Phosphorylcholine End-Capped Poly-ε-Caprolactone: A Novel Biodegradable Material with Improved Antiadsorption Property

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ABSTRACT: In this study, the synthesis, characterization, and properties of a novel biodegradable polymer with improved hemocompatibility were introduced. It was synthesized by end-capping poly-ε-caprolactone (PCL) with phosphorylcholine (PC) groups. The polyester backbone provided the mechanical stability and biodegradability, while the PC-end groups improved its hemocompatibility. The obtained polymer was characterized using ^{1}H NMR, ^{31}P NMR, FTIR, and GPC, its crystallization behavior was studied by DSC. Compared with original PCL, the resulting polymer (PC-PCL) showed a lower crystallization capability and a faster degradation rate in PBS. The degradation rate of the polymer blends of PCL/PC-PCL increased with increasing PC-PCL content. The results of water contact angle measurements revealed a more hydrophilic surface property of PC-PCL than neat PCL. The hemocompatibility of PC-PCL was estimated using rabbit platelet-rich plasma, a better resistance to platelet adhesion and activation was observed. During the human blood plasma contacting process, PC-PCL showed a prolonged activated partial thromboplastin time over neat PCL. Material–cell interaction was evaluated with human umbilical vein endothelial cell, the result indicated that PC-PCL may to some extent have an antihyperplasia property, compared with neat PCL. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 103: 989–997, 2007

Key words: phospholipids; polyesters; biodegradable; biocompatibility

INTRODUCTION

In the past several decades, researchers have searched in vain for a perfect material that could satisfy all the rigorous requirements in the biomedical field. A number of artificial and natural materials have been examined; however, scientists are yet to find ''the one.''

What on earth should a biomaterial be? Biocompatibility is one of the most important properties of biomaterials used in a vital environment. This ensures that the material will not be recognized as a foreign element when in contact with the biological system. For example, as is known to all, the success of blood-contacting appliances is largely determined by their interaction with proteins in blood. Therefore, one way to improve the performance of polymers for medical applications is to control protein adsorption. Many phospholipidlike biomaterials were synthesized,[1–4] among which the phosphorylcholine (PC)-containing polymers, which came from the monomer, 2-methacryloyloxyethyl phosphorylcholine (MPC), showed significantly improved blood compatibility because of reduced plasma protein adsorption. Using this monomer, many PC-containing polymers were synthesized by Ishihara et al.[5–8] They indicated that the denaturing of the proteins adsorbed onto the PC-modified surfaces could be greatly limited because of their biomembranelike structure.[9,10] Lewis, with his team, also did lots of research in the properties and applications of the PC-containing polymers, mainly the copolymers of MPC.[11–14]

Another property of importance for biomaterials is biodegradability, which gives this kind of material the capability to replace the damaged biologic apparatus via tissue engineering,[15] for example, artificial skin, synthetic bones, blood vessels, or even more complex artificial organs. In addition, biodegradable materials could act as soft tissue implants in human bodies when used for drug delivery systems, which may release drugs specifically to the target site to decrease the amount of drugs and the risk of adverse side reactions.[16,17] Significantly, all the compounds produced during the degradation of biodegradable polymers must be nontoxic and nonanaphylactic. The

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most thoroughly investigated and widely used biodegradable polymers are aliphatic polyesters, such as polylactide (PLA), polyglycolide (PGA), poly-ε-caprolactone (PCL), and their copolymers, which can degrade into nontoxic substances that are readily metabolized by the human body.

Phosphorylcholine-modified aromatic polyesters (Dacron) had been reported by Hall et al. many years ago.[18] Lately, Iwasaki et al. introduced phosphorylcholine moieties into biodegradable aliphatic polyesters.[19] l-α-Glycerophosphorylcholine (LGPC) was used to initiate the polymerization of L-lactide in the presence of stannous octoate as the catalyst, which finally produced a PLLA-based phospholipid polymer. In addition, they found that by increasing the LGPC content in the polymer, there was simultaneously an increase in the degradation rate, and a decrease in crystallinity and platelet adsorption.

Recently, Hilborn and coworkers reported that they synthesized a series of PCL with various functional polar end-groups on one end,[20] including the zwitterionic PC group, anionic succinic acid, and cationic quaternary ammonium. However, they did not provide the results of the tests on hemocompatibility and biodegradability.

In this work, we prepared phosphorylcholine end-capped PCL starting from linear PCL with a hydroxyl group on each end, by which, with two PC-terminations in one molecular chain, provided this biodegradable polyester a hydrophilic surface to withstand blood platelet attacking, while maintaining the mechanical performance belonging to the raw polymer. This kind of modification may be highly interesting, since it introduced nonthrombogenic and antiadhesion properties into biodegradable polymers, and provided the potential to develop materials with self-regenerating, antifouling surfaces along with controllable degradation and drug-releasing properties.

EXPERIMENT SECTION

Material

Poly-ε-caprolactone (PCL) with two primary hydroxyl end groups in each chain was synthesized in our lab by a bulk ring-opening polymerization started with glycol. Before use, it was dried *in vacuo* at 40°C over night. 2-Chloro-2-oxo-1,3,2-dioxaphospholane (COP) was synthesized according to the methods of Lucas et al.[21] and Edmundson.[22] The structure of the resulting compound was characterized using the GC-MS technique (Voyager), which also gave the purity of COP (96.95%). All the other raw materials and solvents were dried and purified according to standard methods.

