STRONTIUM HYDROXYAPATITE NANOWHISKER REINFORCED BONE CEMENT

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Introduction: Conventional PMMA bone cement has been used in orthopedic surgery for about 40 years. However, lack of adhesion to bone surfaces, weak interface, highly exothermically reaction and monomer toxicity lead to loosening after 10-15 years of service life. Many approaches have been attempted to reduce setting temperature and increase the biocompatibility such as introducing hydroxyapatite, AW glass ceramic filler to PMMA and using calcium phosphate bone cement. Our group has developed Sr-HA bioactive bone cement for vertebroplasty which has higher biocompatibility, lower monomer toxicity and setting temperature compare with conventional bone cement. The nanowhisker based material has higher fracture toughness in some engineering material designs. The purpose of this study is to develop nanowhisker reinforced bioactive bone cement for hip prosthesis fixation application. Reinforced bone cement is expected to have stronger mechanical properties, better bioactivity than pure HA and similar biocompatibility to HA. Strontium has been proven to stimulate bone growth and provides radiopacity.

Materials and Methods: Strontium hydroxyapatite nanowhisker was synthesized by mixing 36g of Collin salt with tri-ethylamine solution that adjusted to pH 9-9.5. The reaction mixture was heated treated in a Parr 4547 system at 170°C for 15 hours. After that the reaction mixture was air cooled at room temperature. Strontium substituted hydroxapatite was synthesized by neutralization reaction. Sr-HA bone cement was assigned as a control for this experiment. Nanowhisker is a kind of bioactive filler for bone cement reinforcement and was compared with the control. Particle morphology was characterized by Technai 20 at 20kV. (Image 1) Chemical analysis the phases purity and its chemical identity of the samples were characterized by Philips powder X-ray diffractometer PW1830 with Cu Kα radiation (λ= 1.54056) at a scan rate of 0.05°/s in the 2 theta range of 20-60degree. XRD pattern was compared with JCPDS database for chemical identification. The size distribution of nanowire was analyzed by measuring 100 nanowire particles under TEM. FTIR spectrum was collected on BIO-RADFTS-7. Bone cement was fabricated by two types of cement filler, strontium hydroxyapatite nanowhisker and Sr-HA. Sr-HA was used as control filler based bioactive bone cement material. As an initiator, benzoyl peroxide (Fluka) was added to the powder at 0.75 wt% of the monomer. Resin was prepared by mixing Bis-GMA(50%), tri-ethylene- glycol dimethacrylate(35%) and Hydroxyethyl methacrylate(15%). 0.25%(w/w) N,N-Dimethyl-p-toluidene was dissolved into the resin as an accelerator. Each cement formulation was prepared by mixing the powder with the liquid in a vacuum mixer for one min. Mechanical properties such as bending modulus, compressive and bending strength of each cement formulation were evaluated according to ISO 5833. All specimens were tested by 858 (MTS). For compressive mechanical analysis, specimens had dimensions of 12mm length and 6mm diameter. They were polished to remove surfaces defect. The strength measurement was carried out at a crosshead speed of 20 mm/min according to ISO 5833. The tests were carried out at room temperature in air.

Results: The nanowhisker with average length of 2.43±0.6 μm and diameter of 81±12nm. The aspect ratio is 52.28±29.41. X-ray diffraction pattern nanowhisker matches the JCPDS 33-1348. FTIR spectra of the nanowhisker samples showed PO_4 vibrations at 560, 596, 1030 and 1078 cm⁻¹, which was assigned to –OH. The FTIR spectrum shows the nanowhisker was predominantly hydroxyapatite. The reinforced bone cement bending modulus was 5602.60±833.63MPa > 1800 MPa requirement stated in ISO 5833. The bending strength was 58.11± 5.65MPa >50MPa. Compared with its predecessor Sr-HA bioactive bone cement which has the bending strength of 31.3MPa and bending modulus of 1408 MPa the new formulation increased the strength by more than 50%. Nanowhisker reinforced bone cement compressive strength and modulus (136.14±8.35MPa, 3719.05± 306.94MPa) are much more than expected and the ISO 5833 minimal requirement (70MPa, 1800MPa).

Discussion: The Sr-HA bone cement has significant advantages over commonly used PMMA cement for joint prosthesis fixation which is proven by the goat revision model. Despite the mechanical strength of Sr-HA nanowhisker reinforced bone cement’s bending strength is still weaker than the PMMA based bone cement, the bioactive bone cement can still provide better service life due to higher bone-cement interfacial strength. The cement strength can be further modified by surface coupling agent such as acrylpolamidionate a bisphosphate derivative developed for osteoporosis treatment. Applying the vacuum mixing technique is another feasible option on this resin formulation, which is able to achieve a bending strength greater than 60MPa; this is comparable to the commercial available PMMA based bone cement. Full fatigue and tensile strength study will be carried out to evaluate the possibility of utilize this cement in clinical application.


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