Synthesis and Characterization of Novel Degradable Polyesters Derived from D-Gluconic and Glycolic Acids

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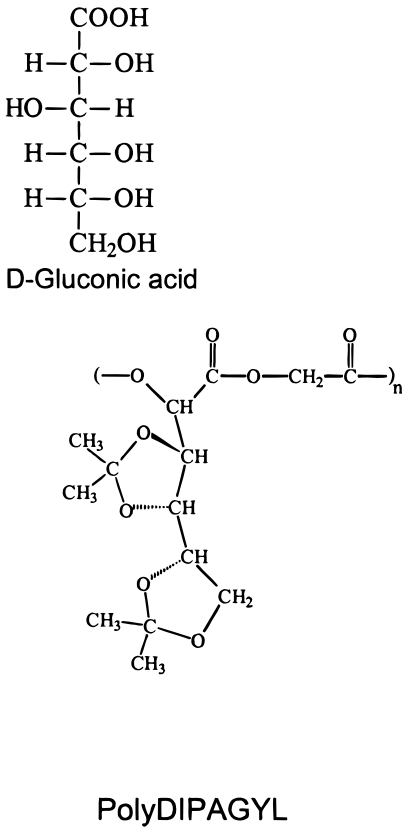
ABSTRACT: The ring-opening polymerization of a novel heterocyclic monomer of the 1,4-dioxane 2,5-dione type, namely 3-(1,2-3,4-tetraoxobutyldiisopropylidene)dioxane-2,5-dione (DIPAGYL), derived from glycolic acid and partially protected gluconic acid, was investigated. Polymerization of DIPAGYL was carried out in the presence of either stannous octoate or antimony trifluoride. The influence of several factors on the polymerization yield and on the molecular weights of the resulting polymers was evaluated using an experimental design. The polymers obtained in the presence of antimony fluoride (polyDIPAGYL-Sb) and stannous octoate (polyDIPAGYL-Sn) had different microstructures according to the distribution of sequences of repeat units as determined by ^{1}H NMR. The main chain of polyDIPAGYL-Sb was primarily composed of alternating g (gluconic) and G (glycolic) units. In contrast, the polymer chain of polyDIPAGYL-Sn resulted from a random distribution of the two comonomer units. The isopropylidene groups which protected the side chain alcohol groups in polyDIPAGYL chains were partially cleaved by acid hydrolysis to yield hydroxyl-bearing hydrolytically degradable polyesters.

Introduction

Degradable aliphatic polyesters that can be bioassimilated are increasingly investigated worldwide for pharmacological, biomedical, and environmental purposes. The presence of aliphatic ester linkage within the polymer main chain is the most critical parameter to provide degradability or biodegradability. By fixing the type of backbone, it limits the range of properties that can be fulfilled. To enlarge this range and cover the specifications of a greater number of potential applications, the development of polyesters with novel chemical structures and physicochemical, mechanical, and thermal properties is necessary. For this, one can take advantage of means such as copolymerization and stereocopolymerization, as already done in the case of the lactic/glycolic acid copolymer family. One can also consider substitution and functionalization of the polymer chain as a means to enlarge the range of possible properties, provided the aliphatic polyester structure and the presence of prometabolite units are preserved.[1] Only a few degradable and functional high molecular weight polyesters have been reported so far, namely poly(*β*-malic acid),[1] poly(α-malic acid),[2] poly(α-malic acid-*alt*-glycolic acid),[3] and poly(L-aminoserinate).[4] They contain either carboxylic acid or amine pendent groups which offer various openings to couple biologically active molecules or to generate polymers with various specific properties, including hydrophilicity and even water solubility.

The challenge remains open in the family of poly(α-hydroxy acids), whose main members are poly(glycolic acid) (PGA), poly(lactic acid) stereocopolymers (PLAX), where X stands for the percentage in L-units, and corresponding copolymers (PLAXGAY) derived from glycolic (GA) and lactic acid enantiomers (LA), where X has the same meaning whereas Y stands for the percentage in GA units. For the functionalization of PLAGA polymers, α-hydroxy acid-type sugars and their 1,4-dioxane-2,5-dione derivatives are potential precursors of degradable hydroxyl-bearing functional polyesters. In a previous contribution, we have introduced novel monomers and polymers based on 1,4-dioxane-2,5-dione-type cyclic monomers derived from gluconic acid and glycolic or lactic acids, namely 3-(1,2-3,4-tetraoxobutyldiisopropylidene)dioxane-2,5-dione (DIPAGYL) and 3-methyl-6-(1,2-3,4-tetraoxobutyldiisopropylidene)dioxane-2,5-dione (DIPALYL).[5]



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In this paper, we wish to report the results of our investigation of the homopolymerization of DIPAGYL using various initiator systems and on the influence of several factors on the molecular weights and polymerization yields. The properties of the resulting polyesters and the results of attempts to deprotect pendent hydroxyl groups are also reported.

