniques the calcium phosphate ceramic nanoparticles were characterized and integrated with a nutritive mixture. This method involves the enzyme  $\beta$ -glucuronidase which cleave the substrate, 4-methylumbelliferyl-p-D-glucuronide (MUG).<sup>1,3</sup> Figure 1 representing the mechanism of bacterial detection by production of fluorescence signal.



**Fig 1: Mechanism of production of fluorescent signal**

A study on the antibacterial activity of copper nanostructures combined with biopolymers such as cellulose was carried out for *Staphylococcus aureus* and *Klebsiella pneumoniae*, as pathogens. The results showed that the chemical nature and morphology of the nano-fillers have great effect on the antibacterial activity, which increases with increasing CuNP content in the composites.<sup>8</sup>

Eco-friendly synthesis of Chitosan-PVA-Silver (CPSNP) nanocomposite was achieved for sustained release of aspirin which only reaffirms their increasing biomedical applications especially for therapeutic purposes. The swelling capacity and anti-microbial activity was appreciable in view of their wound healing applications and demonstrated significant effects against *E. coli*, *Pseudomonas* sp., *Staphylococcus* sp. and *Klebsiella* sp. Drug loading efficiency (LE), encapsulation efficiency (EE) and *in vitro* drug release of aspirin as the model drug from the nanocomposite was highly efficient. Thus the Chitosan-PVA-Silver (CPSNP) nanocomposite as a controlled drug delivery system is a workable model.<sup>2</sup>

For enhanced targeted therapeutic efficacy and safety purpose, combination of therapeutic and diagnostic which results in 'Theranostics' was developed. Integrated theranostic nanoagents can deliver diagnostic imaging agents capable of detecting and monitoring the early onset of diseases and simultaneously transport suitable therapeutics over a prolonged period in order to enhance therapeutic efficacy.<sup>4</sup>

Several Nanocomposite-Polymer complexes (Table 2) and Metal nanocomposites (Table 3) are listed with their multifaceted applications.

**Table 2: Nanocomposite-Polymer complexes and their Applications**

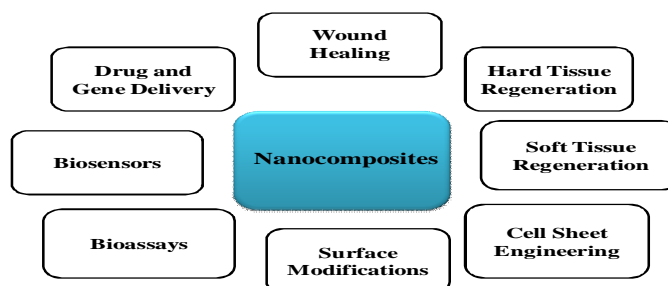
| NANOPARTICLES                                    | POLYMER   | APPLICATIONS   |
|--|---|--|
| Cloisite <sup>15</sup>                           | Ethylene vinyl Acetate                          | Used to increase adhesion and growth of human dermal fibroblasts   |
| Cloisite <sup>15</sup>                           | Polyurethanes                                   | 5 fold lower permeability towards water vapor and enhanced mechanical properties   |
| Laponite <sup>15</sup>                           | poly(N-isopropylacrylamide) hydro gels (PNIPAM) | Ultrahigh elongation with near-complete recovery, rapid de-swelling responses to temperature changes and large equilibrium swellings were observed due to addition of Limonite to the polymeric matrix.                                      |
| Laponite <sup>15</sup><br>Laponite <sup>15</sup> | PNIPAM<br>poly(ethylene oxide)(PEO)             | Cell sheet easily detached by changing temperature. Cells cultured on the surfaces of PEO-Laponite gels attached and proliferated easily.  |
| Cloisite <sup>15</sup>                           | Poly(ethylene-co-vinyl acetate)                 | Used for drug delivery- Addition of nanoparticle resulted in slower release of dexamethasone. Moreover, release kinetics were dependent on the aspect ratio and degree of dispersion of the nanoparticle                                     |
| Laponite <sup>15</sup>                           | Pluronic  | Used for drug delivery- A temperature dependent sol-gel transition was observed in the nanocomposites. Laponite enhanced the dissolution resistant properties of the hydro gels and release of entrapped macromolecular drug was slowed down |
| Bentonite <sup>15</sup>                          | Acrylic acid-PEG methyl ether acrylate          | Used for drug delivery- Elution kinetics strongly depended on the interactions between the surface charges of the clay and the drug  |
| Laponite <sup>15</sup>                           | PEO-Polyamide                                   | Used for drug delivery- Molecular interactions between Laponite and drug resulted in sustained release profiles  |
| Cellulose and Copper <sup>16</sup>               | Poly(vinyl alcohol)(PVA)                        | Similar to Ciprofloxacin and used for wound dressing. Antibacterial Activity of Nanocomposites of Copper and Cellulose   |
| Flax cellulose nanocrystals <sup>17</sup>        | Starch  | Used to improve the mechanical properties and water resistance of the starch-based materials   |
| Silver Nanoparticles <sup>18</sup>               | Chitin  | Used in wound healing applications   |
| Cellulose nanofibres <sup>19</sup>               | Poly(vinyl alcohol) (PVA)                       | Applications in cosmetic industries  |
| Silver nanoparticles <sup>20</sup>               | Chitin  | Antimicrobial activity and Wound healing   |
| Silver nanoparticles <sup>21</sup>               | Chitosan/ polyethylene glycol                   | Drug Delivery system   |
| Silver Nanoparticles <sup>22</sup>               | Chitosan- Poly(vinyl alcohol) (PVA)             | Drug Delivery system   |
| Cellulose <sup>15</sup>                          | Polyvinyl alcohol                               | As taste sensing material  |
| Silicon oxide(SiO <sub>2</sub> ) <sup>22</sup>   | Polylactic acid                                 | For Tissue engineering   |
| Metal nanoparticles <sup>23</sup>                | Hydroxyl petite polymer                         | Tissue engineering   |

