Scanning Electron Microscopy of Surface Irregularities and Thrombogenesis of Polyurethane and Polyethylene Coronary Catheters

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SUMMARY Following routine coronary arteriography, surface irregularities and thrombogenesis of the inner and outer wall of six Ducor polyurethane and six RPX polyethylene coronary catheters were studied by scanning electron microscopy. Polyurethane catheters had rough and highly irregular external and internal surfaces. All catheters showed adherent thrombi on their external surface. The internal surface of three catheters showed evidence of thrombosis. Polyethylene differed from polyurethane in several respects. Although the external surface had an irregular and wavelike appearance, the internal surface was smooth and regular. Two polyethylene catheters showed thrombi on their external surface. The internal surface of one catheter showed single platelets. These results confirm recent reports showing that internal and external surface irregularities play a major role in the initiation of thrombosis in and on intravascular catheters. They stress the need for high quality catheter materials with smooth and regular surfaces in the prevention of thromboembolic complications from coronary arteriography.

THE MOST FREQUENT and serious complications of coronary arteriography are thromboembolic.1 In a survey by Adams and coworkers2 of 46,904 coronary arteriograms performed during 1970-1971, arterial thrombosis at the site of catheter introduction occurred in 1.67% of studies with the brachial approach and in 1.19% of studies with the femoral approach. Major complications, the majority of which were felt to be embolic, were seen in 1.3% of these studies. They included death (0.45%), myocardial infarction (0.61%) and cerebral embolism (0.23%). Postcatheterization arteriograms1, 3 have demonstrated rapid thrombus formation in intravascular catheters. Recent scanning electron microscopic studies4, 7 have shown that internal and external surface irregularities are an important factor in the initiation of thrombosis in and on intravascular catheters. In a recent report of 5250 coronary arteriograms from our laboratory,8 a relatively high incidence of femoral artery thrombosis and a low incidence of systemic embolization were observed, suggesting differences in thrombogenicity between the internal and external surfaces of polyethylene catheters. The present study was undertaken to compare, by scanning electron microscopy, the relative surface irregularities and thrombogenicity of polyethylene and polyurethane and to assess differences between the inner and the outer wall of each catheter.

Material and Methods

Routine coronary arteriography via the percutaneous femoral approach was performed in 12 patients with suspected or documented coronary artery disease. Ten were males and two were females with a mean age of 46 ± 8 years. Polyurethane catheters (Ducor, Cordis Corporation) with Teflon-coated guide wires9 and polyethylene catheters (RPX, B-D) with stainless steel guide wires were used on alternate patients. Each technique was carried out as previously described.10-12

After adequate coronary opacification, the catheters were withdrawn on the guide wires. Two cm lengths of the tips of the right and left coronary catheters were sectioned and immediately placed in a mixture of 4% glutaraldehyde and 4% dimethyl sulfoxide13 buffered with 0.1 M cacodylate-HCl. Average use of catheters was 12 min and 10 min, respectively, for the right and left polyurethane catheters and 8 min and 10 min, respectively, for the right and left polyethylene catheters.

The specimens were dried at a critical point through graded ethanol, Freon 113 and Freon 13. The dried specimens were then mounted on supports and coated with gold. The inner and outer surfaces of six polyurethane catheters (three right and three left) and six polyethylene catheters (three right and three left) were examined in a JEOL model JSM-50A scanning electron microscope. The specimens were studied from 100 times to 30,000 times magnification.

Results

Morphology

Both internal and external walls of polyurethane catheters were markedly irregular with a variety of defects (fig. 1). Both surfaces looked grossly similar. However, the external surfaces showed coarser and more diffuse irregularities. At magnifications of 300 times, both walls had an oatmeal appearance. At magnifications of 3,000 times or more, numerous crests and troughs were clearly visible. Large defects alternated with smaller ones. Some areas also showed fissures, large holes and crack-like defects.

The morphology of polyethylene material was significantly different (fig. 2). The external surface had a rough wavelike appearance with crests and troughs and, in some areas, strands of material crossbridging the crests (fig. 2A). At larger magnifications of 3,000 times or more, large chips of protruding material were seen on top of the crests.

The internal surface of polyethylene, however, was relatively smooth and regular (fig. 2B). At lower mag-
nifications, tiny dips and very few superficial scratches were observed. This contrasted markedly with the highly irregular aspect of polyurethane at these magnifications. At greater magnifications, one could see that the internal wall of polyethylene also had a faint wavelike appearance. However, this was very discrete.

**Figure 1.** External (A) and internal (B) surfaces of polyurethane catheter showing an identical, oatmeal appearance. Crests and troughs are also visible. External surface: ×300; internal surface: ×300.

**Figure 2.** Polyethylene catheter. A) External surface of catheter showing its rough wavelike appearance and localized strands cross-bridging the crests (×300). B) Smooth and regular internal surface of catheter. Only a faint wavelike pattern can be distinguished (×300).
Thrombogenesis

Three different stages of thrombogenesis could be recognized: 1) platelet thrombi; 2) thrombi with platelets and fibrin strands; 3) thrombi with platelets, fibrin deposits and red blood cells.

