Biodegradability and Biocompatibility of Polymers with Emphasis on Bone Scaffolding: a Brief Review

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Abstract- Biomaterials constitute a class of materials that are used extensively in biological systems, particularly in medical research involving scaffolding material. Various polymeric materials fall within this category, and are largely biodegradable, although various applications and particularly, bone scaffolding, involves the use of non-biodegradable polymeric materials such as PMMA that are not biodegradable. Blends of non-biodegradable and biodegradable polymers have been employed in bone implant and regenerative studies; while the biodegradable component disintegrates over time to be replaced by osteogenic or native cells, the non-biodegradable component contributes to the structural integrity of the tissue.

Index Terms- Biodegradable Polymers, Biopolymers, Polymer Biodegradation, Renewable Resources

I. INTRODUCTION

According to Mihov and Katerska (2010), biomaterials are artificial or natural materials used in biological systems. One of the major avenues in medical applications and research on biomaterials concerns tissue regeneration. In natural tissues, cells are distributed in a three dimensional organization, which requires that materials used mimic their natural geometry. In tissue engineering, these materials are used as scaffolds to grow new tissue, either in vivo or in vitro (Langer and Vacanti, 1999). Scaffolds are used to promote or provide an environment that promotes cell growth in a manner that results in the synthesis of new tissue by the body, and are defined as three dimensional porous solid biomaterials that: (i). promote cell-biomaterial interactions, cell adhesion, (ii). permit sufficient transport of gasses, nutrients, and regulatory factors for cell survival, proliferation and differentiation, and (iii). are biodegradable at a rate comparable to the rate of tissue regeneration (Dhandayuthapani et al., 2011).

I. A BRIEF REVIEW OF BIODEGRADABLE POLYMERS

A comprehension of terminology involved is essential in estimating the nature and type of polymers that could be employed in scaffolding applications. The terms biodegradable polymer and biopolymer have often been used interchangeably, leading to misconceptions with regards to their relationship to this day. According to Fakhouri et al. (2013), biopolymers are polymers synthesized under natural conditions within cells of microorganisms via complex metabolic processes catalyzed by enzymes, a definition that is not far off from that of Chandra and Rustgi (1998), apart from a minor variation; Chandra and Rustgi assert that biopolymers are typically formed within cells of organisms, and not just microorganisms, during growth cycles.

According to Greer (2006), the term biopolymer itself refers to polymers resulting from renewable resources, principally carbohydrate and protein based substrates. The author further contends that most biopolymers are biodegradable, and include corn starch, sugar, wood pulp and soy protein.

Thus, depending on the point of reference, a biopolymer can either be a polymer from biomass (agro-resources), obtained by microbial production, or synthesized from monomers derived from biological processes. The common ground to these contentions is the term ‘renewable resource’.

Biodegradable polymers, on the other hand, encompass polymers (both natural and synthetic) that degrade due to microbial action. There is a lack of consensus among researchers on a universal definition of polymer biodegradation and the nature of end products that would render a polymer biodegradable, apart from a lack of correlation between timescales adopted by various researchers (Gautam, 2007). Confusions arising led to legal repercussions as early as the 90’s with regards to ambiguous environmental advertising (Narayan et al., 1999). Thus, the need for standards based organizations to take the lead.

ASTM D 6400-12 (2012) defines a biodegradable plastic as ‘a plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae.’ ASTM 883-12 (2012) regards a degradable plastic as one that undergoes a significant change in chemical structure under specific environmental conditions. Whereas, the ASTM sub-committee D20.96 proposal defines degradable plastics as plastic materials that undergo bond scission in the backbone of the polymer through chemical, biological, and/or physical forces in the environment at a rate which leads to fragmentation or disintegration of the plastics (Chandra and Rustgi, 1998). This definition broadens the spectrum for polymers that may be rendered biodegradable.

II. POLYMERIC BIOCOMPATIBLE MATERIAL IN SCAFFOLDING

Polymeric materials possess the right qualities for tissue regeneration, including comparable strength and hardness to surrounding tissue, light weight, biocompatibility and biodegradability (Washburn et al., 2002). Synthetic polymers are commonly used as biocompatible materials owing to their modifiable properties (Puskas and Chen, 2004). Biocompatible polymers can either be made into devices, or are coated onto devices to reduce risk of rejection by the human body. Other applications include implants (bone pins and screws), catheters and dialysis tubing, vascular graft, membranes for oxygenation and detoxification, injectable drug delivery and porus scaffolds for regenerative tissue engineering (Shastri, 2003).

