The interaction between Implantology and Materials Science

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Abstract

Introduction: Materials Science has been of paramount importance to Dentistry because the biomaterials involved have specific characteristics that allow them to have a predictable application. In Implantology, the following may be emphasized: biomaterials, membranes and implant surfaces. It is of vital importance to study the physicochemical characteristics of biomaterials in order to correctly choose what provides a specific biological outcome. Therefore, analysis of properties such as crystallinity, particle size, porosity, and specific surface area is crucial to understand the *in vivo* performance of materials. Implant surfaces have also been developed to improve the osseointegration process in areas with poor quantity or quality of bone. **Objective:** The aim of this study is to carry out a literature review about the importance of Materials Science in the development of biomaterials used in Implantology.

Keywords: Materials Science. Biomaterials. Membranes. Implant surface.

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Introduction

Nowadays, Implantodontics faces a daunting challenge. Given the increase in the life expectancy of the world population and their relentless pursuit of better quality of life, one often encounters partially or totally edentulous patients who require oral rehabilitation, but have severe limitations in terms of bone availability for implant fixation.

Research in the field of Implantodontics began as early as 1965, when the concept of osseointegration was first introduced. In the past, treatment planning was carried out based on existing bone tissue, and did not take into account the three-dimensional position of implants nor there was any esthetic concern regarding how cases were finished.[2] However, planning is currently reversed, to the extent that it is the prosthesis that determines implant position, and in many situations, the amount of bone available is inadequate for the case.

Materials Science correlates the properties of a given material with its microstructure. Microstructure can be defined as the atomic organization of crystalline solids, and it is related to their intrinsic and extrinsic properties. With the aid of engineering, one can develop materials with controlled characteristics which improve their *in vivo* peformance.[3] Implantodontics makes use of various biomaterials for specific applications, geared towards restoring the form, function and esthetics of patients.

This study aims at reviewing the development and application of biomaterials used in Implantodontics.

Literature review

Biomaterials for bone graft

By definition, a biomaterial is a pharmacologically inert substance or a combination of two or more substances, of natural or synthetic origin used to partially or fully replace, augment or enhance tissues and organs.[4]

Bone reconstructions involving treatment with dental implants have been on the rise, driving the development of materials that enable replacement, or even the use of autogenous graft.[5]

Biomaterials must perform certain key functions for which they were developed in the first place, such as being biocompatible and biofunctional as well as leading to predictable results. Biofunctionality refers to the physical and mechanical properties that enable the implant to perform its intended function, whereas biocompatibility is defined as a state of mutual existence between a material and its physiological environment whereby no harmful effects are produced in either one of them.[6]

Biomaterials can be classified according to their origin and action mechanism. In terms of origin, they may be classified as autografts, allografts (e.g. bone bank), xenogenous (e.g. Bio-Oss®), and alloplastic (e.g. Alobone Poros®).[7] In terms of action mechanism, biomaterials can be classified as osteogenic, osteoinductive and osteoconductive.[8]

Ceramic materials used in Dentistry are known as bioceramics. Among these, calcium phosphate [$Ca_3(PO_4)_2$] and hydroxyapatite [$Ca_{10}(PO_4)_6OH_2$] are widely studied due to the fact that their chemical composition and crystal structures are similar to the inorganic chemical composition of bone tissue. The remarkable advances in bioceramics resulted in the development of materials with chemical, physical and mechanical properties that are suitable for biomedical applications.[9]

Physicochemical properties are responsible for the integration of biomaterials into living tissue. Physical properties comprise the surface area, shape (block or granule), porosity (dense, macro or microporous), and crystallinity (crystalline or amorphous). Chemical properties refer to the calcium/phosphorus (Ca/P) ratio and the chemical composition.[3]

Knowledge of the physicochemical properties of biomaterials is of paramount importance for the implant dentist to select the most suitable biomaterial for a given application.[3]

Membranes

The concept of guided tissue regeneration (GTR) was developed with the purpose of regenerating periodontal tissues lost due to periodontal disease. GTR seeks to exclude unwanted cells during repopulation of the wound area through membrane barriers, thus, fostering proliferation of specific tissue cells in order to ensure that wound healing occurs with the desired tissue type.[10]

