Tailoring biocompatibility: Benefitting patients

Changing scientific fields – for example from physics to materials science – is recommended during an academic career.

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Knowledge and experience acquired in one field can be transferred to another and thus benefit the whole scientific community. Indeed, some of today's most exciting scientific discoveries are made at the borders where different disciplines meet. For this reason, I left surface science and solid-state physics more than a decade ago to become a research associate within the interdisciplinary team 'Biocompatible Materials Science and Engineering' at the Materials Department of ETH Zürich.

At first glance, I expected that biocompatibility could be considered as a specific property of a material, such as reflectivity or colour. Biocompatibility, however, is a strange property and not defined and standardized in the same way as terms such as electric field strength. Nonetheless, everybody has a certain understanding of biocompatibility and is aware of the close relation to biomaterials and medical implants. One can consult definitions and will find: Biocompatibility is the ability of a material to perform with an appropriate host response in a specific application[1]. Using such a definition, however, the physicist is lost since biocompatibility is not only dependent on the specific solid-state material but also on the surrounding tissue. It should be remembered, however, that physicists are also seemingly lost in almost any other situation – is there a physicist who can calculate the exact movement of a monkey along a rope? The best he can do will be to approximate the monkey using a point mass. But how do physicists deal with a term such as biocompatibility, which doesn't even have a dedicated unit?

One of the early and rather simple questions relates to bone implants. A dental titanium implant, for example, contains a rough surface along the thread of this special screw. This roughness generated by sandblasting and etching procedures guarantees osseointegration. But why? I first posed my question to the medical doctors: why does the part to be introduced into the jawbone have to be rough, and which roughness has to be employed? The answer was clear and simple: Roughness improves the osseointegration and the preparation procedures are the secrets of the implant suppliers. So I posed the same question to the materials scientists working for such companies. The answer was less clear - instead a question back: You as physicist should explain how roughness on the nano- to millimeter scale could be described and measured. They further stated that the roughness at all different scales is vital for osseointegration. Hence, I received no real help from either the medical or engineering experts.

So I turned back to physics for an answer. I checked my knowledge on roughness and the related measuring procedures. Certainly, different techniques exist which are suitable for certain length scales, but I have not found any unique parameter for surface roughness. With one exception – the Wenzel ratio, which is the actual surface divided by the projected one. In fact, nobody had measured this on the atomic level and I started to think about the problem. In 1990, when I was a guest scientist in the Köhler team at Hannover University, Germany, we found – although this was published by others[2] – that Ge forms nanopyramids on Si(100) with well-defined facets, termed hut and dome clusters. The height of these nanopyramids can be determined exactly by means of scanning probe techniques. Because the facet angles are known, the Wenzel ratio can be derived by counting the nanopyramids[3].

Now this Wenzel ratio has to be correlated with biocompatibility. The first step, here, is the physico-chemical evaluation by, for example, contact-angle measurements. I was told that such an experiment can be done during lunchtime, but it took about 6 weeks for two scientists to demonstrate that the nanometer roughness has a marginal influence on the advancing contact angle. Instead of abandoning the planned further experiments, we continued with the second step, namely protein absorption and in vitro cell experiments, and finally found huge effects induced by the nanopyramids. A high density of nanopyramids that is related to a rough surface has a very positive effect on inflammatory reactions, whereas the monocytes above a flat surface are exclusively damaged[4].

These studies convinced me that biocompatibility of medical implants can be tailored. This is indeed not only a positive message for the patients but also for the physicist. We have identified parameters to intentionally manipulate a strange and complex material property, i.e. biocompatibility. Each parameter can be used to improve the implant's functionality and also depends on the host tissue or the implantation site, as stated in the definition mentioned above – a lot of fascinating challenges for other generations of scientists and engineers.

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