

Chapter 2

Biomaterials

The most accepted definition of biomaterials is currently the one employed by the American National Institute of Health that describes biomaterial as “any substance or combination of substances, other than drugs, synthetic or natural in origin, which can be used for any period of time, which augments or replaces partially or totally any tissue, organ or function of the body, in order to maintain or improve the quality of life of the individual”. Such a definition, however, does not include materials such as orthodontic brackets and surgical instruments (Fig. 2.1).

The first biomaterials used were gold and ivory for replacements of cranial defects. This was done by Egyptians and Romans. Biological materials such as placenta was used since the 1900s. Celluloid was the first man-made plastic used for cranial defects a polymethyl methacrylate (PMMA) was one of the first polymers accepted since World War II.

The Williams Dictionary of Biomaterials (Williams 1999) defined biocompatibility as “ability of a material to perform with an appropriate host response in a specific situation”. Although this definition seems vague and unhelpful at first glance, it represented a quantum leap forward at the time of its introduction. Prior to this definition, the prevailing view was that successful materials played largely inert roles the body.

A long list of ‘non-properties’ had evolved for ‘successful’ biomaterials: non-toxic, non-immunogenic, non-thrombogenic, non-carcinogenic, and so forth. The above definition required that materials not only provide some function, but also recognized that the interface created by introduction of the material will elicit a biological response. Thus, the idea that the material could be truly inert was essentially rejected with the adoption of this definition. Given today’s level of understanding of our bodies as sophisticated, complex biological environments, the idea that one could place a foreign material without some sort of response seems naïve.

Based on the reaction of the tissue to the biomaterial, these are classified into three distinct categories:

1. Biotolerant Materials: which are separated from bone tissue by a layer of fibrous tissue.

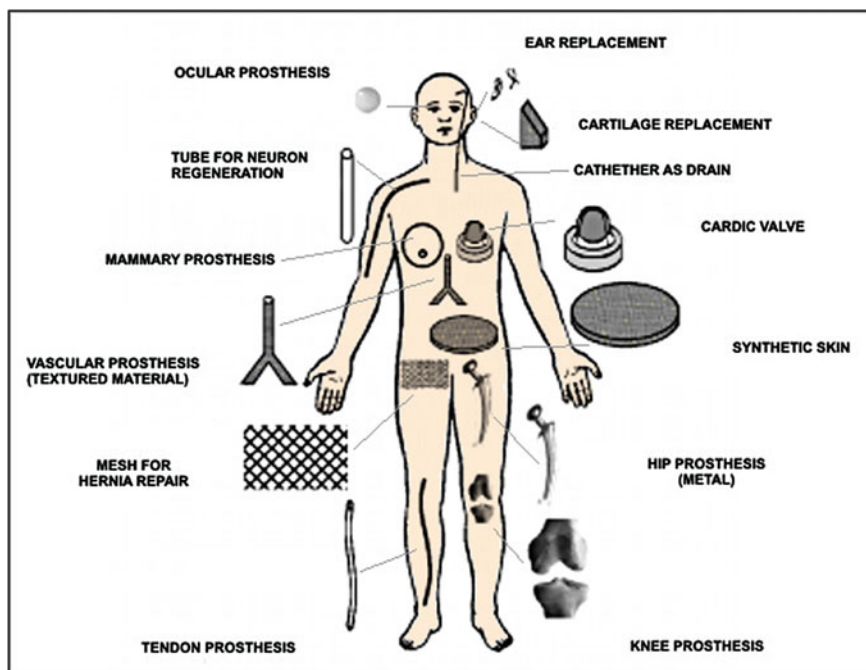


Fig. 2.1 Examples of biomedical materials

2. Bioactive materials: which have the property of establishing chemical bonds with bone tissue, known as osseointegration. The collagen and mineral phase of the adjacent bone is deposited directly on the implant surface.
3. Bioinert Materials: in this class it is possible, under certain conditions, to have direct contact with the adjacent bone tissue. No chemical reactions shall occur between the implant and the tissue.

Recognition of an active interface between biomaterials and biological systems led to several important basic ideas about biocompatibility. These ideas persist today and comprise the essence of biocompatibility.

The first idea is that the interactions at the material–tissue interface occur for both; the material elicits a response from the body and the body elicits a response from the material. All materials will be changed at some level by their introduction into a biological environment—either via corrosion, chemical modification, deposition of substance, degradation, or other mechanism.

This exchange of responses leads to a second idea: that the material–tissue interface is dynamic. As the material and biological tissue are modified by each other, the changes themselves may suppose other changes. Thus, the interface is not static, but is changing over its lifetime. Furthermore, because the human buccal conditions are always changing—by aging, by developing systemic or local

diseases by adopting new activities, by eating differently, etc.—any equilibrium established at a material–tissue interface is subject to perturbation.

A third idea is that reactions at the material–tissue interface are a function of the tissue where the interface is created. A fourth idea about biological–tissue interfaces recognizes the nearly obvious, but often forgotten fact that the materials we use do not belong there. Biomaterials are foreign bodies, and biological responses to these materials are characterized by foreign body responses. Finally, the most recent idea about biocompatibility is that it is possible to customize interactions at the material–tissue interface.

Materials are asked to play more sophisticated, longer-term roles in tissues, customizing and optimizing the material–tissue interface to assure the best long-term clinical outcomes. We may modify the surface of a material to limit non-specific protein absorption, add peptide sequences to encourage native protein or cell interactions, or provide a three-dimensional structure to encourage matrix formation.

To accommodate the bioactive dimension of materials described above, The Williams Dictionary of Biomaterials (Williams 2008) updated his original definition of biocompatibility: “ability of a biomaterial to perform its desired function with respect to a medical therapy, without eliciting any undesirable local or systemic effects in the recipient or beneficiary of that therapy, but generating the most appropriate beneficial cellular or tissue response to that specific situation, and optimizing the clinically relevant performance of that therapy”.

