



## Synthesis and Characterization of Biodegradable Random Copolymers of *L*-Lactide, Glycolide and Trimethylene Carbonate

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### ABSTRACT

Random copolymers of *L*-lactide, glycolide and trimethylene carbonate were synthesized by bulk ring-opening copolymerization of monomers in the presence of stannous octoate as catalyst at 120°C for 48 h. Glycolide and *L*-lactide were prepared from their parent acids and then purified by multiple recrystallizations from ethyl acetate. Six copolymers with various mole% of the monomers were prepared and characterized. <sup>1</sup>H NMR and <sup>13</sup>C NMR spectra of copolymers that were recorded show the random character of the materials. Each <sup>1</sup>H NMR and <sup>13</sup>C NMR signal split to several peaks. Thermal behaviours of the copolymers were evaluated by DSC thermograms. Copolymers that contain *L*-lactide and trimethylene carbonate show an endotherm in DSC, but those containing three monomers do not show any transition in DSC. Mechanical properties of the copolymers were evaluated by measuring stress-strain curves of film specimens prepared by solvent casting.

### Key Words:

glycolide;  
*L*-lactide;  
trimethylene carbonate;  
random copolymer.

### INTRODUCTION

Biodegradable polymers such as lactide-glycolide copolymers have been in use for many applications like surgical sutures, encapsulates, scaffolds, and other advanced bio-medical and pharmaceutical devices [1,2]. Homo and copolymers of lactide and glycolide are hydrophobic relatively rigid and

brittle materials, and as such, their compatibility toward soft tissues is low [3], making them unsuitable as implants. In the other hand, poly trimethylene carbonate (PTC) is an amorphous or low crystalline rubbery polymer with a  $T_g$  of about 20°C [4], with its hydrolytic scission rate being slower in vitro, but

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more rapid in vivo [5]. One of the simplest and most widely used approaches for modifying polymer properties to meet specific requirements is copolymerization. For copolymers, crystallinity, depends on the monomer composition, configuration, and chain sequence structure (random or block copolymers). Introducing trimethylene carbonate in lactide-glycolide copolymers alters the amorphousness and mechanical properties of the resulting materials.

Maxon is a copolymer of glycolide and trimethylene carbonate [6] with a 64:36 molar ratio that can be processed in a monofilament form because of its low rigidity. Monosyn and Biosyn are terpolymers also based on glycolide and trimethylene carbonate with  $\epsilon$ -caprolactone or dioxanone as a third compound, respectively, and they have also recently been commercialized as degradable monofilament sutures [7,8]. Pennings et al. [9] synthesized and characterized star-shaped poly[(trimethylene carbonate)-*co*-( $\epsilon$ -caprolactone)] and its block copolymers with lactide and glycolide. These *D*-sorbitol initiated 6-arm star-shaped trimethylene carbonate/ $\epsilon$ -caprolactone copolymers have a lower intrinsic viscosity than their linear counterparts, indicating the expected branched structure. Recently, ABA type block copolymers of trimethylene carbonate and  $\epsilon$ -caprolactone are synthesized and characterized [10]. These block copolymers possessed specific properties, and with control of their molecular weights, are expected to have potential applications as medical materials, such as nerve guides. Triblock copolymers based on trimethylene carbonate and lactide were prepared [11]. These triblock copolymers are attractive for tissue engineering applications. The thermal and the mechanical properties of the block copolymers can easily be regulated within a wide range by adjusting their composition. A series of poly(trimethylene carbonate)( $\epsilon$ -caprolactone)/poly(*p*-dioxanone) block copolymers were synthesized by using two-step polymerization reactions [12]. The monofilament fibres were obtained using conventional melting spun methods. Results show that the copolymer with ratio 5/5/90 of trimethylene carbonate/ $\epsilon$ -caprolactone/*p*-dioxanone has excellent properties in suture applications.

Random and block copolymers of two-component systems, that is, glycolide and trimethylene carbonate, lactide and trimethylene carbonate, were synthesized

and extensively studied by researchers as mentioned in previous paragraphs. Also their applications as some medical devices such as, monofilament surgical sutures and surgical suture coatings were studied as patents [13-16]. Their random terpolymers, however, have not been studied so far.

For evaluation the effect of trimethylene carbonate component on the thermal and mechanical properties of lactide/glycolide copolymers and potential use of these new materials as monofilament surgical sutures and scaffolds for tissue engineering, random copolymers of these monomers were synthesized using stannous octoate as the catalyst by ring opening bulk copolymerization. The structures of the random copolymers were characterized by using  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR spectroscopies. Thermal properties of the copolymers were investigated by DSC thermograms and mechanical properties of film specimens of the copolymers were measured.