The criteria for selection of a polymeric material for incisive medical applications include its ease of processing, mechanical strength, biological inertness, blood compatibility, tissue adhesivity and permeability of oxygen (Shastri, 2003). The choice of a polymer in a given application, as is the convention in polymer technology and engineering, is to tradeoff properties deemed unnecessary for the particular application.

Polymer biodegradability was noted as a quality possessed by polymers employed in tissue engineering applications, particularly in its application as scaffolds. However, this hasn't always been the main factor. Not all polymers applied in medical applications necessarily need to be biodegradable. For instance, polymethyl methacrylate, or PMMA, is a non-biodegradable polymer that possesses a good degree of compatibility with human tissue, and has been used as scaffolding material (Liu et al., 2009) and 2D cell cultures for many years (Jager and Wilke, 2003). It has therefore found applications specifically in permanent structures, such as bone tissue regeneration and bone structural enhancement. It manifests low toxicity and is used as scaffolding to deliver mechanical stability following its implantation (Downes et al., 1994). Over the years, electrospun PMMA fibers have been used to form 3D tissue engineered scaffolds with good cellular adhesion (Wei and Sampathi, 2011; Zhang and Sun, 2005).

Polymeric scaffolds are usually rendered porous by blending them with salts, whereby the salt component is bleached out following solvent casting upon drying the solution. The salt crystallites possess controllable sizes, and leave behind pores/voids in the polymer matrix with dimensions in the order of or larger than cellular dimensions (Ishaug et al., 1994).

Osseointegration refers to direct structural and functional connection between an ordered, living bone, and the surface of a load carrying implant, where there isn't progressive relative movement between the implant and the bone matter in direct contact (Mavrogenis et al., 2009). In this case, the implant may well be scaffolding that aims to affect the regeneration of tissue in the affected area. The concept involves the seeding of autologous osteogenic cells throughout the scaffold (Hutmacher et al., 2007). Autologous osteogenic cells refer to cells involved in the development, growth or repair of bone, which originate from the same person.

III. POLYMER BLENDS AND COPOLYMERS IN BONE SCAFFOLDING

Multiphase polymer blends, where one component is biodegradable while the other isn't, has been employed in bone implant and regenerative studies; while the biodegradable component disintegrates over time to be replaced by osteogenic or native cells, the non-biodegradable component contributes to the structural integrity of the tissue. Such has been the case in studies involving poly(L-lactide) and PMMA blends (Le et al., 2006). Higher molecular weights of the permanent component (non-biodegradable PMMA) would improve mechanical properties undoubtedly. However, Tai et al. (2007) studied the effect of molecular weight on PGLA scaffolds, and found that pore sizes decreased with increased molecular weight.

Notwithstanding, scaffolding in bone repair applications should mimic properties at the bone repair site, including mechanical properties of the bone. Typical PMMA bone cements have compressive strengths in the range of 75-115MPa and moduli of elasticity at 1700-3100MPa, far exceeding those of trabecular bones, at 5-10MPa and 50-100MPa respectively. However, the mechanical properties of bones depend on the type of bone being investigated. For instance, cortical bones exhibit compressive strengths in the range of 130-225MPa, with a modulus of 17-20GPa (Hedberg and Mikos 2001).

Thus, an important avenue for consideration is the use of multi-phase polymer blends and copolymers, each with one biodegradable and another non-biodegradable component, as potential bone scaffolding material, with the non-biodegradable component serving as a permanent structure within the repair site to perform as a load bearing media with comparable mechanical properties to that of the surrounding bone tissue. As tissue regeneration progresses, the biodegradable or biosorbable component would disintegrate and disappear, leaving behind the structurally enhancing non-biodegradable component.

The presence of the non-biodegradable component in blends and copolymers could not only effect the disintegration rates of the biodegradable component, but also, the integrity of the non-biodegradable component. As such, a brief review on polymer biodegradability is necessary.

IV. CONCLUSION

Research on polymeric scaffolding in bone tissue regeneration and fortification employing biodegradable/non-biodegradable copolymers is virtually lagging, but poses an important avenue for consideration. Bone scaffolding employing either biodegradable, non-biodegradable, or blends of biodegradable and non-biodegradable polymers, has proven feasible and successful. The permanent (non-biodegradable) component would provide the required structural integrity, while the non-biodegradable component would generate pores upon disintegration and be replaced by osteogenic cells, paving the way for tissue regeneration that would be structurally fortified by the non-biodegradable but biocompatible polymer. An important avenue of consideration in further studies involving copolymers includes the effect of molecular weight of component segments towards the effectiveness of the material as a novel scaffolding biomaterial.

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