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Biodegradable Polymers for Nanofibre Production

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ABSTRACT: Nanotechnology is becoming an integral part of almost all of the science and technology sectors in different ways. Nano is offering dynamic tools, which play a crucial role based on their science-dependent manner. Nanofibre is one such tool that has predominant application scope in varied fields including pharmaceuticals, environmental engineering, tissue engineering, energy storage, sensors, etc. Polymers are the fundamental ingredients based on which the nanofibre fabrication is carried out. Varied applications using these polymeric nanofibres demand effective clearing of the nanofibres from the site of action, within the body or from the environment in a relatively shorter period. The biocompatibility and biodegradability is of the greatest concerns in the biomedical application point of nanofibres. Biologically degradable polymers are increasing the interest of the researchers as they can be eliminated from the body during in-vivo applications and from environment relatively at a shorter period. This short review focuses on different biodegradable polymers available for producing nanofibres, especially through electrospinning processes.

Keywords: Nanofibre, biodegradability, biocompatibility, electrospinning, natural polymer, synthetic polymer.

INTRODUCTION

The development and growth of nanotechnology are extending over the decades. Currently, the range of effective products from nanotechnology is boosting different disciplines of science and technology through their typical and excellent physicochemical properties. Top-down and bottom-up approaches in the nanotechnology production process are continuously yielding a range of extraordinary objects in nanosize (1 to 1000 nm) (Ward, 2005) and are highly varied from their bulk forms. Starting from nanoparticles and extending towards nanoemulsions, nanovesicles, nanofilms, nanotubes, nanofibres, etc. nano offers dynamicity in its product profile to its stakeholders and makes them efficient in applying the same.

Among these, nanofibres are one special kind, which attracts researchers greatly in recent time. These nanofibres are novel fibrous structures produced from the polymeric substrates through specialised production techniques. The properties, such as fibrous structure in nanoscale, light-weight nature, high ratio of surface to volume, reproducibility, and alterable size and pore structures, etc. (Bhagwan *et al*., 2019) of the nanofibres make them more preferable for dynamic applications. Nanofibres find attractive applications in sensor making, water treatment, novel medical and protective textile development, energy storage, tissue engineering, etc. (Cai *et al*., 2012).

Different methodologies were found so far for building the nanofibres from the optimal polymeric solvent blend. Some of the most important nanofibre production techniques are drawing, template-based, electrospinning, solution blowing (Zahmatkeshan *et al*., 2018), self-assembly, phase separation, (Gundloori *et al*., 2019) etc. Though the nanofibres can be produced using different methodology the fundamental properties and application nature of the nanofibres is influenced greatly by their core base, polymeric materials.

A range of polymeric materials is available from both natural and synthetic kinds which are being used for the production of nanofibres. Though nanofibres are used across different sectors they are finding more importance in the biomedical field for the purpose of scaffold development in tissue engineering, drug delivery practices etc. These biomedical applications demand some special requirement for nanofibres that they should be biocompatible and biodegradable. Biocompatible nature of the nanofibres is very essential for biomedical applications as such scaffolds can able to be non-toxic against the living tissues. Biodegradable nanofibres are highly being preferred as they can be broken down and can be eliminated from the body relatively faster than the non-biodegradable ones and there by reduces the chances of foreign body reactions. Also the nanofibres destined for usage in other sectors excluding the medical field, also need to be eliminated from the environment after usage. Hence preference of biodegradable components to produce nanofibres is highly being preferred by the researchers. This short review discusses different biodegradable polymers available from both synthetic and natural origin and their applicability innanofibre production.