Experimental Section

Chemicals. Zinc lactate supplied by Sigma (U.S.A.) and antimony fluoride purchased from Riedel-de Haën (Germany) were heated at 150 °C for 30 min and cooled under vacuum in the presence of P_2O_5 prior to use. Potassium acetate was supplied by Sigma (France) and used without purification. Two batches of stannous octoate (95%) supplied by Sigma (France) were distilled under vacuum before polymerization, and the fraction distilling at 100 °C/10^{-3} mmHg was recovered. Iodine was purchased from Aldrich (England). Solvents for polymer fractionation and for the deprotection of OH groups were analytical grade and were used as received.

Polymerizations. In a typical procedure, recently sublimed or twice recrystallized DIPAGYL[5] was introduced in a round-bottom flask and carefully degassed by freeze−thawing using vacuum and argon atmospheres alternatively at least three times. The initiator was then added. The flask was sealed under dynamic vacuum (10^{-3} mmHg), and the feed was allowed to polymerize at a given temperature and period of time. The polymerization product was purified by dissolution in acetone, filtration, and precipitation by a large volume of ethanol. The recovered precipitate was finally dried under vacuum at 40 °C for 3 days to yield a solid polymer.

Deprotection of Hydroxyl Groups. Two methods were used. According to the first one, 1 g of polyDIPAGYL was dissolved in 10 cm^3 of acetone. A 200 mg sample of iodine in 10 cm^3 of methanol was then added. The mixture was stirred at room temperature or at 45 °C for 2 h. The solvents were evaporated under reduced pressure, and the residue was dialyzed against ethanol for 24 h or gel filtered. In the case of the dialysis, the ethanol present inside the dialysis tube was then evaporated under vacuum. In the case of the gel filtration, the residue was filtered through a column loaded with G25 sepharose gel, and an ethanol−water (1:1, v:v) mixture was used as the mobile phase. The first noncolored fraction was recovered. The ethanol present in this fraction was evaporated under reduced pressure, and the residue was freeze-dried. According to the second method of deprotection, 1 g of polyDIPAGYL was dissolved in 10 cm^3 of acetone, and a mixture of 15 cm^3 of acetic acid and 5 cm^3 of water was added. The solution was stirred at various temperatures (≈50 °C) and for different periods of time (≈3 h). Finally, the solvents were evaporated, and the residue was dialyzed against an ethanol−water (1:1, v:v) mixture for 24 h. All the polymers were recovered as white powders.

Methods. NMR spectra were recorded using a 400 MHz (proton) Brucker spectrometer. Differential scanning calorimetry (DSC) analyses were performed with a Perkin-Elmer DSC6 microcalorimeter. The glass transition temperature was measured at the inflection point shown by postquenching runs conducted at a 10 °C/min heating rate. Thermogravimetric (TGA) analyses were performed with Perkin-Elmer TGA 6 equipment after preheating the sample at 130 °C for 10 min under an argon stream in order to eliminate the solvent remnants as well as the absorbed water. The sample was then cooled and analyzed by raising the temperature at a 10 °C/min heating rate. The molecular weight characteristics of the polymers were determined by steric exclusion chromatography (SEC) in tetrahydrofuran using a Waters chromatograph equipped with a 60 cm long 5 μm mixed-C PLgel column. Relative molecular weights were obtained from SEC chromatograms using the Maxima software and expressed with respect to polystyrene standards.

Table 1. Polymerization of DIPAGYL in Bulk (110 °C, 7 days, Initiator-to-Monomer Ratio = 1/300)

compd	initiator	final color	$\bar{M}_w$	yield (%)
1	zinc lactate	light brown	3 000	40
2	antimony fluoride	light brown	20 000	91
3	stannous octoate	light brown	20 000	73
4	potassium acetate	dark brown	5 500	90

Table 2. Extreme Values of the Variables Selected for the Experimental Design Used To Investigate the Polymerization of DIPAGYL

variable	level (−)	level (+)
polymerization temperature (°C)	95	120
polymerization time (days)	5	10
initiator-to-monomer ratio, I/M (mol/mol)	1/400	1/200
initiator batch	1	2
monomer purity	sublimed	recrystallized
degassing time (h)	1	2

