Self-assembly of silanated poly(ethylene glycol) on silicon and glass surfaces for improved haemocompatibility

Zhang Guo a, Sheng Meng a, Wei Zhong a,*, Qiangguo Du a, Laisheng L. Chou b

a Key Laboratory of Molecular Engineering of Polymers of Ministry of Education, Department of Macromolecular Science, Fudan University, 220 Handan Road, Shanghai 200433, China
b Department of Biomaterials, Goldman School of Dental Medicine, Boston University, Boston, MA 02118, USA

1. Introduction

Nowadays, inorganic materials such as silicon and silicon-based materials have already been used in biomedical devices such as controlled release vessels, sensors and other implants because of their appropriate mechanical properties, good processability and relatively low cost. However, their clinical use is still limited because the inorganic interfaces are not in a stable and nonimmunogenic state when in contact with the biological matrix [1–4]. There are lots of silanol groups (Si–OH) on the surface of silicon which results in a negative surface charge in water at neutral pH. A charged surface will produce a streaming potential in the fluid flow and thus may lead to protein adsorption, platelet adhesion or even the formation of thrombus [1]. Therefore, there is currently a strong interest in the investigation of simple and effective strategies which would give inorganic materials bio-compatible or anti-biofouling surfaces.

One of the most effective ways to improve biocompatibility is to graft biocompatible polymer chains, such as poly(hydroxyethyl methacrylate) (polyHEMA) [5–7], polyacrylamide (PAAm) [8,9], heparin [10–14], polyethylene glycol (PEG) [15–19], etc., onto the material surfaces. Among all these polymers, PEG appears to be the best candidate for providing “protein repulsive” surfaces because of its unique properties such as hydrophilicity, flexibility, high exclusion volume in water, nontoxicity, and nonimmunogenicity [20]. Several successful routes have been developed to modify surfaces with PEG derivatives. These approaches include physical adsorption [21,22], covalent coupling [23–26], UV-induced graft polymerization of poly(ethylene glycol) methacrylate macromonomers [27], chemical vapor deposition of ethylene oxide [28], etc. For long-term effectiveness when being used as biocompatible coating material, the PEG chains should not be detached from the surface, especially for endovascular applications. However, PEG coatings prepared by physical adsorption techniques are likely to elute from the surface in body fluids due to the weak forces of adhesion [29]. In the case of graft polymerization, the PEG chains are incorporated as segments of a polymer backbone, and the surface density of the PEG chains are thus limited, which reduces...
their anti-nonspecific adsorption effect [30,31]. Theoretically, the covalent surface immobilization of PEG is the most stable and promising method, and would be preferred for long-term applications. However, complex processing procedures and a long reaction time are required for the covalent coupling of PEG chains to the surface of the substrate, which greatly limits its practical use for surface modification [32,33].

In this study, a self-assembly method using silanated PEG was utilized to modify silicon or glass surfaces to improve their haemo-compatibility. This method involves a one-step coupling procedure which is easier to manipulate than other methods cited above. PEG-modified silicon chips or glassplate surfaces of various coverage densities were obtained by simply changing the initial concentration of silanated PEG in the coating solution (2–30 mM) and soaking time (0.5–120 min), which is easy to do in the practical process of microfabrication. Both the surface topography and wettability of the PEGylated inorganic surfaces were carefully investigated by atomic force microscopy and water static contact angle measurement. To investigate the blood compatibility of the modified surfaces, full blood activated partial thromboplastin time (APTT), prothrombin time (PT) and thrombin time (TT) were measured. The appearance of adherence and denaturalization of blood platelets onto the glassplate surface were also observed with SEM.

2. Experimental

2.1. Materials

Monomethoxy poly(ethylene glycol) (MPEG, MW = 350, 1150, 2000, designated MPEG-350, MPEG-1150 and MPEG-2000, respectively) were purchased from Alfa Aesar. 3-Isocyanatopropyltriethoxysilane (IPTS) (≥95% by GC) was purchased from Fluka. Toluene and tetrahydrofuran (THF) were purified by refluxing with triethoxysilane (IPTS) (resp.) were purchased from Alfa Aesar. 3-Isocyanatopropyltriethoxysilane (IPTS) (≥95% by GC) was purchased from Fluka. Toluene and tetrahydrofuran (THF) were purified by refluxing with calcium hydroxide overnight and by distilling to remove water and other impurities before use. Silicon chips (p-type, boron doped with (1 0 0) orientation) were purchased from Shanghai Kaiqing Photoelectric Materials Co. Hydrogen peroxide (30%), sulphuric acid (98%), anhydrous ether and ethanol were obtained from Shanghai Chemical Co. and used without further purification.