Synthesis

A mixture of 8 g (0.001 mol) PCL and 0.202 g triethylamine (TEA, 0.002 mol) was dissolved in 100 mL of dried THF in a flask purged with nitrogen. The solution of 0.285 g (0.002 mol) COP and 50 mL THF was slowly added dropwise through a predried dropping funnel with magnetic stirring for about 5 h. All the operations above were performed at −15°C. Then the system was slowly heated to room temperature and stirred for another 2 h before rotary distillation to remove the solvent from the intermediate COP-PCL.

Then 40 mL dry acetonitrile saturated with trimethylamine (TMA) was added to another round-bottom flask with COP-PCL. The solution was slowly heated to 70°C and stirred magnetically for 48 h. The reaction product was carefully heated to drive away the residual TMA into H_2SO_4, and then precipitated in cold methanol. Phosphorylcholine-based PCL (PC-PCL), the precipitate, was collected and after another dissolve/precipitation cycle with THF/petroleum ether, it was dried *in vacuo* until constant weight was reached.

Characterization

^{1}H NMR spectra of PCL, COP-PCL, and PC-PCL were recorded with a Bruker model AVANCE DMX-500 spectrometer, using tetramethylsilane (TMS) as reference and solvent ($CDCl_3$) proton signal as an internal standard. Solid state ^{31}P NMR spectra of COP-PCL and PC-PCL were recorded with an InfinityPlus 300 Nuclear Magnetic Resonance apparatus, using $NH_4H_2PO_4$ as reference. The FTIR spectra were obtained with a Magna-550 FTIR spectrometer (Nicolet). Samples were prepared as thin films by casting from THF solutions onto a KCl plate. Degradation of PC-PCL was analyzed by the measurement of the weight change of the granulated samples in the phosphate buffering solution (PBS, pH = 7.4) on a 37°C shaking bath. A differential scanning calorimeter (DSC 204, NETZSCH) was used to study the thermal dynamic properties of the resulting polymer. Analysis was carried out from 80°C to −10°C at a cooling rate of 5°C/min, followed by heating back to 80°C at the same rate. Molecular weight and molecular weight distribution were analyzed by gel permeation chromatography (Agilent 1100 equipped with 3 PL-gel columns) with a flow rate of THF eluent at 0.50 mL/min, and a column temperature of 40°C, standard PS samples were used for calibration. Static-state water contact angle of the resulting polymer membrane was determined with a JJC-1 wetness measurement machine (Zhongcheng, Shanghai). The sample membranes were prepared by spin coating and the data were collected for ten times to give an average value.

Hemocompatibility evaluation

Human blood plasma activated partial thromboplastin time (APTT), prothrombin time (PT), and throm-

boplastin time (TT) of PCL and PC-PCL (Quartz used as the control) was measured on a sysmex CA-1500 using DADE BEHRING Actin, DADE BEHRING Thromburel's, and DADE BEHRING Test-Thrombin Reagents, accordingly, paired *t*-test was used and the significant level was set to $P < 0.03$. Full human blood obtained from healthy volunteers was mixed with 0.2 mL trisodium citrate (109 m*M*) and transferred into plates coated with PCL and PC-PCL, respectively, for a contact time of 1 h. Quartz was used as control. Plasma was prepared by centrifuging the treated blood at 3000 rpm for 15 min and then tested.

Also, the sample was spin-coated on a cleaned PET sheet for platelet adhesion test. Blood was drawn from healthy rabbits and mixed with a 1/9 volume of 3.8 wt % trisodium citrate solution immediately. Platelet-rich plasma (PRP) was obtained by centrifugation of the anticoagulated blood at 1200 rpm for 5 min. Then, it was placed on the polymer surface prewashed by PBS and incubated for an appointed period of time at 37°C. After the incubation, the sample sheets were washed three times with PBS, they were then immersed into 1% glutaraldehyde in PBS for 60 min at 4°C to fix the adhered platelets. The sample was air-dried and sputter-coated with gold using a JEOL JFC-1600 auto fine coater prior to the observation with scanning electron microscopy (JEOL JSM-5600LV).