Results and Discussion

Polymer Synthesis. In the first stage, four initiators were tested to polymerize DIPAGYL in bulk, namely zinc lactate, antimony fluoride, potassium acetate, and stannous octoate (stannous 2-ethylhexanoate). DIPAGYL was purified by sublimation before polymerization. The polymerization conditions were selected after the results of several preliminary tests. The best results of these preliminary tests are presented in Table 1. Two of the initiators yielded polyesters with rather high molecular weights ($\bar{M}_w \approx 20\,000$), namely stannous octoate and antimony fluoride. For further investigations, stannous octoate was selected because it has been approved by the American Food and Drug Administration and because it is largely used worldwide to make industrial PLAGA.

To increase the yield and the molecular weights provided by initiation in the presence of distilled stannous octoate, the influence of several variables was investigated. According to the literature, variables such as polymerization time and temperature, initiator concentration, monomer purity, degassing time, and number of vacuum/argon cycles are among the factors that control the ring-opening polymerization of lactides and the properties of the resulting polyesters.[6] Therefore, the classical investigation of so many possible factors that may not be independent was a difficult task. This is why we decided to approach the problem using the experimental design technique. Six main variables with two levels for each were chosen (Table 2), and eight experiments were conducted according to a 2^{6-3} fractional factorial experimental design.[7] The two batches of stannous octoate that were used had different IR spectra after simple vacuum distillation, as shown in Figure 1. For both, the carboxylate C═O stretching vibration in stannous octoate was observed at 1550 cm^{-1} as assigned by Dahlmann et al.[8] However, batch 1 showed a larger amount of 2-ethylhexanoic acid than batch 2, based on the carboxyl C═O stretching vibration located at 1707 cm^{-1}.

The experimental matrix and the responses measured for each experiment are summarized in Table 3. Calculated effects of each variable and their interactions on the responses are shown in Table 4.

The monomer purity and the initiator-to-monomer ratio (I/M) had the most important effects on the

Table 3. Experimental Matrix and Responses for Each Experiment

expt no.	temp (°C)	time (days)	I/M (mol/mol)	initiator batch	monomer purity	degassing time (h)	$\bar{M}_w$	yield (%)
1	95	5	1/400	2	sublimed	2	19 700	46
2	95	10	1/400	1	sublimed	1	22 700	47
3	95	5	1/200	2	recrystallized	1	5 300	52
4	95	10	1/200	1	recrystallized	2	3 900	65
5	120	5	1/400	1	recrystallized	2	13 200	88
6	120	10	1/400	2	recrystallized	1	7 700	88
7	120	5	1/200	1	sublimed	1	13 000	83
8	120	10	1/200	2	sublimed	2	17 800	93

molecular weights of polyDIPAGYL. Sublimation, performed to supplement two recrystallizations, led to an 83% average increase of the average $\bar{M}_w$ molecular weight. One hour period of degassing was not sufficient to remove all the volatile contaminants of the monomer. Decreasing the initiator concentration from I/M = 1/200 to I/M = 1/400 resulted in a 45% average increase of $\bar{M}_w$. Doubling the degassing time resulted in an 11% average increase of molecular weights. On the other hand, the variable influencing mostly the polymerization yield was the polymerization temperature. Increasing this temperature from 95 to 120 °C resulted in a 50% average increase of yield. The effects of the other variables were less important. For example, increasing the polymerization time from 5 to 10 days led to 8% average increase of the yield. The last variable, namely initiator batch, did not exhibit any significant influence on the two responses under the selected condition scale.

The trends provided by the experimental design allowed us to select suitable conditions for obtaining high molecular weight polyDIPAGYL with yields higher than 80%, namely polymerization temperature = 120 °C, polymerization time = 10 days, initiator-to-monomer ratio = 1/400, degassing time = 2 h, and monomer purified by sublimation after two recrystallization. A significant decrease of coloring was observed when the polymerization was carried out at 95 °C instead of 120 °C; however, the yields were decreased up to ≈50%.