2.2. Synthesis of silanated PEG

As illustrated in Scheme 1, silanated PEG was synthesized from mPEG and 3-isocyanatopropyltriethoxysilane (IPTS) using dibutyltin dilaurate as catalyst. MPEG-350 (14 g, 0.04 mol) were dissolved in 100 mL of benzene. After refluxing for 1 h, 70 mL out of 100 mL of benzene were distilled off to remove the water in the PEG through forming an azeotropic mixture. Residual benzene was further distilled out under reduced pressure (20 mmHg). Then 100 mL of THF was added into the flask to dissolve the MPEG-350, after which the solution was poured into a 250 mL three-necked, round-bottomed flask under dry nitrogen. Then 0.004 mol dibutyltin dilaurate was added to the solution as a catalyst. Next, the system was heated to 60 °C, 11.8 g of IPTS (0.048 mol) in 50 mL of anhydrous THF was added into the solution drop by drop for about 1 h under magnetic stirring, and the mixture was stirred continuously for 12 h under dry nitrogen at 60 °C. After the reaction, silanated PEG was precipitated with anhydrous ether twice. SP-350 was obtained after drying it in a vacuum oven for 1 day.

SP-1150 and SP-2000 were synthesized from MPEG-1150 and MPEG-2000, respectively with the same method described above.

2.3. Cleaning of material surfaces

To remove the organic residues from their surfaces, silicon chips (1 0 0) cut into strips of 1 cm × 1 cm or glassplates (used for the clotting time test) were treated by immersion in a freshly prepared piranha solution of 70% conc. H2SO4 (aq) and 30% H2O2 (aq) (v/v) at 90 °C for 0.5 h [34]. (Caution: piranha solution reacts violently with many organic materials and should be handled with care.) Then the substrates were immersed in deionized water, sonicated for 0.5 h, and again rinsed with sufficient deionized water, dried in a N2 stream and used in 1 h.

2.4. Self-assembly of silanated PEG on a silicon surface

The silanated PEGs with different molecular weights were dissolved in toluene to make solutions of different concentrations. Then the cleaned silicon chips were immersed in these solutions for different times to fix PEG to the surfaces. Afterward, the chips were sequentially washed thoroughly with toluene and ethanol, and then sonicated in ethanol for 15 min to remove non-grafted PEG. The samples were then cured in oven at 80 °C for 1 day.

2.5. Characterization

FTIR spectra (KBr discs) were taken on a Magna-550 FTIR spectrometer (Nicolet) at room temperature. Spectra were recorded with a resolution of 4 cm−1 in the range of 4000–400 cm−1. 1H NMR spectra were recorded with a Bruker model AVANCE DMX-500 spectrometer, using tetramethylsilane (TMS) as a reference and the solvent (CDCl3) proton signal as an internal standard. Molecular weight and molecular weight distribution were analyzed by gel permeation chromatography (GPC, 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.

2.6. Contact angle measurements

Water contact angles of the silicon chips were measured in air by the sessile drop method using a contact angle goniometer (OCA15, Data Physics Inc., Germany). Readings were made after the angles were observed to be stable with time. For each sample, the measurements were performed at least six times in different spots.

2.7. Atomic force microscopy (AFM)

In order to investigate the topography of the self-assembled monolayers, AFM images were obtained with a NanoScope IV (Digital Instruments Inc.) in tapping mode using a silicon cantilever having a typical spring constant of around 40 N/m with a resonance frequency around 160–165 kHz. The AFM images were acquired by scanning the samples in air under ambient laboratory conditions at a scan rate of 1.5 Hz. All the scans were 1 μm × 1 μm in size. The roughness of the surface was determined by measuring the root-mean-square (RMS) roughness parameter Rrms, defined as the root-mean-square average of the height (z) taken from mean data plane, expressed as:

$$R_{rms} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} z_i^2}$$

where $z_i$ is the current z value and N is the number of points within the box cursor.