Cellulose

Cellulose is a naturally occurring biodegradable polymer found extensively in plants. It can also be produced in mass using bacteria, algae and fungi (Barhoum *et al*., 2019). This natural polymer impresses researchers for nanofibre production owing to its properties, such as non-toxicological nature, high mechanical strength, biodegrability and biocompatibility (Ma *et al*., 2014). Individual cellulosic nanofibres or those produced from blends of cellulose find usage in different fields. An improved form of cellulose called cellulose acetate is also being subjected to electrospinning to produce nanofibres with good stability and elasticity (Khalf *et al.,* 2015). The presence of hydroxyl groups and functional groups in the cellulose makes it more attractive for nanofibre synthesis apart from its easy functionalisation.

Silk Fibroin

Fibroin is one of the key components of silk. It is a kind of protein and is present along with sericin. It is insoluble in nature. It is biodegradable in nature. Several research works have been carried out in developing nanofibres based on this silk fibroin. The biodegradability, biocompatibility, lesser immunogenicity make it more suitable for biomedical applications. The handling of silk fibroins, such as isolation, purification, sterilisation and employability in nanofibre making is relatively easier and this increases the interest of the researchers in it (Farokhi *et al*., 2020). Researchers could be able to produce smooth nonwoven fibers, which can be used for tissue engineering and wound healing purposes (Min *et al*., 2004). Silk fibroin nanofibres are also used in the application of drug delivery purposes.

Alginate

Alginate is a carbohydrate-based natural polymer. It is present in seaweeds. It is one of the natural biodegradablepolymers in which several research works have been carried out over several decades. The nanofibre making proficiency of the alginate is being explored recently. It possesses mild gelling, low toxic properties, and it can also be produced at a low cost comparatively. This makes researchers be interested in the polymer for different applications (Lee & Mooney, 2012). Alginate nanofibres were found to be a better carrier of drugs for delivery purposes. However, they should be blend with other polymers like polyethylene oxide in order to produce the fiber. The addition of other polymers is required in order to improve the properties, such as electrical conductivity, surface tension, etc., which improves the fiber formation using alginate polymer (Saquing *et al*., 2013). Alginate fibers have been tested for better metal sorption properties.

Collagen

Collagen is one of the predominant natural polymers. It is present in a high amount in the body of different species of animals. It is protein-based. It is extracted, purified and made available for several research and application purposes under a variety of brands. Collagen is biodegradable and also a good biocompatible agent than the other many available natural polymers. Collagen is applied for developing nanofibres for varied applications including tissue engineering, wound dressing, food technology applications, and cosmetic applications. The unique triple-helical structure of the collagen polymers makes the nanofibre more attractive with varied functionalities. Type I and III are the most used collagen for nanofibre synthesis (Buttafoco *et al*., 2006).

Gelatin

Gelatin is a translucent polymer majorly derived from animal tissue and majorly finds application in food, pharma and cosmetics. Gelatin is yet another biodegradable polymer that can be used in nanofibre production. Though it is soluble in an aqueous medium and other polar solvents, some special solvents, such as trifluoroethanol, formic acid, etc. are required for making a solution of gelatin that can be subjected to electrospinning to produce nanofibre. Gelatin can be mixed with other polymers and can be used to produce nanofibres that are mechanically and chemically stable (Y. Zhang *et al*., 2004). The wider application of this gelatin-based nanofibre is limited as the gelatin is readily soluble in water and fibre structure gets denatured. Still, the gelatin usage is preferred for nanofibre production as a result of its thermoreversible viscosity and pH independency.

Hyaluronic acid

Hyaluronic acid is a polysaccharide-based polymer found in animals, especially in the extracellular matrices. Nanosized fibers can be produced using hyaluronic acid through electrospinning. Different research studies were carried out using hyaluronic acid fibers. It is preferred for its easy functionalisation tendency. However, it is not soluble in an organic solvent which is a demerit in fiber production. Hyaluronic acid nanofibres find usage as dermal fillers, scaffolds in tissue engineering applications, (Fischer *et al*., 2012) etc.

