Biomaterials Highlights

Materials for Biomedical Applications—Bone and Joint Replacements

By Günther Heimke *

This contribution is the first of a sequence of reports on the recent developments in the field of the so-called "biomaterials", which, of course, are not at all "bio" or living materials but, rather, replace those living materials which have ceased to serve their purpose.

The science of biomaterials can be regarded as another prototype of the many interdisciplinary fields of research which have emerged during the last decades. It gained general recognition about the mid nineteen seventies as evidenced by the foundation of societies for biomaterials or similar organizations in most of the industrialized nations of the world. In 1980 the European Society for Biomaterials organized the 1st World Congress on Biomaterials in Vienna, Austria, while the 3rd World Biomaterials Congress in Kyoto, Japan, in April 1988 attracted more than 1000 participants. The 4th Congress of this type will again be organized by the European Society and is scheduled for 1992 in Berlin. Besides these world congresses, individual biomaterials societies organize meetings in their own particular areas. The next US conference will be held in Orlando, Florida towards the end of April 1989, and the 8th European Conference on Biomaterials will be in Heidelberg, Germany, from the 7th to the 9th of September 1989, immediately followed by a more specialized symposium entitled "Ceramics in Medicine".

The field of biomaterials is, of course, one branch of the large area of contact between medicine and the natural sciences and engineering disciplines. Actually, there are two such contact areas; biotechnology and bioengineering. The term biotechnology is now mostly used to describe all activities related to the application of modern biology, in particular the possibility of genetic manipulation of micro organisms, to medicine, chemistry, and all other fields of natural science and engineering. The term bioengineering comprises all other contact areas of the natural sciences and engineering to medicine. Scheme 1 is an attempt to express these correlations and to define the position of biomaterials within such a framework.

In most reports on biomaterials in the different fields of medicine, much more emphasis is placed on the different kinds of tissue reactions the materials stimulate or avoid, than to the materials themselves. The reason is obvious: Most of the presently used implant materials have already acquired bulk properties which satisfy the requirements of their particular applications, and therefore, interest is focussed on the reaction along the interface between the biological tissue and the material. At an early stage of biomaterials development the first approximation was that both

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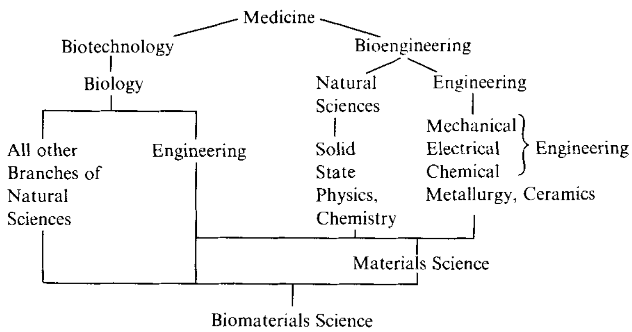
From now on, Professor Günther Heimke (Clemson University, S.C., USA) will be providing a quarterly report on various aspects of biomaterials research and development which will be published as the Biomaterials Highlights column of Advanced Materials. Günther Heimke was educated as a physicist with emphasis on solid state physics at the University of Heidelberg and at the Martin-Luther-Universität, Halle, where he gained an M.Sc. and a D.Sc. After several years of university teaching and research into magnetic materials, in particular ceramic magnets, he moved to the industrial sector continuing work on magnets in both West Germany and in the USA before joining Friedrichsfeld GmbH, taking responsibility for the research and development of oxide ceramics. It was here that he became involved with biomaterials, introducing the use of alumina ceramic materials in medical devices, such as joint replacements and dental implants. After his retirement he recieved an invitation to be a guest professor at the Department of Bioengineering, School of Engineering, Clemson University, where he is now a research professor. He has authored and co-authored more than 150 publications and two books, and holds more than 40 German patents on which many international patents are based.



Scheme 1. The position of the science of biomaterials within the branches of biotechnology and bioengineering.

sides of this interface were required to remain in their original state for as long as possible. But it was soon realized that this was a severe oversimplification if looked at from both sides of the interface.

The tissue adjacent to the implant has, because of this implantation, been separated from those portions which have just been replaced by the implant, and has therefore been deprived of about half of its nutrition pathway. In addition, most of the remaining blood vessels meeting this interface have been blocked by blood clots. Cells have been damaged, and their remnants together with other disrupted materials like collagen stimulate defence processes mainly aimed at their removal.

On the materials side, the electrolytic environment can cause many reactions, starting with the removal of the layers originally absorbed in air or during sterilization, and continuing via, for example, the formation of metal organic complexes, to cell mediated processes. These reactions vary from tissue to tissue and also from material to material.

The knowledge about these interfacial processes has not yet been summarized and generalized in a manner which allows sufficiently reliable predictions about the degree of compatibility of a new candidate implant material to be made. This statement already points to one difficulty; there is no general biocompatibility. The kind of tissue reaction to an implant depends not only on the type of surrounding tissue (e.g. muscle, bone, blood, skin) but also on many more parameters, like the degree of vascularization, stresses and strains, or relative motion.

