Grafting 2-(Methacrylorloxy)ethyl-2-(trimethylammonium)ethyl Phosphate onto Segmented Polyurethane Surfaces To Improve Hemocompatibilities

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We reported herein that 2-(methacrylorloxy)ethyl-2-(trimethylammonium)ethyl phosphate (MTP) was successfully grafted onto a segmented polyurethane (SPU) cast film surface. We found MTP orientated onto a film surface had excellent hemocompatibility, and the addition of the cross-linking agent *N,N′*-methylenebisacrylamide (MBAA) further increased MTP orientation on the surface and lead to better hemocompatibility. 1,4-Butanediol (BD) as a chain extender was used to synthesize the SPU which was based on diphenylmethane diisocyanate (MDI), vinyl group-containing poly(butadiene) diol (PBD), and hydrogenated poly(butadiene) diol (HPBD). To obtain an alcohol-orientated surface of SPU, glycidyl methacrylate (GMA) was copolymerized with the SPU using α,α′-azobis(isobutyronitrile) (AIBN) as a radical initiator, and diethanolamine (DEA) was used to open the epoxy group leading to hydroxylated SPU. Furthermore, MTP and the cross-linking agent MBAA were grafted onto the cast film surface of hydroxylated SPU by using diammonium cerium(IV) nitrate as a catalyst. The bulk characteristics of the resulting polymers were investigated by infrared spectroscopy (IR) measurements. We found that both polymerization time and MBAA concentration accelerated grafting. The phosphatidylcholine groups of MTP orientated on the surface and the addition of MBAA accelerated MTP grafting as revealed by attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) and electron spectroscopy for chemical analysis (ESCA) measurements. The hemocompatibility in vitro was evaluated with rabbit platelet-rich plasma (PRP) contact tests and viewed by scanning electron microscopy (SEM) using commercially available BioSpan and nongrafted SPU (NG-SPU) as references. We found that fewer platelets adhered to the MTP grafted surfaces and that they showed less shape variation than the references. Platelet adhesion to MTP-grafted polymers was inhibited 50−84% compared with NG-SPU. The relative clotting time of the cast films in contact with cow PRP was 2.74, 2.28, 1.79, and 1.00 for MTP grafted-SPU, NG-SPU, BioSpan, and glass, respectively.

Introduction

Since the first paper on 2-(methacryloyloxy)ethyl-2-(trimethylammonium)ethyl phosphate (MTP) was published in 1982,[1] considerable attention has been paid to MTP and its analogues because phosphatidylcholine groups of MTP and its analogues were found to be able to improve hemocompatibility.[2−4] Several groups reported phosphatidylcholine-containing polyurethanes and polyurethane ionomers and their hemocompatibilities.[5−10]

On the basis of the premise of achieving hemocompatibility through mimicking the chemical constituents of the biologically inert surface of the inactivated platelet membrane, we recently developed a series of new polyurethanes bearing phosphatidylcholine analogues on side[11] and main chains.[12] We also reported some new phospholipid-segmented polyurethanes which showed excellent mechanical properties and significant hemocompatibilities.[13−19]

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Another approach to improve hemocomatibility is to modify the surfaces of commercially available materials. Durrani et al.[20] reported phosphatidylcholine polar headgroup-modified silicone polymer surfaces, and Letourneur et al.[21] reported phosphatidylcholine polar headgroup-modified polystyrene surfaces and their potential bioapplications. More recently, we successfully modified surfaces of SPUs by grafting methacrylates and phosphatidylcholine polar headgroups and found that the surface modification significantly inhibited platelet adhesion.[22]

In this study, we grafted MTP and the cross-linking agent *N*,*N*′-methylenebisacrylamide (MBAA) onto a segmented polyurethane (SPU) cast film surface. 1,4-Butanediol (BD) as a chain extender was used to synthesize the SPU, which was based on diphenylmethane diisocyanate (MDI), vinyl group-containing poly(butadiene) diol (PBD), and hydrogenated poly(butadiene) diol (HPBD). To obtain an alcohol-orientated surface of SPU, glycidyl methacrylate (GMA) was copolymerized with the SPU using α,α′-azobis(isobutyronitrile) (AIBN) as a radical initiator, and diethanolamine (DEA) was subsequently used to open the epoxy group leading to hydroxylated SPU. Furthermore, MTP and cross-linking agent MBAA were grafted onto the cast film surface of hydroxylated SPU by using diammonium cerium(IV) nitrate as a catalyst. The bulk characteristics of the resulting polymers were investigated by IR measurements. Both polymerization time and MBAA concentration effects on grafting were discussed. The surface properties of the materials were studied by attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) and electron spectroscopy for chemical analysis (ESCA) measurements. The hemocompatibility of the materials was evaluated by describing the platelet state and shape variation for the attached platelets. The relative clotting time of the cast films in contact with cow platelet-rich plasma (PRP) was also discussed.

Experimental Section

General Method. The IR spectral analyses of the polymers were taken on cast films using a Jasco A 202 spectrometer. GPC measurements were performed on a HLC802UR GPC instrument with G4000H8 and G2000H8 columns; the samples were dissolved in toluene/*N*,*N*-dimethylacetamide (DMAc) (volume ratio 4:1), and narrow-molecular-weight polystyrene was used as the standard. ATR-FTIR spectroscopy was performed on surfaces of films cast from 1,4-dioxane/methanol (volume ratio 4:1). The spectrum was collected at 4 cm^{-1} resolution using a Jasco Micro FT/IR-200 microsampling spectrometer over 50 scans. The sampling area was 25 μm^2, coupled with an ATR accessory and 45° KRS-5 crystal. ESCA spectra were obtained on a Shimadzu ESCA 750 spectrometer using Mg Kα radiation. The cast films were mounted on the specimen holder. Typical operating conditions included maintaining the X-ray gun at 8 kV and 30 mA and reducing the pressure in the sample chamber to about 3×10^{-5} Pa. In addition to taking survey scans (0−1000 eV) to determine the elemental composition of the various surfaces, elemental compositions were also determined on the basis of peak areas from the C_{1s}, N_{1s}, O_{1s}, and P_{2p} orbitals. Peak areas were calculated using standard Shimadzu ESPAC 100 software. The binding energy was referenced by setting the C_{1s} hydrocarbon peak to 285 eV.

