

## Synthesis and Properties of Triblock and Multiblock Copolymers Consisting of Poly(L-lactide) and Poly(oxyethylene-co-oxypropylene)

Chan Woo Lee\* and Young Goo Kang

Department of Innovative Industrial Technology, Hoseo University, Asan-City 336-795, Korea

Kun Jun

Korea Research Institute of Chemical Technology, Taejon 305-606, Korea

Received May 30, 2000

**Abstract :** Both A-B-A triblock and multiblock copoly(ester-ether)s consisting of poly(L-lactide) and poly(oxyethylene-co-oxypropylene) were prepared and characterized. The preparation of the triblock copolymer was done by ring-opening copolymerization of L-lactide with a commercially available telechelic copolyether, Pluronic™(PN) by catalysis of stannous octanoate. The molecular weight and unit composition of the produced copolymers were successfully controlled by changing the L-lactide/PN ratio in feed. However, a high molecular weight copolymer incorporating PN in large amount was not obtained because the molecular weight of the resulting copolymer was limited at a high L-lactide/PN composition. The multiblock copolymer was synthesized by the copolycondensation of oligo(L-lactic acid) prepared by thermal dehydration of L-lactic acid, PN, and dodecanedioic acid as carboxyl/hydroxyl adjusting agent. This polycondensation proceeded by catalysis of stannous oxide to give multiblock copolymers with high molecular weight and wide range of compositions.

### Introduction

Polyglycolide(PGA) and poly-L-lactide(PLLA) have been attracting great attention as they are hydrolyzed in living tissues and eliminated from the human body by the metabolic cycles.<sup>1</sup> Their application, therefore, has been directed to various temporary biomaterials including drug carriers and absorbable surgical sutures. However, the high crystallinity of these polymers has interfered with their clinical application as the biomaterials which contact with soft tissues. One of the effective strategies in making them flexible is to introduce soft segments to the base polymers by block copolymers comprising poly( $\alpha$ -hydroxy acid)s with poly(ethylene glycol)(PEG) or poly(propylene glycol)(PPG).<sup>2-9</sup> These copolymers, however, were of low molecular weights owing to the insufficient control of polymerization conditions, and useful only in

limited use as absorbable coating materials. In the present study, we selected another telechelic polyether, poly(oxypropylene-co-oxyethylene)[PN; the common trade name is Pluronic™(F-68)] as the soft ether segment and block-copolymerized it with L-lactide. PN having number-average molecular weight( $M_n$ ) of 8,400 has been approved by FDA<sup>9</sup> as a safe pharmaceutical surfactant and injective polymer,<sup>10</sup> and can be used as a safe component of biomedical material. The ring-opening polymerization of L-lactide initiated from the hydroxyl groups on both terminals of PN gives an A-B-A triblock type copoly(ester-ether)<sup>11</sup> which is also thought to be a safe biomaterial with improved flexibility and lower crystallinity compared with PLLA homopolymer. However, in this strategy using PN with  $M_n=8,400$ , it is impossible to prepare high molecular weight copolymers incorporating PN in large amount because the molecular weight of the resulting copolymers is limited by PN/lactide composition. Consequently,

\*e-mail : cwlee@office.hoseo.ac.kr

it has been desired to increase molecular weight of the copolymers with large PN content. In the present study, polycondensation method was introduced to synthesize the same block copolymers. In this method, oligo(L-lactide) prepared by thermal dehydration of L-lactic acid and PN were subjected to copolymerization in the presence of a dicarboxylic acid to obtain multiblock copolymers of PLLA and PN. The dicarboxylic acid was added to the system in order to adjust the concentrations relative of hydroxyl and carboxyl groups added in the system. By this direct polycondensation method, block copolymers with high molecular weight and wide range of compositions could be prepared. In the present paper, the two methods of copolymerization of L-lactide and PN, and copolycondensation of oligo(L-lactic acid) and PN were compared. In both copolymerization methods, reaction conditions, (temperature, period of time) were optimized with various catalysts. The resultant copolymers with various compositions were then characterized, and polymer films were also processed for evaluation of their mechanical properties.

