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Review on bioceramic nanofiber using electrospinning method for dental application

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ABSTRACT

Electrospinning method has been widely explored as a useful method for making fibers network. Electrospinning can produce nano size fiber from various materials and provide opportunities for application in the various fields, especially in dentistry. Furthermore, this technique has been also extended to fabricate nanofibers made of bioceramics and composite materials.Bioceramics which are brittle material had been used as a fiber in combination with a polymer to improve properties of that material. The objective of this review is about the fabrication of bioceramic nanofibers with various compositions and properties by electrospinning process in the field of dentistry. Although some articles had covered about nanofiber applications in dentistry, however, this review not only will explore particularly bioceramic nanofiber that recently research but also inform the potential of the material properties which used in dentistry.

Keywords:*Electrospinning, Nanofibers, Bioceramic*

INTRODUCTION

Bioceramics are ceramic materials which are employed to repair and reconstruction of disease and damage part of the body and produced in a variety of forms and phase. Bioceramics have several advantages such as bioinert, bioresorbable and bioactive based on the properties of remaining unchanged, dissolving or actively taking part in a physiological process. Calcium phosphates, silica glass, zirconia, alumina, titania, and pyrolytic carbons were classified as bioceramics materials[1,2,3].

Nowadays ceramics nanostructured are much more attractive to study then bulk counterparts because nano size have been proven to have improved properties and characteristic thus allowing for opportunities in various applications [4,5].

Electrospinning constitute a unique technique that uses electrostatic forces to produce fine fibers. Interestingly, electrospinningcan easily fabricate one-dimensional nanostructures such as nanofibers with diameters, compositions, and morphologies could be controlled[5,6]. Meanwhile, producing bioceramic nanofiber by electrospinning technique offers challenges to the process and control of the orientation[7].

Electrospinning is relatively inexpensive technique that able to produce nanofibers of polymers, composites, semiconductors and ceramics. The most common electrospun material is polymer but the ceramic fiber have also been electrospun with or without the addition of polymers [8,9]. Ceramic nanofiber produced by electrospinning nanoparticle along polymer followed by calcination at higher temperatures to remove polymer residues also reported[7.]

Basic equipments for electrospinning consist of high-voltage power supply, aluminium foil as collector, syringe pump and metallic needle/spinneret. Beginning with load the solution into the syringe, viscous solution will be held in the end of syringe because its surface tension. Once high electrostatic voltage is imposed than exceeds a critical value , the electrostatic force overcome the solution surface tension then distort into conical shape, well-known taylor cone. Latter, a jet will be formed then undergoes a whipping motion due to bending instability than quickly transformed into a solid fiber as a result of solvent evaporation. Eventually, the fiber will deposited on collector [5,10,11].

Structure and properties of nanofiber resulted from electrospinning are influenced by applied voltage, spinneret-collector distance, polymer flow rate, spinning environment, solution concentration, solution conductivity and volatility of solvent[6]. The challenging to produce bioceramics nanofiber started from preparation of a suitable solution and controlling dispersion of the nanoparticle ceramic in the solution to achieved low acceptably viscosity before electrospinning process[9].

DISCUSSION

Bioceramic nanofiber properties and application in dentistry

Recently, materials with one-dimensional nanoscale have attracted the attention of researchers due to roles of dimensionality and size that enable development an optical, electrical, and mechanical properties and alsohave sophisticated applications[12]. The advantages of nanofiber compared regular and bulk fiber are mechanical and thermal properties that marked differences while its biological properties for medical application are largely determined by the materials' properties itself and nature [6,7].

In dentistry, nanofiber have been potential and progreessed for many applications e.c regeneration of pulp dentin complex, guided tissue regeneration for periodontium, caries prevention, modification of resin composite, implant surface modification, cartilage regeneration, drug delivery and repair wound and oral mucosa. Most of them use polymer as main material electrospinning[13]. A brief discussion about bioceramic material on some of the applications in dentistry include the properties of the material itself will be given in the following section.

