Studies on two new radiopaque polymeric biomaterials

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Two new polymeric materials (polymers A and B) containing covalently bound iodine were prepared. These polymers were evaluated with respect to their possible use as radiopaque implant biomaterials—that is, materials that are visible in a noninvasive manner using routine X-ray absorption imaging techniques. Polymer A is a copolymer of methyl methacrylate (MMA) and 1 (80 and 20 mol%, respectively). Polymer B was prepared from MMA, 1, and 2-hydroxyethyl methacrylate (HEMA) (mol ratio 65:20:15, respectively). Compound 1 was synthesized from 4-iodophenol and methacryloyl chloride. The resulting polymers were characterized with GPC, DSC, NMR, and by measuring both the advancing and receding contact angles. Thrombogenicity of the polymers was determined by an in vitro thrombin generation test procedure. The maximum concentration of free thrombin was 76 ± 1 nM for polymer A, and 64 ± 3 nM for polymer B. The lag times (i.e., time onset of thrombin generation) were 392 seconds for polymer A and 553 seconds for polymer B. For PVC-T, which is known as a passive material, a lag time of 583 seconds was found. This indicates that polymer B is comparable to PVC-T, and more passive than polymer A. Polymer A exhibited minor activation of platelets. Polymer B did not induce platelet activation at all. The polymers exhibited, even as fibers with a diameter of ca. 0.3 mm, good radiopacity with routine imaging X-ray techniques in the clinic. It is argued that polymers A and B—which actually represent a whole family of radiopaque polymeric biomaterials—exhibit promising properties with respect to applications as construction materials for a new generation of endovascular stents. © 1994 John Wiley & Sons, Inc.

INTRODUCTION

Recent literature on novel biomaterials shows that there is an increasing interest in radiopaque polymers for the construction of implants.1–3 The reason for this trend is obvious: X-ray imaging (being fast, reliable, convenient and nondestructive) is commonly used in clinical practice. This means that X-ray imaging is an ideal tool to monitor performance and/or exact location of implants (e.g., endovascular stents) in a noninvasive manner. A common approach is to mix metal salts (e.g., barium or bismuth salts) with polymers. However, this deteriorates the mechanical properties of the material, and there is also a risk of leakage; the metal salt can leach into the body fluids over a long time.4 A better approach might be to introduce radiopaque monomeric units during polymer synthesis.1–3 In this way, X-ray visibility can be realized without a negative effect on the mechanical properties, and leakage cannot occur.

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These considerations have inspired us to prepare two new materials that contain radiopaque building blocks. The first new material we describe (designated polymer A) is a copolymer of methyl methacrylate (MMA) and the iodine-containing monomer 1. The second material

![Chemical structure of compound 1](attachment:chemical_structure.png)

(polymer B) is a terpolymer consisting of MMA, 2-hydroxyethyl methacrylate (HEMA), and 1. We describe the chemical synthesis of compound 1 from methacryloyl chloride and 4-iodophenol, the radical polymerization reactions affording polymers A and B, physical and chemical characterization of both polymers, and results of an in vitro evaluation of
their thrombogenicity. The possible use of polymers A and B, and a wide variety of analogous radiopaque materials, is discussed briefly.

EXPERIMENTAL

Materials

Synthesis of compound 1

A solution of methacryloyl chloride (8.55 g, 81.8 mmol) in 75 ml of dry dichloromethane was added dropwise over 60 min to a magnetically stirred and cooled (−5°C) solution of 4-iodophenol (15.05 g, 68.4 mmol) and dry triethylamine (13.80 g, 136.4 mmol) in 200 ml of dry dichloromethane. During the addition, the reaction mixture changed from dark to light brown. After completion of the addition, the cooling bath was removed and stirring was continued for 1 h. Then the reaction mixture was again cooled to −5°C, and 250 ml of distilled water was added carefully. The reaction mixture was transferred to a separation funnel, the organic phase was separated, and was subsequently washed with saturated NaHCO₃ (200 ml, 1×) and brine (200 ml, 1×).