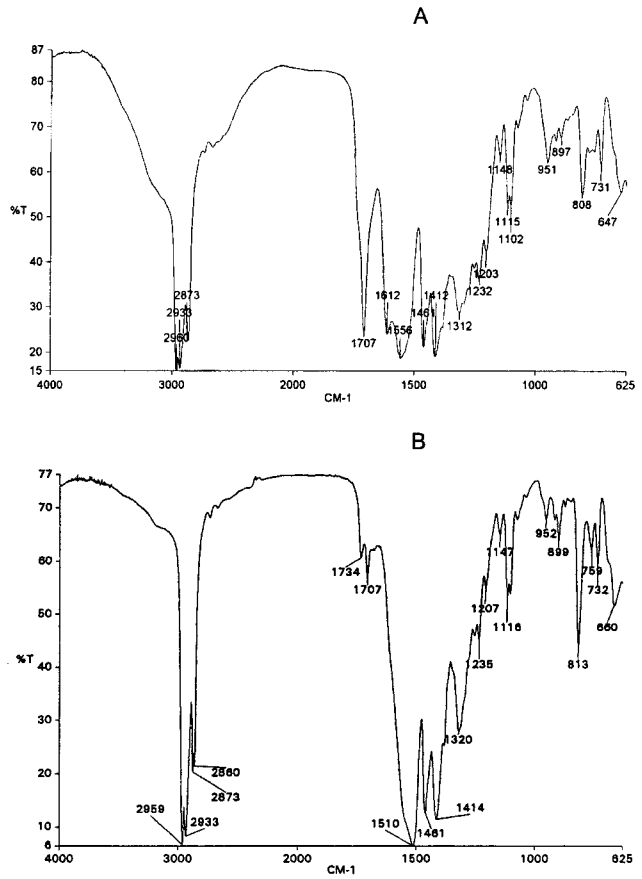


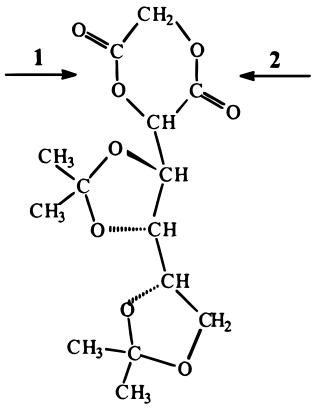
Figure 1. IR spectra of distilled stannous octoate: (A) batch 1; (B) batch 2.

Table 4. Estimated Effects on the Average Molecular Weight and on the Polymerization Yield

variables and interactions	effect on $\bar{M}_w$ (%)	effect on yield (%)
A: polymerization temp, +BD+CE	0	+50
B: polymerization time, +AD+CF	+2	+8
C: initiator-to-monomer ratio, +AE+BF	−45	+8
D: initiator batch, +AB+EF	−4	−1
E: monomer purity, +AC+DF	+83	−8
F: degassing time, +BC+DE	+11	+8
AF+BE+CD	+28	0

Polymer Characterization. Two polymers obtained in the presence of stannous octoate and antimony fluoride were characterized in more detail: polyDIPAGYL-Sn (run 2, Table 3) and polyDIPAGYL-Sb (compound **2**, Table 1). The polymers exhibited a light chestnut color that resisted reprecipitation and activated carbon treatment.

The IR, ^{1}H NMR, and ^{13}C NMR spectra of polyDIPAGYL were already reported.[5] In both types of NMR spectra, several signals were observed as shown in Figures 2 and 3. These peaks were probably due to the presence of different distributions of counit sequences, due to the asymmetry of the DIPAGYL molecule and the two possibilities of ring-opening through O-acyl cleavage, namely 1 and 2 in the following formula:



According to the well-known pair addition mechanism of polymerization of 1,4-dioxane-2,5-diones and in the absence of transesterification side reactions, the polymer chain should be composed of gluconic−glycolic (gG) or glycolic−gluconic (Gg) repeat unit pairs only, depending on the opened cyclic ester site. The probabilities of the existence of the two types of opening are P1 and P2. Of

Table 5. Relative Weights of *n*-ades in PolyDIPAGYL (G = Gluconic Repeat Unit, g = Glycolic Repeat Unit) after Bernoullian Addition of DIPAGYL Repeating Units, P1 Reflecting the Relative Reactivity of the Two Different Ester Bonds Present in the Cyclic Monomer Molecule

dyads	Gg gG h	GG gg H		
	$^1/_2(P1^2 - P1 + 1)$	$^1/_2(P1(1 - P1))$		
triads	GgG gGg hh	Ggg gGG hH GGg ggG Hh		
	$^1/_2(P1^2 + (1 - P1)^2)$	$^1/_2(P1(1 - P1))$		
tetrads	gGgG GgGg hhh	GggG gGGg hHh	GGgg HhH ggGg Hhh GgGG hhH	ggGG HhH gGgg hhH GGgG Hhh
	$^1/_2(P1^3 + (1 - P1)^3 + P1(1 - P1))$	$^1/_2(P1(1 - P1))$	$^1/_2(P1(1 - P1)^2)$	$^1/_2(P1^2(1 - P1))$

