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Nanobiomaterial in Dental Medicine: A Review

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Abstract: Nanobiomaterials are materials with basic structural units, grains, particles, fibers, or other constituent components smaller than 100nm in at least one dimension, have evoked a great amount of attention for improving disease prevention ,diagnosis, and treatment. Tissue engineering and regeneration improve damaged tissue and organ functionality. While tissue engineering has hinted at much promise in the last several decades, significant research is still required to provide exciting alternative materials to finally solve the numerous problems associated with tradi- tional materials. Nanotechnology may have the answers since only nanobiomaterials can mimic surface properties (including topography and energy) of natural tissues. For these reasons, over the last decade, nanobiomaterials have been highlighted as promising candidates for improving dental medicines.

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I. Introduction

There are signs that we are in the midst of an explosion of new health-related technologies. In addition to specific advances in health research, traditional sciences and technology are undergoing significant changes that could have a farreaching impact on all aspects of scientific research, including health. Nanotechnology is defined as the design, characterization, production, and application of structures, devices, and systems by controlled manipulation of size and shape at the nanometer scale (atomic, molecular, and macromolecular scale) that produces structures, devices, and systems with at least one novel/superior characteristic or property. Nanobiomaterials are materials with basic structural units, grains, particles, fibers, or other constituent components smaller than 100nm in at least one dimension, have evoked a great amount of attention for improving disease prevention ,diagnosis, and treatment.

II. Synthetic Antibacterial Nanomedicines

Carbon Nanotubes and Fullerenes

Since the discovery of carbon nanotubes they have flourished and have been applied in a broad range of areas in science and in a way represent the momentum of nanotechnology itself. They have been sourced due to their unique optical, thermal, magnetic, high strength properties as well as the ability to be conductive, almost all of which can be tuned depending on the dimensions of the nanotube. As of late they have been used in medical research in applications such as drug delivery and as components in medical nanodevices. They have also been noted for their apparent toxicity to biological systems, as they themselves are so small that they act like fibers, and have the same toxicological impacts of other known toxic fibers, for example asbestos. A recent study was performed that looked into the antimicrobial properties of carbon nanotubes and showed that they are strong antibacterial agents (Weir et al., 2008). The study conducted by Kang used low metal content, well characterized, narrowly distributed, pristine Single walled nanotubes (SWNTs), which are to observe bactericidal activity on the bacterium Escherichia coli K12. The bacteria were incubated with the SWNTs for 60-mins and microbial viability was checked and showed that over 80% of the microbes were killed. The suggested mode of death was the direct interaction of the SWNTs with the bacterial cell membranes causing significant membrane damage (Seoktae, 2007).

Fullerene C60 is another carbon structure that has been investigated as an antimicrobial agent, as a means of identifying environmental impacts of fullerene C60. Research was conducted to test the toxicity of the fullerene molecules on two species of bacteria, E.coli DH5 and Bacillus Subtilis, the former being a gram negative and the latter being gram positive (Lyon et al., 2005). The study showed that the fullerenes did act as bactericidal agents on both bacteria types, but it was also identified that differences in physical dimension of fullerene C60 types have alternative effects therefore more specific testing would be required.

Silver Nanoparticles

Silver has long been used in medicine, even in ancient times it was used as a preservative and also to reduce inflammation and prevent against infection of wounds (Moghimi, 2005). A study was performed to test the effectiveness of silver nanoparticle antimicrobial activity using E .coli was undertaken by a Sondi (2004). In the study 105 CFU of gram negative E. coli colonies were grown on LB agar plates with different concentrations of Ag-nanoparticles. Ag-NPs at concentrations of 10 µg cm^{-3} showed inhibition of bacterial growth by up to 70%, and at concentrations of 50-60 µg cm^{-3} there was 100% inhibition of bacterial growth (Shahverdi, 2007). A SEM and TEM analysis showed the accumulation of the nanoparticles within membranes and some were able to penetrate into the cell, the SEM also highlights the damage caused by the Ag-NPs where visible “pits” can be observed.

Silver ions antimicrobial activity is believed to work by impairing DNAs ability to replicate and through the inactivation of key proteins by denaturation when they are bound together (Sondi and Sondi, 2004). Although it is still unknown what type of interaction takes place between the nanoparticles and the constituents of the outer membrane. Another study showed that with the use of silver nanoparticles in conjunction with antibiotics such as penicillin G, amoxicillin, erythromycin, clindamycin and vancomycin, provided an increase in the effectiveness of the antibiotics (Shahverdi, 2007). Silver nanoparticles show great potential as antimicrobial agents in applications, as they are of low cost and easily synthesized, and could be used to treat material surfaces to provide highly effective antibacterial materials, medical equipment such as in and devices and paints in dentistry. There is a range of different bioactive glasses but only one has been approved by FDA, known as 45S5 and is composed of SiO_2-Na_2O-CaO-P_2O_5, and is currently used in dentistry (Waltimo, 2007). It is well known that bioactive glasses in a solution exhibit a mild antimicrobial activity, due to the release of their ionic compounds and intake of H_3O^+ protons it is able alter the local environment by increasing alkalinity of the solution. This in turn disrupts bacteria that are tolerant to the high-pH change.

Metal Oxide Nanoparticles

Metal oxide nanoparticles represent a new class of important materials that are increasingly being developed for use in research and medical applications, due to their desirable varying physical and chemical properties and also the apparent antibacterial activity. In this review only a handful of the metal oxides will be examined, but there are many more that have also been shown to exhibit antimicrobial properties (Huang, 2005; Jones, 2008; Anglin, 2008.