Calcium phosphate

Calcium phosphate classified into α-tricalcium phosphate, β-tricalcium phosphate, tetracalcium phosphate and hydroxyapatite (HAp) ($Ca_{10}(PO_4)_6(OH)_2$). The most widely studied amongs them is hydroxyapatite because it is thermodynamically stable at physiological pH and main mineral constituent of teeth and bone thus suitable for hard tissue replacement implant. The first bioceramic nanofiber were obtained by Wu *et al,*they produced hydroxyapatite (Ca10(PO4)6 (OH)2 (HAp) fibers by electrospinning precursor mixture of Ca(NO3)2 _ 4H2O, (C2H5O)3PO, and a polymer additive. Then they acquired pure HAp nanofiber after calcination at 600°C for 1 hour[14,15]. Electrospinning HAp nanoparticle and Polyvinyl alcohol had been conducted by Kim. *et al*, they gained HAp rod-like nanofiber which have unique physiochemical feature and promising to possess dentin regenerative properties[16]. Further, composite HAp/Polycaprolactone/poly (lactid acid) nanofiber had been prepared for material scaffold. It showed significantly higher cell proliferation of osteoblast-like cells. It concludes that this composite bioceramic nanofiber could enhance bone regeneration therefore it shows a tremendous prospect as scaffold for bone tissue engineering[17]. Moreover,Titanium dental implants coated by poly(lactic-co-glycolic acid) (PLGA) /collagen fiber/hydroxyapatite nanofibers had been conducted and revealed much enhanced the adhesion of mesemchymal stem cells. It leads to increase the process of osseointegration for the dental implant treatment[18]. On the other hand, Jose *et al.* tried to improve the mechanical properties of composite PLGA/nano-HAp nanofiber for scaffolds application [19]. However, HAp positively influences adhesion and proliferation of osteoblast but the mechanical properties of amorphous HAp have been reported to be unsuitable for load-bearing applications thus it is commonly combined with natural polymer[20,21].

Silica glass nanofiber

Silica amorphous phases /glass is the most usually used inorganic fiber for reinforcement of dental composite. It has index refraction that greatly close to the dental resin, equipping the composite with semitransparant surface. Silica glass nanofiber with diameter of about 400 nm is much excelled than traditional glass fiber in tension and impact test. It is also raise the tensile strength, youg's modulus, and work of fracture by 12%, 33%, and 52% respectively in comparison with epoxy resin[22,23]. Meanwhile, Gao *et al.* exhibited improvement flexural strength and modulus as much as 44% and 29 % respectively while substitutions of traditional glass filler[24].

Silica glass that incorporated in a group of surface reactive biocompatible ceramic is named bioactive glass. It is developed at very first time by Larry Hench and colleagues at the University of Florida in the late 1960s[25]. The first electrospinning of bioactive glass is reported by Kim *et al* with variable diameter using a sol-gel precursor of the composition 70SiO2·25CaO·5P2O5. It showed excellent bioactivity and osteogenic potential *in vitro* by a bioactivity test and cellular response assay[26]. Furthermore, scaffold bioactive glass nanofiber has been produced by mixing tetraethyl ortosilicate and calsium nitrate then undergo electrospinning process. Later, the nanofiber is calcinated to 600-700°C to decomposed residual organic or inorganic group[27]. While extensively investigated for bone repair, bioactive glass is also researched for regeneration of soft tissue. It has shown the ability to promote angiogenesis thus optimistically could be applied to healing the soft tissue wounds[28]. Composite nanofiber made of biopolymer blend polycaprolactone-gelatin and nanoparticle bioactive glass was investigated to study the effects of materials toward odontogenic differentiation on human dental pulp cells. The result concludesthat the composite is considered to be promising scaffold for culture of human dental pulp cells and dental tissue engineering[29].