## Experimental

**Materials.** L-lactide was supplied from Purac Biochem(Netherlands) and purified by recrystallization from ethyl acetate. Toluene was distilled under a nitrogen atmosphere. 4-Ethyl hexanoate, tin sulfate, L-lactic acid, diphenyl ether, and dodecanedioic acid(DDA) were purchased from Nacalai Tesque(Kyoto, Japan) and used as received. The PN comprising oxyethylene(EO) and oxypropylene(PO) blocks at a unit ratio of 2:8(composition: wt%) was the commercially available Pluronic™(F-68) which was supplied from Asahi Denka Co., LTD., Japan. PN was thoroughly dried at a reduced pressure below  $10^{-3}$  mmHg(1 mmHg = 133.322 Pa) before use. The other reagents and solvents were used without further purification.

**Measurements.**  $^1\text{H-NMR}$  spectra were measured on a Varian Gemini-200(at 200 MHz) spectrometer and a Bruker ARX 500 spectrometer(at 500 MHz) in  $\text{CDCl}_3$  containing 1 vol% tetramethylsilane(TMS) as the internal reference.  $^{13}\text{C-NMR}$  spectra were measured on a Bruker ARX 500

spectrometer(at 125 MHz) in  $\text{CDCl}_3$  containing 1 vol% tetramethylsilane(TMS) as the internal reference. The number-average molecular weight( $M_n$ ) and the molecular weight distribution( $M_w/M_n$ ) were determined by gel permeation chromatography (GPC). The analyzer was composed of a Shimadzu LC-10A pump, a Shodex RI SE-31 RI detector, a Shimadzu C-R7A chromatopac data processor, a Shodex DEGAS KT-16 degassor, and a Sugai U-620 column oven. A combination of two polystyrene gel columns of Toso TSK gel G4000H and G2500H(7.5 mm i.d.300 mm, each) was used with tetrahydrofuran as the eluent at 35°C. The molecular weight was calibrated according to polystyrene standards. The melting point( $T_m$ ) and glass transition point( $T_g$ ) of the polymeric products were determined by differential scanning calorimetry(DSC) on a Mac Science DSC-3100 thermal analyzer at a heating rate of 10°C in $^{-1}$ .  $\alpha$ -Alumina was used as the reference sample. In the first scan, the analysis was made from room temperature to 200°C, and the sample was quenched in a liquid nitrogen bath for 30 min. In the second scan, the sample was heated up from -30 to 200°C.

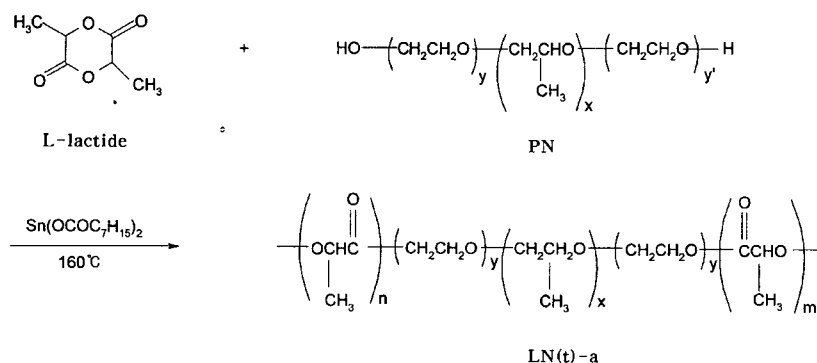
### Preparation of Polymerization Catalysts.

**Stannous 4-ethylhexanoate:** Stannous 4-ethylhexanoate was purified by distillation under high vacuum. Then, it was dissolved in a distilled toluene at a concentration of 0.1 g/mL.

**Stannous oxide and Stannous lactate:** In an appropriate flask, 10 g of Stannous sulfate was dissolved in 50 mL of distilled water, and the solution was adjusted to weak alkalinity by adding an aqueous sodium hydroxide(10 mol  $\text{dm}^{-3}$ ) under nitrogen atmosphere. The solution was refluxed with stirring on a magnetic stirrer at 120°C for 8 h. Then, the resultant black precipitate, which was stannous oxide, was washed with distilled water, filtered, and washed with acetone.

A mixture of 6 g of stannous oxide, 30 mL of 90% aqueous L-lactic acid, and 30 mL of a distilled water was made and filtered. The filtrate was then evaporated to remove water and L-lactic acid at 120°C under a reduced pressure of 10 mmHg. The white residue obtained was washed with water and dried *in vacuo*.