|                         |                             |  |
|-------------------------|-----------------------------|--|
| Silica <sup>15</sup>    | Chitin                      | Chitinous organic matrix provided a template for bio-directed deposition of the silicate mineral phase.  |
| Silica <sup>15</sup>    | Chitosan                    | Improved mechanical properties observed due to addition of bioglass. Bioglass aided in significant increase in cell adhesion, proliferation and alkaline phosphatase activity. Enhanced bone regeneration observed when the nanocomposite was implanted in vivo. |
| Silica <sup>15</sup>    | Collagen                    | Improved bioactivity of the material; accelerated the formation of bone-like apatite and led to the differentiation of human monocytes into osteoclast-like cells.   |
| Bioglass <sup>15</sup>  | PLA                         | Addition of bioglass fiber enhanced in vitro bioactivity of the nanocomposite. Significant increase in alkaline phosphatase activity observed in nanocomposite compared to pure PLA.   |
| Bio glass <sup>15</sup> | Poly L-lactide              | Increase in bioglass concentration reduced water absorption capacity but enhanced degradation rate.  |
| Bioglass <sup>15</sup>  | Chitosan & Chitosan-Gelatin | Bioactive nanocomposite scaffolds promoted osteoblast cell adhesion and spreading.   |

**Table 3: Metal nanocomposites and their Applications**

| NANOCOMPOSITES  | APPLICATIONS   |
|---|--|
| Fe/MgO <sup>24</sup>  | Catalysts, magnetic devices.                               |
| Ni/PZT <sup>24</sup>  | Wear resistant coatings and thermally graded coatings.     |
| Ni/TiO <sub>2</sub> <sup>24</sup>                                   | Photo-electrochemical applications.                        |
| Al/SiC <sup>24</sup>  | Aerospace, naval and automotive structures.                |
| Cu/Al <sub>2</sub> O <sub>3</sub> <sup>24</sup>                     | Electronic packaging.                                      |
| Al/AlN <sup>24</sup>  | Microelectronic industry.                                  |
| Ni/TiN, Ni/ZrN <sup>24</sup>  | High speed machinery, tooling.                             |
| Cu/ZrN <sup>24</sup>  | Optical and magnetic storage materials.                    |
| Nb/Cu <sup>24</sup>   | Structural materials for high temperature applications.    |
| Fe/Fe <sub>23</sub> C <sub>6</sub> /Fe <sub>3</sub> B <sup>24</sup> | Structural materials.                                      |
| Fe/TiN <sup>24</sup>  | Catalysts.   |
| Al/ Al <sub>2</sub> O <sub>3</sub> <sup>24</sup>                    | Microelectronic industry.                                  |
| Au/Ag <sup>24</sup>   | Microelectronics, optical devices, light energy conversion |
| Pd/Chitosan <sup>25</sup>   | Catalytic and antibacterial activity                       |
| Pd-Chitosan/Starch <sup>25</sup>                                    | Suzuki-Miyaura reaction                                    |
| Au/Pt <sup>25</sup>   | Measles virus diagnosis                                    |

Highlights of different applications of nanocomposites<sup>15</sup> are shown in Figure 2.



