Prospects For Preventing Insect Adhesion To Leading Edges of Aircraft

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The ultimate solutions to the plaguing problem of insect adhesion to the leading edges of aircraft may come as spin-off technology from the biomedical field, where similar problems have been encountered and real solutions already are being achieved. In searching for ways to make biological materials hold more permanently to non-biological implants, biomedical scientists are beginning to learn what makes biological and non-biological materials adhere—and what can prevent them from doing so. Ed.

Banking on the conservatism of Mother Nature with regard to rules for adhesion of biological substances, an early clue to what was required to make successful non-adhesive surfaces for biological debris came from a series of experiments with internal reflection prisms. These plates, which allow all of the analytical techniques outlined in **Figure 1** to be applied, were incubated in a rich broth of some of the most adhesive organisms ever cultured: bacteria originally scraped from human teeth (1).

These small "beasts" were coccoidal organisms cultured to about 10^8 individuals per milliliter, each having an egg shape with a preformed sticky tuft at one end. No matter what the surface properties of the test material incubated in these broths, prior to the adhesion of any organism, there was the spontaneous adsorption of a conditioning film of protein-dominated material (very much like the acquired pelli-

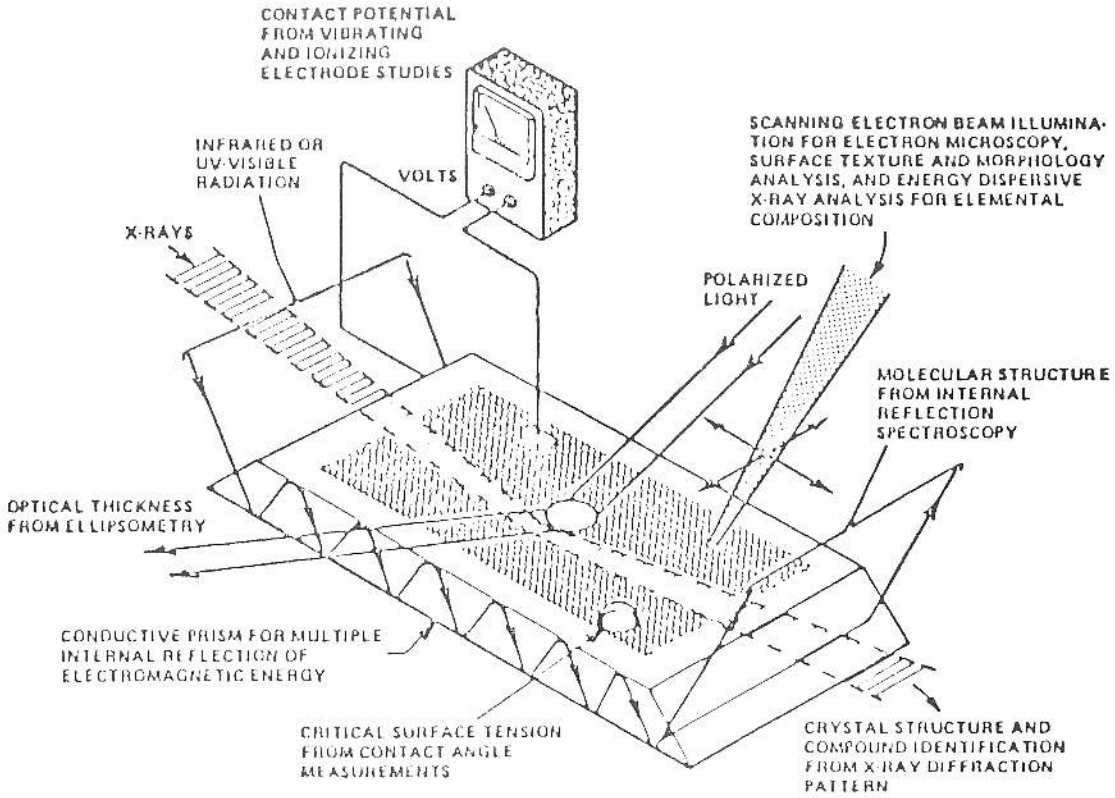

Figure 1: Experiments with internal reflection prisms

cle on human teeth, but in this case formed by components of the tissue culture medium) and exudates of the bacteria themselves. On medium- and high-surface-energy substrata such as clean metallic test plates, the adhesive oral bacteria plated out on top of this conditioning film in a close-packed array, shoulder to shoulder like eggs in a crate with their sticky tufts down, and began to grow up into real plaque-forming layers that looked a lot like the brown film you would get on your teeth if you didn't apply a brush to them from time to time.