2.8. Haemocompatibility evaluation

The experimental procedure addressing the haemocompatibility evaluation of the PEGylated glassplate surfaces was described in our previous publication [35]. Human full blood activated partial thromboplastin time (APTT), prothrombin time
(PT), and thromboplastin time (TT) of silanated PEG coated glass plate (untreated glass plate used as the control) were measured on a Sysmex CA-1500 automated blood coagulation analyzer using DADE BEHRING Actin, DADE BEHRING Thromb Burl's, and DADE BEHRING Test-Thrombin Reagents, accordingly. A paired t-test was used and the significance level was set to $P < 0.03$. Full human blood was obtained from one healthy volunteer who had the following blood routine test result—RBC: 5.17 $\times 10^{12}$/L; HGB: 151 g/L; HCT: 44.4%; MCV: 85.9 fL; MCH: 29.2 pg; MCHC: 340 g/L; PLT: 154 $\times 10^{9}$/L; WBC: 5.0 $\times 10^{9}$/L; LYMPH: 1.7 $\times 10^{9}$/L; NEUT: 55.2; MPV: 11.0 fL; P-LCR: 32.9%. The blood was mixed with 0.2 mL trisodium citrate (109 mM) and transferred into plates grafted with SP-350, SP-1150 and SP-2000, respectively, for a contact time of 1 h.

Since platelet adhesion is one of the important steps during blood coagulation on biomaterial surfaces [36,37], a platelet adhesion study was performed to evaluate the interactions between blood and PEGylated silicon surfaces. Whole blood from the same healthy volunteer was 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 PEGylated surfaces pre-equilibrated with PBS (pH 7.4) and incubated for an appointed period of time at 37°C. After the incubation, the samples were rinsed three times using PBS and mild shaking to remove the non-adherent platelets. The adhered platelets were then fixed in 1% glutaraldehyde in PBS for 60 min at room temperature. After the glutaraldehyde fixation, the samples were dehydrated sequentially with ethanol of 25%, 50%, 75%, 90% and 100% (v/v) for 30 min each. Then the samples were dried in air, sputter-coated with gold and observed with SEM (TESCAN 5136MM).

### 3. Results and discussion

#### 3.1. Structure of silanated PEG

FTIR spectra (Fig. 1) were used to investigate the structural changes which occurred during the synthesis process. It could be seen from the spectra of SP-350, SP-1150 and SP 2000 that an N–H band appeared at 3345 and 1532 cm$^{-1}$. The urethane carbonyl band split into two peaks at 1723 cm$^{-1}$ (free carbonyl) and 1705 cm$^{-1}$ (bonded carbonyl). The band at 777 cm$^{-1}$ corresponded to the adsorption of the stretching of the Si–C bond. The bands of NCO from IPTS (2250 cm$^{-1}$) and the OH from MPEG (3475 cm$^{-1}$) disappeared after the coupling reaction, which indicated that the reaction was complete (Scheme 1).

![Fig. 1. FTIR spectra of MPEG-350, SP-350, SP-1150 and SP-2000.](image)

A $^1$H NMR spectrum of SP-350 is shown in Fig. 2 as a representative example of the synthesized silanated PEGs. The proton NMR spectrum showed a peak at 4.91 ppm which was assigned to the proton of the imino bond of the urethane group. The appearance of a multiplet between 1.49 and 1.33 ppm for methyl protons of the ethoxysilyl groups further confirmed the coupling reaction between IPTS and MPEG. The single peak at 3.38 ppm was from the methoxyl endgroups of the PEG chain. The peak for the methylene protons of PEG and methylene protons from the ethoxysilyl groups all appeared at 3.65 ppm.

As shown in Table 1, all the number-average molecular weights of the silanated PEG samples increased about 250 Da compared to the corresponding MPEG molecules, and was close to the molecular weight of an IPTS molecule. The molecular weight distribution of the three silanated PEG samples was 1.072, 1.061 and 1.06, respectively, with symmetrical single peaks on their eluting curves. This indicated that each IPTS molecule reacted with only one PEG chain. The reaction between the hydroxyl end-groups of MPE and the resulting urethane groups were not significant.

