BİYOKOMPOZİTLER

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ÖZET

Biyomalzemelerin gelişimine başlangıçta metal, polimer ve seramik malzemeler ışık tutmuştur. Fakat biyomalzemelerden beklentilerin artması ile metal-plastik, metal-seramik ve plastik-seramik gibi yeni biyokompozit malzeme grupları ortaya çıkmıştır. Biyokompozit malzemelere gün geçtikçe ilginin artması, bu malzemelerin kullanımı, özellikleri ve biyo uyumluluklarıyla ilgili bilimsel ve ticari çalışmaları arttırmıştır. Biyokompozitler başlıca ortopedide kırık kemiklerin iç-dış bağlantı sistemi onarımında, eklem ve kemik yenilemelerinde ve diş tedavilerinde kullanılmaktadır. Bu çalışmanın amacı biyokompozitlerin kullanım ve özelliklerine dikkat çekmek; bilimsel hedeflere ışık tutmak; ticari anlamda devlet ekonomisinde önemli yeri olan bu konuda altyapı oluşturulması ve geliştirilmesi için bilgilendirme yapmaktır.

Anahtar Kelimeler: Biyomalzeme; kompozit; alaşım; mühendislik

BIOCOMPOSITES

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ABSTRACT

Initially metal, polymer and ceramic materials shed light on the development of biomaterials. However, due to increasing expectations from biomaterials, new biocomposite material groups emerged such as metal-plastic, metal-ceramic and plastic-ceramic. The day by day increasing interest in biocomposite materials, increased scientific and commercial studies related to using these materials, their characteristics and biocompatibilities. Biocomposites mainly are used in internal - external connection system repairing of orthopedic broken bones, bone and joint replacements and in the dental treatments. The aim of this study is to draw attention to use and the characteristics of biocomposites; to shed light on the determination of the objectives of the scientific studies; to inform about this issue, which has a commercially important role in the economy of the state, for creating infrastructures and developments.

Keywords: Biomaterial, composite, biocompatibility

1. Introduction

Biomaterials are materials of natural or man-made origin that are used to direct, supplement, or replace the functions of living tissues of the human body [1]. Composites are engineered materials made from two or more constituents, each offering different physical properties, which can be combined synergistically. Composites typically possess a superior strength to weight characteristic compared to monolithic materials and offer excellent biocompatibility. They are, therefore, favorable for both hard- and soft-tissue applications as well as the design of prostheses [2].

The biocompatibility of a material indicates its ability to perform in conjunction with a living system [3]. Specifically, one distinguishes between the chemical, biological and physical suitability of a material (surface compatibility) and its compatibility in terms of mechanical properties (structural compatibility) such as stiffness, strength and optimal load transmission, at the implant/tissue interface [3, 4]. In nature, mechanical function and structural support is provided by the musculoskeletal system, consisting of hard- and soft-tissues.

2. Hard-tissue applications

Bones of the skeletal system provide the supporting structure for the body. Bone is a structure composite composed of collagen fibers with hydroxyapatite nanocrystalls precipitated along the collagen fibrils [5].

Hard-tissue applications of fiber reinforced composite materials include: skull reconstruction, bone fracture repair, total knee, ankle, hip and other joint replacements, as well as dental applications. An overview of some exemplar applications is given at figure1.

2.1. Bone fracture repair

There are two distinct types of bone fracture repair, namely external and internal fixation. External fixation keeps the bone fragments aligned by means of casts, splints, braces or similar fixation systems. Traditional casting materials are generally made from plaster of calcium sulphate with woven cotton fabrics or fabrics of glass and polyester fibres providing the necessary reinforcement [3].