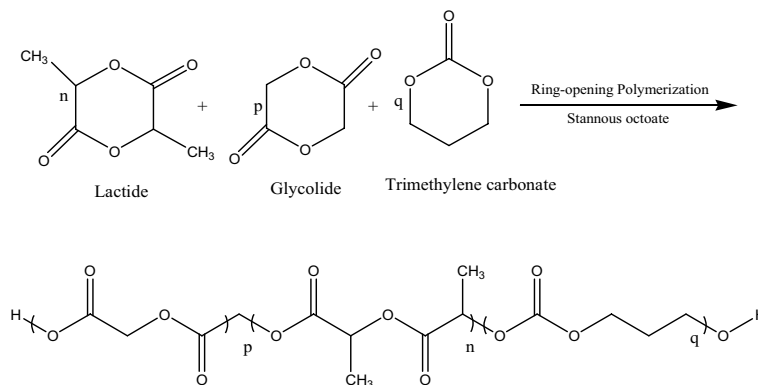
## EXPERIMENTAL

### Materials

*L*-Lactide was prepared from 90% *L*-lactic acid solution (Merck Inc. Darmstadt Germany) according to Gilding [17]. Glycolide was prepared likewise from glycolic acid (Merck). Both monomers were purified by multiple recrystallizations from ethyl acetate. The catalyst, tin-2-ethyl hexanoate (Sigma, St. Louis, USA) was purified by vacuum distillation. Trimethylene carbonate was from Boehringer (Germany). All other chemicals or solvents were reagent grades (Merck, Darmstadt, Germany) and, if necessary, were purified according to established procedures [18].

### Polymerizations

Appropriate amounts of lactide, glycolide and trimethylene carbonate were charged into a polymerization tube and kept under vacuum at 50°C for 2 h. Thereafter, 0.5 mL catalyst solution (3%  $\text{Sn}(\text{Oct})_2$  in toluene) was then added and kept under vacuum until all volatiles were removed. The tubes were then sealed under vacuum and polymerization was carried out at 120°C for a period of two days. Tubes were subsequently broken and the contents were dissolved in



**Scheme I.** Copolymer constituted of 3 monomers, *L*-lactide, glycolide and trimethylene carbonate.

chloroform, filtered and finally precipitated with hexane.

### Measurements

$^1\text{H}$  and  $^{13}\text{C}$  NMR spectra of the copolymers were recorded on a Bruker-DRX-500 spectrometer at 500 and 125 MHz, respectively. Chloroform- $d_1$  and TMS were used as solvent and internal standard, respectively. Stress-strain behaviour of the copolymer films were studied via an Instron Universal Testing Machine Series IX with a 100 mm/min cross-head speed. Film specimens (70 mm $\times$ 20 mm $\times$ 0.1 mm) were prepared by solution casting from a 20% chloroform solution. Differential scanning calorimetry (DSC) thermograms were obtained using a thermal analysis (TA) DSC-60. The intrinsic viscosity of the copolymers was measured in a dilute chloroform solution at 25°C, using an Ubbelohde viscometer.

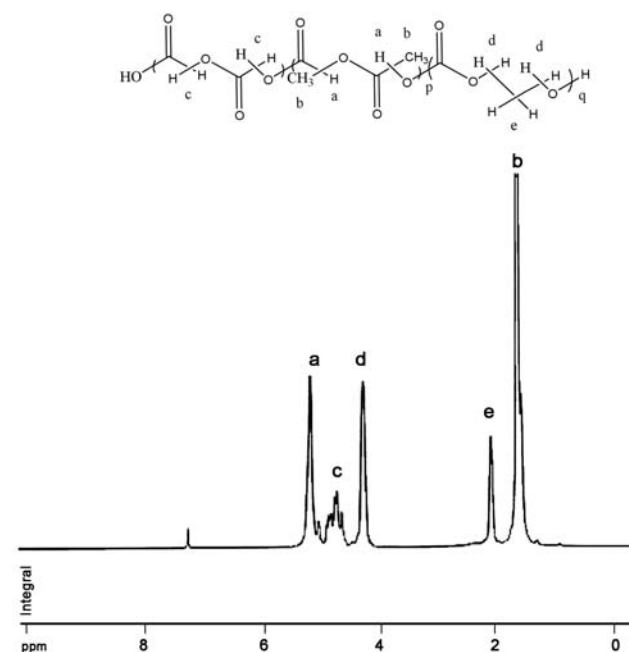
## RESULTS AND DISCUSSION

Direct bulk ring-opening copolymerization of *L*-lactide, glycolide and trimethylene carbonate with the use of stannous octoate as catalyst leads to random copolymers. The copolymerization procedure is shown in Scheme I.

