Preface

New technologies don't simply replace old ones... they just add another layer of complexity to our lives.

David Rooney

Wise words extracted from Rooney's book *Ruth Belville: The Greenwich Time Lady*. This phrase may stand for the mix of facts and figures, historical backgrounds, old and new ground breaking designs, and state-of-the-art and future perspectives in the biomedical world. That is all what this book is intended to be about. Bridging past and present – the highway to the top, the z-axis – is particularly cherished throughout the text. Distinct exits of the highway are taken for roaming through the landscape for an xy-view on the biomedical field.

In the early 1980s, *new materials* were the magical keys, which opened doors when applying for grants with the hope to have a share in the European flesh pots. Ceramics are one of those miracle products: a full ceramic motor block and ceramic ball bearings without lubrication would allow to start the engine with just one click of the contact key even in the middle of a night in Siberia. Just one or two cars with ceramic engines were ordered to be manufactured but thirty years later, few cars with ceramic motors can be found on the road, neither here nor in the arctic. Corrosion and wear were a nightmare for metal implants but inert aluminum oxide solved these problems. In fact, nothing was less true and only in the course of the last decade, the manufacturing of complex composites of aluminum and zirconium oxide emerged as a mature technology for manufacturing heads and cups for hip prostheses. The new magical key is 'nano'. Not mentioning these four letters is begging for problems in grant applications. But, fortunately, capturing part of the flesh pot is not the aim of this book and therefore, the reader will not be flooded with exaggerated promises by innovative proposals.

Research follows odd ways. Another hot research topic three decades ago was the manufacturing of complex metal parts in near net shape using metal powders, an adaptation of a technology practiced by ceramists since ages. In the chapter *Layer by layer*, the reader will find how a variety of *custom-made* metal implants are manufactured today by techniques that are fundamentally different from what was proposed three decades ago. Nickel-free alloys such as iron–manganese–aluminum, glass–fiber composites, porous coatings, and many other proposals to solve recognized risks or shortcomings of existing materials and implants did not result in the breakthroughs they promised: while conventional stainless steel is still an alloy in use for some (successful) implants, today's porous coatings or porous devices are distinctly different from designs proposed in the 1980s. Fortune-telling is a risky profession!

Myths are vivid reflections on the invincible will of man to lengthen life in a comfortable way, so the eagerness to insert some mythological stories in the text was irresistible. Archaeological biomedical artefacts look less romantic than myths but they are the tangible witnesses of ancient creativity. They instruct us about the biomedical progress, or any other kind of progress. They are never stand-alone acts but are a universal conversation between aspiration, technology and science – xyz-space.

The generic class of materials in this book are not bound to separate chapters. A story or case study at the beginning of a chapter introduces a problem and invites the readers explore solutions: for example, adequate implant design and manufacturing by adequate selection of (bio-)materials or combination of materials. Occasionally, an excursion from the mainframe is made to situate artificial and natural materials in a wider context, trace elements in the body or biominerals in relation to the mineral world…

Science is a sustained effort to arrive at a unifying theory. Efforts are made to point to those characteristic properties of matter and materials that go beyond the typical characteristics of one generic class. To name a few, the austenite–martensite transformation as a physical process common to steel, shape memory alloys as well as to ceramics; grain size and its relation to strength in ceramics and metals alike; the role of grain boundaries and sensitivity to corrosion or chemical degradation; and scaling, similarity of properties at different scale lengths. The driving force for all physical or chemical processes is dictated by the Second Law of Thermodynamics, paraphrased in the text as *Water does not flow uphill* or, viewed from the top of the hill, *All nature's streets are one way and downhill*. The ultimate definition of the law is *that in a closed system* (like the universe), *all irreversible processes lead to an increase of entropy*. An apocalyptic consequence of the Second Law is the inevitability of death. This statement was, unintentionally we guess, nicely illustrated in an otherwise very charming German village: next to a sign post, which mentioned *Zum Friedhof*, we saw another sign post saying *Einbahnstrasse* (to churchyard, one-way street)! But despite these discouraging statements, we do stay alive quite a number of years. In a way, our body succeeds cheating the second law by built-in negative feedback systems or homeostatic mechanisms to keep the increase of entropy under control. These mechanisms have direct consequences for implants as well as for the body. *Homeostasis* (Homeodynamics in reality) will often be referred to in the text.