Cell culture

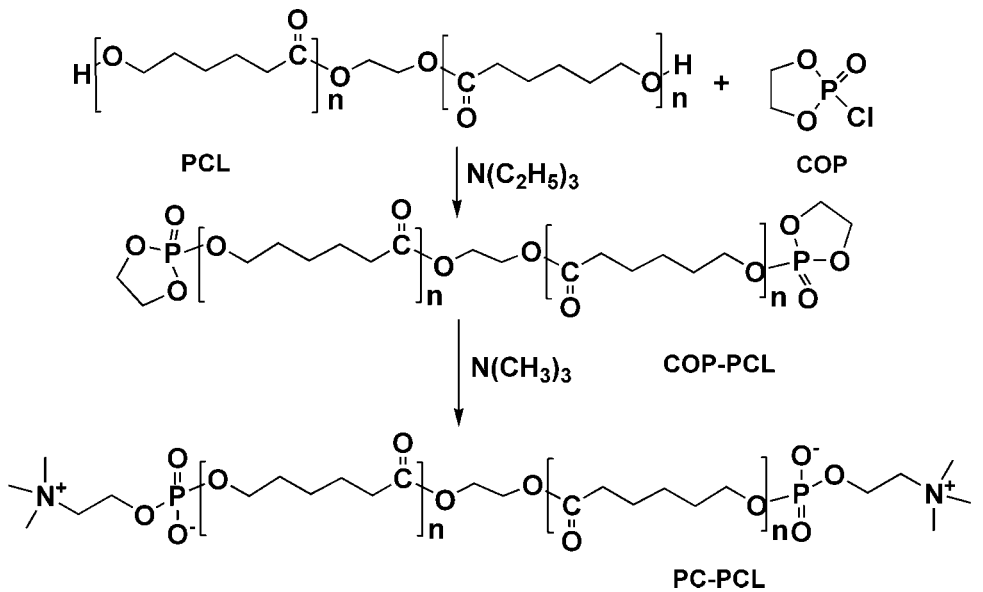
HUVECs were used because they are well characterized and ECs isolated from vein sources are likely candidates for clinical harvest and cell seeding applications.[23] The HUVECs (purchased from Nanjing University of traditional Chinese medicine), which were cultured in EC growth medium (EGM), consist of 10% new born calf serum (NCS) and Dulbecco's modified Eagle's medium (DMEM, Life Technologies). The HUVECs were grown in six-well plates coated with PCL and PC-PCL, respectively, incubated at 37°C and 5% CO_2; tissue culture-treated polystyrene six-well plates (Orange Scientific) were used as normal control. HUVECs, which had grown for 24 h on the materials, were imaged with a Leica DM IRB microscope equipped with a Leica DC100 camera and cell number was counted manually. The cell cycles were analyzed using a FACS Calibur (BECTON DICKINSON) with CycleTEST^{TM} PLUS DNA Reagent Kit (BECTON DICKINSON). The results are expressed as mean ± standard deviation (SD). All significant data in this work were demonstrated using the paired *t*-test and the significant level was set to $P < 0.05$.

RESULTS AND DISCUSSION

Structure analyses of PC-PCL

As is shown in Scheme 1, the synthesis process for the preparation of PC-PCL requires two separate steps. ^{1}H NMR and ^{31}P NMR analysis was used to monitor the buildup of the resulting polymer and the intermediate products, which showed the conversion of the three-step end-group conversion procedure.

From the NMR spectrum of neat PCL, ^{1}H NMR ($CDCl_3$): δ = 1.39 (m, 2H, —CH_2—, poly), 3.64 (s, 1H, —OH, ω-end), 1.64 (m, 4H, —CH_2—, poly), 2.30 (m, 2H, —$CH_2C(O)O$—, poly), 4.07 (m, 2H, —CH_2O—, poly), the two hydroxyl groups in the raw PCL gave out a peak located in a comparatively low chemistry



Scheme 1 Synthesis of PC-PCL.

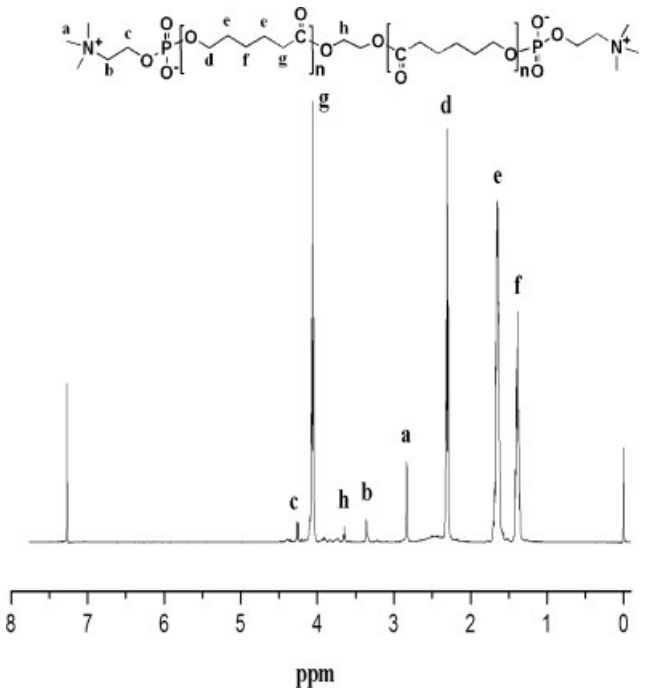


Figure 1 ^{1}H NMR spectra of PC-PCL. The inset shows the respective chemical structure.

displacement, which indicated the strong hydrogen bonding effect in this crystalline polymer. With the change in the terminal group, the modified product, PC-PCL, its ^{1}H NMR ($CDCl_3$) spectrum (Fig. 1): $\delta = 1.39$ (m, 2H, —CH_2—, poly), 1.64 (m, 4H, —CH_2—, poly), 2.30 (m, 2H, —$CH_2C(O)O$—), 2.83 (m, 9H, —$N^+(CH_3)_3$, ω-end), 3.36 (s, 2H, —N^+CH_2—, ω-end, poly); 4.07 (m, 2H, —CH_2O—, poly), 4.24 (m, 2H, —CH_2O—, ω-end); showed an increase in the resonances at 2.83, 3.36, and 4.24 ppm, which corresponded to the appended phosphorylcholine. The solid-state ^{31}P NMR spectrum of PC-PCL (Fig. 2, right) showed only one peak located at $\delta = 7.6$ (s), which indicated that there is only one chemical environment for the phosphorus in PC-PCL. Combined with the disappearance of the signal of the hydroxyl group, the terminal hydroxyl groups of PCL were thus proved to be highly converted.