Hemocompatibility Evaluation. The procedure of hemocompatibility evaluation for blood platelet adhesion and shape variation was the similar to that described previously.[2] Briefly, the films were washed with saline at 37 °C for 3 min and then incubated at 37 °C for 1 h with freshly prepared, PRP obtained from the blood of Japanese male white rabbits (45 mL of blood and 5 mL of 3.8% sodium citrate aqueous solution) by centrifugation at 1000*g* (rpm) for 20 min. Samples were rinsed with saline and treated with 2.5% glutaraldehyde in saline and kept at 4 °C overnight. The sample was rinsed with saline and dehydrated by systematic immersion in a series of ethanol−water solutions: 60, 70, 80, 90, 95, and 100% v/v. Following being soaked in a mixed solvent of ethanol and isoamyl acetate (volume ratio 1:1) and then in isoamyl acetate, the samples were dried by the critical point-drying method with carbon dioxide and coated with gold prior to being observed in a electron probe microanalyzer (EPM-810, Shimadzu) operated at an accelerating voltage of 20 kV. BioSpan and nongrafted SPU (NG-SPU) were used as control samples.

Clotting Time. The fresh PRP was prepared by mixing the cow blood and 3.8% sodium citrate aqueous solution (volume ratio 9:1), followed by centrifugation at 3700*g* (rpm) for 15 min. The films (2 cm × 2 cm) were washed with distilled water at 37 °C and incubated at 37 °C for 10 min. Then, 0.025 M calcium chloride aqueous solution was added onto the films, and the clotting time was measured.

Materials. Vinyl group-containing PBD with a number-average molecular weight of $M_n = 1950$ and 92.1% of 1,2-vinyl and 7.9% of 1,4-trans structure components and HPBD with a number-average molecular weight of $M_n = 2150$ were kindly provided by Nisso Kasei Co. Ltd. The BD was commercially obtained from Nacalai Tesque, Inc., Japan, and purified by vacuum distillation. Methanol was distilled in the presence of magnesium methoxide to ensure dryness. Acetone was distilled from anhydrous potassium carbonate. Toluene was distilled over phosphorus pentoxide. All other solvents were purchased as the best commercial grade and dried over Molecular Sieves 4A (Wako Pure Chemical Ind. Ltd., Japan) prior to use.

Synthesis of MTP. Synthesis of MTP has been described in detail previously.[1] Briefly, 2-chloro-2-oxo-1,3,2-dioxaphospholane was reacted with 2-hydroxyethyl methacrylate in tetrahydrofuran or diethyl ether in the presence of triethylamine to give 2-(2-oxo-1,3,2-dioxaphospholan-2-yloxy)ethyl methacrylate in nearly quantitative yield. Target monomer MTP was afforded by ring-opening reaction of 2-(2-oxo-1,3,2-dioxaphospholan-2-yloxy)ethyl methacrylate with trimethylamine in acetonitrile in a pressure bottle at 55 °C for 15 h.

Synthesis of SPU. As shown in Scheme 1, SPU based on vinyl-containing PBD and HPBD and extended with BD was synthesized according to a conventional two-step solution polymerization procedure under a nitrogen atmosphere.[23] This polymer was based on 1:1:4:2 molar ratio of PBD:HPBD:MDI:BD, and the reaction was carried out in a 4:1 mixture of toluene/DMAc without catalyst. In the first step, 10.0 g (0.04 mol) of MDI dissolved in 100 mL of the mixed solvent was added to a stirred solution of 19.5 g (0.01 mol) of PBD ($M_n = 1950$), 21.5 g (0.01 mol) of HPBD ($M_n = 2150$), and 300 mL of the same mixed solvent under a dry nitrogen atmosphere.