The dense, highly pure alumina ceramic can be used to demonstrate this problem: This oxide ceramic is now widely regarded as the prototype of a bioinert material as nearly nothing goes into solution, and densely adsorbed body molecules even "camouflage" such an implant against the body's immune system. Thus, if implanted in connective tissue (muscle, bone) all reactions have been shown to be essentially controlled by the stress and strain field created in the surrounding tissue and the relative motions resulting from them. As this stress and strain field can be controlled by the shape of the implant, a reliable osseo-integration of such implants can be achieved in bony tissue, as has been documented by the clinical success rates of dental implants and acetabular components of total hip replacements in long term follow-up studies.[1-4] This same material cannot be used in the cardiovascular system because of its blood clotting potential.[5] The reasons for this behavior have not yet been fully understood. Some attempts to correlate the initial process of clot formation to surface properties like the work function or the band gap and width have not yet led to conclusive results.[6]

Because of this lack of a sufficiently general set of rules for the selection or tailoring of implant materials, it will be the task of this series to present the most recent knowledge and developments in a sequence of contributions, each devoted to the most recent achievements in one particular field of implantology. Observations made at the combined meeting of the American Orthopedic Research Society and the American Academy of Orthopedic Surgeons (AAOS) in Las Vegas in February 1989 are the motivation behind these reports in the field of bone and joint replacements. In comparing the topics of the papers presented during these meetings with those presented on similar occasions in the early and even in the mid eighties, some shift can be seen as expressed in Table 1.

Table 1. The shift of emphasis in research on bone and joint replacement materials during the last decade.

Time period	Basic materials related research	Clinical studies
Late seventies and early eighties	Description of the results of interface reactions to potential new implant materials	Relatively short term follow-up studies with essentially phenomenologic description of results
Late eighties	Nearly no new materials; studies on causes for different kinds of interface reactions, e.g. from immunological points of view	Eight to more than ten years follow-up studies with attempts to statistically analyse results.

In basic materials related research it appears that the ceramics explored essentially during the seventies (see the recent survey in this journal[7]) have been the last large, unique group of solids introduced into the field of implant materials. Now, some hopes for further improvements rest with different kinds of material combinations like fiber reinforced plastics, e.g. for bone plates in order to avoid the stress shielding which is assumed to compromise the results of metal plates.

One means for implant fixation, porous coatings consisting of beads sintered or otherwise attached to the surfaces of the anchoring portions of joint replacements, have become widely used, particularly in the USA since the late seventies. Now, longer term clinical follow-up studies increasingly reveal that the success rates are not much better or more predictable than with implants anchored via the polymethylmethacrylate bone cement. This has even resulted in recommendations to abandon such coatings completely and return to the cementing technique.[8]

In order to overcome these problems much interest is presently focused on bioactive coatings (hydroxyapatite [HA] ceramics, Ca-phosphate containing glasses or glass-ceramics). Nearly all experts in this field agreed at last years biomaterials meeting in Kyoto, Japan, that dissolution of at least the HA coatings occurs within about four to six years in the body environment, and that only their combination with undulating surfaces will provide the reliable mechanical interlocking with the surrounding bony tissue necessary to yield some improvements.

The multivariant statistical evaluations of the more recent follow-up studies gave further details on the influence of different implant shapes and sizes as well as operational procedures. There was even the recommendation to abandon the use of conically shaped acetabular components (*D. A. Fisher*, Indianapolis, IN, USA and *T. H. Mallory*, Columbus, OH, USA, paper no. 9 of the AAOS Meeting). A marked detrimental influence of medication by making interface remodeling necessary for osseo-integration was demonstrated for indomethacin and ibuprofen and, to a lesser degree, aspirin (*T. M. Trancik* and *M. Mills*, Trans. 35th Meeting ORS, Las Vegas, 1989, p. 338).

Besides the overview already given in Table 1, it appears that the now nearly 30 years (since *Charnley*'s introduction of the PMMA bone cement) of large scale clinical experience with implants in orthopedic surgery allow for a much more detailed understanding of implant related responses and many of the side effects. Their feedback in the application of implants, however, will become more and more difficult to judge because of the relatively high success rates already achieved.

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Conference Reports

Molecular Electronics—Science and Technology

By Ari Aviram *

The conference on molecular electronics took place during the week of February 19. to 24. 1989 on the island of Hawaii in Kona, under the sponsorship of the Engineering Foundation. Seventy scientists took part in the program that consisted of 34 invited talks, 16 contributed talks and 10 posters.

Molecular Electronics is the study of molecular properties that may lead to signal processing. Though the name of the field implies technological applications, the state of the art is at a stage that requires considerable basic science groundwork to foster a solid foundation for building future technology. In essence this is an exciting aspect of the field, since it provides an opportunity to break new ground in our understanding of the molecular universe and to develop new techniques for interaction with single molecules or small groups of molecules.

Recent advances in nanolithography and scanning tunneling microscopy have given a boost to the field of molecular electronics. As such, the conference program was organized around these developments as well as several other themes that represent the multidisciplinary facets of this young science. The organizers prepared the program to probe the following questions: What are the limits of current solid state technology? What is the status of nanolithography? What are the current approaches to molecular signal processing and the theoretical basis for those approaches? What are the current methods that will permit interaction between the macrocosm and the molecular world?

The trend for miniaturization and compaction in current solid state technology for microchip fabrication may stall

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