The organic layer was dried over MgSO₄, filtered, and concentrated. The residue was chromatographed in two runs on a silica gel column (ø 3 cm, height 20 cm) using petroleum ether 40-65 and 2-butanone (95: 5 vol:vol) as the eluent. Fractions containing pure product (Rₖ = 0.33 in the same eluent) were pooled and concentrated. This afforded the desired product (15.96 g, 55.4 mmol) as a colorless oil, which crystallized on standing. The yield was 81.0%. mp: 29.2 ± 0.3°C. ¹H-NMR(CDCl₃): δ 7.71 (2H, d, arom), 6.90 (2H, d, arom), 6.35 (1H, s, olef. H trans to Me), 5.78 (1H, s, olef. H cis to Me), 2.06 (3H, s, Me). Splittings due to small mutual J-coupling are seen on the signals at δ 5.78 and 2.06 ppm. ¹³C-NMR(CDCl₃): δ 165.3, 150.7, 138.4, 135.5, 127.6, 123.8, 89.7, 18.3. IR(KBr): 1743 (C=O), 1646 (C=C, alkene), 1576 and 1486 cm⁻¹ (C=C, aromatic). Elemental analysis (calculated): C, 41.69; H, 3.15; I, 44.05. Found: C, 41.84; H, 3.21; I, 44.07.

Polymer synthesis

Commercial MMA was washed with 0.5 M NaOH (3×) and water (3×), dried over MgSO₄, and filtered. Pure MMA was then obtained after distillation at atmospheric pressure (bp 101°C). A relatively large pre-run was discarded. Commercial HEMA was distilled directly under reduced pressure (13 mbar). A relatively large pre-run was discarded.

In the radical polymerization of A, pure MMA (5.82 g, 58.1 mmol) and compound 1 (4.19 g, 14.5 mmol) were transferred into a Teflon tube (length ca. 20 cm), which was tightly closed with a glass stopper on one end. The internal diameter of the tubes was 12 mm. In the radical polymerization of B, we analogously combined MMA (4.58 g, 45.7 mmol), HEMA (1.37 g, 10.5 mmol), and compound 1 (4.06 g, 14.1 mmol). Radical initiator and chain transfer agent were added from freshly prepared stock solutions. Final concentrations are given in Table I.

The contents of the tube were thoroughly mixed. Then, the tubes were placed in a thermostated oil bath, equipped with a programmable time-temperature control system (PM LAUDA, Germany). The time-temperature profile, as outlined in Figure 1, was then run.

This procedure afforded both materials as colorless glassy rods. The Teflon was removed using a scalping knife and the upper and lower part (1 cm each) of the rods were cut off and discarded. Part of the remaining material was used for physical characterization (elemental analysis, GPC, DSC, NMR) and another part was spun into thin fibers (ø ca 0.3 mm). A small part of the fibers (ca 0.3 g) was dissolved in distilled dimethylformamide; this 10% (wt/wt) solution was used in the preparation of polymer films on glass (film casting).

Polymer surfaces were obtained by coating glass coverslips, which were thoroughly cleaned with ethanol p.a., in 10% (wt/wt) solutions of the polymeric materials in distilled dimethylformamide. The coated coverslips were pre-dried under clean room conditions, and subsequently, the coatings were dried in vacuo just below the respective glass-transition temperatures of the polymers.

For the thrombin generation tests we used circular glass coverslips (Ø 22 mm, Menzel-Glaser), and for the contact-angle measurements square glass coverslips were used (20 × 20 mm; Assistent, Germany). Note that double-sided coatings were applied for the contact-angle measurements. Scanning electron micrographs showed that the coatings were uniform and smooth and were uniform and smooth.

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Initiator *</th>
<th>Chain Transfer Agent t</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: MMA/HEMA/1</td>
<td>(80/20)</td>
<td>0.080 mol%</td>
</tr>
<tr>
<td>B: MMA/HEMA/1</td>
<td>(65/15/20)</td>
<td>0.068 mol%</td>
</tr>
</tbody>
</table>

*Initiator = tert-butyl peroxycarboxate (Trigonox C, Akzo, The Netherlands).
†Chain transfer agent = 2-mercaptopropanol (Janssen Chimica, Belgium).
 Molar fraction.

TABLE I

Concentrations of Initiator and Chain Transfer-Agent Used during Preparation of Polymers A and B
Figure 1. Time-temperature profile during synthesis of polymers A and B. Cooling at the end of the synthesis was unforced; it took approximately 4 h before room temperature was reached.

croscopy indicated that the films were smooth, homogeneous, and particle-free. $^1$H-NMR of polymer A: (DMSO-d$_6$): $\delta$ 7.9–7.6 (br, arom H), 7.1–6.8 (br, arom H), 3.7–3.4 (br, OMe), 3.36 (trace of H$_2$O), 2.3–1.5 (br, CH$_2$ in chains), 1.3–0.5 (br, Me). $^1$H-NMR of polymer B: (DMSO-d$_6$): $\delta$ 7.9–7.6 (br, arom H), 7.1–6.8 (br, arom H), 4.9–4.7 (br, OH), 4.1–3.8 (br, CH$_2$ of HEMA), 3.7–3.4 (br, OMe and CH$_2$ of HEMA), 3.36 (trace of H$_2$O), 2.3–1.5 (br, CH$_2$ in chains), 1.3–0.5 (br, Me).