Chitin

Chitin is a kind of polysaccharide-based biopolymer. It is usually obtained from the exoskeleton of certain fungi and certain invertebrates, such as arthropods. Crab and prawn are the major sources of this chitin polymer. Properties, such as the presence of amino groups, other functional groups and easy functionalisation make it more preferable for nanofibre production. Chitin-based nanofibres find applications in environmental applications, tissue engineering, drug delivery, food technology as wrappers, water treatment, antibacterial filters or membranes,(Li *et al*., 2016) etc.

Chitosan

Chitosan is one important biopolymer with highly dynamic application potential. It is derived from chitin through the deacetylation process under an alkaline environment. It can also be produced through the enzymatic method using the enzyme chitin deacetylase. This biodegradable polymer can be used to produce in different forms for different types of applications including beads, gels, microparticles, nanoparticles, nanofibres, membranes, etc. The antimicrobial property of chitosanmakes it more useful in the preparation of nanofibres for antimicrobial fabric development. The wound healing nature of the chitosan helps in fiber form to be used in wound dressing and in severe burn treatments. Chitosan will also make perfect blends with other polymers and even with nanoparticles to form different composites that can be used for the development of nanofibres of varied usage.

Polyhydroxyalkanoates

Polyhydroxyalkanoates are biodegradable polymers produced by a range of microorganisms. Chemically, they are polyester biomolecules. In recent years, different research works have been reported to use these bioplastic compounds in nanofibre production. The lesser acidity, surface tunability, biocompatibility make them more choosable for biomedical research. Their biodegradability, non-toxic breakdown nature during the degradation process and non-carcinogenicity improve their preference (Datta & Menon, 2019). Poly (3-hydroxybutyrate), polyhydroxyhexanoate, poly(3-hydroxyvalerate), etc. are some of the well-known types of polyhydroxyalkanoates. They can be subjected to different modification processes, such as chlorination, hydroxylation, carboxylation, pyrolysis and epoxidation to produce an output with modified efficacy. This tailored ability makes them more effective for nanofibre production. These polymers have a high scope for microbial degradation enforced by a different range of microorganisms and hence their environmental degradation is more faster (2 to 6 months).

Polyvinyl alcohol

Polyvinyl alcohol (PVA) is one of the most common polymeric entities used for nanofibre production. It is a kind of synthetic polymer produced through the hydroxylation process of the monomer, polyvinyl acetate (Baker et al., 2012). Polyvinyl alcohol is a biodgradable polymer which has been reported to produce nanofibres with desired porosity, high surface area, and nanosize diameter (Sargazi *et al*., 2018). Polyvinyl alcohol can be used alone, as a blend with other polymers and also with reinforced constituents as composites to produce nanofibres. Polyvinyl alcohol is proved to be non-toxic and non-carcinogenic in nature, which makes it best suitable for medicinal applications. PVA based nanofibres are reported to be applied in wound dressing, smoke filtering, water purification (Abd El-aziz *et al*., 2017; Kusumaatmaja *et al*., 2016; Sudirman *et al*., 2020), etc. Apart from the positive side, PVA also have disadvantages, such as high viscosity, bad water solubility, lower thermal decomposition temperature than its melting temperature (Es-saheb & Elzatahry, 2014) etc.

Polycaprolactone

Polycaprolactone (PCL) is a synthetic polymer which finds usage in the development of nanofibre in the recent past. It is produced based on the polymerisation of a monomer obtained from caproic acid called caprolactone. Polycaprolactone exhibits fine physio-chemical quality in terms of viscoelasticity, rheology, etc. It has been reported to use individually or in blends to produce nanofibres with desirable characteristic features. Polycaprolactone in blending with gelatin is used to produce nanofibres, which can be used in drug delivery as well as in the development of antimicrobial fabrics. The polycaprolactone-based nanofibres have been applied in different biomedical applications including drug delivery, cell growth and tissue engineering (Rad), wound healing, water purification, (Adeli-Sardou *et al*., 2019; Hivechi *et al*., 2019; Rusli *et al*., 2017) etc. Special advantages of polycaprolactone include purity, high strength, biodegradability and biocompatibility. It is also considered a very cooperative polymer for excellent electrospinning properties (Dobrzanski *et al*., 2015). Though there are several advantages of using polycaprolactone, its high hydrophobicity and its solubility in selected solvents, which are toxic are some limiting factors for the biomedical application of this polymeric nanofibre (Dobrzanski *et al*., 2015). Also, the time consumption of biodegradation of this polymer is from two to a few years.