The principle of mechanical barrier is also applicable in reconstructive bone surgery, in which placing a barrier membrane prevents soft connective tissue growth within the bone defect. The membrane is placed in direct contact with the bone surface, thereby positioning the periosteum on the outer surface of the membrane. The ultimate goal of guided bone regeneration (GBR) is the use of a temporary material that promotes a suitable environment, allowing the body to deploy its natural healing potential and regenerate lost and missing tissues.[11]

It is imperative that the membranes used in regenerative procedures meet certain prerequisites if they are to act as a passive physical barrier, i.e., biocompatibility, space maintenance, integration with tissues, adequate clinical management and occlusive properties.[12]

Occlusivity is intended to prevent the migration of cells from the connective and epithelial tissues into the defect, whereas tissue integration stabilizes the wound and develops a biological seal between the tissues. Maintaining the space produced by the membrane is essential for blood clot formation and subsequent tissue regeneration.[12]

In order to maintain adequate space for regeneration, the membrane must have mechanical or structural characteristics capable of withstanding the forces exerted by the tension of the flaps or by chewing, thereby preventing the membrane from collapsing over the defect. Furthermore, barrier function must be maintained for as long as necessary for tissue regeneration to occur.[13] To ensure bone formation and maturation, a period of at least six months is recommended.[8]

While meeting the criteria described above, nonresorbable and resorbable membranes have been developed for both GTR and GBR.

Nonresorbable membranes

Most nonresorbable membranes comprise cellulose or expanded polytetrafluoroethylene (e-PTFE). Because they feature high stability in biological systems and do not generate immune responses, e-PTFE membranes (Gore-Tex Augmentation Material, WL Gore) used to be the most widely employed.[12]

The e-PTFE membranes feature chemical and biological inactivity, as demonstrated by absence of adverse tissue reactions.[14] Their greatest advantage is the ability to maintain the function of a barrier throughout the period required for bone formation. Their major disadvantage is the need for a second surgical intervention to remove the nonresorbable membrane.[15]

Resorbable membranes

Resorbable membranes must be fully made of bioresorbable materials which belong to the group of natural or synthetic polymers (collagen or polyester). Collagen, polylactic acid, polyglactin 910, poly-glycolic acid and polyurethane[16] membranes can be cited as examples of resorbable membranes.

Resorbable collagen membranes feature several advantages. They stabilize the wound, allow early vascularization by attracting fibroblasts through chemotaxis, and are semipermeable, which facilitates the transfer of nourishing elements.[17] Furthermore, resorbable membranes do not require a second surgery to be removed. The major disadvantage of resorbable membranes is that their barrier function does not last long.

Resorption may occur before the minimum period required for bone formation and maturation. Moreover, space creation and the collapse resistance characteristics (hardness) of a GBR membrane are important considerations when choosing a suitable material. This is true for degradable materials, as they will lose mechanical strength during the degradation process.[12]

Implant surfaces

Implant surfaces have undergone a number of changes not only with the purpose of improving osseointegration in areas with poor quantity and/or quality of bone, but also accelerating bone healing in order to enable early or immediate loading protocol. Among the different parameters that help to determine a successful implant, the implant-bone interface plays an important role in longevity and improves the function of implant-supported prosthesis.[18]

Different kinds of surfaces are available in the market, vary according to the treatment received, and can be grouped into five types, i.e., untreated, machined surface; surfaces of which roughness is modified by abrasive particles through acid etching, coating by deposition of titanium oxide particles or laser treatment; modified by hydroxyapatite or other chemical products; electrochemical treatment with alkaline solutions to change the surface energy of titanium or vary the thickness of the oxide layer (anodizing); and mechanical subtraction by means of ion bombardment.[19]

On titanium surfaces, the biological effects of surface chemistry are mainly related to the architecture of the titanium oxide layer (TiO_2). Given that osseointegration is directly related to dynamic thickening of the layer of TiO_2, implants with a thick TiO_2 layer, such as anodized implants, exhibit a better bone response since they increase mineral bone matrix precipitation on the surface of the implant.[20]