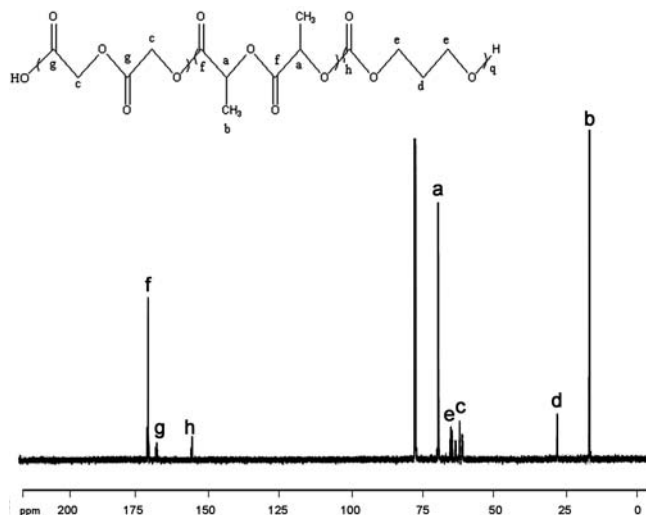
$^1\text{H}$  NMR Spectrum of a resulting random copolymer is shown in Figure 1, with the chemical shifts being assigned as follows: a doublet at  $\delta$  1.61 ppm and a quartet at  $\delta$  5.20 ppm are attributed to the  $\text{CH}_3$  and  $\text{CH}$  protons of lactide, respectively. A multiplet at  $\delta$  4.6-5.0 ppm is attributed to the  $\text{CH}_2$  protons of glycolide moiety. The centre  $\text{CH}_2$  protons of trimethylene carbonate component is appeared at  $\delta$  2.07 ppm and

two other  $\text{CH}_2$  protons of it are appeared at  $\delta$  4.27 ppm. The multiplet signal of  $\text{CH}_2$  protons of glycolide moiety shows that glycolide segment has a microblock structure in the random copolymer because of its high reactivity than lactide and trimethylene carbonate.

$^{13}\text{C}$  NMR Spectrum of one of the copolymers is shown in Figure 2. The  $\text{CH}$  and  $\text{CH}_3$  carbons of lactide moiety are appeared at  $\delta$  69.5 and 17.1 ppm, respectively. The centre  $\text{CH}_2$  carbon and two other  $\text{CH}_2$  carbons of trimethylene carbonate moiety are appeared at  $\delta$  28.3 and 65.2 ppm, respectively. The peak at  $\delta$  61.3 ppm attributed to  $\text{CH}_2$  carbon of glycolide moiety. The peaks at  $\delta$  155, 167 and 170 ppm



**Figure 1.**  $^1\text{H}$  NMR Spectrum of a resulting random copolymer.

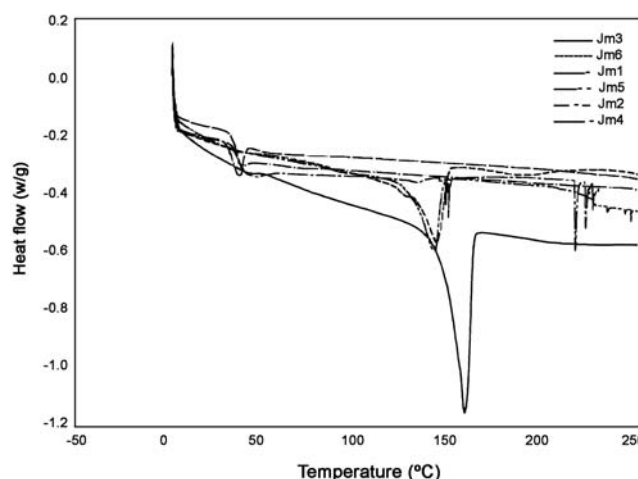


**Figure 2.**  $^{13}\text{C}$  NMR Spectrum of a resulting random copolymer.

are attributed to carbonyl carbons of trimethylene carbonate, glycolide and lactide moieties, respectively. Usually,  $^{13}\text{C}$  NMR spectra can be used to distinguish different block copolymers and random copolymers. The splitting of the resonance signals of  $^{13}\text{C}$  NMR implies the random character of copolymer.

The composition of the resulting copolymers can be calculated directly by integration of the ratios of the signals at  $\delta$  2.07 ppm (trimethylene carbonate),  $\delta$  5.20 ppm (lactide) and 4.6-5.0 ppm (glycolide) in the copolymers. The calculated results are shown in Table 1.