**Fig 2: Applications of Nanocomposites**

1. **Rapid and Economical:** Nanocomposites are widely applied in clinical laboratories for bacterial detection in human samples due to the reduced costs of reagents and equipment. In addition, chromogenic and fluorogenic methods have been developed for faster and more accurate detection and identification of microbes. These methods can provide data in a shorter time with higher accuracy (95%–100%) than those based on current methods.<sup>24</sup>

2. **Antibacterial activity:** Antimicrobial tests revealed that the Cu nanocomposites have antibacterial action for both bacteria, though with a more pronounced effect in respect to *Staphylococcus aureus* and *Klebsiella pneumoniae*.<sup>26</sup> It has been also reported that photosynthesized palladium nanoparticles showed the bactericidal activity against both Gram Negative as well as Gram Positive bacteria. Polyaniline/Pd-Pt nanocomposite are showing the superior antimicrobial activity.<sup>27</sup>

3. **Drug Delivery and Thermal Ablation:** Gold nanoshells-hydrogels composite materials have been located with protein and then illuminated at the Plasmon resonance to stimulate release and shrinking the hydrogels. The nanoshells caused enhanced drug release and enable multiple bursts of protein by modulated heating. Such devices could have significant drug delivery applications, especially if the stimulant radiation can be administered exogenously to NIR resonant nanoparticles.<sup>28</sup> It is reported that Chitosan-montmorillonite (Cs-Mnt) nanocomposite showed increased drug release profile. Montmorillonite is a clay of soft phyllosilicate mineral group. Some properties of montmorillonite clay which are contributing to drug delivery are large surface area which shows good cation exchange capacity, adsorption capacity, adhesive ability and drug carrying capability.<sup>29</sup>

4. **Biomedical imaging contrast:** From a single gold nanoparticle the Plasmon resonant scattering produces brighter signal as compared to other single fluorophores, fluorescent beads or quantum dots in microscopic imaging application. The large nanoparticle size relative to fluorophores and quantum dots may limit intracellular imaging application. The two-photon luminescence from NIR resonant gold nanorods has been used to monitor microscopic blood flow in vivo.<sup>28</sup>

5. **Biosensors:** An important goal for biosensors is the capability of continuously monitoring concentrations of specific targets in a simple and reliable manner within the physico-chemical and biological constraints of their microenvironment. Recognition-based biosensors capable of specifically detecting chemical and bio-agents in their environment are under active development using fluorescent metal nanos. Huang et al. developed new competitive homogeneous for analyzing proteins using bioconjugated photoluminescent Au nanodots as donors and bioconjugated spherical Au nanoparticles as accepters. An oligonucleotide Aptamer (Apt) has a higher affinity for specific proteins such as a breast cancer marker protein, platelet-derived growth factor (PDGF). Nanoclusters of PDGF-modified fluorescent gold nanoparticles can attach onto Apt-modified particles,



consequently resulting in fluorescence quenching (“off” state) through resonance energy transfer. Addition of free PDGF can further recover the fluorescence of PDGF-modified nanoclusters through the competitive binding, releasing the quenched nanocluster to “on” state. Another example of sensing proteins, are capable of sensing concanavalin A with high sensitivity and remarkable selectivity over other proteins and lectins also has the capability of binding, yielding brightly fluorescent cell.<sup>28</sup> Different Nanocomposites are used as biosensor by various techniques (Table 4)