Magnesium Oxide Nanoparticles

Nano-MgO has been involved in many different areas of research due to its novel properties, particularly in nanocomposite materials but now has been approached as antibacterial agents. MgO was originally known to be an antibacterial agent and it was thought that the damage caused to bacteria was due to the formation of superoxide anions on its surface; this inspired further research into understanding the mode of action that allows nano-MgO to exhibit antibacterial activity (Stoimenov, 2002). It was found that nano-MgO particles are able to take up halogen gases due to its defective natured surface and its positive charge, which results in a strong interaction with bacteria and spores as they are negatively charged. In this study the nano-MgO particles were produced and bromide and chloride were absorbed into the particles and then tested against E. coli, B. cereus and B. globigii as well as the spores from the Bacillus species. Experimental results showed that nano-MgO in conjunction with the uptake of halogens, in particular chloride, that effective destruction of the bacteria and bacterial spores was observed (Stoimenov, 2002)

Zinc Oxide Nanoparticles

It is known that zinc oxide exhibits antibacterial activity like many other metal oxide groups and like the others only few have been scaled down to the nano size and researched further, such as ZnO nanoparticles. It has been shown that ZnO nanoparticles show significant antibacterial activity over a broad range of bacterial species and in particular against Staphylococcus aureus where it out competes five other commonly used metal oxide nanoparticles (Jones, 2008).

Research that was carried out by Jones (2008) to test the antibacterial activity of nanoparticles as well as the impact of particle size on bactericidal efficiency.

Silicon Dioxide Nanoparticles

SiO_2 is used very extensively in material sciences and has also been more recently used in a range of medical research such as drug delivery (Anglin, 2008). Nano-SiO_2 is not used directly as an antimicrobial agent itself but acts as a carrier for antimicrobial and bactericidal agents due to its exceptionally porous structure. Due to this porous structure SiO_2 is able to absorb ions and organic molecules quite easily, making it highly efficient and a promising carrier for antimicrobial applications. As observed in previous examples in this review, metal-containing inorganic materials has shown to be effective as antimicrobial agents; therefore a study was conducted and has implemented zinc and silver into SiO_2 nanoparticles as a means of creating a high-performance bactericidal agent (Jia, 2008).

III. Biological Based Antibacterial Nanomedicines

Chitosan Nanofiber

Chitosan is a polysaccharide that is found in the exoskeleton of crustaceans and used in a range of commercial and biomedical applications such as a plant growth enhancer and even as a blood clotting agent (Prabaharan, 2008). But a recent study by Ignatova (2006)has been carried out using Chitosan to create electrospun nano-fiber mats that have antibacterial activity. The experiment involves creating fibers in the range of 60-200nm out of quaternized Chitosan (QCh) mixed with poly (vinyl alcohol) (PVA) and were stabilized successfully against dissolution in the aqueous environment using photomediated cross-linking. The bactericidal ability of the QCh mats is due to the damaging interaction of polycations with the negatively charged surface of bacteria which results in the loss of bacterial membrane permeability, cell leakage and eventually cell death. The results highlight the potential of electrospun mats to be used for wound-dressings as they are able to reduce the threat of secondary infection by bacteria. Additional chitosan also provides all the desirable properties that are required for fast wound healing that is non-toxic, has hemostatic activity, biodegradability and the ability to affect macrophage function (Ignatova, 2006).

Targeted Drug-Carrying Phage Medicines

Various specific indicator cultures were tested for providing clear plaques after phage infection. There are currently many highly antibacterial agents that have been developed but due to the lack of selectivity they are too potent to be used clinically. A way to overcome this shortcoming is to increase the selectivity of the agent by targeted therapy which is indeed what a group of researchers have accomplished. A phage was used as the drug-carrier as it has nanometric parameters that offer a unique and excellent drug-carrying ability, when compared to other particle drug-carrying devices that are commonly used such as liposomes or virus-like particles (Prabaharan, 2008; Ignatova, 2006). This feature was also enhanced by use of clever chemistry through the introduction of amino sugar-based aminoglycosides as branched, hydrophilic linkers. This addition enabled two added benefits that are essential to the criteria required for a targeted drug carrying system, firstly providing the salvation of hydrophobic materials, which in this case is the drug chloramphenicol. This in turn enables a far greater uptake of the drug to the phage in aqueous solution, while also increasing the drug-carrying capacity of the phages from around 3000 molecules of chloramphenicol/phage to 40,000 (Ignatova, 2006).

Poly-L-Lactide Nanoparticles

Nisin is an antimicrobial protein produced by Lactococcus lactis and is known as a lantinobiotic due to the fact that it contains unusual amino acids such as lanthionine. Nisin has just recently been approved by the FDA for use as a food additive to provide preservation due to its broad spectrum antibacterial activity against gram-positive bacteria. One major problem when implementing nisin as a food additive is due to its weak structural integrity and certain bacteria having a minor tolerance to its effects, hefty amount of nisin is required. But it has now been combined with the use of Poly-Lactide nanoparticles in a study by Salmaso (2004). Poly-L-Lactide was used as it is biodegradable and nontoxic and could be used in certain applications of interest, as well as being easily producible

IV. Conclusion

Nanobiomaterial has provided new avenues for therapeutics, diagnostics as well as treatment by enhancing current systems through the use of new novel nanomaterials. It has affected almost every branch of dentistry. Basically the material properties and their applied uses of quite a nanomaterials have been inspired from the bulk materials themselves such as silver and bioactive glasses, nanocomposites, nanoglass ionomers, etc. for their antibacterial and physical properties which were already recognized, but it was shown to be optimized when present in nanometric scales. The performance of these materials has been shown to be increasing multifold when used at nanoscale.

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