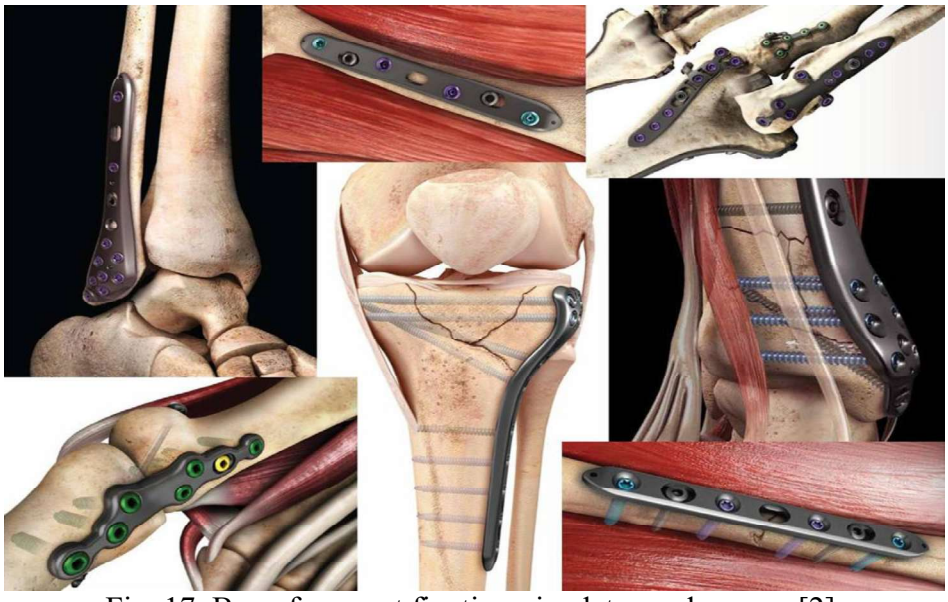


Fig. 17. Bone fragment fixation via plates and screws [2].

Other external fixation systems (Fig. 2) have only recently gained popularity as lightweight carbon fibre designs have become more readily available. In the particular case of carbon fibre orthoses a 10% reduction in patient heart rate and oxygen consumption was reported, following weight savings of around 29% compared to stainless steel equivalents [6]. Furthermore, due to the low density of carbon fibre reinforced plastic, an improvement in agility, gait and walking speed can be noticed [7].



Fig. 2. External bone fixation systems [2].

Resorbable bone plates have become of particular interest because they permit the gradual increase of stress on the bone as it progresses through healing; thus stress shielding can be reduced and osteopenia may be eradicated. Fully-resorbable composite implants provide a major advantage over conventional metallic plates as they do not need to be removed during a second surgical procedure. A number of resorbable polymers including poly (l-lactic acid) (PLLA), poly(glycolic acid) (PGA) or their copolymers and poly(llactic- co-glycolic acid) (PLGA) have readily been approved for human clinical uses [8]. However, it generally proves difficult to achieve non-toxic degradation at an acceptable rate and yet retain good mechanical properties. To enhance mechanical performance, resorbable polymers have recently been fibre-reinforced (making them partially-resorbable) and finite element analysis has been applied to assist in optimising volume fractions [9].

2.2. Total hip replacement

Total hip replacements are the most common joint replacements with more than 150,000 operations a year in the US alone [1]. At present, metal hip implants are still predominantly used as clinical success rates of 93% at 10 years and 85% at 15 years post-surgery are high [10]. Nevertheless, problems of prosthesis loosening and induced non-physiological stresses in the bone, directly affecting bone remodelling, have been reported repeatedly, following the implantation of artificial hip joints. Modern prostheses (Fig. 3) made from polymer composites have the potential to meet spatially varying mechanical requirements

such as strength and stiffness. Consequently, regions of high stress concentration can be minimised and stress can be transferred more effectively at the bone/prosthesis interface [3].



Fig. 18. Total hip replacement

However, while a more compliant hip implant reduces stress shielding it must maintain a minimum level of stiffness in order not to cause residual pain due to low-amplitude oscillatory micromotion [11]. Micromotion describes the deformation and relative movement between prosthesis and bone under loading. Further, investigations on the response of laminated composite prostheses that were, in shape, based on the standard metal alloy hip design, suggest that these may not be structurally adequate [12]. Finite element analysis is, therefore, often employed to test and optimise artificial hip joints. Following multiscale, structural analysis, a set of guidelines for designing future composite hip implants has been proposed by Srinivasan et al. [13]. In addition to design and mechanical performance, fixation techniques play an important role in total hip replacements. The development of composite materials for use in hip joint fixation currently concentrates mostly on the approaches of cementing and bone ingrowth [14].

2.3 Bone replacement (synthetic bone graft) materials

Synthetic bone grafts are necessary to fill bone defects or to replace fractured bones [15].the bone graft material must be sufficiently strong and stiff and also capable of bonding to the residual bones. Bone cement is one of the most commonly used products in orthopaedic surgery. Among common indications for use of bone cement are total joint replacement, bone and joint reconstructions, fracture fixation, and treatment of osteoporotic vertebral fractures. Bone cement is often used synonymously with ‘acrylic bone cement.’ It has two main components: a liquid monomer and a powder polymer [16].

PE is considered biocompatible from its satisfactory usage in hip and knee joint replacements for many years. Stiffness and strength of PE are much lower than those of the bone. For load bearing applications, properties of PE need to be enhanced. In order to improve the mechanical properties some resears[17,18,19,20] reinforced PE using HA particles, which are bioactive.