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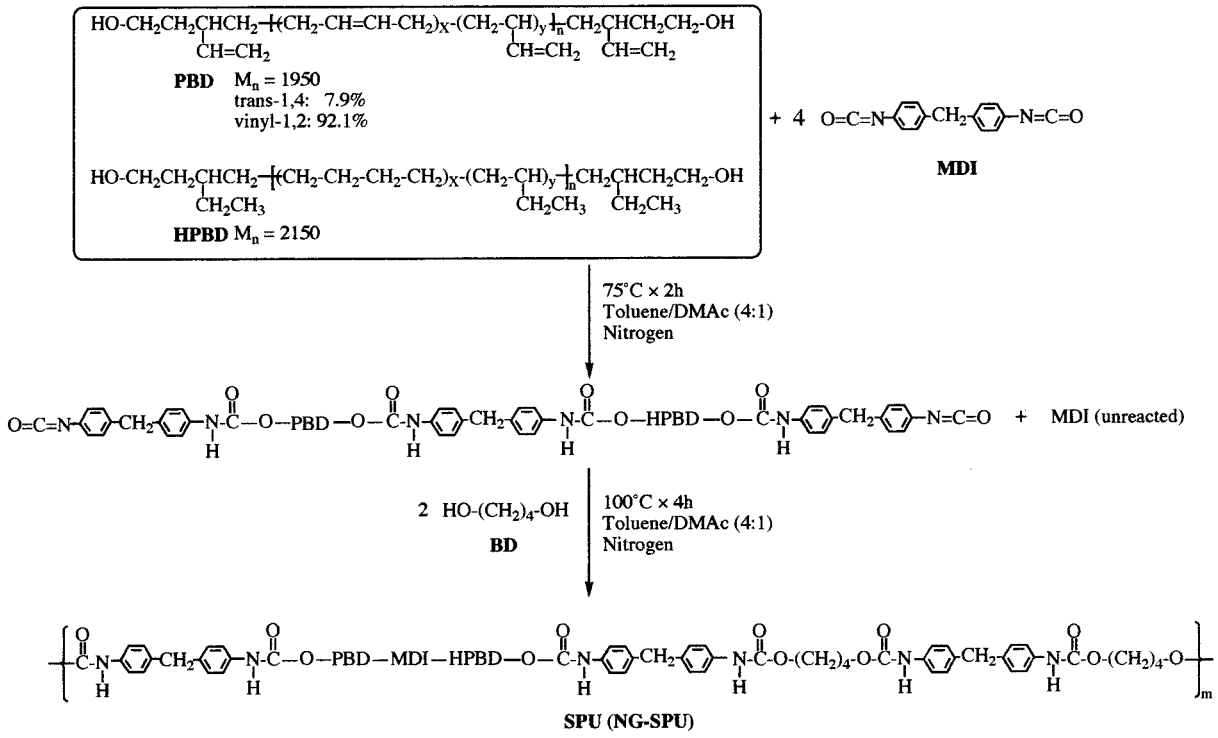
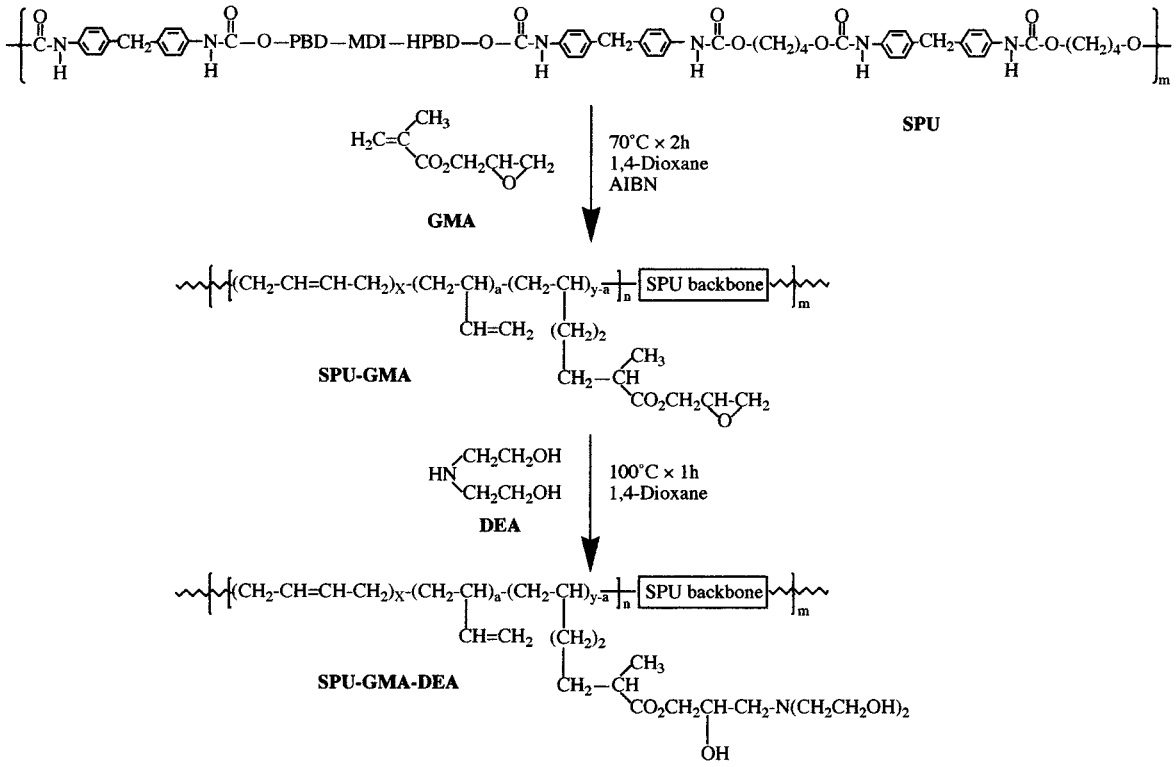
Scheme 1. Synthesis of SPU



Scheme 2. Synthesis of SPU−GMA−DEA



After stirring at 75 °C for 2 h, the solution was cooled to room temperature slowly. In the second step, 1.8 g (0.02 mol) of BD, which was previously dissolved in 15 mL of the mixed solvent, was added dropwise over 10 min to the reaction mixture with stirring. Stirring was continued at 100 °C for 4 h. The resulting SPU was precipitated in methanol. Then, the polymer was washed with methanol, and the washing procedure was performed three additional times with methanol. The polymer was dried in a vacuum oven at 70 °C for at least 48 h. A pale yellow elastomer of SPU (47.5 g, 90%) was obtained. IR (film): 3300 (NH), 2900 (CH_3), 2850 (CH_2), 1710 (carbonyl of NHCOO), 1640 (C=C), 1600, 1515 cm^{-1} (aromatic CH). M_w = 78 000. M_n = 60 000. M_w/M_n = 1.3.

Hydroxylation of SPU (SPU−GMA−DEA). As shown in Scheme 2, GMA and DEA were grafted onto SPU by two steps.[24]

In the first step, the synthesized SPU and GMA were dissolved into 1,4-dioxane with 10% (w/v) concentration, together