Taking advantage of the controllable depth of penetration of the analytical infrared evanescent wave into the rarer (in this case biological) material at its surface, we were able to look up into the sticky tuft and discover that it was, in fact, made of that biological glue *par excellence* glycoprotein, and not the oft-proposed lipoteichoic acid (polyglycerol phosphate) material.

Other test objects, placed side by side with the clean metallic materials in the same culture broth, emerged 24 hours later devoid of the brown film; in fact, devoid of any obvious coating at all, looking as clean and shiny as when they were first immersed. These were plates that had been deliberately coated with as little as a few monomolecular layers of surface-energy-modifying materials, especially covalently linked polydimethylsiloxanes, replicating the best surface properties of medical-grade silicone rubber.

Inspection by the infrared technique showed that the same conditioning film deposits had been laid down by the culture medium, but contact angle analysis illustrated no significant change from the intrinsically low-surface-energy, and even hydrophobic, surface condition of the closely packed methyl-group-dominated layer of the silicone polymer. Scanning electron microscopy revealed the total absence of bacteria from the surface, displaying instead only the lacelike remnants of the conditioning film that could not get a grip, that could not wet and spread and adhere to the waxy solid surface. The result was similar to that with a water-based latex paint applied to a greasy garage door without taking the trouble to put on a primer coat!

It was learned in that experiment and many others like it that creation of a passive methyl-group-rich surface layer could minimize biological adhesion even in circumstances where there was not much shear force or mechanical work to help detach the depositing debris from the surface. In contrast, it was learned that if enhancement of biological adhesion were desired, such as in dental implants or in the use of the femoral stem artificial hip prosthesis, a really beneficial surface treatment could be applied by glow discharge treatment (plasma treatment) which simultaneously cleaned, energized and sterilized the implants prior to their emplacement into the biological environment. When cobalt chromium disks (using the identical material used for fabrication of dental implants and artificial hips) were so treated and then implanted in rabbits, it was discovered that the

adjacent cell density was dramatically increased; it became our routine procedure to glow-discharge-treat subperiosteal implants for both our animal and human clinical subjects from that point on (2).

Another example comes from observations of blood contact with foreign solid substances. The main sticky elements of blood are the platelets. Platelets are present in quantities from about 200,000 to 400,000 per cubic millimeter and are lozenge-shaped 3-micron-diameter discs that, when brought into contact with a nonphysiologic boundary, adhere, flatten, throw out pseudopodal extensions, and spill some of their contents into the surrounding medium to induce an avalanche of coagulation events; they also become very sticky to their arriving siblings. The platelets grow into small pyramids and often are joined by white cells, chemotactically stimulated to join in the fray in a vain attempt to clean up the accumulating debris. The interaction accounts for the typical white thrombus that will occlude the atherosclerotic coronary blood vessels of so many American males.

We have discovered, using surface energy control coatings on various test plates, that a useful correlation can be made between the spread surface areas of human platelets simply settled onto these test plates and the propensity of the materials to induce platelet distress reactions (3). All we have really done is to systematize, and embellish with the necessarily large numbers required for statistical significance, the original observations of Schoen and Bernstein reported nearly fifteen years ago (4). They demonstrated that platelets remaining rounded, though temporarily adherent to foreign solid materials, were least likely to be involved in thrombogenic or other unhappy consequences for such early biomedical devices as centrifugal blood pumps. It has been shown over and over in any number of circumstances that living cells remain rounded and poorly adherent on intrinsically waxy, low-energy surfaces, and that they flatten and spread on more polar, aggressive surfaces like those of clean glass microscope slides or appropriately oxidized polystyrene culture dishes. The cells mainly involved in secondary wound healing, however, actually require the activating qualities of a higher energy substratum (usually provided *in vivo* by the fibrous proteins of clotted blood and scabs) to flatten, spread, reproduce and export the necessary fibrous protein precursors to make the collagen reinforcements for the cellular matrix that holds us all together.