The thermal properties of the random copolymers, were investigated by DSC, with the results obtained are presented in Figure 3. Homopolymer of TMC is



**Figure 3.** DSC Thermograms of the resulting random copolymers.

amorphous, with no melting point being observed. But homopolymer and copolymers of lactide and glycolide are semicrystalline materials. It is obvious from DSC thermograms that three-component copolymers, that are, Jm1, Jm2 and Jm4 (Table 1), are amorphous materials, and have not detectable melting point in DSC thermograms. In the case of two-component copolymers (lactide and trimethylene carbonate), that is, Jm3, Jm5 and Jm6 (Table 1), one melting point is detected in DSC thermograms. In these copolymers melting point and enthalpy of melting are affected by two parameters (lactide mol% in copolymer and average molecular weight), Jm3 has high molecular weight and then has high melting point and high enthalpy of melting. With the same molecular weight with increasing lactide mol% in copolymer both melt-

**Table 1.** Random copolymers of different compositions.

Copolymer	LA/TC/GL (molar ratio) <sup>a</sup>	LA/TC/GL (molar ratio) <sup>b</sup>	$[\eta]$ ( $\text{dL.g}^{-1}$ )	$T_m$ ( $^{\circ}\text{C}$ )	$\Delta H_m$ (J/g)
Jm1	50/25/25	72/11/17	0.64	-	-
Jm2	60/20/20	76/13/11	1.6	-	-
Jm3	75/25/0	80/20/0	2.7	156	40.2
Jm4	75/12.5/12.5	80/10/10	1.9	-	-
Jm5	50/50/0	65/35/0	1.8	140	17.9
Jm6	80/20/0	86/14/0	1.5	141	22.5

(a) Initial feed ratio.

(b) Composition of the resulting random copolymers calculated from  $^1\text{H}$  NMR spectroscopy.

**Table 2.** Mechanical properties of the various random copolymers.

Copolymer	Tensile stress at maximum (MPa)	Tensile strain at maximum (%)	Modulus of elasticity (MPa)
Jm1	13.4	346	281
Jm2	6.5	390	131
Jm3	30.8	10.9	760
Jm4	41.6	219	1104
Jm5	21.25	315.8	298.5
Jm6	33	26	897

ing point and enthalpy of melting are increased.

The mechanical properties of the various random copolymers of lactide, glycolide and trimethylene carbonate were investigated under identical conditions, with the results obtained are listed in Table 2. The stress-strain behaviours of the copolymers are shown in Figure 4. It is observed that random copolymers with different molar ratios possessed dramatically different mechanical properties. Sample Jm4 that has 75 mol% lactide and 12.5 mol% of each glycolide and trimethylene carbonate moieties, possessed the highest tensile stress at maximum and modulus of elasticity and also high toughness. In copolymers that contain lactide and trimethylene carbonate, with increasing of mol% of lactide, tensile stress and modulus of elasticity are increased and toughness is decreased. In copolymers that contain three components no regular relationships have been observed but increasing of mol% of trimethylene carbonate, the tensile stress and

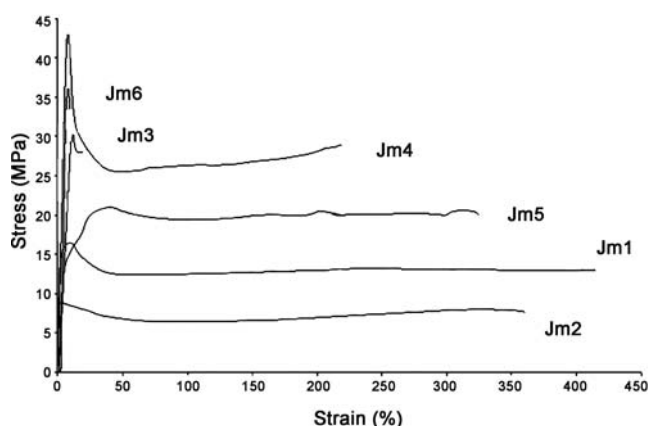
modulus of elasticity are decreased and copolymer toughness and its elasticity are increased.

## CONCLUSION

Three-component random copolymers from lactide, glycolide and trimethylene carbonate are synthesized and characterized. Whereas the lactide glycolide copolymers are semicrystalline copolymers but the obtained three-component copolymers have amorphous nature. With introducing trimethylene carbonate moiety in the copolymer the mechanical properties of the copolymers of lactide and glycolide are improved. These copolymers with mentioned improved mechanical properties have potential use in the tissue engineering and other medical applications.

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**Figure 4.** Stress-strain curves of the resulting random copolymers.

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