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Recent advances in degradable lactide-based shape-memory polymers☆

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ABSTRACT

Biodegradable polymers are versatile polymeric materials that have a high potential in biomedical applications avoiding subsequent surgeries to remove, for example, an implanted device. In the past decade, significant advances have been achieved with poly(lactide acid) (PLA)-based materials, as they can be equipped with an additional functionality, that is, a shape-memory effect (SME). Shape-memory polymers (SMPs) can switch their shape in a predefined manner upon application of a specific external stimulus. Accordingly, SMPs have a high potential for applications ranging from electronic engineering, textiles, aerospace, and energy to biomedical and drug delivery fields based on the perspectives of new capabilities arising with such materials in biomedicine. This study summarizes the progress in SMPs with a particular focus on PLA, illustrates the design of suitable homo- and copolymer structures as well as the link between the (co)polymer structure and switching functionality, and describes recent advantages in the implementation of novel switching phenomena into SMP technology.

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1. Introduction

Therapeutic devices such as implants, scaffolds, and drug release systems demand materials with controllable and adjustable properties. Biodegradable polymeric biomaterials are preferred candidates for their unique physical, chemical, and mechanical properties, which can easily be varied by the material composition and polymer architecture, and their degradation rates can be adjusted as required for an efficient therapeutical treatment. In the last decade, synthetic biodegradable polymers, such as poly(lactide acid) (PLA), poly(ε-caprolactone) (PCL), and its copolymers or blends, approved by the US Food and Drug Administration (FDA), have been widely used in medical devices as well as for fast wound healing or tissue repair [1–6]. In particular, PLA polymer networks based on dilactides are promising candidates for such applications, as their material properties are highly dependent on the conformation of the stereo center (LL, DD, or LD) (Fig. 1) and glass transition temperatures (T_gs) are close to the physiological relevant range.

At present, engineering of multifunctional materials has become an exciting strategy to overcome the limitations of the devices used in the fields of medicine and pharmaceutics. This includes the opportunities that arise from introducing the capacity of shape switching into medically accepted materials, which can be realized with shape-memory polymers (SMPs). SMPs are actively moving polymers, which can be deformed from a permanent to temporary shape and are able to recover the original, permanent macroscopic shape on the application of suitable external stimuli, such as temperature, magnetic field, light, electricity, and pH (Fig. 2) [7–18]. As the combination of this functionality with the degradability of the material is of special interest in the medical field, SMPs based on PLA were intensively discussed as highly innovative materials for future applications. For example, the synthesis, characterization, and paclitaxel release studies of an SMP double-layer system, whose layers based on trimethylene carbonate (TMC), glycolide, and L-lactide, were reported to be suitable for medical devices designed for endovascular applications [19]. Furthermore, biodegradable electrospun fiber scaffolds based on D,L-dilactide (DLLA) and TMC monomers featuring a shape-memory effect (SME) and bone-forming ability were shown [20]. Finally, yet importantly, a series of three-dimensional (3D) biodegradable shape-memory polyurethane scaffolds has been synthesized and applied for intravascular aneurysm embolization [21].

This study presents a comprehensive review of the recent progress and important developments related to degradable lactide-based SMPs. A wide overview of the latest applications, relationships between the properties and structure and morphology of SMPs, their synthesis and functions, as well as the PLA degradation mechanism are presented.

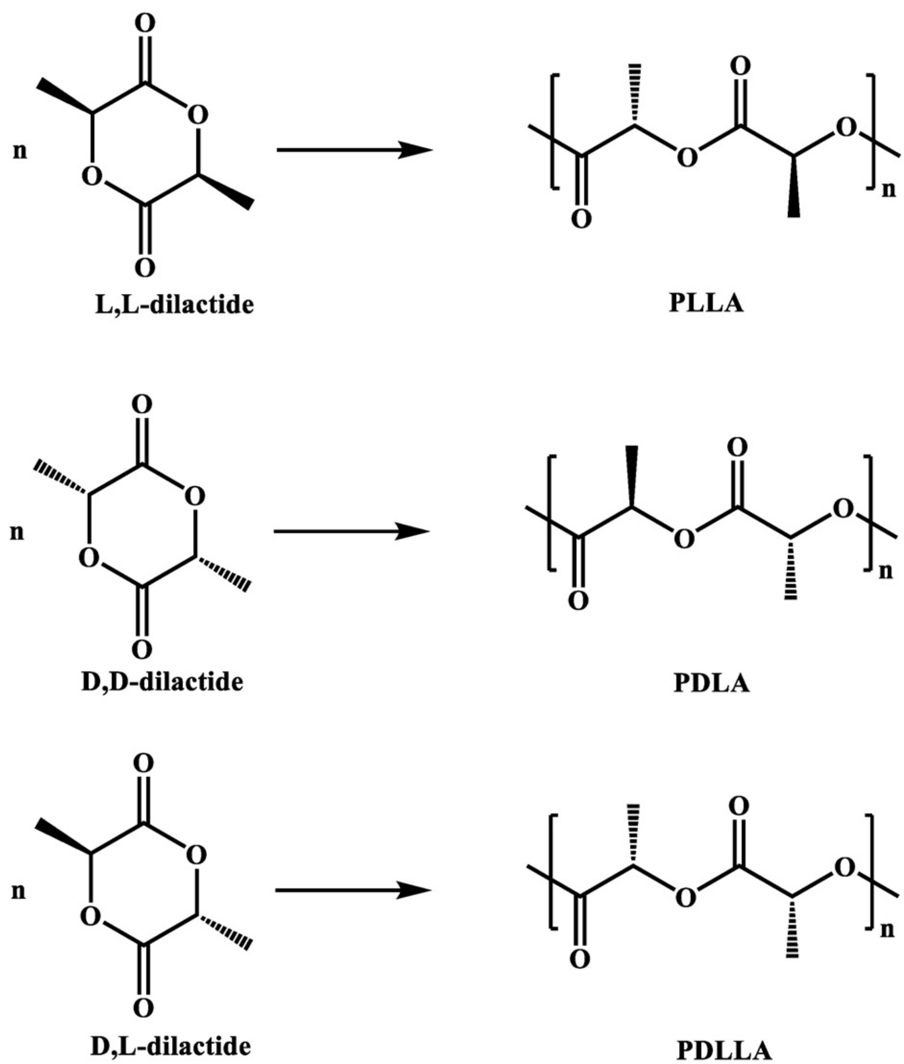

Fig. 1. Dilactides with different stereocenters and their polymers.