An inspection of the Table of Contents shows that conventional items such as metals, toxicity, corrosion, ceramics or, in general, materials for hard tissue replacements are, discussed in a number of pages, apparently overrepresented with respect to cellular or physiological response. The counterbalance are the two chapters on heart valve substitutes and tissue engineering. Should it not be the other way round? On the one hand, it is beyond doubt that substantial progress has been made in understanding tissue response to foreign materials. On the other hand, the long-term success of, say, (even conventional) total hip prostheses is undeniably remarkable, while decades long studies of surface modification to enhance biochemical and physiological compatibility resulted in rather modest successes. Exception might be made for orthopedic hydroxyapatite coatings, but the initial success of hydroxyapatite-coated dental implants is vanishing. Experience taught us that *close fit* seems to be more beneficial than surface modification, selecting of course materials with an otherwise good record of service. The Gallo–Roman dental implant (Chap. 10) is a quite unexpected support for that view. New forming technology permits manufacturing custom-made prostheses fast and at reasonable cost. One chapter is devoted to forming techniques for metals as well as for ceramics and polymers (Chap. 7). The elastomer-coated prosthesis discussed in Chap. 11 is another proposal for meeting, among other requirements, a close fit. But history teaches us that once a technology is nearly perfect – think about steam engines – one no longer needs it. Tissue engineering is lurking at the corner to undermine the world of the materials scientists, from cartilage to heart valves. May not be tomorrow, but somewhere down the line it is bound to happen.

Permanent implants need materials with long-term stability and resistance to corrosion and wear, for example, definitely when considering that even young patients are getting implants. For controlled drug delivery devices, which do not endure high loads, materials that dissolve gradually in the course of time are required. Nonpermanent implants subject to moderate loads, which are currently removed when functional support is no longer needed, are potential candidates for being manufactured out of very corrosive alloys, whose dissolution rates (and production of hydrogen) can be tightly monitored. Chapter 8 is devoted to a discussion of these alloys.

The excellent survival rate of permanent implants demands an updated attention to toxicity. The toxic behavior of the major elements is elaborately studied. No alloy, however, is inert. Many of the minor elements have documented toxic, mutagenic or cancerogenic properties but the effect of sustained exposure over long periods of time is not known.

Understanding macroscopic processes by studying (inter-)reactions at molecular, atomic, or cellular level is a noble goal and the ultimate dream of scientist. The trend is already seen as toxicity testing is carried out on human cells instead of animal cells, to study friction at nanoscale level or similar research in almost every domain of science and technology. The question remains whether it can reflect the behavior of materials at the macroscopic level. For the time being, it is not (yet) true, for example, in friction research. It has long been a concern of physicists and Robert March formulated it already forty years ago in his elegant book *Physics for Poets* ([1], p. 96), when he wrote:

> *Though laws describing the behavior of atoms are, at least in principle, the basis for the behavior of larger objects, it is inconvenient and perhaps even impossible to so use them in practice. On the basis of this, a physicist might well suspect that, for example, even if psychology were to become a perfectly exact science, it would be of little value in understanding society.*

Were March's statements in the 1970s too pessimistic toward an atomistic approach? The theory of complex systems was not as advanced as it is today but the cited text certainly fits the modern line of thought on *emerging properties*: a system is more than the sum of its component parts. It is a warning against oversimplification. Properties cannot (yet?) simply be scaled up from nano- or subnano- to the macroscopic level.

To conclude this introduction, the book is not a revolutionary pamphlet but a trial to offer the reader an integrated view on the field of biomaterials: cherishing the past, discussing robust state-of-the-art materials and opening a prudent, although modest, window to the future. Through this book, the authors hope to attract readers desiring an introduction to the field, not too general and not too specialized, students or beginning scientists in the field, as well as more experienced readers in an engineering and/or medical environment. The incentive to introduce a chapter by a clinical case study was also to emphasize the necessity of the close interaction between clinical practice and engineering, a close interaction that was too often absent in the earlier days of biomaterials research. Or, as Marie Csete (CIRM) expressed it in *Nature* (2 October, 2008) *We've had a crisis finding someone who understands clinical medicine and basic science*.

Bibliography

The bibliography is quite extended, tough, not exhaustive. Our excuses if not always the most representative papers are cited. In many instances, reference is made to older, but not at all, obsolete books. They were selected because of their intrinsic and historical value.

About the Book Title

Read the story on p. 109 (Sect. 5.3).

Illustrations and Italics

When not otherwise stated, photographs and graphical illustrations are produced by the author. When a name is added without affiliation, the person's name is listed in the acknowledgments.

Printed in italics are:

- Terms which are introduced in the text for the first time.
- Latin words or other non-English words.
- Text excerpts from other authors.
- Sentences or part of sentences that need to be emphasized.

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