Polyurethane

All six samples showed adherent thrombi on their external surfaces. Two catheters showed isolated clumps of platelets on and between the crests (fig. 3). Two catheters showed large thrombi with abundant fibrin deposits around the platelets. Finally, two catheters showed thrombi with platelets, fibrin deposits and red blood cells.

The internal surface was free of thrombosis in three catheters and showed evidence of thrombosis in three catheters. One had localized platelet thrombi. Two had numerous platelet thrombi with fibrin deposits and red blood cells (fig. 4). Two were right coronary catheters and one was a left coronary catheter.

Polyethylene

Two of the six catheter samples showed thrombi with platelets, fibrin deposits and red blood cells on their external surface (fig. 5). Both were left coronary catheters. The external surface of the other samples were free of thrombi.

One internal surface showed, in one area, single platelets (fig. 6). This was a right coronary catheter. In all the others thrombosis did not occur.

Discussion

Lack of compatibility of nonbiological surfaces with blood and its components has long been known and has recently received increasing attention.\textsuperscript{14-18} The need to develop biocompatible artificial prostheses and organs has necessitated a better understanding of the problems involved. In cardiac catheters the pertinent factors include the material, the surface irregularities, the wettability and the electrical charge. Vascular walls and blood components both have negative electrical charges.

Although intravascular catheters have been used extensively for several decades, problems associated with thrombosis on their surfaces were not described and their clinical consequences were not well documented until relatively recently. Reports of thrombus formation on the external surfaces of catheters and the association of a relatively high incidence of thrombosis at the site of arterial entry, detected clinically and requiring surgical treatment, have appeared since 1960.\textsuperscript{16-19} Since 1970, a distressing incidence of coronary and cerebral embolic accidents from selective coronary arteriography has been described.\textsuperscript{20-24}

Recent scanning electron microscopic studies\textsuperscript{6,7} have shown marked surface irregularities of intravascular catheters. These studies have also demonstrated that such surface irregularities are an important factor in the initiation of thrombosis in and on intravascular catheters. Nachmani and coworkers\textsuperscript{6} have illustrated the marked irregularities and thrombogenesis of polyurethane. They stated that polyethylene showed some degree of linear grooving but generally appeared more homogeneous and smooth than polyurethane at magnifications up to 3,000 times. However, they did not present illustrative photographs of their polyethylene material. In a subsequent short communication,\textsuperscript{25} they indicated that they had learned that the material referred to in their report as polyethylene was in fact teflon.

This rectification appears somewhat surprising, since teflon

\textbf{Figure 3.} Wafer-like platelets on top of a crest on the external surface of polyurethane catheter (× 10,000).

\textbf{Figure 4.} Internal surface of polyurethane catheter with a few platelets on some of the hillocks (× 3,000).
Platelet thrombi were frequently seen throughout the lumen attached to the inner lining. Thrombi with fibrin and red blood cells were seen in four of 12 catheters.

In the present study, marked differences in the morphology and thrombogenesis of polyethylene and polyurethane were observed at scanning electron microscopy. These findings are of particular interest since they confirm previous studies showing that surface irregularities of intravascular catheters appear to be coincident with a greater tendency to thrombogenesis.\(^5\)\(^,\)\(^7\) They are in agreement with previous clinical observations from our laboratory. In a survey of 5250 patients undergoing coronary arteriography with preformed polyethylene catheters,\(^8\) the incidence of femoral artery thrombosis was relatively high (0.68%), whereas the incidence of documented embolic complications was very low. Finally, certain conclusions applicable to the prevention of thromboembolic complications from coronary arteriography can be drawn from these results.

Thermoplastic catheters are extruded from rigid metallic molds and, possibly, the use of perfectly regular molds and more adequate methods of extrusion could result in catheters with minimal surface defects.

Heparin is a mucopolysaccharide with a negative electrical charge and decreases the interaction of nonbiological surfaces with blood. Systemic heparinization decreases the incidence of thromboembolic complications.\(^28\)\(^-\)\(^29\) However, in some recent reports\(^1\) it had no effect and in most reports it did not eliminate the occurrence of these accidents.\(^28\)

Some reports have suggested that application of a benzoalumineparin complex to the external surface of catheters was effective in reducing femoral artery thrombosis.\(^29\) In our experience, the incidence of femoral thrombosis was not significantly reduced by this method.\(^8\) Heparin applied in this fashion is probably rapidly washed from the surface of the plastic material.

Adequate methods of securely bonding heparin or other thrombolytic agents to both surfaces of catheters could have several advantages. The film obtained could result in increased smoothness of the wall, increased lubrication and the addition of negative electrical charges. Several techniques are currently being evaluated with different materials.\(^30\)\(^-\)\(^33\)

To assess the value of these preventive measures, continued examination of catheter surfaces by scanning electron microscopy is advisable.

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**References**

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