**Table 4: List of Nanocomposite biosensors**

| NANOCOMPOSITE BIOSENSOR                                    | SUBSTANCE TO BE MONITORED     | TECHNIQUE                 |
|--|-------------------------------|---------------------------|
| Fluorescent gold NC(AuNC@MUA) <sup>1</sup>                 | Mercury Hg(II)                | Fluorescence Quenching    |
| glutathione-protected gold nano(AuNC@GSH) <sup>1</sup>     | Calcium Ca <sup>2+</sup>      | Fluorescence Quenching    |
| fluorescent mannose-protected Au NCs AuNC@Man <sup>1</sup> | FimH of type 1 in E. coli     | Fluorescence microscopy   |
| Aptamer modified NCs <sup>1</sup>                          | PDGF (a breast cancer marker) | Fluorescence microscopy   |
| Reduced graphene oxide-Chitosan NCs <sup>27</sup>          | Hydrogen peroxide             | Electrochemical detection |
| Chitosan-graphene/glucose oxidase NCs <sup>27</sup>        | Glucose                       | Electrochemical detection |

**6. Bioimaging:** Multilevel imaging from molecular to medical scales demonstrates the need for the development of advanced nano-size fluorophores that can be used in all kinds of labelling and imaging techniques, such as PET, SPECT, MRI, CT, TEM and confocal microscopy etc. Tunable fluorescence, strong quantum-size confinement, stability to photo bleaching, higher biocompatibility these novel optical properties render the fluorescent noble-metal quantum dots(QD's) ideal fluorophores for multicolor and multiplexing applications in biomedical engineering and molecular biotechnology.<sup>8,14</sup> The semiconductor quantum dots (QDs) have already become a new class of fluorescent labels due to their unique optical properties as well as offering potential invaluable benefits such as cancer targeting and biomedical imaging. QDs containing heavy metals are unsuitable for in vivo clinical use because of their toxic, and may pose risks to human health as well as the environment under certain conditions. In contrast to QDs and organic dyes noble metal nano-clusters (NCs) are highly attractive for bioimaging and bio labeling applications due to their low toxicity as well as its ultra-fine size. The labeling of endothelial cells with fluorescent gold NCs was found to detect cellular functions including angiogenesis, vasodilatation, coagulation, adhesion, and junction integrity. Human fluorescent gold nanocluster-labeled late endothelial progenitor cells also possessed angiogenic potential in vitro and in vivo.<sup>28</sup> Various Magnetic Fluorescent nanocomposites are depicted in Fig.3.