Methods

$^1$H- and $^{13}$C-NMR spectra were recorded at 400.1 and 100.6 MHz, respectively, on a Bruker AM 400 spectrometer. Chloroform-d was used as the solvent for the monomer and DMSO-d$_6$ was used as the solvent for the polymers. Tetramethylsilane was used as the internal standard ($\delta$ = 0.00 ppm).

Elemental analyses were performed by Galbraith Laboratories (Knoxville, TN).

The glass-transition temperature of the polymers was measured using a heating rate of 10°C/min and determined from the second heating scan using a Perkin Elmer DSC 7. Argon was used as the carrier gas. The DSC was calibrated using indium and zinc.

Gel permeation chromatography (GPC) was used to determine the number-average molecular weight ($M_n$), the weight-average molecular weight ($M_w$), and the polydispersity ($M_w/M_n$) of the polymers. GPC was performed using a Waters Wisp autoinjection apparatus, equipped with 10$^5$, 10$^4$, 10$^3$ μ-Styrage columns (Shodex KF 80 M 2x, 40°C). THF was used as the mobile phase at a flow rate of 1.0 ml/min. The GPC measurements were determined independently by UV (UV 440; ambient conditions) at 254 nm and refractive index (RI 410, 40°C). Calibration was performed with polystyrene standards (580–6 × 10$^6$ g/mol). The polymeric films were characterized by dynamic contact-angle measurements using the Wilhelmy plate technique as described by van Damme et al.$^5$

The water contact-angles of the polymeric surfaces were measured at 20°C. In our biochemical experiments we used blood obtained by venipuncture from a healthy donor who had not taken aspirin or other platelet-active agents for at least 7 days before donation. The blood was anticoagulated with 1/10 vol 130 mmol/l trisodiumcitrate. Platelet-rich plasma (PRP) was prepared from citrated whole blood by centrifugation at 1000 rpm for 10 min. In the thrombin generation tests circular glass coverslips (diameter 22 mm) coated with the polymer were placed in a 24-well titer plate and exposed to citrated PRP (500 μl) during 10 min at 37°C while the plate was shaken at 150 rpm on an orbit shaker (Lab-line Instruments, Metrose Park). The surface to volume ratio (7.6 cm$^2$/ml) was kept constant for all testings. Thrombin generation was initiated by the addition of 20 μl of a 0.5 M CaCl$_2$ solution. The final free Ca$^{2+}$ concentration was 4 mmol/l. Samples were taken from the recalciﬁed PRP and analyzed for thrombin using the chromogenic substrate S2238 (Chromogenic, Mölndal, Sweden) as previously described by Lindhout et al.$^6$

The thrombin generation curves obtained were analyzed for the concentration of free thrombin according to the method of Hemker et al.$^7$ The lag time of the plasma was assessed by monitoring the appearance of fibrin strands (time onset of thrombin generation). Circular glass coverslips, coated with polymer and incubated with citrated platelet rich plasma for 30 min at 37°C, were rinsed with a saline buffer and treated with 2.5% glutaraldehyde in 0.1 M phosphate buffer at 4°C overnight. The samples were removed, rinsed with 0.1 M phosphate buffer, and dehydrated in ethanol series (subsequently increasing from 50 to 100% ethanol). Subsequently, the coverslips were dried by the critical point drying method. The dried samples were gold-sputtered and subjected to scanning electron microscopic observations at an accelerating voltage of 5 kV using a Philips 500 microscope.

RESULTS AND DISCUSSION

Physicochemical characterizations

Polymers A and B were subjected to different analytical techniques to establish their identity and purity, and to measure characteristic properties such as
the glass-transition temperature ($T_g$), weight-average molecular weight ($M_w$), and contact angles.

Gel permeation chromatography (GPC)

The number-average molecular weight, the weight-average molecular weight, and the polydispersity of polymers A and B were determined as described in the Experimental section. Two independent techniques, UV extinction and refractive index, were applied. Both techniques produced consistent results, as summarized in Table II.

