Piezoceramics

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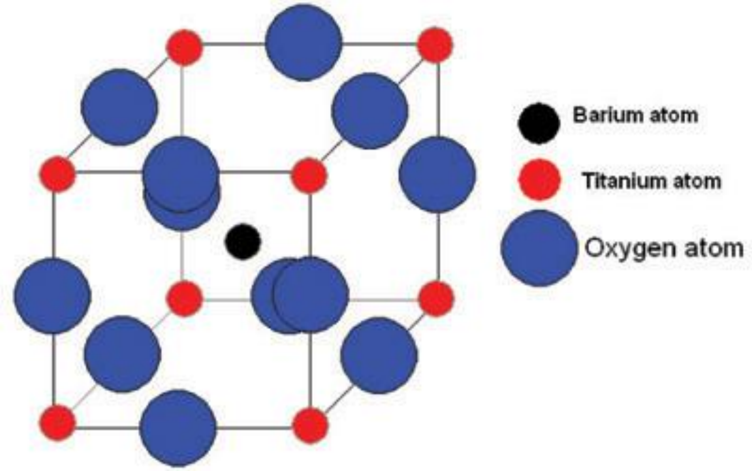
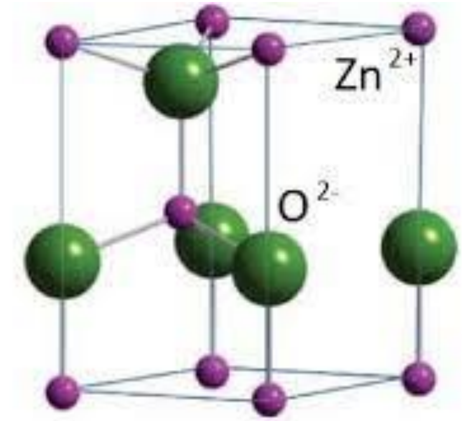
A large number of piezoceramics are available with a very high piezoelectric coefficient, such as lead zirconate titanate (PZT), barium titanate (BT), zinc oxide (ZnO), potassium sodium niobate (KNN), lithium sodium potassium niobate (LNPN) and boron nitride nanotubes (BNNT). The common concern related piezoceramics in tissue engineering is its cytotoxicity. In general, lead contained ceramics have limited application in tissue engineering due to their toxic nature. The PZT possess the very high piezoelectric constant ranges from 200 to 350 pC/N is a highly cytotoxicity . Hence, PZT would not be preferred in tissue engineering application and the lead-free piezo ceramics could be an alternative choice. Other ceramic also have dose dependent toxicity so they are applicable for tissue engineering up to some extent

Barium Titanate $BaTiO_3$



Barium titanate (BT) is highly biocompatible with d33 coefficient of 191pC/N . It has been reported that the BT nanoparticles have demonstrated cytocompatibility, even at higher concentrations like 100 µg/ml . The studies have been demonstrated that the PLGA matrix reinforced with BT nanoparticles supports the cell attachment and proliferation of osteoblast and osteocytes . Also, TiO2 powders have the ability to improve the osteoconductivity hence have improved efficacy to promote osteoblast adhesion . Significantly, it has been reported that the piezoelectric property of BT has a positive influence on the cellular proliferation . Furthermore, the incorporation of barium titanate nanoparticles into the polymeric matrix would improve the mechanical properties of the composite scaffold structure [99]. Hence, it is quite evident that the piezoelectric as an ability to promote the cellular activities in tissue engineering applications

Zinc oxide ZnO



Zinc has a critical role in cell proliferation and differentiation in the biological system by modulating the activity of different enzymes including transcription factors, metalloproteinase and polymerases . Piezoelectric zinc oxide has not shown any toxic effects in micrometer and larger size ranges , but it has been demonstrated toxicity in nano size due to the production of reactive oxygen species . Significant results has reported on zinc oxide nanoparticles dispersed in the polymeric scaffold along with hypoxia have shown ability to synthesis cartilage . According to Material Safe Data Sheet (MSDS) databases LD50 of acute oral ZnO is 7950 mg/kg for mice shows no significant toxicity . Moreover, the cytotoxicity of the nanoparticles can be reduced by chemical and physical modification for medical application.

Potassium sodium Niobate (KNN) and lithium sodium potassium Niobate (LKNN)

N and LKNN are lead free piezoelectric ceramic materials with piezoelectric coefficient 63 pC/N and 98 pC/ N, respectively . Addition of lithium (Li) has largely enhanced piezoelectric properties, while it would increase the cytotoxicity due to the release of Li ions when it is exposed to the bio-environment . The electric charge of the ferroelectric lithium niobate crystals enhances the proliferation and osteoblastic activity to rapid bone regeneration . It has been reported that the utilization of piezoelectric property of KNN in drug delivery devices and also it is applicable for bone, cartilage, skin and nerve repair and regeneration.

Boron nitride

Boron nitride nanotube has superior piezoelectric property than that of piezoelectric polymers . Researchers are exploited BNNTs as nano vectors to carry electrical /mechanical stimuli on demand within a cellular system. After BNNT internalization, the electrical stimulation has conveyed to tissue or/ cell culture using a wireless mechanical source (i.e., ultrasound) . Its cytocompatibility can be improved by improving its dispensability in the solvents. It is reported that its dispensability can be improved by non-covalent polymeric wrapping or by using non-toxic surfactants, which has been increased its potential for biomedical application . The proper functionalization of BNNT with glycol-chitosan or the addition of surfactant poly-Llysine (PLL) or polyethyleneimine (PEI) results in the formation of BNNT dispersion and improves the cytocompatibility of BNNT . The studies have been emonstrated that biodegradable polymeric scaffold reinforced with BNNT has a positive influence on osteoblast proliferation and differentiation . The studies report that the BNNT has a negative influence on the chondrocytes, fibroblast and smooth muscle cells. It decreases the adhesion of chondrocytes, fibroblasts and smooth muscle cells while it can increase the adhesion of osteoblast cells. Moreover, it has excellent mechanical properties and highly crucial for orthopedic applications . Hence BNNT is an excellent material for bone tissue engineering.