### Copolymerization of L-lactide and PN.



**Figure 1.** Block copolymerization scheme of L-lactide and PN.

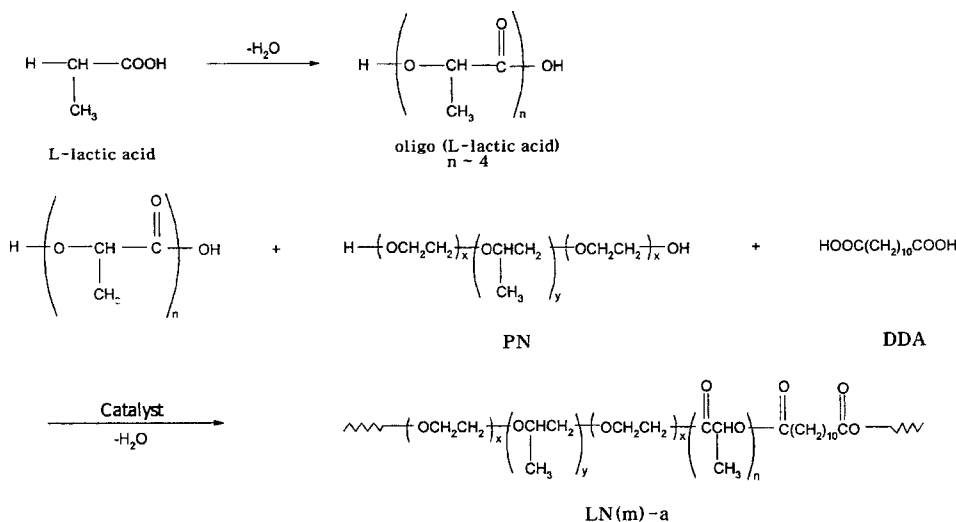
Two grams of L-lactide and a prescribed amount of PN were placed in a flask equipped with a mechanical stirrer (Figure 1). The flask was evacuated by a vacuum pump for several hours in order to dry up the mixture thoroughly and then filled with nitrogen gas. Then, 0.05 mL (0.045 mol% relative to L-lactide) of the toluene solution of stannous 4-ethylhexanoate was added, and the flask was evacuated again for several hours to removal of toluene. Then, it was heated at 160°C with stirring for 30 min. In this process the mixture turned from liquid to solid. After the reaction had finished, the product was dissolved in 20 mL of chloroform, and the solution was poured into an excess amount of methanol. The precipitated product was filtered and dried *in vacuo*. The product finally obtained was a white fibrous solid. The  $^1\text{H-NMR}$  spectrum signals of the product are as follows;  $^1\text{H-NMR}$  ( $\text{CDCl}_3/\text{TMS}$ )  $\delta = 1.17$  ( $\text{CH}_3$  for PO), 1.57 ( $\text{CH}_3$  for LA), 3.3–3.5 ( $\text{CH}_2\text{CH}$  for PO), 3.5–3.6 ( $\text{CH}_2\text{CH}$  for PO), 3.6–3.7 ( $\text{CH}_2\text{CH}_2$  for EO), 4.3 ( $\text{CH}_2\text{CH}_2$  for EO bonded with LA), and 4.9–5.1 ( $\text{CH}$  for LA), where LA, EO, and PO denote the L-lactate unit in PLLA, EO unit in PN, and PO unit in PN, respectively.

By changing the PN ratio to L-lactide in feed, a series of copolymers with different composition were prepared. Their name is abbreviated as “LN(t)-a”, where L, N, (t) and a denote PLLA, PN (the constituent segments), triblock type (copolymer type), and PN content, respectively.

**Oligomerization of L-lactic acid.** 200 g of a 90% aqueous solution of L-lactic acid was dehydrated at 150°C first, at atmospheric pressure for 2 h, further at a reduced pressure of

100 mmHg for 2 h, and finally under a pressure of 30 mmHg for another 4 h. Then, a various liquid of oligo(L-lactic acid) was formed and subject to the following copolymerization (Figure 2). The  $^1\text{H-NMR}$  spectrum signals of the product are as follows;  $^1\text{H-NMR}$  ( $\text{CDCl}_3/\text{TMS}$ )  $\delta = 1.5$  ( $\text{CH}_3$  due to the hydroxyl terminal of 2-hydroxypropionate unit), 1.6 ( $\text{CH}_3$  for the L-lactate unit), 4.4 ( $\text{CH}$  due to the hydroxyl terminal of 2-hydroxypropionate unit), and 5.2 ( $\text{CH}$  for the L-lactate unit). From the integral ratio of the methyne signal at  $\delta = 4.4$  ppm relative to that at  $\delta = 5.2$  ppm, the degree of polymerization was calculated to be  $\sim 4$  and the number average molecular weight was about 280 dalton.

