FACTORS AFFECTING THE BIOLOGICAL PROPERTIES OF VARIOUS CARBONS IN THE PHYSIOLOGICAL ENVIRONMENT

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Introduction

The biocompatibility and blood compatibility of materials may be enhanced by various surface modifications, including the chemical attachment of suitable macromolecules, biologically active agents, hydrogels, or by the deposition of thin, essentially impermeable surface coatings (1). Although LTI (low temperature isotropic) carbons have been successfully used in biomedical applications for several years, their deposition parameters bestow limitations. Guided by the biocompatible properties of LTI carbons, vacuum processes are being applied for the deposition of thin, carbon films onto a variety of substrates, including polymers (2). In addition, investigations are being also conducted with ion-beam deposited carbons (3). The ultimate biological properties of these carbons will be influenced by their structural parameters and by the substrates on which they are deposited (4).

Discussion

Diamond-polished LTI carbons are known to exhibit excellent blood and tissue compatible properties. This assessment is based on a variety of procedures including the in vivo (canine) vena cava and renal embolus tests, in vitro tests involving the effect on plasma proteins and enzymes, calcium replacement clotting time, adherence of the formed blood elements, platelet activation and aggregation and cell growth (5). LTI carbons have been evaluated in a variety of animals, and most importantly performed well in humans. This is significant because species-related hematological differences of experimental animals have received less than adequate attention in the past and is the subject of another paper by this author (6). LTI carbons are deposited on smooth, rigid surfaces, such as graphite (7). The porosity of the carbon coatings which may extend up to a depth of approximately 25 microns is eliminated by diamond-polishing, thus leaving a smooth surface which is essentially impermeable to gases and liquids. LTI carbons are turbostratic and the microcrystallites (10 to 30 Å) form aggregates that contain large fractions of disorganized carbon. Although the properties of the individual crystallites are anisotropic, when they are randomly oriented in the aggregates, the anisotropy is averaged and the aggregate structures display isotropic properties (7).

Despite the good biological performance of LTI carbons, the relatively high temperature required for deposition represents limitations for certain biomedical applications. Consequently, vacuum deposition processes are being studied with a variety of polymeric and non-polymeric substrates requiring temperatures of less than 100°C to yield carbon coatings in the thickness range of 500 to 250 Å (2). The vacuum deposited carbons exhibit isotropicity, crystallinity, and density 1.8 gm/cm^2) similar to LTI carbons (2). The preliminary biological data underline the importance of substrate effects. These become especially important when either impermeable or permeable coatings are attached to appropriate materials to enhance their blood compatibility and are discussed in more detail elsewhere by this author (4). Both diamond-polished LTI carbons (deposited on graphite substrates) and carbons deposited in a vacuum onto smooth stainless steel substrates exhibit low levels of hemolysis under shear stresses below 100 dyne/cm^2 with human blood, although LTI carbons performed somewhat better (8). Rotating disk experiments using blood of heparinized shunted dogs show low level of platelet adhesion with both diamond-polished LTI carbons on graphite substrates and polished vacuum deposited carbons on glass, in comparison to the control polyurethanes (9). Canine ex vivo studies with a rotating shaft device show significantly less thrombotic deposit for vacuum deposited carbons on smooth stainless steel shafts than for control silicone rubber (10). Although the data are preliminary, canine vena cava tests (10) conducted with vacuum deposited carbons using stainless steel substrate rings showed no clots on two rings after two weeks of implantation.

In the case of ion-beam deposited carbons (11), preliminary studies thus far involved carbons deposited on "as machined" polypropylene and solution cast segmented polyether-urethanes. The thickness of the ion-beam deposited carbons is in the order of 500 Å with a density of 2.36 gm/cm^2, and differ from LTI carbons. Preliminary biological evaluations thus far involved mainly the canine in vivo vena cava (10) and renal embolus tests (12). The former yielded mixed results, whereas the latter showed various degrees of renal infarctions despite the relative absence of clots on the rings themselves. The scatter of the available data probably reflects, at least in part, substrate irregularities which apparently have a dominant effect on the thin carbon coatings. It remains to be seen how the structural differences between ion-beam deposited carbons and vacuum deposited carbons affect their respective overall biological properties.

In any case, smooth substrates seem to be needed with ion-beam deposited and vacuum deposited carbon coatings. Although both types of carbons adhere well to polymeric substrates, their potential biomedical applications should find greatest usefulness with non-elastomeric substrates to avoid surface cracks.

References

1. Bruck S. D., Blood Compatible Synthetic Polymers - An Introduction, C. C. Thomas Publisher, Springfield, Illinois (1974).
2. Haubold A. D., Shim H. S. and Agarwal N. K., Contract No. NIH-NO1-HV-4-2928, Annual Report, March 1976, PB 254 201/AS.

3. Aisenberg S. and Chabot R. W., Contract No. NIH-NO1-HV-3-2919, Annual Report, February 1976, PB 253 089/AS.

4. Bruck S. D., paper in press.

5. Bruck S. D., Rabin S. and Ferguson R. J., Biomat., Med. Dev., Art. Org., 1, 191-222 (1973), and references therein.

6. Bruck S. D., Biomat., Med. Dev., Art. Org., (in press); see also, Bruck S. D., in Abstract of Papers, 3rd Annual Meeting of the Biomaterials Society, New Orleans, Louisiana, April 15-19, 1977.

7. Bokros J.C. and Akins R. J., in Proceeding of the Fourth Buhl International Conference on Materials, Pittsburgh, Pennsylvania, November 16-18, 1971, Carnegie Press, Pittsburgh (1971).

8. Williams M. C., Contract No. NIH-NO1-HV-3-2952, Annual Report, August 1976, PB 259 119/AS.

9. Leonard E. F., Kochwa S, Litwak R. S. and Rosenfield R. E., Contract No. NIH-NO1-HV-3-2910, Annual Report, May 1976, PB 255 113/AS.

10. Schultz J.S., Ciarkowski A. A., Goddard J. D., Lindenauer S. M. and Penner J. S., Contract No. NIH-NO1-HV-4-2962, Annual Report, July 1976, PB 257 219/AS.

11. Daniels A. U. and Mortensen J. D., Contract No. NIH-NO1-HV-4-2979, Annual Report, November 1975, PB 248 222/AS.

12. Kusserow B. K. and Larrow R. W., Contract No. Contract No. NIH-NO1-HV-5-2939, Annual Report, August 1976, PB 259 118/AS.

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