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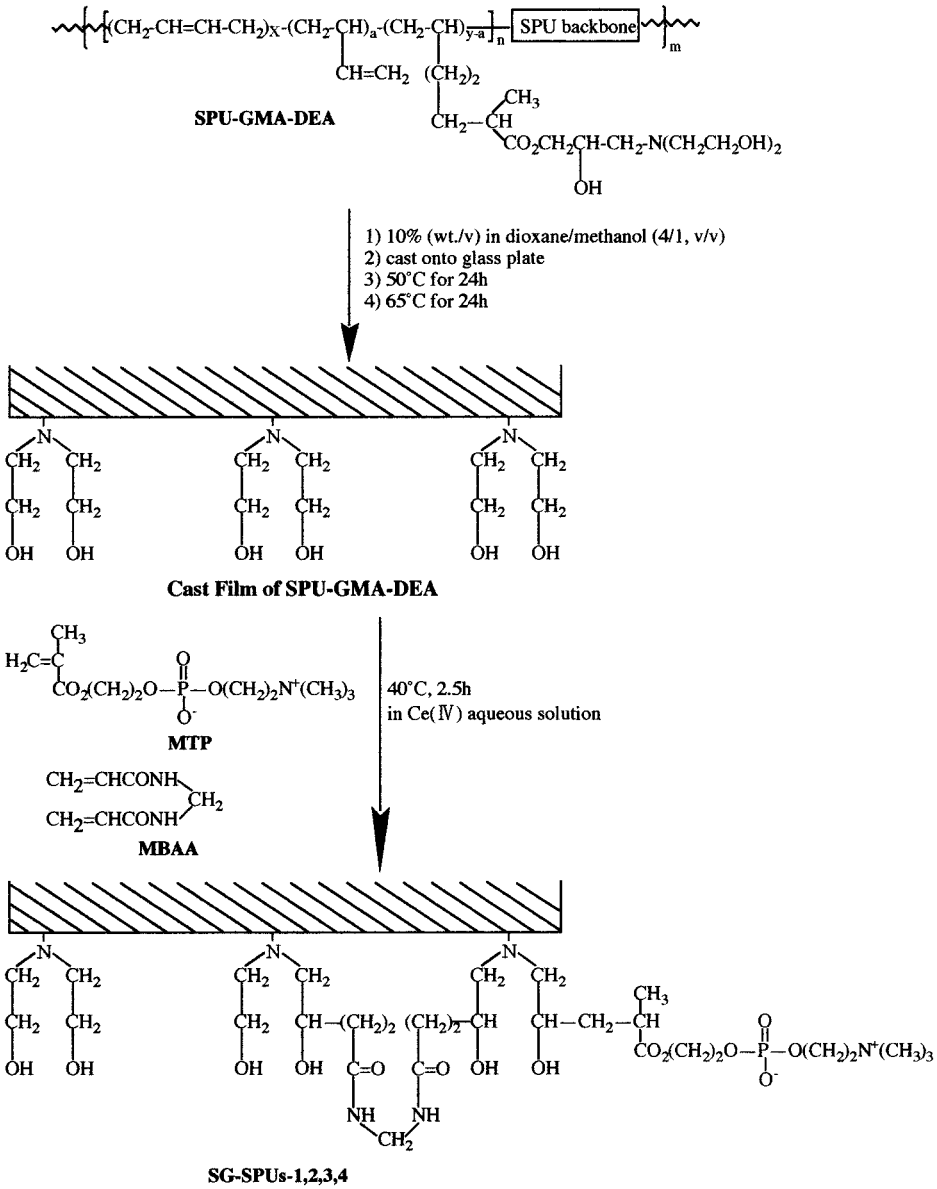
Scheme 3. Procedure of Grafting MTP onto SPU−GMA−DEA Cast Film Surface



with AIBN (1.0% mol of GMA monomer) as an initiator. The solutions were transferred into sealable ampules and flushed with nitrogen under a dry ice/methanol bath (−20 °C) for 10 min. Then, the ampules were sealed and shaken at 70 °C for 2 h. After being cooled to room temperature, the ampules were opened. The polymerization solutions were concentrated and poured into a large excess of dry methanol to give pale yellow precipitates. The obtained precipitates were washed with dry methanol three times; the precipitates were filtered off and then dried in a vacuum at 60 °C for 24 h to afford grafted polymer SPU−GMA as a white solid.

In the second step, epoxy group of the SPU−GMA was opened by reacting with DEA. SPU−GMA was dissolved into 1,4-dioxane and then reacted with an excess of DEA at 100 °C for 1 h. The solution was concentrated and poured into an amount of dry acetone to give pale yellow precipitates. The obtained precipitates were washed with dry acetone three times; the precipitates were filtered off and then dried in a vacuum at 60 °C for 24 h to afford SPU−GMA−DEA as a white solid (62%). IR (film): 3350 (OH), 2910 (CH_3), 2840 (CH_2), 1710 (carbonyl of NHCOO), 1640 (C═C), 1600, 1510 cm^{-1} (aromatic CH).

Preparation of Cast Films of SPU−GMA−DEA. As shown in Scheme 3, after briefly drying under vacuum to remove residual methanol, the polymer SPU−GMA−DEA was dissolved in 1,4-dioxane/methanol (volume ratio 4:1) solution by using an ultrasonic generator. The polymer solutions (10% w/v) were cast onto glass plate and dried in an oven at 50 °C for 24 h to remove most of the solvents. The final drying stage involved drying the sheet in a vacuum oven at 65 °C for 24 h to remove residual solvents.

Surface Grafting (SG−SPUs−1,2,3,4). MTP and the cross-linking agent MBAA were grafted onto the film surface by using the method of Ming and Kaizerman.[25] Aliquots of 0.05 M diammonium cerium(IV) nitrate, 0.5 M MTP, and 0, 5, 10, or 20 mM MBAA were mixed and maintained with the cast films at 40 °C for 2.5 h under a nitrogen atmosphere to afford corresponding MTP and MBAA surface-grafting polymers SG−SPU-1 (MBAA free), SG-SPU-2, SG-SPU-3, and SG-SPU-4, respectively. The grafted film surfaces were washed with water and dried in a vacuum at 60 °C for 24 h and weighted. Grafting was defined herein:

$$\text{Grafting (\%)} = (W - W_0)/W_0 \times 100$$

Where W represents the weight of SG-SPUs and W_0 is the weight of cast films of SPU−GMA−DEA before surface graft-

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ing. Grafting was 12, 30, 33, and 77% for SG-SPUs-1−4, respectively. IR (film): 3300 (NH), 2910 (CH_3), 2840 (CH_2), 1720 (carbonyl of NHCOO), 1640 (C═C), 1600, 1515 (aromatic CH), 1165 (COO), 1230 (P═O), 1070 cm^{-1} ($POCH_2$).