**Copolymerization of Oligo(L-lactic acid) and PN.** Prescribed amounts of oligo(L-lactic acid), and PN were charged into a flask equipped with a reflux condenser and an equimolar amount of DDA relative to the PN quantity, DDA that is equivalent to the molar quantity of PN, diphenyl ether as solvent, and a given amount of catalyst were added to it. The resulting mixture was refluxed with stirring on a magnetic stirrer at 180°C under reduced pressure for a prescribed time. The coolant water passing the reflux condenser was adjusted at 60°C to allow removal of water out of the reaction system and to feedback the distilled diphenyl ether into the reaction system. After 15 h, a brown precipitate deposited out. It was dissolved in 20 mL of chloroform and the solution was poured into an excess amount of methanol to isolate the polymeric product. The precipitated product was filtered and dried *in vacuo* giving white fibrous powders.  $^1\text{H-NMR}$  ( $\text{CDCl}_3/\text{TMS}$ )  $\delta = 1.17$  ( $\text{CH}_3$  for PO), 1.3 ( $\text{CH}_2$  for



**Figure 2.** Multiblock copolymerization scheme of oligo(L-lactic acid), PN, and DDA.

DDA), 1.57( $\text{CH}_3$  for LA), 2.4( $\text{CH}_2\text{CO}$  for DDA), 3.3~3.5( $\text{CH}_2\text{CH}$  for PO), 3.5~3.6 ( $\text{CH}_2\text{CH}$  for PO), 3.6~3.7( $\text{CH}_2\text{CH}_2$  for EO), 4.3( $\text{CH}_2\text{CH}_2$  for EO bonded with LA), and 4.95.1( $\text{CH}$  for LA).

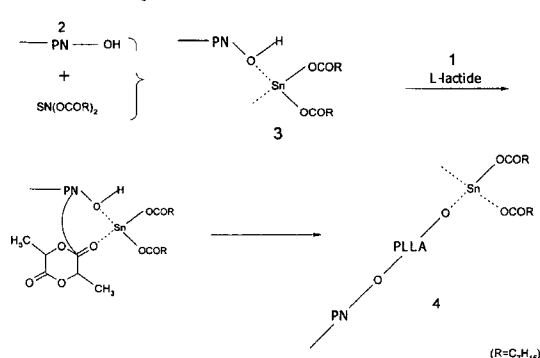
$^{13}\text{C}$ -NMR( $\text{CDCl}_3/\text{TMS}$ )  $\delta = 16.7(\text{CH}_3$  for LA), 17.4( $\text{CH}_3$  for PO), 24.8[ $\text{CH}_2(\text{CH}_2)_3\text{CO}$  for DDA], 29.3 [ $\text{CH}_2(\text{CH}_2)_3\text{CO}$  for DDA], 33.9[ $\text{CH}_2(\text{CH}_2)_3\text{CO}$  for DDA], 69.1( $\text{CH}$  for LA), 70.6( $\text{CH}_2\text{CH}_2$  for EO), 73.4( $\text{CH}_2\text{CH}$  for PO), 75.5( $\text{CH}_2\text{CH}$  for PO), and 169.6 [ $\text{CHC}(\text{O})$  for LA].

By a similar method, a series of copolymers with different composition were prepared by changing the ratio of PN to oligo(L-lactic acid) in feed. The name of the products is abbreviated as "LN(m)-a", where L, N, (m), and a denote PLLA, PN(the constituent segments), multiblock type (copolymer type), and PN content, respectively.

**Film Preparation.** A concentrated solution (ca. 10 wt%) of each of the triblock and multiblock PLLA/PN copolymers in chloroform was prepared. This solution was poured into a glass petri dish, solidified in air at  $4^\circ\text{C}$ , and dried *in vacuo*. The resulting film was transparent and ca.  $80\ \mu\text{m}$  in thickness.

## Results and Discussion

**Block Copolymerization of L-lactide and PN.** In the present study, a telechelic oligomer PN having hydroxyl groups on both ends was



**Figure 3.** Copolymerization mechanism of L-lactide with PN.

selected as soft segment and copolymerized with L-lactide. As reported before,<sup>11</sup> this copolymerization should proceed through the mechanism shown in Figure 3. In the initiation, the catalyst reacts with PN to form **3** which reacts with L-lactide successively and A-B-A type copolymer **4**.