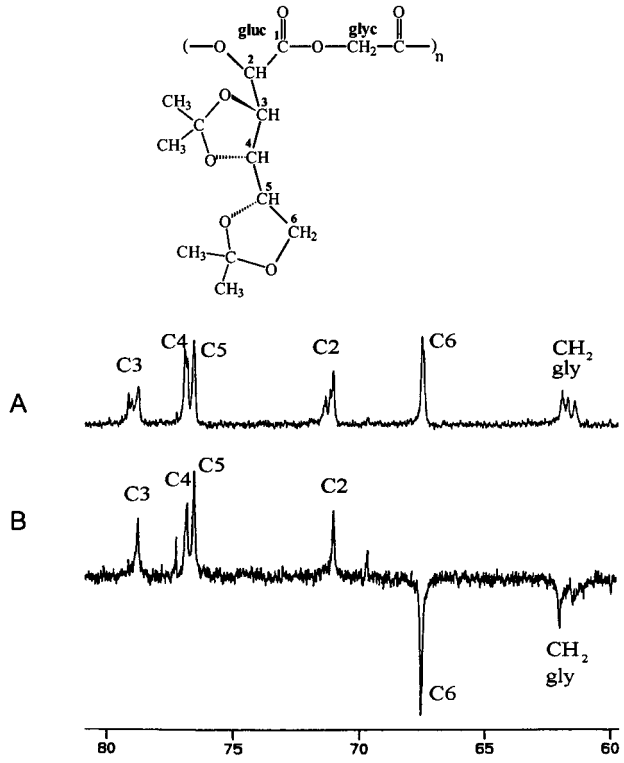


Figure 2. ^{13}C NMR spectra of polyDIPAGYL-Sn (A) and polyDIPAGYL-Sb (B) (DEPT), both in DMSO-d_6 (CH and CH_2 tertiary carbon atom resonances).

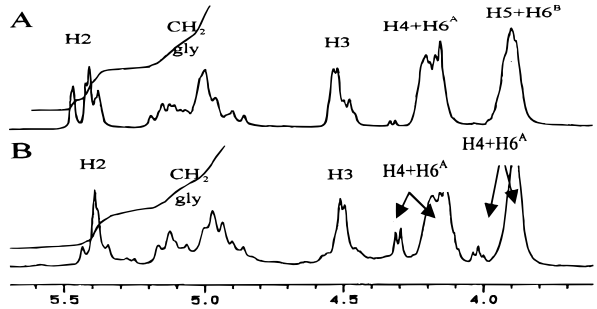


Figure 3. ^1H NMR spectra of polyDIPAGYL-Sn (A) and polyDIPAGYL-Sb (B), both in DMSO-d_6 (CH and CH_2 proton resonances).

course, P2 = 1 − P1. The calculation of the probability of occurrences of the various *n*-ades in the polymer chain can be evaluated by supposing that P1 is not dependent on the nature (g or G) of the end of the living chain according to a process similar to that used to calculate the frequency of *n*-ades in the case of DL-lactide ring-opening polymerization, as shown in Table 5. gG or Gg can be considered as "hetero"-dyads (instead of DL syndio-dyads) while GG and gg are "homo"-dyads (similar to DD and LL iso-dyads). By comparing with the results of Coudane et al.,[9] *n*-ades can be written as sequences of hetero (h)- or homo (H)-dyads of G and g units. In the case of a selective addition (P1 = 0 or P1 = 1), only alternating sequences are observed, and the relative weights of *n*-ades are dyads gG = Gg = $^1/_2$ (h = 1), triads gGg = GgG = $^1/_2$ (hh = 1), and tetrads GgGg = gGgG = $^1/_2$ (hhh = 1). For a totally nonselective addition (P1 = 0.5), corresponding to a Bernoullian-type addition, the following probabilities of sequence-forming were thus calculated:

$$gG = Gg = {}^3/_8 \ (h = {}^3/_4)$$
$$gg = GG = {}^1/_8 \ (H = {}^1/_4)$$
$$gGg = GgG = {}^1/_4 \ (h = {}^1/_2)$$
$$gGG = GGg = ggG = Ggg = {}^1/_8 \ (Hh = hH = {}^1/_4)$$
$$\text{etc.}$$

In Figure 2, the ^{13}C NMR spectra of polyDIPAGYL-Sn and polyDIPAGYL-Sb are compared. In the ^{13}C NMR spectrum of polyDIPAGYL-Sn, fine structures can be observed for the C2, C3, C4, and CH_2 of glycolic units. According to the relative positions of these carbon atoms in the polymer chain, they were more or less sensitive to the sequence effect. Three peaks are clearly observed for the glycolic C2, C3, and CH_2. The sequence sensitivities of C4, C5, and C6 were lower because of their position far from the polymer chain. According to these observations, one can suppose that at least three different sequences exist in polyDIPAGYL-Sn. In contrast, the ^{13}C NMR spectrum of polyDIPAGYL-Sb exhibits one signal only for each carbon atom. Therefore, these singlets were assigned to alternating sequences (gG and Gg).