Results and Discussion

Synthesis of Surface Grafting (SG-SPUs-1,2,3,4). MTP and the cross-linking agent MBAA were grafted onto a SPU cast film surface through Schemes 1−3.

As shown in Scheme 1, SPU was synthesized according to a conventional two-step solution polymerization procedure under a nitrogen atmosphere.[23] This polymer was based on 1:1:4:2 molar ratio of PBD:HPBD:MDI:BD, and the reaction was carried out in a 4:1 mixture of toluene/DMAc without catalyst.

As shown in Scheme 2, to obtain an alcohol-orientated surface of SPU, GMA and DEA were grafted onto the synthesized SPU by using the method of Tsuneda et al.[24] GMA was copolymerized with the SPU using AIBN as a radical initiator, and DEA was subsequently used to open the epoxy group leading to hydroxylated SPU (SPU−GMA−DEA). The ATR-FTIR data in later discussions revealed that the OH stretches of the hydroxylated SPU occur at 3335 cm^{-1}, thus indicated that OH groups remain on the surface.

As shown in Scheme 3, MTP and the cross-linking agent MBAA were grafted onto the cast film surface of SPU−GMA−DEA by using the method of Ming and Kaizerman.[25] The mechanism of the initiation reaction can be written quite generally as follows: alcohols (RCH_2OH) reacted with the ceric complexes (Ce^{IV}) as they exist in aqueous solution leading to a free radical ($R\dot{C}HOH$) through the ceric alcohol complex; if a vinyl monomer is present, the free radical initiates polymerization.

Bulk Property Characterization. GPC measurements showed the synthesized polymer SPU had relatively high molecular weights. From the relationship between retention time and molecular weights derived for narrow-distribution standard polystyrene, the weight-average molecular weight (M_w), number-average molecular weight (M_n), and corresponding polydispersity of the synthesized SPU were 78 000, 60 000, and 1.3, respectively.

The IR spectral analyses of the synthesized polymers were taken on cast films. An adsorption band owing to OH stretches at 3350 cm^{-1} was observed on IR spectrum of SPU−GMA−DEA. This showed that epoxy groups were successfully opened, leading to OH groups in SPUs. All of the SG−SPUs include both MDI and MTP, as is clear from the IR spectrum of each material. Adsorption bands due to NH stretches at 3300 cm^{-1}, C−H stretches at 2910 and 2840 cm^{-1}, urethane carbonyl stretches at 1720 cm^{-1}, C═C stretches at 1640, aromatic C−H stretches at 1600 and 1515 cm^{-1}, ester ether CO−O at 1165 cm^{-1}, P═O at 1230 cm^{-1}, and P−O−CH_2− at 1070 cm^{-1} were observed.

Figure 1 shows the polymerization time effect on grafting. The grafting of SG-SPU-1 was 1, 3, 8, and 13%, and that of SG-SPU-3 was 7, 16, 24, and 34% when polymerization time was 0.5, 1, 1.5, and 2.5 h, respectively. Three specimens for each condition were measured and error bars were also included in the figure. The results showed the longer the polymerization time, the higher the grafting, and that the addition of the cross-linking agent MBAA stimulated grafting.

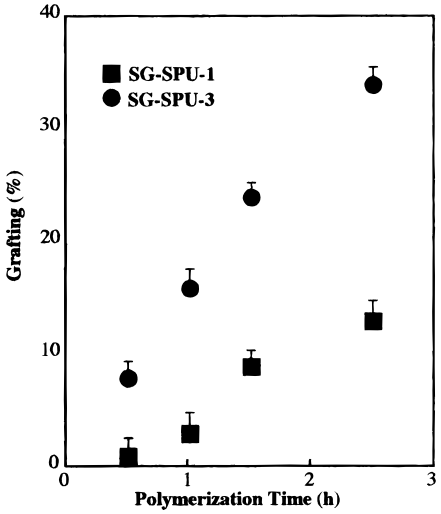

Figure 1. Polymerization time effect on grafting.

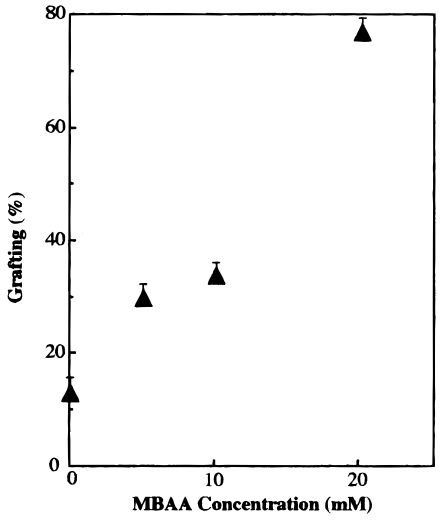

Figure 2. Cross-linking agent MBAA concentration effect on grafting.

Figure 2 shows the cross-linking agent MBAA concentration effect on grafting. The grafting of SG-SPUs-1−4 was 12, 30, 33, and 77% when polymerization time was 2.5 h, and MBAA concentration was 0, 5, 10, and 20 mM, respectively. Three specimens for each condition were measured and error bars were also included in the figure. The results further showed that the higher the mole ratio of MBAA versus MTP, the higher the grafting. So, high concentrations of the cross-linking agent MBAA more effectively stimulated grafting. This result, together with the ATR-FTIR and ESCA data discussed later, confirmed our hypothesis that the cross-linking agent MBAA will aid MTP orientation on the surface of the polymer, thus leading to more MTP orientated on the surface and better hemocompatibility. So, we used the cross-linking agent MBAA when we designed the synthesis. As shown in Scheme 3, one possible explanation for MBAA improving grafting efficiency is that cross-linking between alcohol groups, reduced entangled and coiled opportunities of MTP and −$N(CH_2CH_2OH)_2$ groups, thus leading to more space for new MBAA and MTP grafting. Another explanation for