Table I summarizes the results of the copolymerization with various PN to L-lactide ratios in feed. The yield of the precipitated copolymers exceeded 90% in every case, and their unit composition determined by  $^1\text{H}$ -NMR spectroscopy was almost identical with the feed ratio.

Figure 4 shows the typical GPC curves of these copolymers, which are compared with those of the PLLA homopolymer and PN. Each curve is uni-modal, while its peak maximum shifts to the

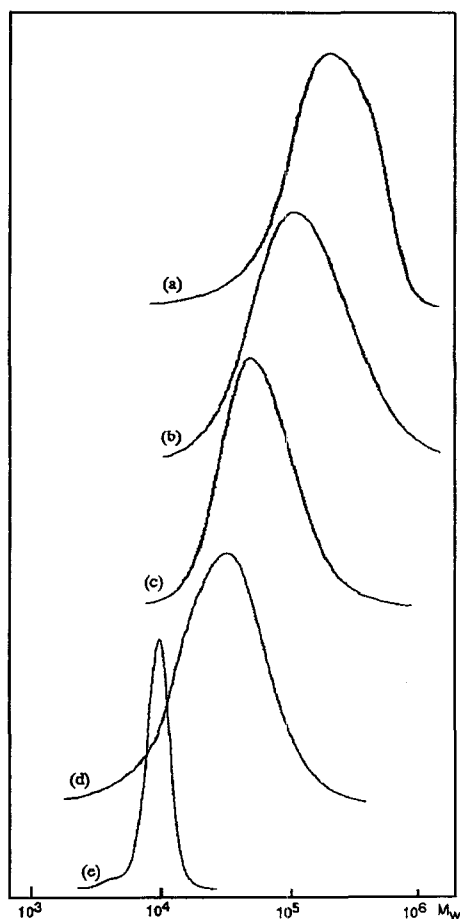
**Table I. Results of Triblock Copolymerization<sup>a</sup> of L-lactide and PN**

Polymer	Feed Ratio		Polymeric Product			Estimated $M_n \times 10^{-4}$
	L-lactide/PN (wt/wt)	Yield(%)	LA/EO/PO <sup>b</sup> (unit ratio)	$M_n \times 10^{-4c}$	$M_w/M_n$	
PLLA	100/0	93	100/0/0	10.2	1.96	
LN(t)-10	90/10	94	85/12.0/3.0	7.0	2.14	8.4
LN(t)-15	85/15	95	79/16.8/4.2	4.6	2.09	4.8
LN(t)-20	80/20	92	72/22.4/5.6	3.8	1.54	3.4

<sup>a</sup>At 160°C for 30 min with 0.1 mol% of stannous 4-ethylhexanoate relative to L-lactide.

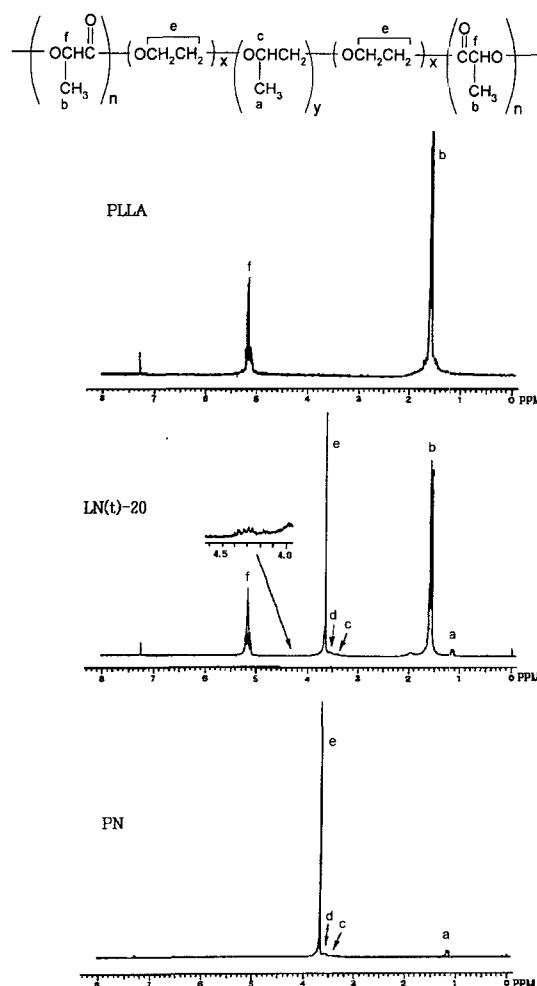
<sup>b</sup>By <sup>1</sup>H NMR spectra.

