Biodegradable materials

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Abstract

Biodegradable materials are a type of biomaterial. They are used to provide a specific application within the body and subsequently degrade over a given time. To function as a suitable biodegradable implant, degradation should occur once the purpose of the application has been achieved. Degradation is influenced by different variables, including the type of material used, its composition and the manufacturing process. Whilst much attention is now being focused on the development of such materials, the choice of bio-inert and biodegradable materials must be carefully considered before being used for a given application. Whilst biodegradable materials share similarities with their bio-inert counterparts, a number of advantages and disadvantages also exist. Numerous material types have been used for this purpose including polymers, metals and ceramics. This article aims to review the recent developments and advances of these materials, focusing on synthesis, degradation, advantages and disadvantages as well their potential clinical application. Future developments in this field will focus on augmenting mechanical strength whilst controlling degradation rate ultimately broadening their use and achieving enhanced clinical results.

Keywords biodegradable; ceramics; magnesium; metals; PGA; PLA; PLGA; polymers; resorbable; tricalcium phosphate

Introduction

Biodegradable materials are materials that disintegrate over a given time following implantation in the body. Many different terms have been used to describe them including absorbable, resorbable and degradable. They are a type of biomaterial. Biomaterials can be defined as a type of material used to interface with biological systems to treat or augment any tissue, organ or function in the body. They can be divided into bio-inert or biodegradable.

The essential prerequisite of a biomaterial is biocompatibility; the ability of a material to perform a specific application with an appropriate host response. Bio-inert materials such as titanium, stainless steel and cobalt-chromium alloys do not initiate a host response when placed in biological tissue and as a result are commonly used in orthopaedic surgery today. Whilst their key advantage is mechanical strength numerous disadvantages exist including the effect of stress shielding, failure of metalwork resulting in the need for subsequent surgery, release of metal ions to surrounding tissues and distortion of imaging modalities.

These drawbacks have led to the development of biodegradable alternatives. Not only can they overcome the disadvantages of bio-inert materials but they can also be degraded and replaced by host tissue over a given time. For biodegradable materials to be successful they must possess key characteristics including:

- no potential to cause an inflammatory or toxic response on implantation
- a degradation time that matches the healing/regeneration process
- appropriate mechanical properties for the intended application
- degradation products that are non-toxic and that can also be metabolized and cleared from the body
- an acceptable shelf-life
- an appropriate processibility and permeability for the intended application.

The main types of biodegradable materials are polymers, metals and ceramics. This article will briefly review their synthesis, degradation, advantages/disadvantages and clinical application.

Polymers

Polymers are macromolecules composed of covalently bonded monomers. The monomer, or repeating unit, can be the same or different, termed homopolymers or co-polymers respectively. Polymer chains can be linear, branched or cross-linked, as well as amorphous, crystalline or both all of which influence the strength and degradation of the material. In addition they are influenced by temperature and as such it is important that polymers are designed with a glass transition temperature (T_g) above body temperature to prevent them becoming too flexible in vivo.

Polymers can be categorized into natural (biologically derived) or synthetic. Natural polymers are derived from proteins such as collagen and gelatin, as well as polysaccharides such as cellulose and chitin. Synthetic polymers can be further divided based on their mode of degradation namely hydrolytically or enzymatically degradable. Hydrolytically degradable polymers tend to be preferred as implants due to their minimal site-to-site and patient-to-patient variation.[1] Many different types of hydrolytically degradable polymers exist including poly(α-hydroxy acids)/polyesters, polyurethanes and poly(ester amides). This article will focus on poly(α-hydroxy acids) as they are the earliest and most extensively investigated class of synthetic hydrolytically degradable polymer.

Synthesis

Poly(α-hydroxy acids) can be manufactured from a range of different monomers. Ring-opening polymerization (ROP) and condensation polymerization are the two main processes used in

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their development. ROP is preferred due to milder reaction conditions, shorter reaction times and the absence of reaction by-products.