Zirconia

Zirconia fiber are an important category of advanced material for high strength reinforcement. There were many studies have been investigated for preparation of zirconia fiber using sol-gel spinning method and blowing spinnig but only zirconia fiber 3-20 μm is diameter have been prepared. Zhang and Edirisinghe did eletrospinning zirconia in instance, fiber from a suspension. The suspension containig zironia particle 5-10 nm and combined PEO and PEG and calcinated at 1200 ºC for 1 hour. Eventually,They gained zirconia fiber down to about 200nm with 150 nm size grain of zirconia were found [30]. Zirconia, which is studied as an alternative material alumina, it possessed good biocompatibility as ZrO2 implant then shiwed direct bone apposition as well[1,31]. On the other hand, Xu *et al* produced zirconia-yttria (ZY), zirconia-silika (ZS) and zirconia-yttria-silica (ZYS) nanofiber as reinforcing materials for dental composite[2].

Alumina

Alumina (Al2O3) is a bioinert ceramic with the characteristics of high abrasion resistance and chemical inertness. The biocompatibility of alumina has made it clinically reliable for more than 30 years[32]. Alumina nanofiber has been produced and shown increase osteoblast adhesion compared another form nanosphere alumina and promising as potensial material for dental application and bone tissue implant[33]. Alumina fiber had been conducted using PVP and aluminium acetate as precursor. It resulted α-alumina crystallite phase which is the the strongest, stiffnest and the most stable then another phase. The diameter of the fiber are found in the range of 100-500 nm by TEM study. α-alumina crystalize phase had been confirmed at 1000ºC by XRD analysis [34,35]. Moreover hao yu et al showed alumina nanofiber with diameter ranging 150-500 nm after calcining at 1200 ºC . Using TEM the resulting alumina fiber were confirmed to be α-alumina crystallite phase with crystallite size were approximately 10 nm [36].

Titania

Lim *et al* had successfully produced Immobilized TiO2 nanofiber by electrospinning of sol comprising PVP and TiP for implant application[37]. Later, Li *et al.* reported the biocompatibility of BaTiO3 to have enhanced effects on the bioactivity of the nano-titania ceramics, which made the osteoblasts proliferate faster on the nano-titania ceramics in cell culture experiments[38]. Silica-doped titania (SiO2/TiO2) was later reported to be biocompatible with potential implant applications[39]. Antimicrobial activity of Zn-doped titania by Anna *et al* showed the lowest concentration of Zn-doped titania nanofiber solution inhibiting the growth of S. aureus and E. coli[40].

Carbon

Carbon exists in a variety of forms, including vitreous carbon and pyrolytic carbon. Intrinsic brittleness and low tensile strength limit its use in major load bearing applications. The key properties of pyrolytic carbon, such as biocompatibility, thrombo-resistant, good durability, wear resistance and strength, has made it applicable in the field of biomedical engineering[41]. Electrospun carbon nanotubes and nylon fibers have been successfully used to reinforce resin composites[42].

CONCLUSION

There have been many researchs proved the application of nanotechnology could greatly improve the mechanical and biological properties of materials. Electrospinning method which can produce nano size fiber gained popularity nowadays and provide opportunities for application in various field especially in dentistry. Electrospinning is able to produce nanofiber from a various material, one of them is bioceramic. Bioceramic which have shown good biocompatibility with dental tissue were fabricated based on the need and application. Bioceramic nanofiber has been used to reinforce the dental composite restoration. The mechanism is when the restoration under external pressure, it is susceptible to undergo microcrack in the body of dental matrix. When the crack is coming, the gap between crack planes bearing load constantly until bioceramic nanfiber are broken completely. So, the crack expansion is inhibited by the bioceramic nanofiber. Bioceramic nanofiber which are promising material not only to restore or replace the damage of the hard tissue such as dentin, enamel and bone but also to heal wound of soft tissue like pulp and mucosal tissue in scaffold form. The mechanical response of scaffold bioceramic nanofiber is the key for repair of loaded bone. The scaffold should have mechanical properties approach the properties of the tissue to be replaced. Bioactive glass with compressive strength and elastic modulus whice are comparable to human cortical bone, have potential application in regeneration of load bearing bone. The mechanical properties of nanofiber depend on type of material, the microstructure and the fabrication method.

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