These data revealed that we obtained genuine polymeric materials. We believe that this is an important conclusion because it was reported that other iodine containing monomers (triiodophenyl methacrylate or the iothalamic ester of HEMA) are markedly resistant to homopolymerization and copolymerization with for example, MMA and HEMA. In fact, we have made contradictory observations: polymerization was almost completed 1 h after start of the reaction whereas the temperature in the oil bath had not exceeded 65°C. In addition, we have observed that decreasing the concentration of the chain-transfer agent results in weight-average molecular weight values that markedly exceeded the values listed in Table II.

Differential scanning calorimetry (DSC)

The results of these experiments are compiled in Table III. Based on these $T_g$ values it is expected that further physical processing of polymers A and B, such as fiber spinning or compression moulding, is possible. In addition, the partial substitution of MMA by HEMA results in a lower $T_g$. This is in agreement with the well-known fact that PMMA has a higher $T_g$ (114°C) than PHEMA ($T_g = 48°C$).

Nuclear magnetic resonance (NMR)

Polymers A and B were studied by 400 MHz $^1$H-NMR in a DMSO-$d_6$ solution. In each case, a small amount (ca. 10 mg) was dissolved in 0.5 ml of solvent. Parts of the $^1$H-NMR spectrum of polymer B are shown in Figure 2. The spectra of polymers A and B clearly reveal the presence of the different constituents in the polymers. This is especially the case for the aromatic protons of the 4-iodophenoxy group, which appear as broadened signals centered at 7.8 and 6.9 ppm for both polymers (see also subspectrum c in Fig. 2). Integration of these signals, and comparison with the integral of the CH$_3$ groups attached to

<p>| TABLE II |
| Results from Gel Permeation Chromatography on Polymers A and B |</p>
<table>
<thead>
<tr>
<th>Polymer</th>
<th>$M_n$ (g/mol)</th>
<th>$M_w$ (g/mol)</th>
<th>$M_w/M_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>22,700</td>
<td>61,500</td>
<td>2.71</td>
</tr>
<tr>
<td>B</td>
<td>12,200</td>
<td>41,300</td>
<td>3.37</td>
</tr>
</tbody>
</table>

Data refer to UV extinction as the detection technique.

<p>| TABLE III |
| Glass-Transition Temperature and Specific Heat Capacity of Polymers A and B |</p>
<table>
<thead>
<tr>
<th>Polymer</th>
<th>$T_g$ (°C)</th>
<th>$\Delta C_p$ (J/g°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>107</td>
<td>0.2</td>
</tr>
<tr>
<td>B</td>
<td>103</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Figure 2. Expansions of the 400 MHz $^1$H NMR spectrum of polymer B, dissolved in DMSO-$d_6$. (A) Aliphatic protons; pattern i is due to the methylene groups in the main chain, pattern ii corresponds with the methyl groups, attached directly to the main chain. (B) Pattern iii: OH group of HEMA; pattern iv: one of the methylene groups of the CH$_2$-CH$_2$-OH side chain of HEMA; Pattern v: methoxy groups of MMA, and the other methylene group of the HEMA side-chain (C) Patterns vi and vii: aromatic protons. Integration of the patterns confirmed the compositions MMA : HEMA: compound 1 = 65 : 15 : 20 (mol%); see text.
the polymer chain (1.3–0.5 ppm, see also subspectrum a in Fig. 2) confirm the presence of ca. 20 mol% of iodine containing monomeric building blocks in both polymers.

The NMR spectra also show the presence of traces of residual monomer. For example, the small and sharp signals in subspectra a and c (Fig. 2) are due to unreacted monomer molecules. Based on the NMR spectra, it is clear that the content of residual monomer in both polymers is below 1%.

Contact-angle measurements

The Wilhelmy plate technique was used to determine dynamic contact angles. This approach is suitable to measure contact-angle hysteresis; both the advancing and receding angles are measured in a single run as averages over the whole surface. Glass coverslips, coated with polymer A or B, were immersed with a speed of 11 mm/min. in a beaker containing hyperfiltrated water. The temperature of the water was 20°C. The results of these measurements are summarized in Table IV.