Degradation

Poly(α-hydroxy acids) generally undergo bulk erosion. Due to their chemical properties, breakdown occurs through de-esterification resulting in hydrolytic degradation. Once degraded, monomeric components are removed from the body via natural pathways.[2]

Advantages/disadvantages

Key advantages of polymers include modifiable mechanical properties as well as degradation kinetic. Due to a high crystallinity, poly(α-hydroxy acids) exhibit a high tensile strength and a high modulus (stiffness) in organic solvents. These properties in comparison to cortical bone can be seen in Table 1. Certain poly(α-hydroxy acids) also exhibit excellent fibre–forming ability and as such has found use in the development of suture material. The main disadvantage lies with its degradation products causing a reduction in the local pH. This may not only further accelerate the degradation process but also induce a local inflammatory reaction.[3]

Clinical application

Polymeric materials are used in numerous biomedical applications including, large implants such as bone screws and plates, small implants such as staples and sutures, plain membranes for guided tissue regeneration and multifilament meshes or porous structures for tissue engineering.[4] Many different types of poly (α-hydroxy acids) exist, of which the most common are poly (glycolic acid) (PGA), poly(lactic acid) (PLA) and their co-polymer poly(lactic-co-glycolide) (PLGA). A summarized list of advantages, disadvantages and clinical applications of some polymers can be found in Table 2.

PGA possesses excellent fibre-forming potential and was first used as a biodegradable synthetic suture under the name of DEXON®. Due to good initial mechanical properties its use has been investigated in the use of internal fixation devices, namely Biofix® screws. PGA has also shown use as a glue composite due to excellent skin-closing ability negating the need for sutures and aiding in the regeneration of tissue.[5]

PLA exists as two active optical isomers, D-lactide (PDLA) and L-lactide (PLLA) both of which are semicrystalline polymers. The polymerization of racemic (D,L)-lactide (PDLLA) results in the formation of an amorphous polymer. PLLA is a slow-degrading polymer relative to PGA, with a high tensile strength, a high modulus and low extension giving it use in load-bearing applications. Examples include the Phantom Soft Thread Soft Tissue Fixation Screw® and the Phantom Suture Anchor®. Similar to PGA, PLA can also form high-strength fibres and has been used as an improved suture material over Dexon®.[6] PDLLA shows much lower strength compared to PLLA due to its amorphous nature and when combined with a faster degradation rate it has found use as a drug delivery vehicle and as a low-strength scaffolding material for tissue regeneration.[6]

PLGA: by combining PGA and PLA, the co-polymer PLGA can be formed. By varying the ratios of the polymers PLGA can be used in different applications. The multifilament suture Vicryl® is formed from the co-polymer containing 90% PGA and 10% PLLA. Further to this, Vicryl Rapide® is also available, which is an irradiated version of Vicryl® resulting in an increased rate of degradation of the suture. A suture available with a decreased rate of degradation is PANACRYL® with a higher ratio of PLLA:PGA. As PLGA demonstrates good cell adhesion it has shown use as a potential candidate for tissue engineering applications.[7] It has shown use in guided tissue regeneration by providing a permeable material for space preservation. This product is currently marketed as CYTOPLAST Resorb®. PLGA has also shown use as a drug delivery vehicle in the form of microspheres, microcapsules, nanospheres and nanofibres. Unlike PGA and PLA polymers, PLGA has a low mechanical

Mechanical properties of cortical bone and polymers

	Density (g/cm^3)	Elastic modulus (GPa)	Compressive strength (MPa)	Tensile strength (MPa)
Cortical bone	1.8–2.1	5–23	160 trans/240 long	35 trans/283 long
Polymers	1.06–1.69	2–7	20	40

Table 1

Advantages, disadvantages and current clinical applications of biodegradable polymers

Advantages	Disadvantages	Clinical applications
□ High tensile strength	□ Rapid degradation:	□ Suture anchors
□ Excellent fibre-forming ability	— loss of mechanical strength	□ Meniscus repair
	— undesired inflammatory response	□ Interference screws
		□ Screws in fracture fixation

Table 2

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