Impregnation or coating with inorganic elements stimulate a biochemical imbrication between the bone matrix and the TiO_2 layer.[21] Impregnation with calcium phosphate[22] and coating techniques[23] have been widely investigated and show favorable bone responses, but a consensus has yet to be reached regarding the precise underlying mechanism, the optimum levels of calcium phosphate and the methods of incorporation. Impregnation with phosphorus[24] or magnesium[25] also significantly increases bone response, and low impregnation with fluoride[26] stimulates bone cell differentiation by means of direct cell signaling. Nevertheless, the exact mechanism is still unclear. The biological results yielded by crystal architecture are positive, as previously shown in implants covered with anatase titanium oxide.[27] The ideal microroughness for bone formation is found in moderately rough implants, with an average height deviation (Sa) of 1.5 μm.[1]

Modulation in the nanotopography of an implant surface exerts a significant impact on the behavior of bone cells. It is possible to design a specific nanotopography geared towards increasing or controlling the proliferation and differentiation of bone cells.[28]

The application of nanotechnology represents a step forward in the development of the surface of dental implants, and the results point to an improvement in the response of bone implants known as nanomodified.[29]

Discussion

There is a wide range of dental biomaterials available in the market that exhibit different behavior *in vivo*, and are dependent on their physicochemical features.[3]

Porosity increases the surface area of bone graft biomaterials, enabling bone formation. Therefore, the higher the porosity the faster biomaterials are resorbed.[30] The pores must have a minimum diameter of 100μm.[31]

Porosity can be affected by temperature in the sintering process of thermally treated bioceramics. Increases in sintering temperature result in lower porosity of the biomaterial.[32]

Crystalline biomaterials have a well defined atomic organization, unlike amorphous materials which have an irregular crystal form. Crystallinity is a property that alters the resorption rate of bone graft biomaterials.[3] Highly crystalline biomaterials are more resistant to degradation.[33]

There are differences in the crystal structures of bone graft materials, which shows that small crystals resembling those of the bone are desirable. The different sizes of crystals may stem from differences in processing. Biomaterials processed at temperatures above 1000°C induce crystal growth.[34] High sintering temperatures can cause changes in the atomic structure of HA crystals[35] and can thus substantially affect the behavior of bone graft materials.[36]

Particle size is an important factor because it directly affects the surface area available to react with cells and biological fluids. Thus, the smaller the particle size the smaller the resorption time and, as a consequence, the new bone formation.[37]

A balance must be struck between the rate of resorption of the biomaterial and the rate of bone formation, whereby the biomaterial cannot be resorbed too quickly, nor can it fail to be resorbed as it is the case of crystalline biomaterials.[38]

It has been shown that when bone graft biomaterials are used in conjunction with membranes a higher success rate is achieved due to the fact that a greater proportion of vital bone if formed.[39] Membranes produce an efficient barrier against the invasion of mucosal tissue while inducing bone regeneration without complications.[12]

With the advent of resorbable membranes, the use of nonresorbable membranes has been decreasing since resorbable membranes eliminate the need for removal surgery. Nevertheless, e-PTFE membranes remain the benchmark in GBR procedures.[15]

Stabilizing the membrane during GBR procedures is essential for achieving predictable results. This was demonstrated in a study in which the authors compared the results of regenerative procedures using allograft, bioresorbable membrane and membrane stabilization. They reported that in cases in which the membrane was stabilized with screws, bone loss was lower after the healing period in areas where the width had been increased.[40]

In addition to the use of biomaterials for bone grafts and membranes for GBR, studies have investigated various surface treatments of dental implants in order to improve clinical outcomes related to rehabilitation with this therapeutic approach. In this context, the results of different experiments showed increased implant-bone contact in implants that combined micro and nanostructures.[41] Studies have shown increased bone response thanks to this combination (micro + nano) compared with micro only, in both humans[41] and mice.[42] However, in an eight-week follow-up of dogs, similar values of bone-implant contact were found between implants with microstructure versus micro + nano.[43] The benefits of nanostructures are not yet widely acknowledged by the scientific community, and several factors contribute to this reluctance. Noteworthy among these factors is a difficulty in attaining an adequate characterization of 3D topography on a micrometric and nanometric scale. Future experiments are warranted to clarify the importance of nanostructures in bone response. A correct characterization of the surface is a key factor in comparing and analyzing results.[29]

Conclusions

It can be concluded that Materials Science plays a crucial role in the development of metallic, ceramic and polymeric biomaterials. Stringent control should be exerted when processing these materials to ensure that their microstructure indeed contains the properties required by any given clinical application.

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