<sup>c</sup>By GPC with chloroform as the eluent.



**Figure 4.** Typical GPC curves of (a) PLLA, (b) LN(t)-10, (c) LN(t)-15, (d) LN(t)-20, and (e) PN.

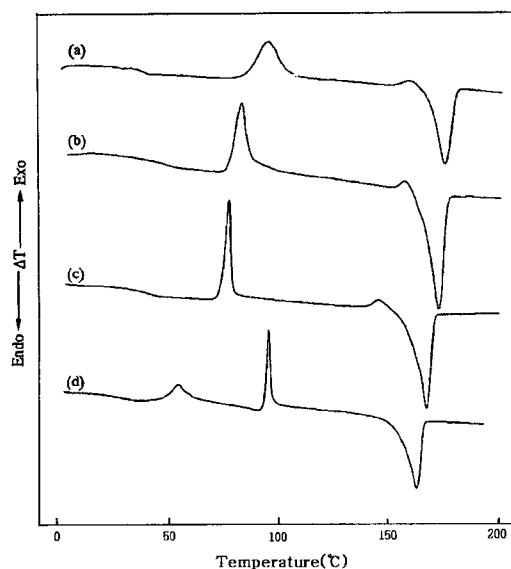
lower molecular weight region with increasing the feed ratio of PN. The  $M_n$  values of these copolymers are summarized in Table I. It is known that the  $M_n$  values determined by GPC were comparable with values estimated from the feed ratios,



**Figure 5.** <sup>1</sup>H-NMR spectra of (a) PLLA, (b) LN(t)-20, and (c) PN.

supporting formation of the A-B-A triblock type copolymer.

Figure 5 shows the typical <sup>1</sup>H-NMR spectrum of



**Figure 6.** Typical DSC curves of (a) PLLA, (b) LN(t)-10, (c) LN(t)-15, and (d) LN(t)-20.

the copolymer LN(t)-20 as compared with those of PLLA and PN. The signal assignments are also involved in this Figure 6. The signals due to the PLLA unit can be clearly detected at  $\delta$  1.57 and 4.9~5.1, and the signals due to the PN unit can also be detected at 1.17 and 3.3~3.7. Their signal assignments are involved in this Figure 5. The unit composition was determined by integration of these peaks. The expanded spectrum around  $\delta$  4.0~4.5 ppm for LN(t)-20 shows complex signals which are assigned to the oxymethylene terminal groups connected with the PLLA segment through ester bond.

#### Properties of the A-B-A Triblock Copolymers.

Figure 6 shows the DSC curves of the copolymers with different unit compositions as compared with that of PLLA. The copolymers exhibited exother-

mic peaks at around 80~90°C and an endothermic peak at temperatures lower than the  $T_m$  of PLLA. They are ascribed to the crystallization and crystal fusion of the PLLA segments, respectively. There is a tendency that  $T_m$  became lower with increasing PN composition. While PN showed an endothermic peak at 56°C due to the crystal fusion of poly(oxyethylene) segments, the copolymers showed no peak around the temperature, probably because of the active motion of the polyether segment. The inflection due to the glass transition of the amorphous phase of the PLLA shifted to a low temperature region with increasing PN composition. These results suggested that the PN segments and PLLA are well compatible and mixed in the amorphous phase of PLLA without forming a microphase separation in solid state. The compatibility of both polymers, however, would not be so high as to prevent crystallization of PLLA.

Table II shows the tensile properties of the films of the A-B-A triblock copolymers having different composition as compared with those of a PLLA film. The tensile modulus decreased with increasing PN composition, suggesting that the introduction of PN segment is quite effective to improve the flexibility of the PLLA. The concomitant decrease in tensile strength should be attributed to decrease in molecular weight of the copolymer formed by copolymerization of PN.

**Block Copolymerization of Oligo(L-lactic acid), PN, and DDA(multiblock type copolymerization).** In the copolymerization of PLLA and PN, the molecular weight of resultant copolymer decreased with increasing feed ratio of PN, and triblock copolymers incorporating higher amount of PN could not be processed into film or other forms for biomaterials.