To calculate the proportions of different sequences, ^1H NMR spectra of polyDIPAGYL-Sn and polyDIPAGYL-Sb shown in Figure 3 were used. In both spectra, H2 is the proton exhibiting three peaks located between 5.3 and 5.5 ppm. The H2 peaks were correlated to the three C2 signals in ^{13}C NMR spectra as shown by $^1H-^{13}C$ COSY NMR spectroscopy. H2 was also coupled to the H3 protons, but the coupling constant was low and did not allow the visualization of the splitting in the polymer spectra, based on the coupling constants of ca. 1 Hz observed for the H2 signals in the spectra of the monomer precursors.

The presence of H2 and C2 triplet signals led us to assume that the peaks corresponded to the GgG (hh), ggG (Hh), and Ggg (hH) triads. The probability of the occurrence of an Hh hetero triad is $^1/_2(P1^2 + (1 - P1)^2)$, as shown in Figure 4.

Table 6. Partial Deprotection of the Hydroxyl Functions of PolyDIPAGYL-Sn ($\bar{M}_w$ = 32 000)

reagents	reaction time (h)	temp (°C)	purification method	% of free OH groups[a]	$\bar{M}_w$[b]
acetic acid−water−acetone (3:1:2)	3	50	dialysis	60	5000
	5	40	dialysis	10	20000
iodine (1%)−acetone−methanol (1:1)	2	25	dialysis	45	4000
	2	45	gel filtration	50	6500

[a] As determined by ^{1}H NMR. [b] As determined by GPC in tetrahydrofuran.

Table 7. Solubility of Protected and Partially Deprotected PolyDIPAGYL in Various Solvents[a]

solvent	protected polymer	deprotected polymer (≈50%)	solvent	protected polymer	deprotected polymer (≈50%)
ether	−	−	DMSO	+	+
toluene	−	−	DMF	+	+
tetrahydrofuran	+	+	ethanol	−	+
chloroform	+	−	methanol	−	+
acetone	+	+	water	−	×
dioxane	+	+			

[a] Symbols: (−) insoluble, (+) soluble, and (×) partially soluble according to the molecular weight.

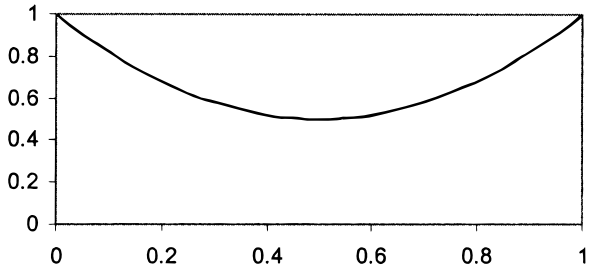


Figure 4. Variations of the relative weight of hh triads vs the probability of type 1 ring opening (P1).

The central peaks of the H2 signals were assigned to the hh sequences. The two remnant peaks correspond to Hh or hH sequences. In the spectrum of polyDIPAGYL-Sn, the surface areas under the three H2 signals count for about 20, 50, and 30%, respectively. These values are very close to those calculated for a nonselective DIPAGYL ring opening as described above (P1 = 0.5, hh = 0.5, Hh = hH = 0.25). The surface areas of H2 signals in the spectrum of polyDIPAGYL-Sb were 12, 75, and 13%, respectively. These values correspond well to the intermediate case of preferential opening at one side of the DIPAGYL ring (P1 = 0.85, hh = 0.75, Hh = hH = 0.125) only. In this case, the probabilities of occurrence for the two types of ring opening are 85 and 15%. However, the information necessary to correlate these probabilities to each of the two existing ester bonds is still missing. Dimeric model molecules of the H and h dyads could provide such information, but their syntheses failed so far.