![Scheme 1. Synthesis route of silanated PEG.](image)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mn</th>
<th>Mw</th>
<th>$d$ (Mw/Mn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPEG-350</td>
<td>368</td>
<td>383</td>
<td>1.041</td>
</tr>
<tr>
<td>SP-350</td>
<td>608</td>
<td>652</td>
<td>1.072</td>
</tr>
<tr>
<td>MPEG-1150</td>
<td>1102</td>
<td>1185</td>
<td>1.075</td>
</tr>
<tr>
<td>SP-1150</td>
<td>1343</td>
<td>1425</td>
<td>1.061</td>
</tr>
<tr>
<td>MPEG-2000</td>
<td>2085</td>
<td>2213</td>
<td>1.061</td>
</tr>
<tr>
<td>SP-2000</td>
<td>2346</td>
<td>2487</td>
<td>1.060</td>
</tr>
</tbody>
</table>
These results suggested that silanated PEG with well-defined structure could be synthesized through this method.

3.2. Static water contact angle measurement

Static water contact angle measurement was used to evaluate the surface hydrophilicity of the PE Gylated silicon chip surfaces with SP-350. As shown in Table 2, the contact angle of the neat silicon surface was 47.8°. A salient decrease in contact angle by 7° could be observed after the substrates were treated with SP-350 by soaking in its 1 mM solution for only 0.5 min. It indicated that the surface became obviously more hydrophilic and that the self-assembly process of the silanated PEG molecules from the solution onto the substrate surfaces began as soon as the substrate was immersed in the PEG solution. That the self-assembly monolayer (SAM) of the silanated PEG could be formed quickly was further confirmed by the AFM result. However, with the increase of soaking time from 0.5 to 120 min in the same solution, the surface contact angle of the modified surfaces merely decreased from 40.4° to 35.5°, which suggested that the deposition of the grafted silanated PEG molecules on the substrate surface slowed down with the increase of soaking time. On the other hand, with the same soaking time of 120 min, when the solution concentration was increased from 1 to 30 mM, the contact angle merely decreased from 35.5° to 34°. It could be concluded that in this case, a regular and integrated SAM of the silanated PEG could be obtained even in a dilute solution with enough soaking time. In addition, the contact angle did not change much in the cases of different molecular weights of the PEG chains. After the surface was covered with a compact layer of PEG molecules, the length of the molecular chain was found to have less effect on the final hydrophilicity of the modified surface.

### Table 2

<table>
<thead>
<tr>
<th>Sample</th>
<th>Static contact angle (°)</th>
<th>RMS (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>47.8 ± 1.2</td>
<td>0.127</td>
</tr>
<tr>
<td>SP-350-1 mM-0.5 m</td>
<td>40.4 ± 0.6</td>
<td>0.915</td>
</tr>
<tr>
<td>SP-350-1 mM-15 m</td>
<td>37.9 ± 1.1</td>
<td>0.418</td>
</tr>
<tr>
<td>SP-350-1 mM-30 m</td>
<td>37.8 ± 0.4</td>
<td>0.385</td>
</tr>
<tr>
<td>SP-350-1 mM-120 m</td>
<td>35.5 ± 0.5</td>
<td>0.257</td>
</tr>
<tr>
<td>SP-350-5 mM-120 m</td>
<td>35.6 ± 0.6</td>
<td>0.569</td>
</tr>
<tr>
<td>SP-350-20 mM-120 m</td>
<td>34.3 ± 0.6</td>
<td>0.592</td>
</tr>
<tr>
<td>SP-350-30 mM-120 m</td>
<td>34.0 ± 0.8</td>
<td>0.787</td>
</tr>
<tr>
<td>SP-1150-5 mM-120 m</td>
<td>35.2 ± 0.7</td>
<td>0.533</td>
</tr>
<tr>
<td>SP-2000-5 mM-120 m</td>
<td>33.8 ± 0.6</td>
<td>0.435</td>
</tr>
</tbody>
</table>

3.3. Surface morphology of the PE Gylated silicon surface

Since implantable microdevices are normally used directly in contact with biological fluids, surface condition greatly affects protein adsorption behaviors, and further affects cell adhesion and proliferation. This suggests that the topography of device surfaces is of extreme importance. We used AFM to investigate the topography of various surfaces that were prepared in different conditions. AFM is a very effective tool for studying the topography as it can display the real-space morphology and nanostructure of the sample surfaces. The information on the homogeneity of the surfaces could also be obtained in terms of the analysis of the roughness values [38].