Here, the copolycondensation of oligo(L-lactic

**Table II. Tensile Properties of PLLA/PN Triblock Copolymer Films**

Polymer	Feed Ratio		Tensile Strength (MPa)	Tensile Modulus (MPa)	Tensile Elongation (%)
	L-lactide/PN (wt/wt)	LA/EO/PO <sup>a</sup> (Composition)			
PLLA	100/0	100/0/0	57	1.23	29
LN(t)-10	90/10	85/12.0/3.0	55	1.10	67
LN(t)-15	85/15	79/16.8/4.2	47	0.96	89
LN(t)-20	80/20	72/22.4/5.6	40	0.74	135

<sup>a</sup>By <sup>1</sup>H NMR spectra.

acid), PN and DDA was examined to prepare the copolymers with high-molecular weight and higher composition of PN. The copolymerization was carried out by solution condensation with diphenyl ether as solvent. DDA was used as the adjusting agent for controlling the carboxyl/hydroxyl ratio in the system. Therefore, the molar ratio of PN and DDA was unity. There were many variable terms for optimization of this copolycondensations.

First, the effect of pressure on the solution condensation was settled at a constant temperature of 180°C and at a constant feed ratio of oligo(L-lactic acid) to PN of 7:3 by using stannous 4-ethylhexanoate. Removal of the water generated during the polymerization from the reaction mixture seemed to be a key factor to increase the molecular weight of the polycondensate. Some results of copolycondensation at various reduced pressures are compared in Table III. At 10 mmHg, the yield became lower because of the sublimation of L-lactide produced in equilibrium with PLLA. The molecular weight of the resultant copolymer increased with increasing pressure, and reached the maximum 16000 at 30 mmHg. At pressure higher than 30 mmHg, the refluxing of diphenyl ether

was not enough (boiling point: 146°C/30 mmHg) to remove the condensed water from the reaction mixture effectively.

Table IV summarizes the effect of solvent. The molecular weight and yield of the copolymer were the highest when the amount of diphenyl ether as solvent was 10 g, that is, the concentration of the starting monomers [including oligo(L-lactic acid), PN, and DDA] was 50%.

Among the metallic catalysts examined, stannous catalysts were found to be the most effective. Stannous 4-ethylhexanoate was the most effective in the synthesis of A-B-A triblock type copolymer. In the polycondensation, however, it may afford octanoic acid by ligand exchange which may be incorporated into polymer chain make the number of the carboxyl ratio larger than unity, resulting insufficient propagation. So, stannous chloride, stannous lactate, stannous oxide, and stannous powder were examined in detail in addition to stannous 4-ethylhexanoate. It is not necessary to consider incorporation of these catalysts to the copolymer by the transesterification. The data are shown in Table V. It was known that the yield and the molecular weight of the copolymer were the highest with stannous oxide, while no copolymer-

**Table III. Effect of Reaction Pressure on the Multiblock Copolymerization<sup>a</sup>**

Run No.	Pressure (mmHg)	Yield(%)	LA/PN (wt/wt)	LA/EO/PO <sup>b</sup> (Composition)	$M_n^c$	$M_w/M_n$
1	10	25.7	63/37	52/38.4/9.6	2600	2.83
2	20	53.3	63/37	53/37.6/9.4	12400	1.32
3	30	65.9	67/33	57/34.4/8.6	15600	1.31

<sup>a</sup>Oligo(L-lactic acid) : 7.0 g, PN : 3.0 g(3.5710<sup>-4</sup> mol), DDA : 0.081 g(3.5710<sup>-4</sup> mol), Diphenyl ether : 20 g, Catalyst : stannous octanoate(0.1 wt% relative to all amount), conditions : 180°C, 20 h.

<sup>b</sup>Determined by <sup>1</sup>H NMR spectra.

<sup>c</sup>Determined by GPC with tetrahydrofuran as the eluent.

**Table IV. Effect of the Amount of Solvent(diphenyl ether) on the Multiblock Copolymerization<sup>a</sup>**

Run No.	Solvent Diphenyl ether(g)	Yield(%)	LA/PN (wt/wt)	LA/EO/PO <sup>b</sup> (Composition)	$M_n^c$	$M_w/M_n$
1	20	65.9	67/33	57/34.4/8.6	15600	1.31
2	10	83.0	69/31	59/32.8/8.2	21600	1.50
3	5	72.9	66/34	56/35.2/8.8	18300	1.38

<sup>a</sup>Oligo(L-lactic acid) : 7.0 g, PN : 3.0 g(3.5710<sup>-4</sup> mol), DDA : 0.081 g(3.5710<sup>-4</sup> mol), Catalyst : stannous octanoate (0.1 wt% relative to all amount), conditions : 180°C, 20 h.

<sup>b</sup>Determined by <sup>1</sup>H NMR spectra.