The profiles of the CH_2 proton signals of glycolyl units were also different (4.8−5.3 ppm). The presence of a majority of alternating sequences in polyDIPAGYL-Sb resulted in two regular groups of peaks (4.8−5 and 5.05−5.3 ppm). In contrast, the polyDIPAGYL-Sn signal exhibited irregular multiplets. The low-intensity signals located at 4.3 and 4.0 ppm in the spectrum of polyDIPAGYL-Sb were assigned to part of the multiplets of protons $H6^A$ and $H6^B$ after the ^{1}H−^{13}C COSY NMR spectrum, thus showing the differences in repeat unit distributions between the two differently initiated polymers.

The polymer thermal properties were investigated by using DSC and TGA. According to TGA thermograms, both polymers appeared rather resistant to thermal degradation. The loss of weight started above 210 °C and a ca. 90% weight loss occurred between 220 and 340 °C. According to DSC, the glass transition temperature was at ca. 95 °C. None of the copolymers exhibited melting endotherm, suggesting an amorphous morphology which was confirmed by X-ray scattering analysis.

Attempts were made to process the polyDIPAGYL copolymers to films by solution casting and solvent evaporation. The films were brittle and could not be recovered from the glass dishes. Compression molding led to similar problems. Failures were probably due to insufficient initial molecular weights. The presence of the bulky pendent sugar residues could also be the source of polymer chain rigidity. The poor processability of the homopolyDIPAGYL limited the range of possible applications as a biomaterial, so far. However, this polymer should be usable to make micro- or nanoparticles. It could also be combined with other PLAGA-type polymers to make blends and thus enlarge the accessible property ranges. It is likely that increasing the molecular weight will be possible in the future as it was the case for PLAGA polymers in the early days.

Deprotection of Hydroxyl Pendent Groups. The cleavage of isopropylidene groups is usually conducted under acidic conditions. Several methods were investigated to deprotect polyDIPAGYL-Sn, but most of them degraded the polyester chain completely. The best results were obtained in the presence of iodine and methanol or aqueous acetic acid as shown in Table 6. GPC data in THF showed an important decrease of molecular weights. However, the exact effect of the hydroxyl groups on the hydrodynamic volume of poly(DIPAGYL) as compared with polystyrene standard is still unknown. The maximum deprotection, determined via the integration ratio of the CH_3 peaks of the isopropylidene on the CH or CH_2 peaks of the polymer, was 60% under the tested conditions. Only about half of the isopropylidene groups were removed, suggesting that some of the protecting groups could not react either because of steric hindrance or maybe because all the groups were not equivalent according to their position in the side chains. According to the literature,[10] iodine in methanol or acetic acid selectively cleaves isopropylidene groups protecting primary alcohols. In the present case, the cleavage of the 5,6-isopropylidene group was preferential as shown by comparing the ^{1}H and ^{13}C NMR spectra of the polymers before and after deprotection (Figure 5).