The surface morphology of the neat silicon chip used as a control is shown in Fig. 3. From the images, it can be seen that the surface was very flat and smooth with a very low RMS value, only 0.127 nm. Surface undulation was below 0.5 nm. AFM images of the surfaces grafted with 1 mM SP-350 for different soaking times are shown in Fig. 4. For the surface grafted in 1 mM SP-350 for 0.5 min, the morphology changed remarkably, with many small uniform pores appearing. The RMS value increased to 0.915 nm accordingly. The light region in the AFM images represented the silanated PEGs grafted onto the surface and the dark region was the exposed substrate without PEG chains grafted. It was indicated that lots of SP-350 molecules had already been covalently coupled onto the surface and a self-assembled monolayer was formed but with a low coverage which resulted in the large number of pores. However, the number of pores on the surface disappeared obviously, with surface coverage increasing and the RMS lowering. In the case where the soaking time was further increased to 120 min, almost no pores could be found at all and the RMS value reduced continuously, approaching the RMS value of an unmodified silicon surface. And the surface was completely covered with a uniform SAM, with only some aggregates appearing on the surface which was probably due to the minimized aggregation of silanated PEG in bulk solution before grafting onto the surface. As shown in the section plots, the height and number of the peaks of the surface grafted in the 1 mM SP-350 for 0.5 min were much larger than those of the neat silicon chip surface. With the soaking time further prolonged, the number of peaks was remarkably reduced while the peaks were also smoothed, which demonstrated that the amount of silanated PEGs grafted to the surface increased as the soaking time increased. However, the morphology changed slowly after the soaking time was longer than 15 min.

AFM images of the PEG immobilized interfaces resulting from different concentrations of SP-350 for 2 h are illustrated in Fig. 5. The surfaces grafted with 1 and 5 mM SP-350 for the prolonged
immersing time were both even and smooth. However, when the solution concentration was high, surfaces became much rougher, with some broader and higher peaks appearing, which might be due to the oligomerization reaction between the silanated PEG molecules in the concentrated solutions. This indicated that more silanated PEG molecules were grafted at higher concentrations. The RMS value was found to increase along with the increasing concentration. When the solution concentration was increased to 30 mM, the RMS value reached 0.787. Due to the high chain flexibility, PEG molecules are supposed to be random coils in their dry state, collapsing on the substrate surface. As long as the concentration increased, the density of the surface-grafted PEG chains became higher. The distance between adjacent chains decreased and the repulsive force increased, which would lead to

Fig. 4. AFM images (1 μm × 1 μm) and section plots for PEGylated surfaces of silicon chips formed at different soaking time in 1 mM SP-350 solution; (a) 0.5 min; (b) 15 min; (c) 30 min; (d) 120 min.
the vertical stretching of the PEG chains and an increase in film thickness. From the section plots, it could be observed that the number of peaks decreased while the sample concentration increased.

Fig. 6 shows the 2D and 3D AFM images of PEG interfaces grafted with SP-350, SP-1150 and SP-2000 at 5 mM for 2 h. It can be seen that the morphologies do not appear to have much difference from each other. Surfaces were completely covered with uniform and smooth coatings of PEG, with very low RMS values (<0.6 nm). The AFM characterization results demonstrated that uniform and smooth PEG surface layers could be obtained on silicon chips with silanated PEG molecules of different chain lengths by the use of appropriate solution concentration or soaking time.

3.4. In vitro anticoagulation properties

In this work, the activated partial thromboplastin time (APTT), prothrombin time (PT), and thrombin time (TT) of the SAMs on glassplates were obtained to evaluate their anticoagulation activities. PT corresponds to the extrinsic pathway of the blood-
clotting system, and APTT detects the intrinsic coagulation, i.e., an influence on Factor XIIa, XIa, IXa, VIIIa and high molecular weight kininogen. TT is the assay for the last step of coagulation: i.e., the thrombin-mediated fibrin formation [39]. Therefore, blood plasma APTT, PT, and TT tests are commonly used to evaluate the in vitro anticoagulation properties of different materials.