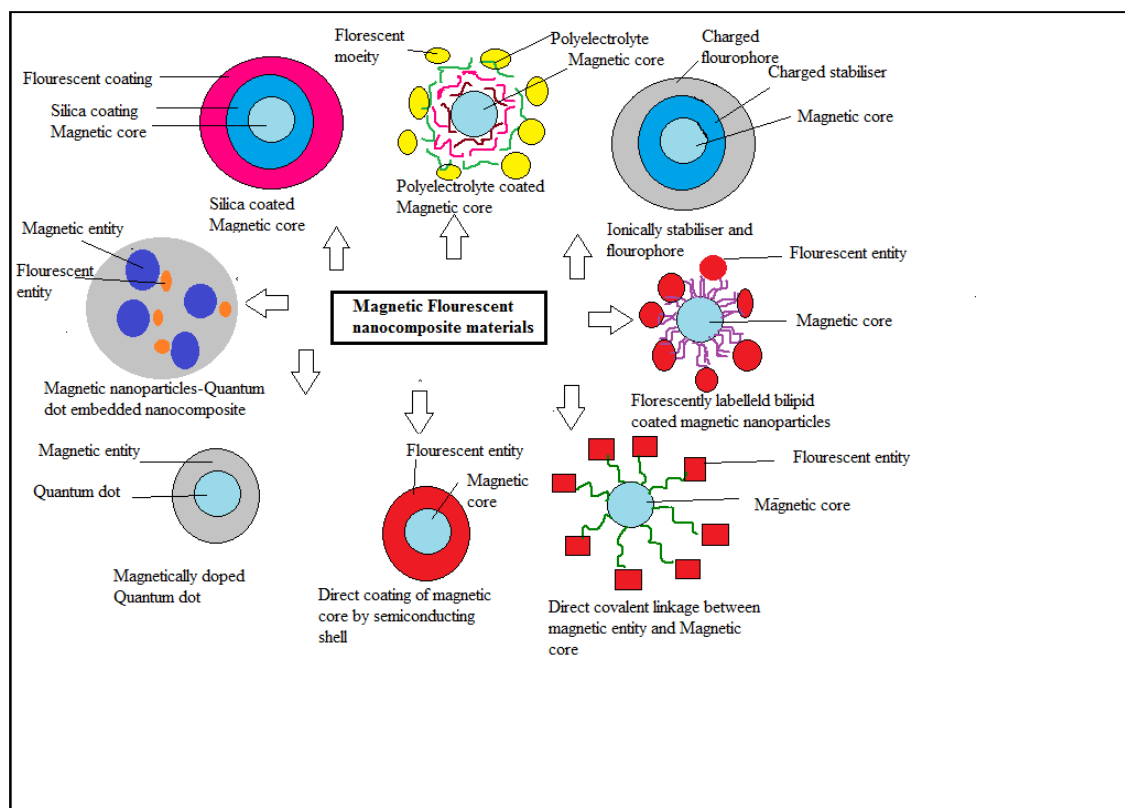


Fig 3. Magnetic-Fluorescent Nanocomposites Material

**7. Tissue regeneration:** Bone defects, ranging from small voids to large segmental defects are a prevalent and persistent problem in clinical orthopedics and dentistry. Bone defects arise from a variety of causes including fracture nonunion, dental and orthopedic implant fixation, trauma or tumor resection, periodontitis, and musculoskeletal disorders such as rheumatoid arthritis. So in these clinical circumstances, bone repair and regeneration and can be accelerated by using natural and synthetic bone grafts are desired to ensure rapid restoration of skeletal function. Hence, Nanocomposite polymer scaffolds for tissue engineering are prepared.<sup>29</sup> Perspective materials for production of new generation of scaffolds for bone tissue regeneration are polymeric-based nanocomposites, which plays a role of an artificial extra-cellular matrix (ECM) which serves as temporary support where isolated cells are introduced to form a tissue (Fig 4). These scaffold should be biocompatible, biodegradable, promote cell attachment and mechanically stable. The ideal scaffold should possess mechanical properties adequate to support growing bone tissue, degrade upon bone tissue growth and have high porosity with interconnecting pores enabling in growth of osteoblasts cells. The new direction in tissue engineering is modification of a polymer matrix with nanoparticles which can influence on mechanical, electrical, physicochemical and biological properties much more suitable for human body. Bioactive compounds of nanocomposite materials can be prepared with silica ( $\text{SiO}_2$ ), hydroxyapatite (HA), tricalcium phosphate (TCP) or carbon nanotubes (CNT). Silica

(SiO<sub>2</sub>) plays a fundamental role in bioactive glasses because silanol groups interact with calcium and phosphate ions forming an amorphous calcium phosphate which also can be found in the natural bone. Polylactic based nanocomposite scaffolds containing SiO<sub>2</sub> as a ceramic bioactive nanoadditive were prepared. Preliminary studies showed that 2 wt. % of the nanofiller improves mechanical properties. It was observed that small amount of the nano-filler resulted in increasing proliferation of osteoblast-like cells contacted with PL/DLA. The studies proved that nano-SiO<sub>2</sub> altered so far inert polymeric material to bioactive one.<sup>30</sup>