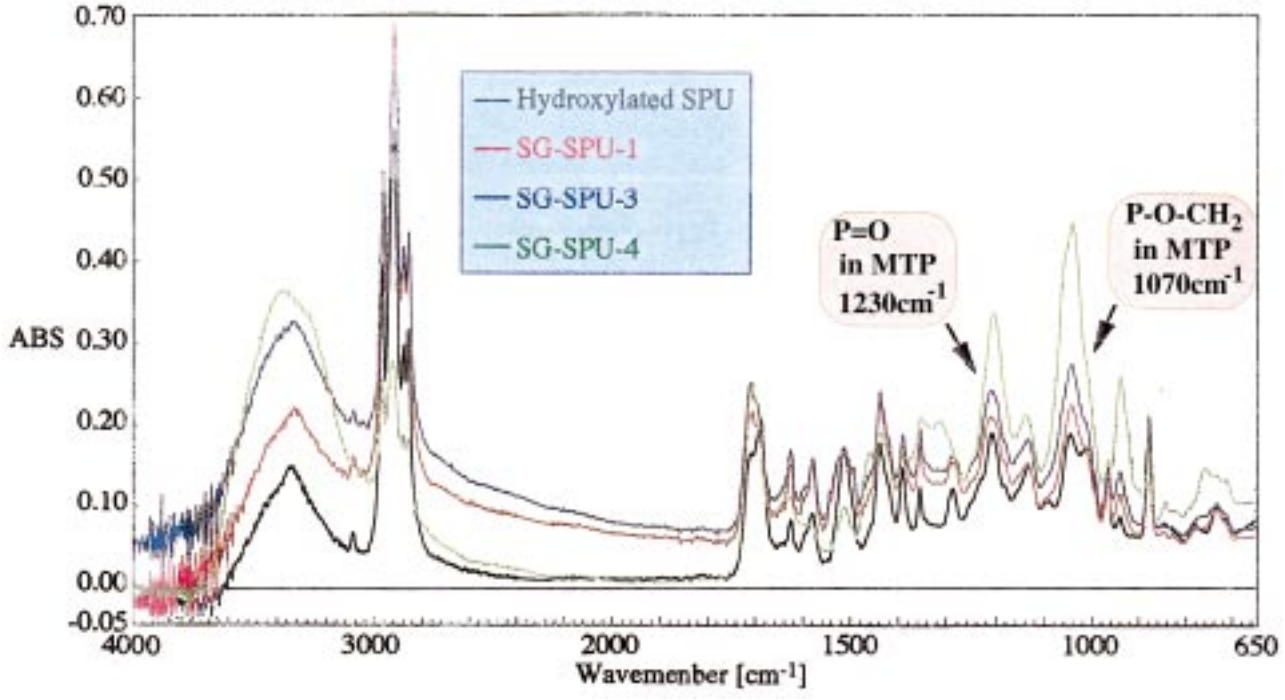

Figure 3. ATR−FTIR spectra of the hydroxylated SPU (SPU−GMA−DEA), SG-SPU-1, SG-SPU-3, and SG-SPU-4.

MBAA improving grafting efficiency is that the more reacted MBAA there is , the higher the grafting polymer weight is, according to our definition for grafting (%) mentioned above.

Surface Property Characterization. Surface properties of the polymer films were investigated by ATR-FTIR and ESCA measurements. The air-facing surface of the films were the blood-contacting surface; therefore, all surface and hemocompatible properties were related to the air-facing surface.

Figure 3 shows the ATR-FTIR spectra of the SPU−GMA−DEA (hydroxylated SPU), SG-SPU-1, SG-SPU-3, and SG-SPU-4. For SPU−GMA−DEA, trans 1,4-addition of C═C stretches occurs at 964 cm^{-1}, and 1,2-addition of C═C stretches occurs at 993 and 906 cm^{-1}. The OH stretches occur at 3335 cm^{-1}, and the peak is sharper than other polymers at similar position. The saturated C−H stretches occur at 2915 and 2842 cm^{-1}. The peak at 1710 cm^{-1} is assigned to carbonyl groups that are hydrogen-bonded (presumably to the urethane hydrogens), and the peak at 1720 cm^{-1} is assigned to carbonyl groups that are not hydrogen-bonded. Moreover, the band at 1639 cm^{-1} of the amide I stretch and the peaks at 1597 and 1508 cm^{-1} due to aromatic C−H stretching were clearly observed.

Compared to SPU−GMA−DEA, SG-SPUs-1, -3, and -4 displayed additional stretches at 1230 and 1070 cm^{-1} due to P═O and P−O−CH_2−bond. This indicates that the phosphatidylcholine monomer MTP was successfully grafted onto the SPU−GMA−DEA. Moreover, the trend of these additional stretches increase is more clear as MBAA mole ratio increases in polymers. This result further proved the findings of MBAA stimulating grafting as discussed above.

Table 1 lists ESCA elemental surface compositions of the SPU−GMA−DEA and SG-SPUs-1−4. The ratio of the peak area of phosphorus to that of carbon (P_{2p}/C_{1s}) was also calculated and summarized in Table 1.

Table 1. ESCA Elemental Surface Composition (%) of SPUs

SPUs	MTP (mol)	MBAA (mol)	C_{1s}	O_{1s}	N_{1s}	P_{2p}	P_{2p}/C_{1s}
SPU−GMA−DEA	0.0	0.000	85.10	14.35	0.5	0.00	0.0000
SG-SPU-1	0.5	0.000	86.98	11.18	0.93	0.91	0.0105
SG-SPU-2	0.5	0.005	75.32	24.47	1.72	1.49	0.0206
SG-SPU-3	0.5	0.010	71.81	24.23	2.10	1.86	0.0260
SG-SPU-4	0.5	0.020	65.71	28.52	3.00	2.77	0.0422

ESCA measurements showed the presence of phosphorus for SG-SPUs-1−4, which is a strong indication of the presence of phosphatidylcholine groups on the film surface. In addition, the phosphorus content was increased (SG-SPU-4 > SG-SPU-3 > SG-SPU-2 > SG-SPU-1) as feeding mole ratio of cross-linking agent MBAA versus MTP increased. This finding indicated that the cross-linking agent MBAA stimulated MTP grafting on the film surface.