The data in Table IV result from experiments with six different coated coverslips (coating on both sides). Especially from the receding contact angles, it is concluded that the (wetted) surface of polymer A is more hydrophobic than that of polymer B. This is in agreement with our expectations: Polymer A is merely composed of hydrophobic monomers, whereas polymer B is partly composed of HEMA, which has marked hydrophilic properties. As can be expected, the contact angles of polymers A and B are comparable with those of MMA/HEMA copolymers. The contact angles of polymer A are comparable with those of PMMA. The contact angles of polymer B closely resemble those of the copolymer composed of 75 mol% MMA and 25 mol% HEMA.

Evaluation of in vitro thrombogenicity

Thrombin generation test

Polymers A and B were subjected to the in vitro thrombin generation test procedure as originally described by Lindhout et al. Because thrombin plays a key role in hemostasis and thrombosis, this test performed with platelet rich plasma provides a valuable impression of the thrombogenicity of foreign surfaces. The test is essentially comparative—that is, control experiments must be executed simultaneously under the same experimental conditions and with the same plasma. The controls used were the reference materials polyethylene (PE) and polyvinyl chloride with tri-(ethyl-hexyl)-trimellitat as plasticizer (PVC-T). Both reference materials were obtained from the EC program "Eurobiomat."

The principle of the thrombin generation test can be briefly outlined as follows. Blood from a healthy donor is mixed with a 0.13 M sodium citrate solution in a 9:1 (vol/vol) ratio. Complexation of citrate with Ca²⁺ in the blood effectively prevents coagulation, and leaves sufficient free Ca²⁺ (=50 μM) required for normal platelet reactivity.

The citrated plasma is incubated with the polymer surface and left to stand for 15 min under continuous gentle shaking. Clotting is started through addition of Ca²⁺ ions (final free [Ca²⁺] = 4 mM). Subsamples were assayed for thrombin using the chromogenic substrate S2238 (H.-D.-phenylalanyl-pipecoly-arginine p-nitroanilide). The reaction can be monitored conveniently by virtue of the extinction of liberated p-nitroanilide at 405 nm.

We have used circular glass coverslips (Ø 22 mm) coated with polymer A or B in our thrombin generation tests. Experiments with coated polymer A and B were performed in triplo. Figure 3 shows the thrombin generation in PRP exposed to polymer B after recalcification.

In general, a thrombin generation curve shows a lag phase, which is followed by a shorter phase in which formation of thrombin proceeds in an explosive manner. Subsequently, the thrombin concentration is seen to pass a maximum. We have used the thrombin generation curves merely to obtain two parameters, which are directly related to the thrombogenicity of the material. The first parameter is the duration of the lag phase (lag time), and the second parameter is the maximal concentration of free thrombin reached during the experiment. Note that the lag time corresponds with the classical clotting time, as the increase of thrombin concentration will directly start the formation of fibrin. The results of our experiments with polymers A and B, and the reference materials glass, polyethylene (PE) and polyvinyl chloride-T (PVC-T) are presented in Table V. The maximum thrombin concentrations listed in Table V were obtained after correction of the experimental thrombin generation curve for the residual amidolytic activity of the thrombin-α₂ Macroeglobulin complex (thrombin-α₂M). The procedure of Hemker et al. was applied to perform this correction. The polymeric reference materials were examined as foils, not as a
coating on glass. In the case of PVC-T, we have verified that the same lag time is found for the polymer as a film, and for the polymer as a coating on glass (see Table V).

In comparison with PE and glass (see Table V), polymers A and B are less thrombogenic. It is seen that polymer B is comparable with PVC-T in terms of lag-phase duration. For polymer A, thrombin generation proceeds faster than for polymer B. Comparing the maximum thrombin concentrations reached with polymers A, B, and PVC-T, it is seen that polymer B and PVC-T are highly comparable (max. [thrombin] = 70 nM). Note also that relative low max. [thrombin] = 75 nM was found for polymer A.