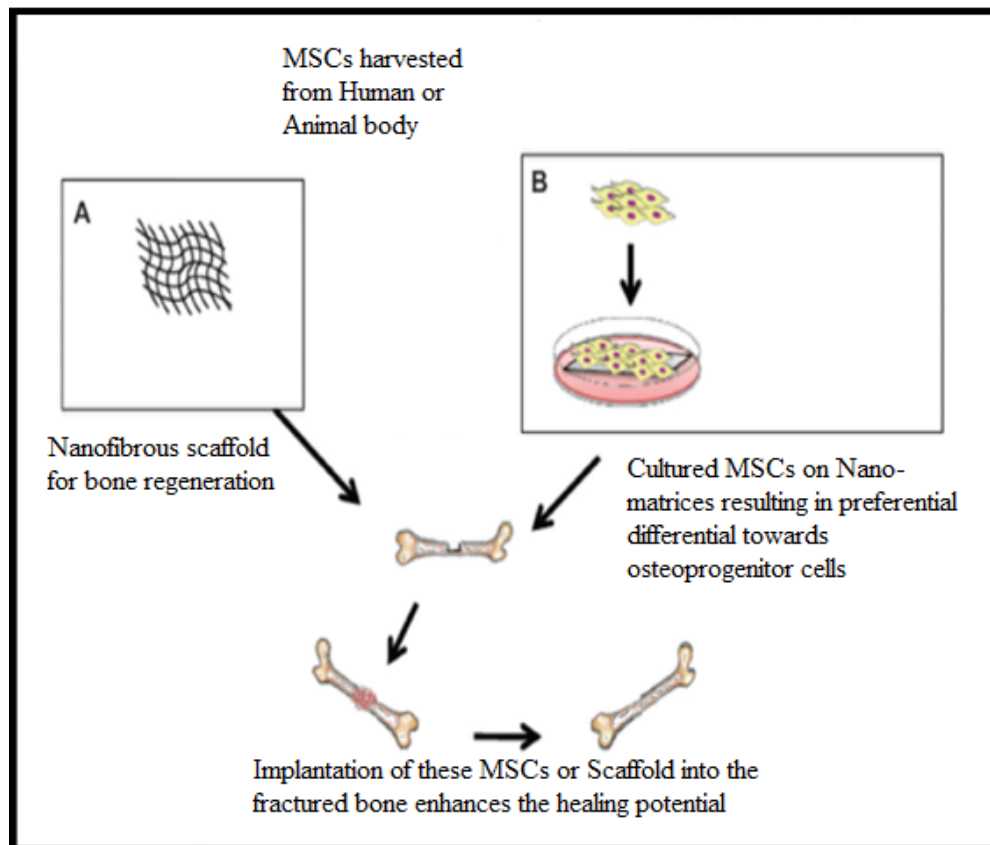


Fig 4. Tissue Regeneration by Nanotechnology

## CONCLUSION

Nanotechnology is an emerging field which has immense applications especially in the field of medicine. Nanocomposites are used for diagnosis and therapy. Metal nanocomposites play different roles as optical and magnetic storage materials, structural material for high temperature applications. Some nanocomposites are used as biosensors. Fluorescence labeled magnetic nanocomposites are playing an important role in bioimaging.

## REFERENCES

1. Claudio R. and Tamara L. "Development of a Calcium Phosphate Nanocomposite for Fast Fluorogenic Detection of bacteria". *Molecules*. 2014 ;(9):13948-13964.

2. Devipriya R., Pruthvi C., Deepali B. et al. "Eco-friendly synthesis of chitosan-pva-silver nanocomposite for sustained release of aspirin". *World Journal of Pharmaceutical Research*. 2018; 7(4):71-88.
3. Devipriya R., Juned P. and Hemant Z. "Calcium phosphate nanocomposite for rapid fluorogenic detection of pathogen". *World Journal of Pharmaceutical Research*. 2018; 7(4):18-30.
4. Devipriya R. "Nan biotechnological Applications in Health and Medicine". Lambert Academic Publishing, GmbH & Co. KG. 2017; 7(4):1-113.
5. Fuli Z., Dan Y., Ruiwei G. et al. "Composites of Polymer Hydrogels and Nanoparticulate Systems for Biomedical and Pharmaceutical Applications". *Nanomaterials*. 2015 ;(5):2054-2130.
6. Mansura S., Devipriya R. "S-layer Proteins Tailor- made Nanoparticles". *International Journal of Innovative Research in Science engineering and Technology*. 2013; 2(9):4693-4706
7. Feng H., Tianhong C., and Yuri M. "Ultrathin Cantilevers Based on Polymer-Ceramic Nanocomposite Assembled through Layer-by-Layer Adsorption". *Institute for Micro manufacturing, Louisiana Tech University*. 2004; 4(5): 823-825.
8. Marco B., Assunta B., Laura Mayol et al.: "Nanoparticle-Integrated Hydrogels as Multifunctional Composite Materials for Biomedical Applications". *Gels*. 2015;(1):162-178
9. Mohd. A., Saba T., Aijaz A. et al. "Dendrimer-PLGA based multifunctional immunonanocomposite mediated synchronous and tumor selective delivery of siRNA and cisplatin: potential in treatment of hepatocellular carcinoma". *RSC Advances*. 2015 ;( 5): 39512-39531
10. Jonshy G., Vallayil A., Karna V. et al. "Augmented properties of PVA hybrid nanocomposites containing cellulose nanocrystals and silver nanoparticles". *J. Mater. Chem*. 2012 ;(22): 22433-22439
11. Cypes, S., Saltzman, W., Giannelis, E. "Organosilicate-polymer drug delivery systems: controlled release and enhanced mechanical properties". *J. Control. Release*. 2003 ;(90):163-169.
12. Gen W., Jia Y., Ken O. et al. "Dual layer semiconducting nanocomposite of silicon nanowire and polythiophene for organic-based field effect transistors". *Organic Electronics*. 2016; (35):158-163
13. Jing-Jing Z., Jun-Tao C., Gui-Fang S. et al. "Sandwich-format electrochemiluminescence assay for PDGF-BB using quantum dots-dendrimer nanocomposites as probe". *Talanta*. 2015;(141):158-163