We have calculated the phosphorus content in PC-PCL from the ^{1}H NMR results (see Table I), in which the peak area of the 9 H atoms located at $\delta = 2.83$ in the —$N^+(CH_3)_3$ end and the 4 H atoms in —CH_2— of the polymer located at $\delta = 2.30$ were compared. Considering the equimolar feed of COP and terminal hydroxyl groups of PCL in the first step, the whole conversion of the synthesis was thus confirmed to be 73.87% according to the ^{1}H NMR results. The comparatively high conversion may result in the relatively low molecular weight of PCL we used.

^{1}H NMR was also used in characterizing the intermediate production COP-PCL. ^{1}H NMR ($CDCl_3$) $\delta = 1.39$ (m, 2H, —CH_2—, poly), 1.64 (m, 4H, —CH_2—, poly), 2.30 (m, 2H, —$CH_2C(O)O$—, poly), 4.07 (m, 2H, —CH_2O—, poly); ^{31}P NMR $\delta = 8.0$ (s), in which the resonances of hydroxyl groups ($\delta = 3.64$) almost disappeared, indicated the high conversion of the end-groups. As a result, there we observed an almost indiscernible signal ranging from 1.8 to 2.2 ppm in

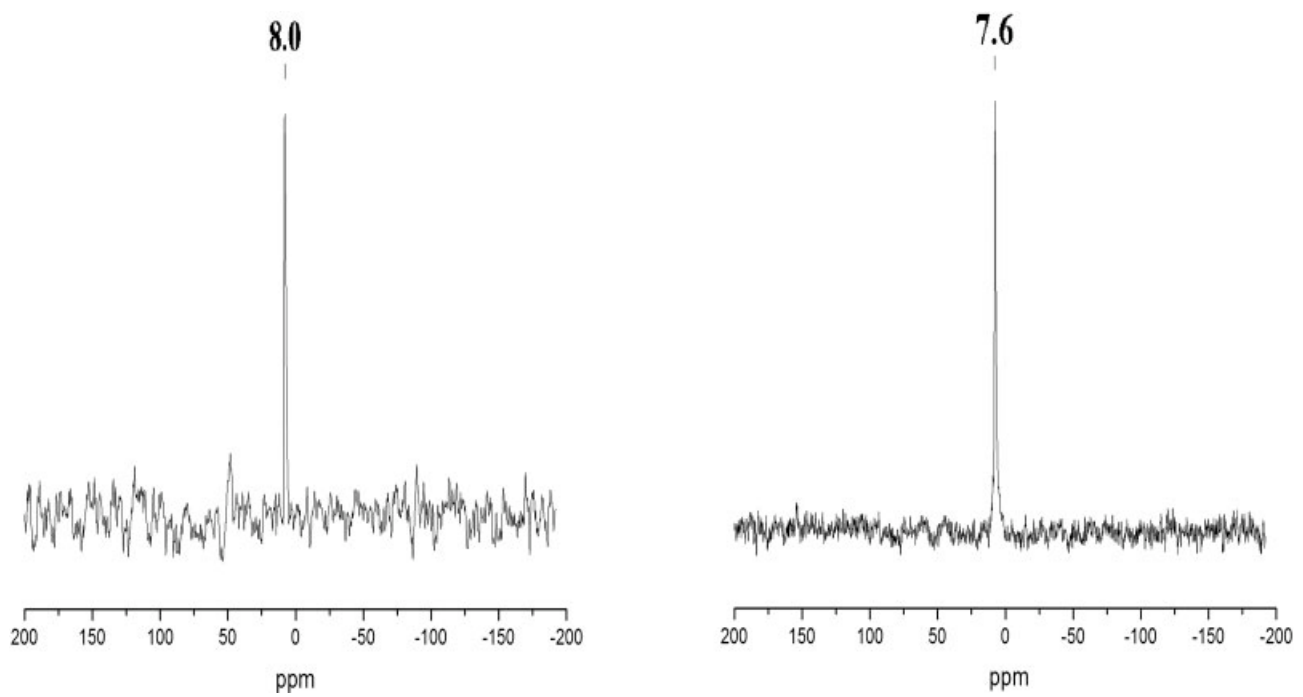


Figure 2 ^{31}P NMR spectra of COP-PCL (left) and PC-PCL (right).

TABLE I
Characterization of PCL and PC-PCL

	M_w (10^3)	M_n (10^3)	M_w/M_n	P content (μg/g)		Water contact angle (°)
				In feed	Calculated[a]	
PCL	11.72	7.51	1.56	–	–	42.28 ± 10.30
PC-PCL	11.69	8.12	1.44	1550	1145	17.00 ± 3.89
PCL[b]	11.95	5.71	2.09	–	–	–
PC-PCL[b]	7.13	2.69	2.65	–	–	–

[a] Calculated from ^{1}H NMR results.
[b] For the samples degraded *in vitro* in PBS (pH = 7.4) after 240 h.

the case of the four hydrogen atoms of the same chemical environment in the COP ring.

FTIR spectra (Fig. 3) were used to investigate the structural changes during the synthesis process. Unfortunately we could barely recognize the characteristic absorption peaks, due to a strong absorbance in the 1000–1500 cm^{-1} domain ascribed to the vibrations of C—C bond and C—O bond in the polyester backbone. Similarly, we could not find signals referring to the P=O stretching, because of the screening effect of the carbonyl group. It is normally difficult to clearly locate structural changes on terminal functional groups of polymers, because the intensities of the end-groups were low and the repeating units of the polymer backbone obscured the resonance of the modified end-groups. The only recognizable vibration band of the PC group was the N^+—C stretch in $—N^+(CH3)_3$ at 970 cm^{-1}.