Polyglycolic acid

Polyglycolic acid is a kind of aliphatic polyester chemically. It is also termed polyglycolide. It is a biodegradable and biocompatible polymer and finds a large amount of usage in nanofibre production. It is produced through polymerisation (ring-opening kind) of glycolic acid. Polyglycolic acid blended with sucrose has been used in developing electrospun nanofibre scaffolds for cell and tissue growth (Wulkersdorfer *et al*., 2010). Blends of polyglycolic acid and poly (ε-caprolactone) have been reported to be used in degradable nanofibres for the biomedical applications with good physical and mechanical properties (Aghdam *et al*., 2012). Reportsare also strengthening its application scope in tissue engineering, dental and orthopedic applications, and drug delivery activities.

Poly (N-isopropylacrylamide)

Poly (N-isopropylacrylamide) is a synthetic polymer produced by the polymerisation of N-is opropylacrylamide. It is commonly referred to as PNIPAM. It is also a kind of degradable polymer, which is of thermoresponsive nature. It is being used in different applications that aim at thermo responsiveness. The nanofibres produced from the PNIPAM are being used in cell culturing and tissue engineering applications greatly (Young *et al*., 2019). The lower critical solution temperature of the PNIPAM is the major source of attraction. Since it is a thermoresponsive polymer, it undergoes a reversible phase transition when there is a change in the temperature. This makes the nanofibres produced from PNIPAM to be used as a smart material, which can change their functional property on temperature changes (Q. Zhang *et al*., 2017).

Polylactic acid

Polylactic acid (PLA) is a biodegradable polymer made from the monomer lactic acid. Chemically, it is a thermoplastic polyester. PLA is found to be one of the key components for nanofibre preparation. PLA nanofibres were found to be effective in applications of the scaffold in tissue and organic engineering, wound healing dressings, dental treatment, drug delivery practices, etc. Different composites of PLA have been developed to produce improved nanofibres (Ranjbar *et al*., 2019). Super-hydrophobic nanofibres are also produced with PLA for water treatment applications, especially oil separation, dye removal,(Zhou *et al*., 2019) etc.

Poly (lactic-co-glycolic acid)

Poly (lactic-co-glycolic) acid shortly termed as PLGA, is a biodegradable copolymer. It is made up of polymerisation of two different monomers, namely glycolic acid and lactic acid. PLGA is considered as one of the active components for biodegradable nanofibre synthesis. PLGA-based nanofibres find usage in tissue and organ engineering, biosensing, and controlled drug delivery. PLGA nanofibres can be able to exhibit a good rate of drug delivery through a non-linear and dose-dependent manner (Makadia & Siegel, 2011). Different nanocomposites have been reported to be produced by blending PLGA with different polymers and also with different nanoparticles for producing fibers with improved functionality.

FUTURE ASPECTS

The polymers which are claimed to be biodegradable contain functional groups which are unstable owing to their hydrolytic nature. The green polymers or biopolymers contribute greatly to nanofibre synthesis because of their biodegradable nature, which has been briefed in this review. The biocompatibility, sustainability, cost, recycling, eco-friendly nature, etc. are some of the parameters of these polymers that attract nanofibre fabricators. However, each polymer discussed has its own merits and demerits in terms of its usage in nanofibre synthesis. Newer versions of these polymers through functional modification or through blending with other eco-friendly chemicals or nanoparticles, etc. could further expand the scope of these polymers in nanofibre synthesis. Till that, the research on finding biodegradable polymer with excellent fiber making physio-chemical properties will be continuing.

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