Hemocompatibility Evaluation. The MTP and MBAA surface-grafted SPUs were assessed as biomaterials by the degree and nature of blood platelet adhesion resulting from exposure to PRP for 60 min. The specimens incubated in PRP were viewed by scanning electron microscopy (SEM). In Figures 4 and 5, the typical SEM photographs of BioSpan (a and b), NG-SPU (c and d), SG-SPU-1 (e and f), SG-SPU-2 (g and h), SG-SPU-3 (i and j), SG-SPU-4 (k and l) are shown.

For MTP and MBAA surface-grafted SPUs, the hemocompatibilities of the materials were significantly improved. The MTP- and MBAA-grafted SPUs showed a relatively limited number of platelets adhered, and the cells remained rounded with no extensions formed relative to BioSpan and unmodified SPU. Generally, it seemed that magnitude of morphology changed in the following order: BioSpan > NG-SPU > SG-SPU-1 > SG-SPU-2 > SG-SPU-3 > SG-SPU-4.

The platelet density in 10 μm × 10 μm was 8.49, 4.92, 2.46, 1.08, 0.89, and 0.77 for BioSpan, NG-SPU, and SG-

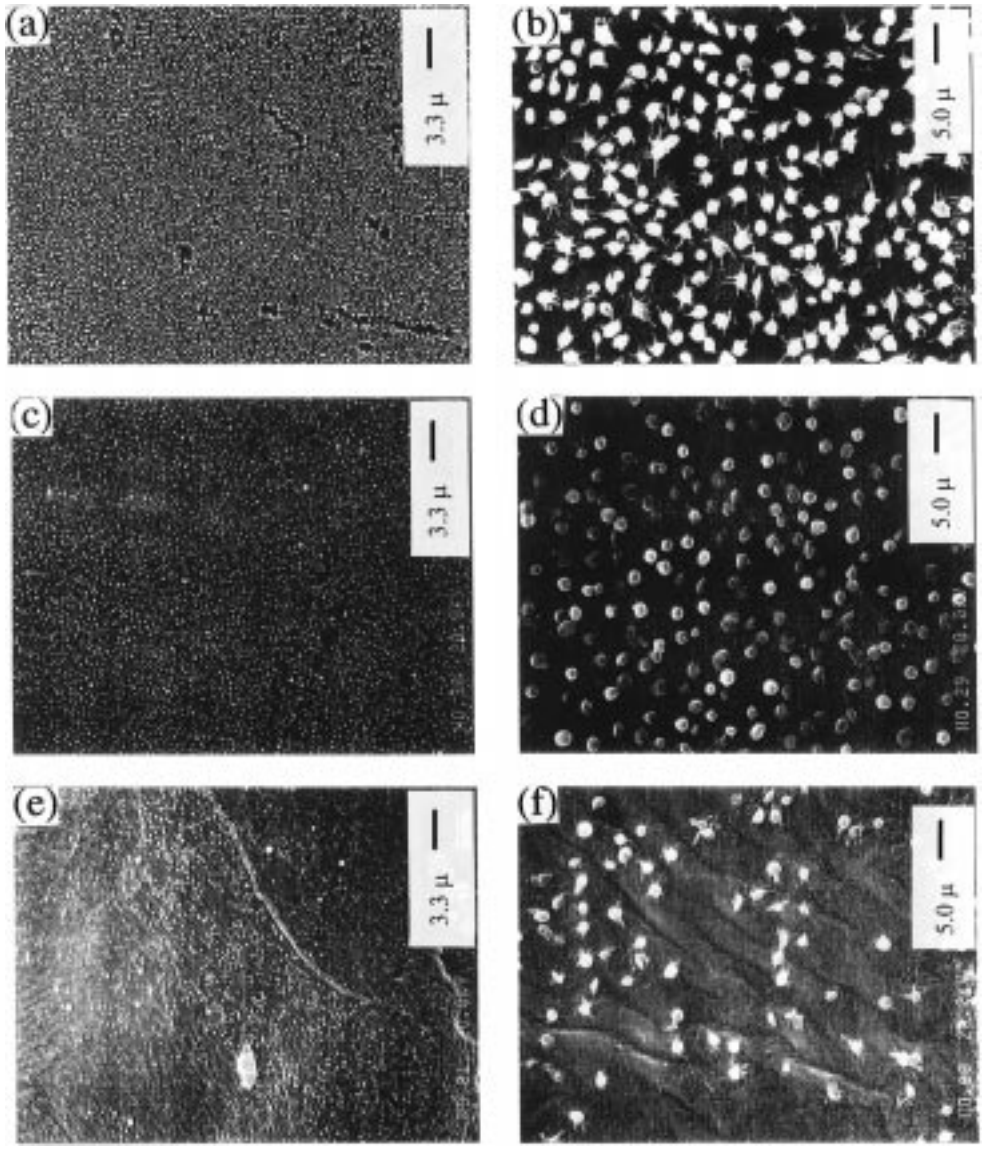

Figure 4. SEM photographs of the surface of (a) and (b) BioSpan, (c) and (d) NG-SPU, and (e) and (f) SG-SPU-1 film after 60 min of PRP exposure. Actual magnification: parts a, c, and e are ×300 and parts b, d, and f are ×2000.

SPU-1−4, respectively. These results indicated phosphatidylcholine monomer MTP surface-grafted SPUs did not support platelet adhesion.[26−28] Moreover, combined with the ESCA measurement results, the greater the phosphorus content on the surface, the better the hemocompatibility of the polymers. This indicates that the addition of the cross-linking agent MBAA could improve hemocomatibility through stimulating MTP grafting. Platelet adhesion to phosphatidylcholine MTP surface-grafted polymers SG-SPU-1−4 was inhibited 50%, 78%, 82%, and 84% compared with NG-SPU, respectively. All of these results indicate that MTP with a phosphatidylcholine analogous group orientated onto a film surface have excellent hemocompatibility. Moreover, the addition of the cross-linking agent MBAA can further increase MTP orientation on the surface and lead to better hemocompatibility.