However, another interesting phenomenon could be observed when comparing the IR spectra of PCL and PC-PCL. As reported by Keroack and coworkers,[24] there were two absorption peaks situated at 1242 and 1189 cm^{-1}, which related to the crystallizing state of PCL. From the IR spectrum of PC-PCL, it can be seen that the peak at 1242 cm^{-1} moved to 1235 cm^{-1}, while the 1189 cm^{-1} peak moved to 1164 cm^{-1}. The peak at 1164 cm^{-1} was proved to be related to the amorphous state, whereas the peak at 1189 cm^{-1} referred to the oriented arrangement and conformations among PCL chains.[24] Thus, it suggested that with the modification of PCL by PC end-groups, which replaced the intrinsic hydroxyl groups, the assembling behavior among the polymer chains changed from crystalline to amorphous. This conclusion could be further confirmed with the result of DSC measurement, a subsequent test.

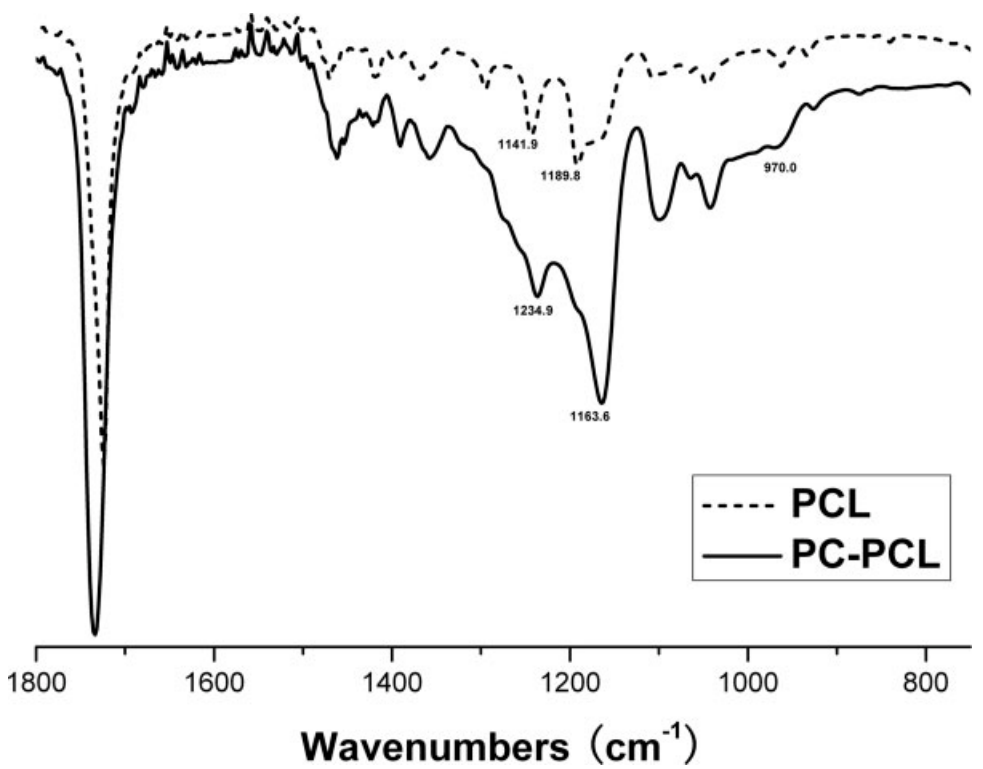


Figure 3 FTIR spectra of PCL and PC-PCL.

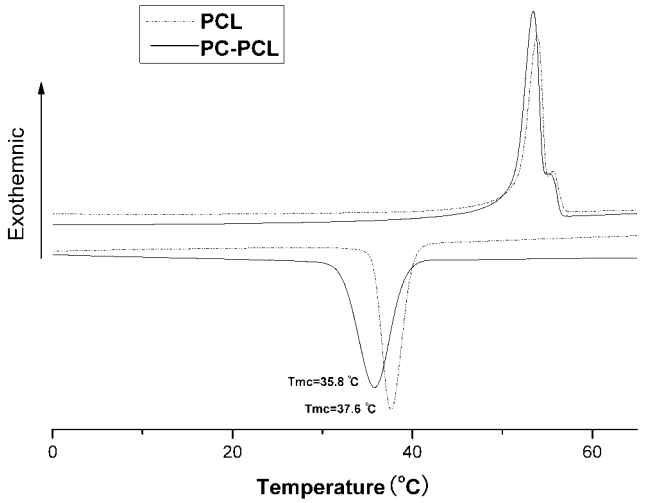


Figure 4 DSC curves of PCL and PC-PCL.

Properties of PC-PCL

DSC measurement

Thermodynamic characteristics of PC-PCL were analyzed with DSC test. The DSC curve of the crystallization process of the PC-modified PCL along with the original PCL was shown in Figure 4, in which we could observe a narrow exothermic peak of PC-PCL located at 35.8°C that began from 39.2°C, compared with the crystallizing peak of PCL at 37.6°C that began from 40.1°C. The crystallization temperature during melt cooling (T_{mc}) of PC-PCL was ~2°C lower than the unmodified polymer. This was in accordance with what we learned from the FTIR results. With the introduction of PC end groups to PCL molecules, there has been an obvious trend of morphology change from crystalline to the amorphous form. The lower T_{mc} of PC-PCL also suggested that the crystallization of PCL was interfered by the replacement of the terminal hydroxyl groups with PC groups.