Inappropriate attention to these features in early versions of synthetic blood vessels led to quite unhappy outcomes, including blood cell adhesion and coagulation on the inside surfaces of substitute blood vessels that one would desire to be passive and non-adhesive. Aggressive cellular growth (hyperplastic response) sometimes took place on the outside of the vessels in response to strengthening high-surface-energy synthetic meshes placed on the outside for incorporation into the tissue bed.

There have been a number of interesting surprises along the way, most of which have been quite positive in their implications for the bioengineers attempting to make practical biomedical devices and artificial organs with materials available today. For example, it was a major premise of most bioadhesion students over most of the past two decades that any contact of blood with an adverse material surface would so potentiate the blood's responses downstream that, no matter how perfect the remainder of the system was, widespread clotting and thrombogenesis would be the result (5). Work published within the last few years by Schultz and Barenberg of the University of Michigan (6) and, more recently, work in the Chemical Engineering Department at the University of Wisconsin/Madison (7), has provided convincing evidence that bioadhesion phenomena are extremely local and that, like the sharp boundary between bright light and shadow, thrombus and coagulum formation on synthetic materials surfaces can be observed to transition from complete fouling to essentially no fouling over as short a distance as a few red cell diameters. This bodes well for the construction of increasingly useful biomedical devices such as improved synthetic heart valves, where tenacious biological adhesion around the sewing ring that holds the device in place must exist immediately adjacent to the struts and valve poppet where no bioadhesion is wanted.

On a grander scale, for the U.S. Navy, we have succeeded in the production of automatic devices that treat clean periscope windows by coating them with minimum-surface-energy coatings that allow strategic submarines to better fulfill their missions without their periscope windows becoming obscured by oceanic fouling films.

The big payoff, of course, will come in the production of truly non-toxic fouling-resistant marine paints, to replace the poisonous resins that are now used in significant volume around the world. As biomedical engineers and biosurface chemists, we have not been given the privilege to poison our patients under the guise of keeping their plumbing clean; therefore, we should not assume the privilege of poisoning our environment under the guise of keeping our ship bottoms or coastal powerplant plumbing clean. We are now engaged in such a fouling prevention project, and our most significant successes to date have been with formulations similar in almost all respects to those that were utilized in the artificial heart. Nature has indeed been very conservative, accepting as its minimum adhesive surface the same cluster of closely packed methyl groups for all biological systems.

Obviously, we are enthusiastic about the progress yet to be made and welcome the many new practitioners of this exciting science of surfaces.

REFERENCES

1. Mouton, C.; Reynolds, H.S.; Gasiecki, E.A. and Genco, R.J.; "In Vitro Adhesion of Tufted Streptococci to Bacterionema Matruchotii"; Current Microbiology; 3; 1979; pp 181-186.
2. Baier, R.E.; Meyer, A.E.; Akers, C.K.; Natiella, J.R.; Meenaghan, M.A. and Carter, J.M.; "Degradative Effects of Conventional Steam Sterilization on Biomaterial Surfaces"; Biomaterials; 3; 1982; pp 241-245.
3. Baier, R. E. and Meyer, A. E.; "Surface Chemistry and Physics Relevant to Platelet Interactions with Prosthetic Devices and Other Biomaterials"; Chapter 5 in *Blood Platelet Function and Medicinal Chemistry*; ed. A. Lasslo; Elsevier Biomedical; 1984; pp 175-227.
4. Schoen, F.; Discussion; Fed. Proc.; 30; 1971; p 1647.
5. Symposium on Problems in Evaluating the Blood Compatability of Biomaterials; Bull. NY Acad. Med.; 48, 1972; pp 211-493.
6. Barenberg, S.A.; Schultz, J.S.; Anderson, J.M. and Geil, P.H.; "Hemocompatability: Macromolecular Motions and Order of the Polymer Interface"; Trans. Am. Artif. Intern. Organs; 25; 1979; pp 159-162.
7. Lelah, M.D.; Lambrecht, L.K. and Cooper, S.L.; "A Canine ex-vivo Series Shunt for Evaluating Thrombus Deposition on Polymer Surfaces"; J. Biomedical Mat. Res.; 18; 1984; pp 475-496.