Of course, in addition to biocompatibility and tissue response, other factors are important in the adaptation and longevity of a biomaterial. These factors are: material used, load applied during function, patient well-being and age, technique used. The development of new technologies is therefore essential in order to develop new biocompatible materials capable of supporting new specifications and applications.

The global market of biomaterials was estimated in 150–200 US\$ billion in 2012 including all diagnostic and therapeutic equipment. The ten largest markets are US, Japan, Germany, France, Italy, UK, Brazil, China, Canada and Spain. The growth of US market share is 9 % per year being the leading market in the world followed by Europe, with 25 % market share, and Japan. The largest market for biomaterial based products is orthopedic biomaterials followed by cardiovascular and drug delivery materials. The dental biomaterials market is around 1 US\$ billion.

2.1 Biomaterials in Dentistry

The market for the development of Dentistry materials has been increasing in recent years. In the United States of America, spending on Dentistry is rapidly increasing, resulting in the need for new biomaterials. The American Dental Association (ADA) reports in a 2008 survey that 94 % of the U.S. population is concerned about the rising costs of dental treatment. The ADA attributes this

increase to the higher cost of new dental materials and diagnostic tools. Therefore, the market for biomaterials and alternative materials in this field is huge.

The U.S. Food and Drug Administration (FDA) recognizes several broad types of substances that are used to promote human health; the two most common of these are drugs and devices. Most dental biomaterials are classified as devices, including filling materials, diagnostic aids, cements, bonding agents, and implants. The FDA defines a device as: “an instrument, apparatus, implement, machine, contrivance, implant, in vitro reagent, or other similar or related article, including a component part or accessory”.

Biomaterials are used in Dentistry in such restorative procedures as dental restorations, dentures, dental implants and surgical procedures, endodontic materials, in devices such as orthodontic materials (braces, elastic bands and wires) and tooth piercings.

Currently, there is pressure both from patients, who demand more esthetics, and from government agencies, which require materials that cause less environmental impact. Because of this, traditional materials such as silver amalgam are being replaced by composite resins and ceramic materials.

Restorative biomaterials are designed to recover the shape and the function of the teeth. Included in this category are materials for fillings as well as materials for the preparation of cavities. The latter can be used both to protect the pulp tissue and to create adhesion between the tooth surface and the restorative material. Dental materials should not be toxic, irritating or corrosive, and should be easy to use. The biomaterials used in Dentistry may be metals (silver amalgam, titanium and gold), ceramics (feldspar, alumina, zirconia, silica reinforced porcelain) and composites.

There are two useful concepts that help demystify dental ceramics by providing a structure within which to organize thinking. First, there are only three main divisions to the spectrum of dental ceramics: (1) predominantly glassy materials; (2) particle-filled glasses; and (3) polycrystalline ceramics. Defining characteristics are provided for each of these ceramic types. Second, virtually any ceramic within this spectrum can be considered as being a “composite”, meaning a composition of two or more distinct entities.

Many seemingly different dental ceramics can be shown to be similar or closely related to each other when reviewed within the framework of these two simplifying concepts. Additionally, the rationale behind the development of ceramics of historic and recent interest can be more easily understood. Two examples of the utility of these concepts include these statements: (1) Highly esthetic dental ceramics are predominantly glassy, and higher strength substructure ceramics are generally crystalline; and (2) the history of development of substructure. Ceramics involves an increase in crystalline content to fully polycrystalline.

Dental ceramics that best mimic the optical properties of enamel and dentin are predominantly glassy materials. Glasses are three-dimensional (3D) networks of atoms having no regular pattern to the spacing (distance and angle) between nearest or next nearest neighbors; thus, their structure is amorphous, or without form.

Glasses in dental ceramics derive principally from a group of mined minerals called feldspar and are based on silica (silicon oxide) and alumina (aluminum oxide); hence, feldspathic porcelains belong to a family called aluminosilicate glasses. Glasses based on feldspar are resistant to crystallization (devitrification) during firing, have long firing ranges (resist slumping if temperatures rise above optimal), and are biocompatible.

In feldspathic glasses, the 3D network of bridges formed by silicon-oxygen-silicon bonds is broken up occasionally by modifying cations such as sodium and potassium that provide charge balance to non-bridging oxygen atoms. Modifying cations alter important properties of the glass, for example, by lowering firing temperatures or increasing thermal expansion/contraction behavior.

Polycrystalline ceramics have no glassy components; all of the atoms are densely packed into regular arrays that are much more difficult to drive a crack through than atoms in the less dense and irregular network found in glasses. Hence, polycrystalline ceramics are generally much tougher and stronger than glassy ceramics. Polycrystalline ceramics are more difficult to process into complex shapes (e.g. prosthesis) than are glassy ceramics.

Well-fitting prostheses made from polycrystalline ceramics were not practical before the availability of computer-aided manufacturing. In general, these computer-aided systems use a 3-D data set representing the prepared tooth or a wax model of the desired substructure. This 3D data set is used to create an enlarged die upon which ceramic powder is packed (e.g. systems of PROCERA[®] of Nobel Biocare[®]) or to machine an oversized part for firing by machining blocks of partially fired ceramic powder (e.g. systems of Cercon[®] of Dentsply Prosthetics, Lava[™] of 3M[™]-ESPE; In-Ceram[®] YZ of VITA[®] Zahnfabrik). These approaches rely upon well-characterized ceramic powders for which firing shrinkages can be predicted accurately.

Reference

Williams, D.F.: Williams dictionary of biomaterials, Liverpool University Press (1999)

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