T_m of both PCL and PC-PCL were estimated from the melting DSC curve, and there seemed to be no obvious difference between these two polymers. According to Ref. 25, the parameter T_{mc} is used to evaluate the nucleation during polymer melt crystallization. The higher the T_{mc}, the easier the stable nucleus can be formed via the regular arrangement of polymer segments, and thus the higher crystallizing ability of the polymer. Since stable nuclei are difficult to form near the melting point, the supercooling degree is the thermodynamic drive. The smaller value of T_m and T_{mc} indicates the higher crystallization ability of the polymer.

Furthermore, the enthalpy during the crystalline process of PC-PCL (69.93 J/g) was smaller than that of the unmodified PCL (75.87 J/g), which indicated a comparatively low crystallinity of PC-PCL. So it can be concluded that the modification of PCL with PC end-groups lowers the crystallizing ability of this biodegradable polymer. This may accelerate both the diffusion of small molecules like water and drug throughout the material and the degradation rate of the polymer matrix. This material may found its application as a potential controlled release carrier.

T_g of PCL was observed at −67.7°C, while there was no T_g detected for PC-PCL, this phenomena may be caused by the physical crosslinking induced by the addition of the zwitterionic polar terminal groups,[26] which may also contribute to the self-assembly ability of this material, offering a potential application for self-assembling nanoscaled drug loading particles or coatings in the future application.

Degradation test

The blend of PCL and PC-PCL can be easily made by solution-mixing in THF and then casting. Granules of PCL, PC-PCL, and their blends weighing around 0.1 g each were prepared for the degradation test. The content of PC-PCL in the blends was 20, 40, 60, and 80 wt %, respectively, and accordingly named PC20, PC40, PC60, and PC80. The polymer granules were quantified accurately before being immersed into PBS in a 37°C, 60 rpm thermostatic shaking table. The extent of degradation was measured by the solid remaining ratio, as shown in Figure 5.

The degradation data indicated that PC-PCL particles exhibited a rather faster rate of degradation, compared to the original PCL particles. For PC-PCL/PCL blends, the more PC-PCL it contained, the faster degradation rate it reached. The reason may lie in the weakened crystallizing ability of PCL after the modification process as well as the introduction of hydrophilic phosphorylcholine end groups. These two fac-

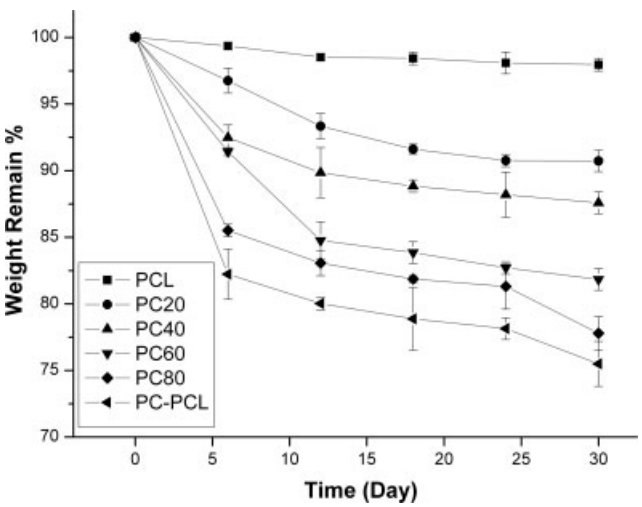


Figure 5 Degradation test of the PCL, PC-PCL, and their blends in PBS.

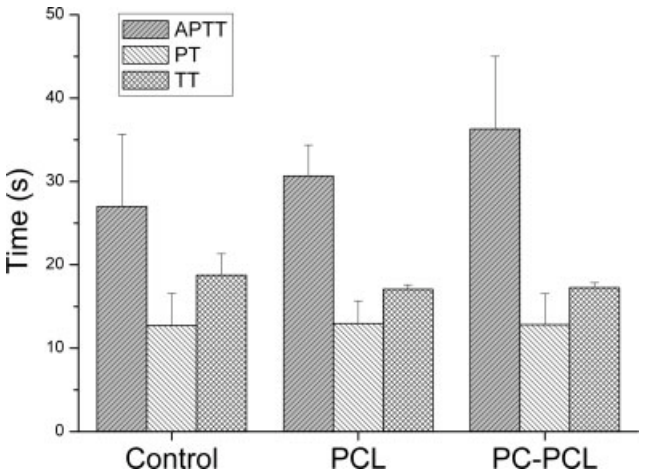


Figure 6 APTT, PT, and TT of PCL and PC-PCL (quartz used as control).

tors greatly enhanced the water diffusion among the PC-PCL chains; therefore, the hydrolization rate of PC-PCL was accelerated as a result. This kind of fast-degraded PCL derivative offered us a convenient method to adjust the degradation rate of PCL by easily blending it with PC-PCL.

The molecular weight and molecular-weight distribution of the polymers in this study were determined by GPC. As shown in Table I, the number-average molecular weight (M_n) of the PC-PCL became a little bit larger compared to neat PCL, which is the consequential result of the addition of the phosphorylcholine end-groups. It can also be found that the molecular-weight distribution became narrower at the same time, possibly because of the multiple manipulations of dissolving and precipitation during synthesizing. We also measured the molecular weight of the sample after degradation for 240 h, at which point the weight-average molecular weight (M_w) of the PC-PCL decreased almost in half, while the neat PCL showed little obvious change. Furthermore, the molecular-weight distributions of both the samples broadened, which indicated that there was a considerable amount of degradation products, which had a comparatively lower molecular weight. This result matched commendably with the data of weight-loss we mentioned above and also proved that the introduction of the PC groups accelerated the degradation rate remarkably.