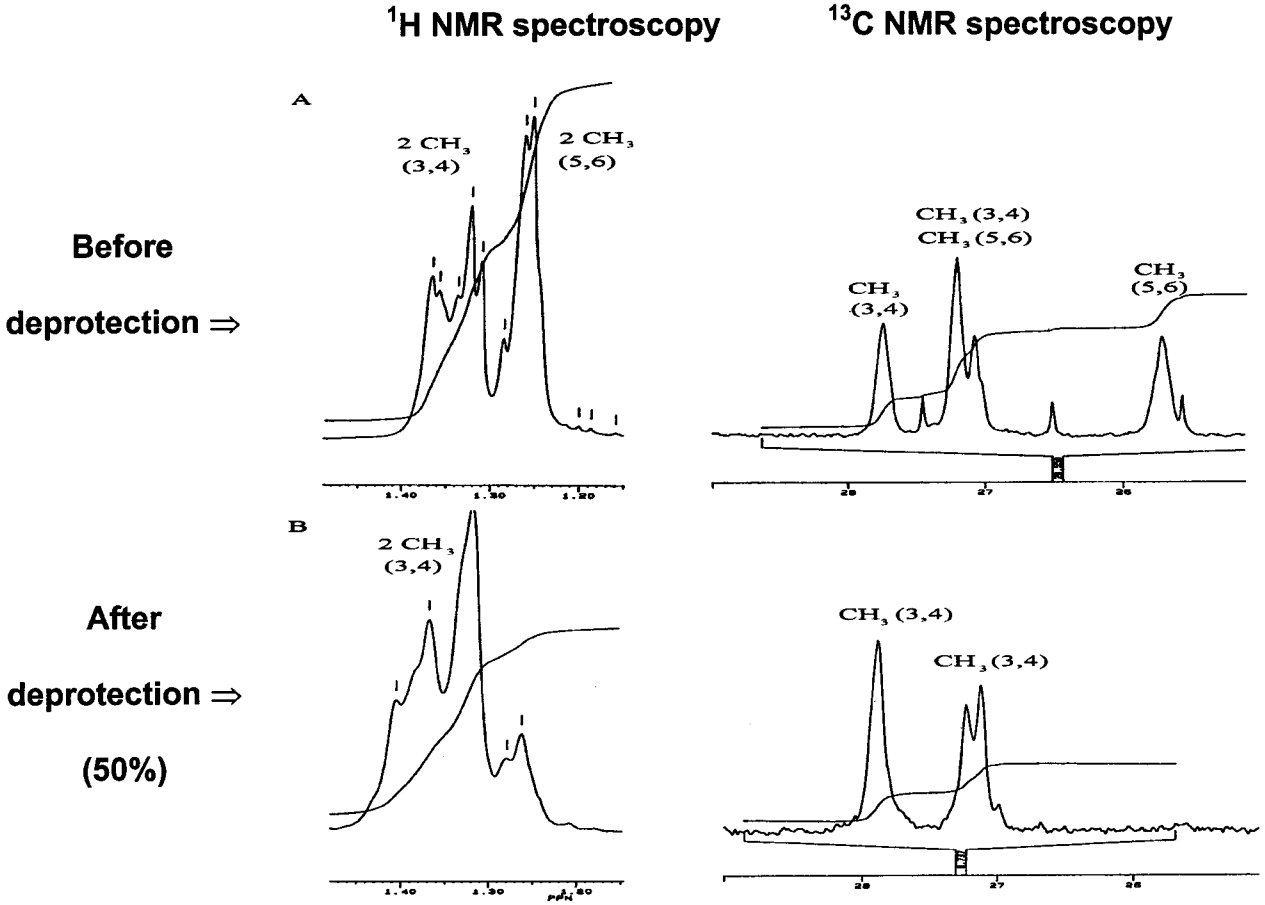


Figure 5. Selective cleavage of 5,6-isopropylidene groups of polyDIPAGYL.

In Table 7 comparison is made of the behavior of polyDIPAGYL and of partially deprotected polyDIPAGYL in water and organic solvents. The presence of the free OH groups in the partially deprotected polymer chains promoted solubilization in hydrophilic solvents such as methanol and ethanol and partial solubility in water probably according to molecular weight.

The partially deprotected polyDIPAGYL containing different ratios of free OH groups can be chemically modified and their physicochemical properties adjusted. The presence of pendent hydrophilic groups as well as a possibility of coupling biologically active molecules is of great potential interest for biomedical and pharmacological applications.

Conclusion

A new degradable polyester of the PLAGA family, namely polyDIPAGYL, was synthesized from gluconic and glycolic acids and characterized. High molecular weight polymers can be obtained by bulk polymerization using stannous octoate or antimony fluoride as initiator. The influence of six variables on the polymerization yield and on the molecular weights of the polymers was studied. The monomer purity and the initiator-to-monomer ratio had the most important influence on the molecular weights. The polymerization temperature was the only variable significantly influencing the yield of the polymerization. The present polyDIPAGYL polymers were amorphous and interestingly enough had rather high glass transition temperatures ($T_g \approx 95$ °C) as compared to those of PLAGA polymers and copolymers. The analysis of NMR spectra of polyDIPAGYL-Sn led to the conclusion that the two different ester bonds present in the DIPAGYL cyclic molecule had the same reactivity when allowed to react in the presence of stannous octoate. In contrast, antimony fluoride opened the DIPAGYL ring preferentially from one side (with a probability of 85%) and formed regular alternating sequences in majority. The more reactive group has not been identified yet. The hydroxyl functions of polyDIPAGYL can be deprotected at least partially, the cleavage being selective for the 5,6-isopropylidene group. PolyDIPAGYL with 50% of free OH groups was soluble in alcohols and partially soluble in water. PolyDIPAGYL enlarges the family of degradable polymers and is among the first synthetic degradable polyesters bearing pendent hydroxyl groups. These types of polymers are generally aimed at pharmacological applications for controlled drug delivery. The high glass transition temperature makes polyDIPAGYL a very interesting material for commodity applications; however, the low molecular weights and the low processability are the major shortcomings of the polymer for the moment. It is likely that molecular weight, yield, and the different properties reported in this contribution will be improved in the future as was the case for PLAGA polymers in the past, due to a better understanding of the monomer properties and purification.

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