14. Cheng-An J., Chih-Hsien L.,Jyun-Tai H. et al."Synthesis of Fluorescent Metallic Nanoclusters toward Biomedical Application:Recent Progress and Present Challenges".*Journal of Medical and Biological Engineering*.2009;29(6): 276-283.
15. Chia J., Akhilesh K.,Patrick J. et al."Development of Biomedical Polymer-Silicate Nanocomposites".*A Materials Science Perspective Materials*.2010 ;(3):2986-3005.
16. Ricardo J., Sara D., Patrizia S. et al."Antibacterial Activity of Nanocomposites of Copper and Cellulose".*Hindawi Publishing Corporation. BioMed Research International*.2013; 1-6.
17. Xu R.,Manias E., Snyder A. et al."Low permeability biomedical polyurethane nanocomposites". *J.Biomed. Mater. Res*.2003 ;(64): 114-119.
18. Xu R.,Manias E., Snyder A. et al."New biomedical poly (urethane urea)—layered silicate nanocomposites".*Macromolecules*.2001 ;(34):337-339
19. Ray, S.,Yamada K.,Okamoto M. et al."Polylactide-layered silicate nanocomposite: A novel biodegradable material". *Nano Letter*.2002 ;(2):1093-1096.
20. Rohan A. Hand D."Polymer Nanocomposites for Biomedical Applications".*MRS Bulletin*.2007 ;(32):354-358.
21. Lee J., Park, T.,Park, H. et al."Thermal and mechanical characteristics of poly (L-lactic acid) nanocomposite scaffold". *Biomaterials*.2003 ;(24):2773-2778
22. Lee Y.,Lee J.,An I. et al."Electrospun dual-porosity structure and biodegradation morphology of Montmorillonite reinforced PLLA nanocomposite scaffolds". *Biomaterials*.2005 ;(26): 3165-3172.
23. Majumdar S. and Adhikari B."Polyvinyl alcohol–cellulose composite: a taste sensing material". *Bull. Mater. Sci*.2005 ;(28): 703–712.
24. Doss, S."Surface properties of hydroxyapatite:The effect of various inorganic-ions on electrophoretic behavior". *J. Dent. Res*.1976 ;(55):1067–1075.
25. Dhanavel S., Manivannan N.,Mathivanan N. et al."Preparation and characterization of cross-chitosan/palladium nanocomposites for catalytic and antibacterial activity".*Journal of Molecular liquid*.2018 ;(257):32-41
26. Haraguchi, K. and Takehisa, T."Nanocomposite hydrogels: A unique organic-inorganic network structure with extraordinary mechanical, optical, and swelling/de-swelling properties". *Advan. Mater*.2002 ;( 14):1120-1124.
27. Dimitrios P."Polyelectrolyte-graphene Nanocomposites for Biosensing Applications".*Current organic chemistry*.2015 ;(19):1819-1827.
28. Sanjay T."Development of Fluorescent nanoparticles "Quantum Dots" for biomedical application".*UCL Press*. 2013; 1-223

29. Stodolak Z., Fraczek S., Wiechecb A. et al. "Nanocomposite Polymer Scaffolds for Bone Tissue Regeneration". *Acta physica polonica*. 2012 ;(121):518-521.
  30. Lee, W. and Chen, Y. "Effect of bentonite on the physical properties and drug-release behavior of poly (AA-co-PEGMEA)/bentonite nanocomposite hydrogels for mucoadhesive". *J. Appl. Polym. Sci.* 2004 ;(91):2934-2941.
-