Static water contact angle

Static water contact angle measurement was used to evaluate the surface hydrophilicity of PC-PCL. As it is shown in Table I, the surface of poly-ε-caprolactone after the modification exhibited a salient decrease in water contact angle, i.e., the polymer surface became much more hydrophilic as a result of the introduction of the phosphorylcholine groups with strong hydrophilicity. According to Brunius' theory,[27] it would lower the surface energy while improving the hydrophilicity of the material, and would greatly influence the interactions and activations between organism and material surface when in contact. To some extent, the hydrophilicity of the surface has a direct relationship to the biocompatibility or hemocompatibility of this material.

Hemocompatibility of PC-PCL

Blood plasma APTT, PT, and TT test are the most commonly used methods to evaluate the anticoagulant property of the materials. As shown in Figure 6, only APTT varied remarkably. The prolongation of APTT indicated a better anticoagulant property of PC-PCL and was always related to the lack of factor VIII, IX, and XI, in consonance with the antithrombogenic mechanism of phosphorylcholine moieties proposed before. The TT value distinguished little between PCL and PC-PCL, for it was only sensitive to heparin or heparinlike substance contained in the blood.

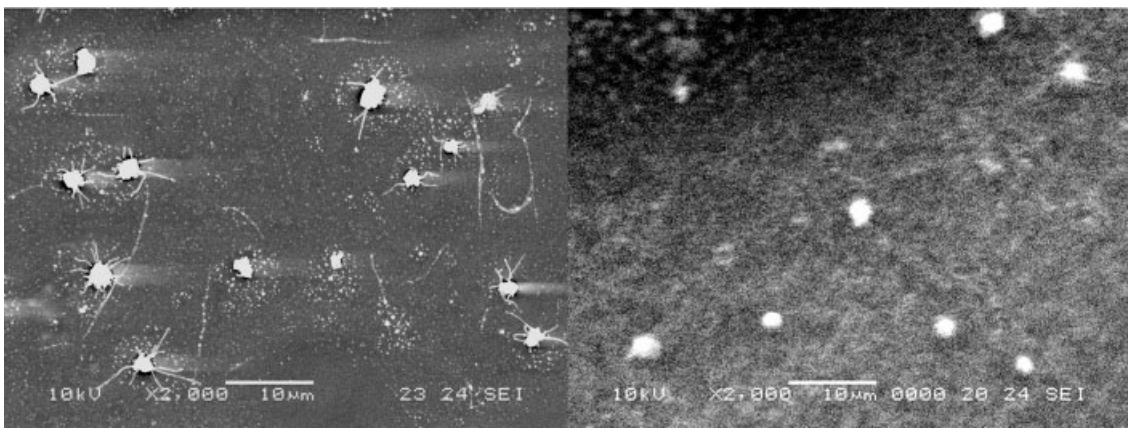


Figure 7 SEM images of polymer surface after contact with PRP for 2 h (Left: PCL, Right: PC-PCL).

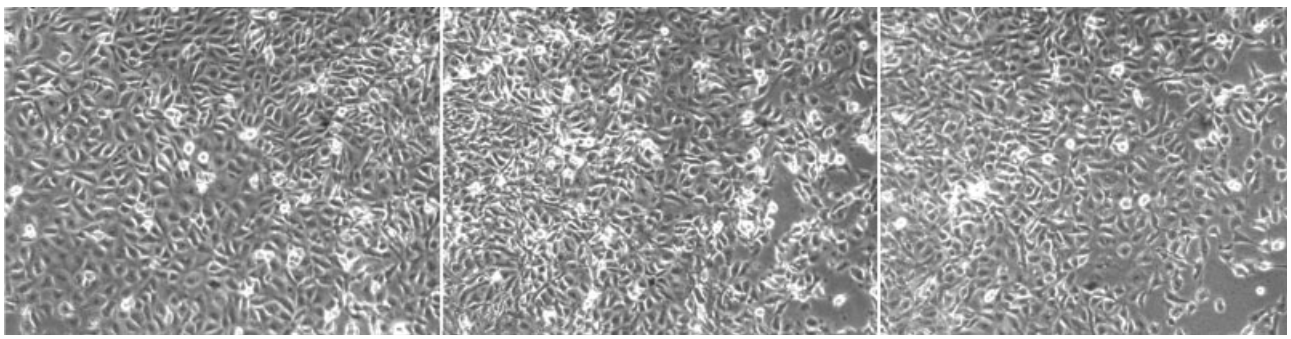


Figure 8 Microscope images of HUVECs growth on tissue culture-treated polystyrene (control) (left), PCL (middle), and PC-PCL (right) for 24 h (×100).

The platelet adhesion test was thought to have a sufficient validity to estimate the fundamental hemocompatibility.[28] From our results, it was just like what was expected that the amount of adhered and spreaded platelets would decrease on PC-PCL compared to the unmodified PCL. Moreover, morphological changes in the adhered platelets were clearly reduced on PC-PCL as shown in Figure 7. They kept their original spherical shape. On the contrary, platelets adhered to the PCL surface was obviously activated with lots of ''pseudopods'' stretching out.