Polymer B is thus less thrombogenic than polymer A. This may correlate with our finding that the surface of polymer B is more hydrophilic than that of polymer A (vide supra). Our data are reminiscent of other reports that state that a balance of hydrophobicity and hydrophilicity of the surface is needed for good blood-compatibility features.10-12

**Adhesion of blood platelets to polymers A and B**

Polymers A and B were incubated with citrated platelet rich plasma for 30 min at 37°C. Scanning electron micrographs showed adhesion of platelets to the polymer A surfaces whereas virtually no adhesion was seen for polymer B. Figure 4 shows the morphol-

TABLE V

<table>
<thead>
<tr>
<th>Material</th>
<th>Lag Time (s)</th>
<th>Max. Thromb. Conc. (nM)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>217</td>
<td>154</td>
</tr>
<tr>
<td>PE</td>
<td>335</td>
<td>227</td>
</tr>
<tr>
<td>PVC-T foil</td>
<td>587</td>
<td>71</td>
</tr>
<tr>
<td>PVC-T coated</td>
<td>583</td>
<td>64</td>
</tr>
<tr>
<td>Polymer A†</td>
<td>392 ± 14</td>
<td>76 ± 1</td>
</tr>
<tr>
<td>Polymer B†</td>
<td>553 ± 13</td>
<td>64 ± 3</td>
</tr>
</tbody>
</table>

*Calculated for thrombin generation curves according to Hemker et al.7
†Experiments with coated polymer A and B were performed in triplo; the reported lag time and maximal thrombin concentrations are averages of three experiments; the standard deviations are also given.

**Figure 4.** SEM micrographs of polymer A (coated on glass) after incubation with platelet rich plasma for 30 min at 37°C. (A) Overview. The length of the bar = 0.1 mm. (B) Detail showing the morphology of adhered platelets. Formation of small pseudopods is noted. Bar = 10 μm.
ogy of platelets adhered to polymer A; Most of the surface is uncovered (see a in Fig. 4).

The corresponding detail (b) reveals that the few platelets extend small pseudopods—that is, a minor change in platelet morphology has occurred upon adsorption to polymer A. It is interesting to compare the results with the controls—platelets of the same plasma adhered to the reference materials PE and PVC-T. For PE, complete spreading of the platelets was found in the way that the entire surface was covered. Virtually no adhesion of platelets was found for PVC-T; in fact these SEM micrographs resemble those found for polymer B. It can be concluded that the surface of polymer B did not induce platelet activation in this test. For polymer A, minor activation of adhered platelets was found.

X-ray visibility

An important additional question concerned the radiopacity: Are small objects made out of polymers A or B detectable using X-ray absorption imaging techniques that are routine in the clinic? To address this question, we have drawn fibers from polymers A and B (diameter ca. 0.3 mm). Figure 5 shows four fibers: a polymer A; b: polymer B; c: the terpolymer MMA/HEMA/1 (75/15/10 mol%); and d: the copolymer MMA/HEMA (80/20 mol%) as a control.

These fibers were glued on a paper sheet, which was subsequently submitted to fluoroscopy. X-ray absorption from the patient's body was mimicked by a 15-cm-thick layer of Plexiglas. In this setup, the two fibers built of 20 mol% of 1 (polymers A and B) were clearly visible. A clearly reduced contrast was observed for the polymer that contained only 10 mol% of 1. Visibility of these thin fibers virtually ensures that greater objects out of polymers A and B are easily detectable using routine imaging techniques. This feature, combined with our data on thrombogenicity, leads us to expect that our materials are particularly suitable for the manufacture of a new type of endovascular stents. This is especially the case for polymer B. It is known that metallic stents (easily visible with X-ray) frequently fail to prevent restenosis and/or acute thrombus formation after PTCA.

Two examples of routinely used metallic stents are shown in Figure 6, and illustrate the visibility under fluoroscopy after implant in patient coronary arteries. Panel A of Figure 6 shows a Johnson and Johnson stent, composed of 0.15-mm stainless-steel wires, in a coronary artery of a patient. Panel B in Figure 6 shows the Wiktor stent, made of 0.15-mm tantalum wires, in a coronary artery of a patient. Both stents are indicated by arrows. Obviously, visibility of tantalum is superior to that of stainless-steel under X-ray.

Use of polymers A and B, or a whole range of analogous polymeric materials, may provide us with a means to construct stents with combined X-ray visibility and improved hemocompatibility. Studies focused on further improvement of the mechanical properties of polymers A and B, and analogous materials, as well as on other biomedical applications, are currently in progress in this laboratory.

CONCLUSIONS

In the present work we prepared and characterized two novel polymeric materials (polymers A and B),
The new polymers were found to exhibit satisfactory low thrombogenicity in our in vitro test system. Both thrombin generation tests, and SEM studies of platelet adhesion led to this conclusion. These materials were even visible as fibers with a diameter of ca. 0.3 mm using routine imaging X-ray techniques. It is foreseen that fibers of especially polymer B will be suitable for the manufacture of an all-polymeric endovascular stent.

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References