A further investigation on the clotting time of the new materials versus glass suggested that it was apparent that the trend of hemocompatibility of the new polymers was better than that of glass and BioSpan. The relative clotting time of the cast films in contact with cow PRP was 2.74, 2.28, 1.79, and 1.00 (5′04″7) for MTP-grafted polymer SG-SPU-3, NG-SPU, BioSpan, and glass, respectively.

Conclusion

In summary, to achieve better hemocompatibility, phosphatidylcholine vinyl monomer MTP was successfully grafted onto a SPU cast film surface. We found MTP orientated onto film surface had excellent hemocompatibility and the addition of the cross-linking agent MBAA further increased MTP orientation on the surface and lead to better hemocompatibility. BD as a chain extender was used to synthesize the SPU which was based on MDI, vinyl group-containing PBD, and HPBD. To obtain the alcohol-orientated surface of SPU, GMA was copolymerized with the SPU using AIBN as a radical initiator, and DEA was subsequently used to

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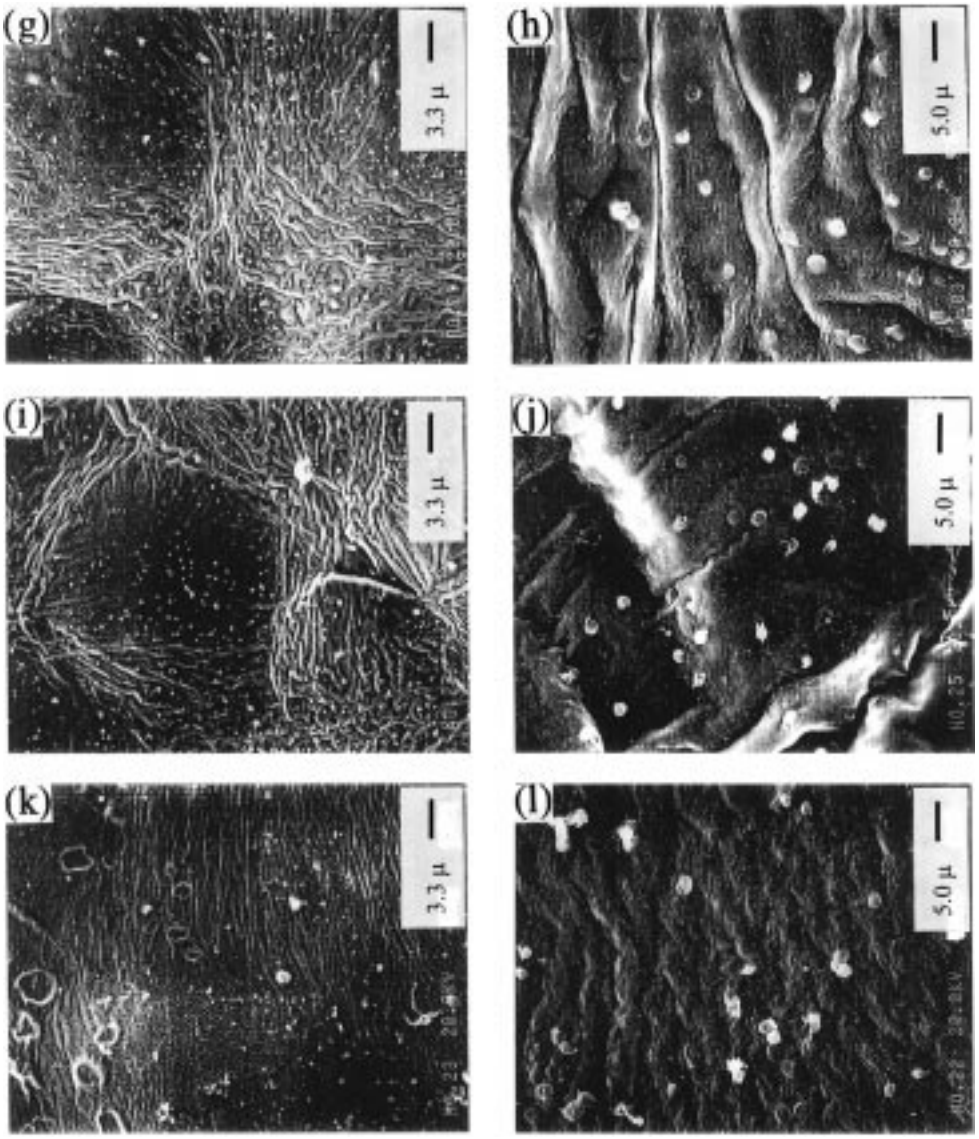

Figure 5. SEM photographs of the surfaces of (g) and (h) SG-SPU-2, (i) and (j) SG-SPU-3, and (k) and (l) SG-SPU-4 films after 60 min of PRP exposure. Actual magnification: parts g, i, and k are ×300 and parts h, j and l are ×2000.

open the epoxy group leading to hydroxylated SPU. Furthermore, MTP and the cross-linking agent MBAA were grafted onto the cast film surface of hydroxylated SPU by using diammonium cerium(IV) nitrate as a catalyst. It was found that both long polymerization times and high MBAA concentrations greatly accelerated the grafting. The phosphatidylcholine groups were orientated on the surface of these materials and the addition of MBAA accelerated MTP grafting as revealed by ATR-FTIR and ESCA measurements. The hemocompatibility in vitro was evaluated with PRP contact tests and viewed by SEM using BioSpan and unmodified SPU as references. It was found that fewer platelets adhered to the modified surfaces and that they showed less shape variation than the references. Platelet adhesion to MTP-grafted polymers was inhibited 50−84% compared with NG-SPU. The relative clotting time of the cast films in contact with cow PRP was 2.74, 2.28, 1.79, and 1.00 for MTP-grafted polymer SG-SPU-3, NG-SPU, BioSpan, and glass, respectively.

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