From the above-mentioned blood-contacting test, it can be concluded that the end-capping of phosphorylcholine end-groups to the PCL chains to some degrees offered this modified polyester a better hemocompatibility.

Culture of HUVECs on PC-PCL

Microscope images of HUVECs grown on PCL and PC-PCL were laid out in Figure 8, from which we could find that most of the cells maintained their original shapes, rounded and spread out, though the distribution of cells seemed relatively sparse on PCL and PC-PCL compared with tissue culture-treated polystyrene dish control.

As illustrated in Figure 9, the growth of HUVECs varied on different coating materials. On control, the cell density of HUVECs reached a value around 22,044 (±665) cm^{-2}, while in the case of PCL, it decreased to about 16,471 (±814) cm^{-2}, due to the relatively hydrophobic surface of polyester as revealed in the water contact angle testing. However, the relatively more hydrophilic PC-PCL showed an even lower value (15,665 ± 1310); it seems that the antiplatelet-adhesion phosphorylcholine groups might be also not favorable to the adhesion of HUVECs.

Cell cycle analysis has already been used in the research of interaction between materials and cells, as well as in the estimation of biocompatibility of different materials.[29–31] In this study, flow cytometry was employed to analyze the cell cycles of HUVECs cultured on the surfaces of the above materials. In all the samples tested, no exceptional DNA diploid (diploid: 100%) was found, indicating that both materials were safe to cells without mutagenicity. As listed in Figure 10, S phase, which was related to the cells synthesizing DNA, decreased when HUVECs were grown on PCL and PC-PCL. The ratio of S phase/G_0-G_1 decreased in the sequence of control, PCL, and PC-PCL. From those results, we may conclude that both the PCL-containing samples restrained the cells in G_0-G_1 phase from entering S phase, and thus postponed the cell differentiation and multiplication. These results fit well with the cell number count results on different materials. PC-PCL and neat PCL might both not be favorable surfaces for HUVEC growing. It has been reported in a lot of cases that polyester surfaces are not cytophilic because of their hydrophobicity. Our results indicated that although the hydrophilicity of PCL can be greatly improved by end-capping the PCL chain with PC groups, the cellular affinity of the resulting PC-PCL can not be improved simultaneously. This kind of material may find application on

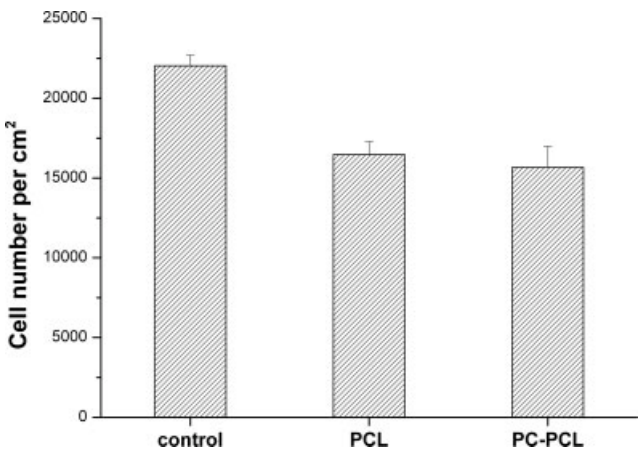


Figure 9 HUVECs growth on tissue culture-treated polystyrene (control), PCL, and PC-PCL for 24 h.

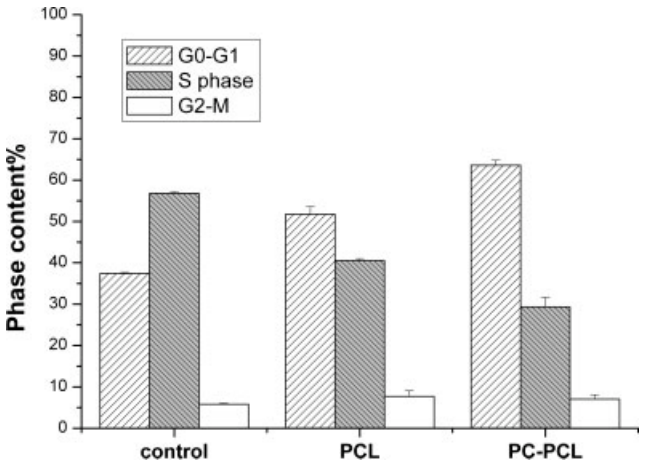


Figure 10 Comparison of HUVECs multiplication cycles on tissue culture-treated polystyrene (control), PCL and PC-PCL.

some medical implants in which antihyperplasia property are favorable.

CONCLUSIONS

In this work, the synthesis, characterization, and properties of a new biodegradable and antiadhesion polyester were reported. This phosphorylcholine-modified, biodegradable polymer was synthesized by combining the use of poly-ε-caprolactone with phosphorylcholine end-groups. The polyester backbone provided mechanical stability and biodegradability, while the PC group provided hydrophilicity and antiadhesion property. The structure of the obtained polymer was well characterized. In addition, the crystallization behaviors and the surface properties were analyzed, revealing the low crystallizing capability of this material and its antiadhesion behavior during the blood and cell contacting process. The improved hemocompatibility of PC-PCL was also confirmed with prolonged APTT. The stronger slow-down effect of HUVECs on PC-PCL than on neat PCL was observed in cell-cycle analysis.

All the above properties of the resulting polymer suggest that these molecules may have the potential to be used in biological environments as new carriers for controlled drug release or coatings for the endovascular implant systems.

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