<sup>c</sup>Determined by GPC with tetrahydrofuran as the eluent.

**Table V. Effect of the Catalysts on the Multiblock Copolymerization<sup>a</sup>**

Run No.	Catalyst	Yield(%)	LA/PN (wt/wt)	LA/EO/PO <sup>b</sup> (Composition)	$M_n^c$	$M_w/M_n$
1	Stannous octanoate	83.0	69/31	59/32.8/8.2	21600	1.50
2	Stannous chloride	52.6	67/33	57/34.2/8.6	38500	1.53
3	Stannous lactate	50.9	79/21	71/23.5/5.5	5300	2.00
4	Stannous oxide	87.6	68/32	58/33.6/8.4	40200	1.78
5	Stannous powder	20.4	36/64	27/58.4/14.6	6500	1.34

<sup>a</sup>Oligo(L-lactic acid) : 7.0 g, PN : 3.0 g( $3.5710^{-4}$  mol), DDA : 0.081 g( $3.5710^{-4}$  mol), Catalyst : stannous octanoate (0.1 wt% relative to all amount), conditions : 180°C, 20 h.

<sup>b</sup>Determined by <sup>1</sup>H NMR spectra.

<sup>c</sup>Determined by GPC with tetrahydrofuran as the eluent.

ization with the stannous lactate.

The unit composition of the copolymers prepared with stannous oxide and stannous chloride were almost identical to oligo(L-lactic acid)/PN composition in the feed. Only a small amount of L-lactide was detected in the soluble part, which had been recovered from the precipitant. The absence of PN in this part supports the incorporation of all the fed PN in the copolymer. On the other hand, when stannous lactate and the stannous powder were used, the PN content in the copolymers was higher than the feed ratio. This was mainly ascribed to the sublimation of L-lactide. Judging from the similar reactivities of stannous oxide and stannous chloride with carboxylic acid, an identical intermediate or catalytic environment should be formed from the both catalysts, which the latter should liberate hydrogen chloride into the condensation system and include color change of the product. Therefore, stannous oxide was thought to be the best catalyst for present copolycondensation.

## Conclusions

The PLLA/PN copolymers were prepared by bulk copolymerization of L-lactide and PN. Bulk copolymerization proceeded through the ring-opening reaction of L-lactide initiated from the both hydroxy terminals of PN by the catalysis of stannous 4-ethylhexanoate to produce the A-B-A triblock type copolymers of PLLA(A) and PN(B) were obtained.

The solution condensation was induced by the

dehydration catalyzed by stannous oxide in refluxing diphenyl ether to produce multiblock copolymers. The molecular weight of the copolymers reached 50,000~60,000 at any feed ratio in spite of rather low yield of 70~80%.

**Acknowledgement.** This work was supported by grant No. (2000-1-31400-003-3) from the Basic Research Program of the Korea Science Engineering Foundation.

## References

- (1) E. Echeverria and J. J. Jimenez, *Surgey*, **131**, 1 (1970).
- (2) Y. Kimura, Y. Matsuzaki, H. Yamane, and T. Kitao, *Polymer*, **30**, 1342 (1989).
- (3) K. J. Zhu, L. Xiangzhou, and Y. Shilin, *J. Appl. Polym. Sci.*, **39**, 1 (1990).
- (4) D. S. G. Hu, H. J. Liu, and I. L. Pan, *J. Appl. Polym. Sci.*, **50**, 1391 (1993).
- (5) D. S. G. Hu and H. J. Liu, *Macromol. Chem. Phys.*, **195**, 1212 (1994).
- (6) Y. J. Du, P. J. Lemstra, A. J. Nijenhuis, H. A. M. van Aert, and C. Bastiaansen, *Macromolecules*, **28**, 2124 (1995).
- (7) S. M. Li, J. L. Espartero, and M. Vert, *Macromolecules*, **29**, 57 (1996).
- (8) I. Rashkov, N. Manolova, S. M. Li, J. L. Espartero, and M. Vert, *Macromolecules*, **29**, 50 (1996).
- (9) M. Vittaz, D. Bazile, G. Spenlehauer, T. Verrecchia, M. Veillard, F. Puisieux, and D. Labarre, *Biomaterials*, **17**, 1575 (1996).
- (10) T. G. Park, S. Cohen, and R. Langer, *Macromolecules*, **25**, 116 (1992).
- (11) C. W. Lee and Y. Kimura, *Bull. Chem. Soc. Jpn.*, **69**, 1787 (1996).