The normal ranges of APTT, PT and TT for healthy human plasma are regarded to be 34 ± 7, 14 ± 2 and 17.5 ± 2.5 s, respectively. PT, APTT and TT values for the glassplates grafted with silanated PEG of different molecular weights are shown in Fig. 7. It was found that the APTT values of all the samples grafted with silanated PEGs were significantly prolonged. However, the TT and PT values of all the samples did not change obviously. From the figure, it also can be observed that all the PT, APTT and TT values appear to have no variation when the molecular weight of the silanated PEG changes. Therefore, the in vitro anticoagulation and platelet adhesion properties were mainly investigated through the surfaces grafted with SP-2000 of different concentrations. From Fig. 8, for the samples grafted with SP-2000 at concentrations of 2 and 10 mM, all three values did not vary remarkably, compared to the control. Nevertheless, when the concentration increased to 30 mM, APTT was prolonged obviously.
from 28.1 to 36.3 s. This was considered to be due to the different grafting coverage caused by different sample concentrations.

3.5. Platelet adhesion

The adhesion and activation of platelets on a material’s surface always leads to coagulation. The activated platelets can further activate many kinds of coagulation factors, which results in thrombus on the material surface. Therefore, the in vitro platelet adhesion test can be carried out to investigate the blood compatibility of the material surface. The shapes of the adhered platelets should be carefully observed by scanning electron microscopy. Once the platelets were activated, “pseudopods” would stretch out, accompanied by the aggregation of the platelets.

Typical SEM photographs of platelet adhesion results for surfaces grafted with SP-2000 are shown in Fig. 9. It can be seen that the neat glass surface incubated in PRP for 1 h showed a large number of adhered platelets with lots of “pseudopods” stretching out. In contrast, the surface grafted with 2 mM SP-2000 exhibited fewer adhered platelets and these did not change their shapes. Surprisingly, almost no substantial platelet attachment could be found on the surfaces grafted with 10 and 30 mM SP-2000. When the incubation time was prolonged to 3 h, it can be seen from Fig. 10 that, on the neat glass plate, there were more adhered platelets with their shapes greatly changed. Furthermore, thrombus could be found on some areas of the surface. In the case of the sample grafted with 2 mM SP-2000, the number of platelets adhered to the surface also increased, which might be due to the incomplete coverage of PEG on the surface. However, the surfaces grafted with 10 and 30 mM SP-2000 still appeared very clear. These results proved that haemocompatibility could be effectively improved by modifying the surfaces with this kind of silanated PEG.

3.6. Stability of the films

The practical utility of this SAM is based on both its performance and its stability which can ensure its application
The silicon chips PEGylated in 5 mM SP-2000 solution for 120 min were incubated in PBS for weeks to investigate the stability of the SAM. As shown in Fig. 11, their contact angle and RMS values increased during incubation in the first week. The contact angle increased from 33.8° to 36°, while RMS increased from 0.435 to 1.763 nm. This was possibly caused by the detachment of some silanated PEG molecules from the surfaces which were not substantially grafted onto the substrate. However, even after 4 weeks, both the contact angle and RMS values remained stable at a low level, indicating that the remaining PEG chains were covalently coupled to the substrate and the films were stable in PBS.

4. Conclusions

In the present research, a series of silanated PEGs were synthesized by the direct coupling of monomethoxy poly(ethylene glycol) with 3-isocyanatopropyl triethoxysilane through a urethane bond. The structure of this silanated PEG was confirmed by using FTIR spectra, 1H NMR and GPC. An easy and efficient method, immersing the cleaned silicon-containing substrate into the PEG solution, was used to modify the surface. Stable and uniform self-assembled monolayers on these substrates could be obtained by this method. The morphologies of the surfaces grafted from various conditions were carefully investigated by AFM. The real-space morphology and nanostructure combined with the hydrophilicity changes confirmed the covalent coupling of PEG onto the substrate surface. The small changes in surface topography and static contact angle during the longer incubation period in PBS solution proved the stability of the film. All the PEGylated surfaces prepared from silanated PEG of different molecular weights prolonged the APTT obviously without apparent adhered platelets on the surfaces. It demonstrated that it was effective in improving the surface haemocompatibility of silicon-containing materials through the formation of SAMs using silanated PEG.
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References