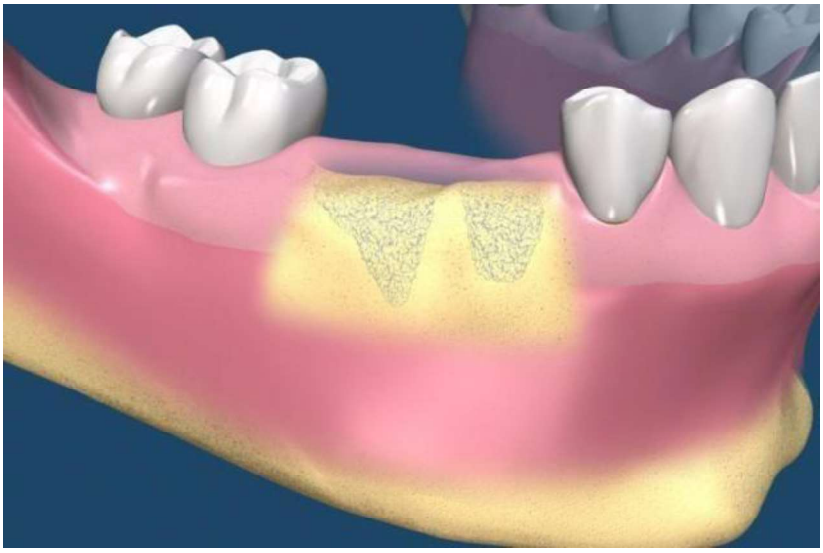


Fig. 19. Schematic illustration of bone cement

The resulting composite has an elastic modulus of 1-8 GPa and strain to failure value of over 90-3% as the volume fraction of HA increases to 50%. It was reported that for HA particulate volume fractions above 40% the composite is brittle. More over the the bioactivity of the composite is less than optimal because the surface area of HA available is low and rate of bone bonding of HA is slow. Further work requires consideration of using more bioactive materials such as Bioglass as reinforcements in PE [21, 22]. To increase the interface between HA particles and the bone tissues, some researchers developed partially resorble composites. They reinforced resorbable polymers such as PEG, PBT,PLLA, PHB with bioactive particles[23,17]. The wide range of material combinations offers the possibility of making composites with various desired properties such as stiffness, strength, biodegradation and bioactivity[1].

2.4. Total knee replacement

The application of composites in total knee replacements has proven to be extremely difficult. Attempts to improve wear resistance of ultra-high molecular weight polyethylene (UHMWPE) by means of reinforcing carbon fibres failed due to poor bonding between the two constituents. Similarly, other efforts such as reinforcing UHMWPE with UHMWPE fibres did not lead to increases in wear resistance; however, improved stiffness, strength and creep resistance were achieved [3].

A number of desirable characteristics for materials employed as the articulating surfaces in any type of total joint replacement have been summarised by Rahaman et al. [24] and are laid out below:

► High strength, elastic modulus, fracture toughness, and fatigue resistance to sustain mechanical reliability whilst resisting deformation under loading; loads in the body range from 3 kN during normal walking to 8 kN when jogging or stumbling.

►High corrosion resistance for bioinertness and biocompatibility in vivo.

► High hardness and good surface finish supporting wear resistance in the long-term together with low friction.

► Good wetting at the bearing surface/synovial fluid interface for lubrication in the body.

2.5. Dental applications

In dental applications, including orthodontic archwires, brackets and dental posts, conventional restorative materials such as amalgam, gold, alumina, zirconia and many others have essentially been fully replaced by composite resins. Modern composite resins have a refractive index matching that of enamel and can thus not only restore the function but also the appearance of biological tissue [25]. The main shortcoming of these materials is their lifetime; issues such as polymerisation shrinkage, shrinkage-stress development, thermal expansion mismatch, wear resistance or toxicity are yet to be resolved, leaving large scope for advancement. Furthermore, typical orthodontic prosthetic composites have poor thermal conductivity leading to altered perception of taste [2]. A viable solution to this problem has been proposed by Messersmith et al. [26] who incorporated ceramic microwires of aluminium oxide into poly (methyl methacrylate) (PMMA) in order to attain a higher diffusivity.



Fig. 5. Composite fillings [27,28]

There is concern over the long-term toxicity of silver-mercury amalgam fillings. Acrylic resins and silicate cements have been used for anterior teeth. However, they exhibit poor mechanical properties, which lead to short service life and clinical failures. Dental

composite resins, which are translucent with a refractive index matching that of the enamel, have virtually replaced these materials and are very commonly used to restore posterior teeth as well as anterior teeth. The dental resin comprises of BIS-GMA as the matrix polymer and quartz, barium glass, and colloidal silica as fillers. The BIS-GMA is derived from the reaction of bis(4-hydroxyphenol) and glycidyl methacrylate. In other types of composites urethane dimethacryate resin is used rather than BIS-GMA. The filler particle concentration varies from 33 to 78 % by weight and size varies from 0.05 to 50 µm [1].

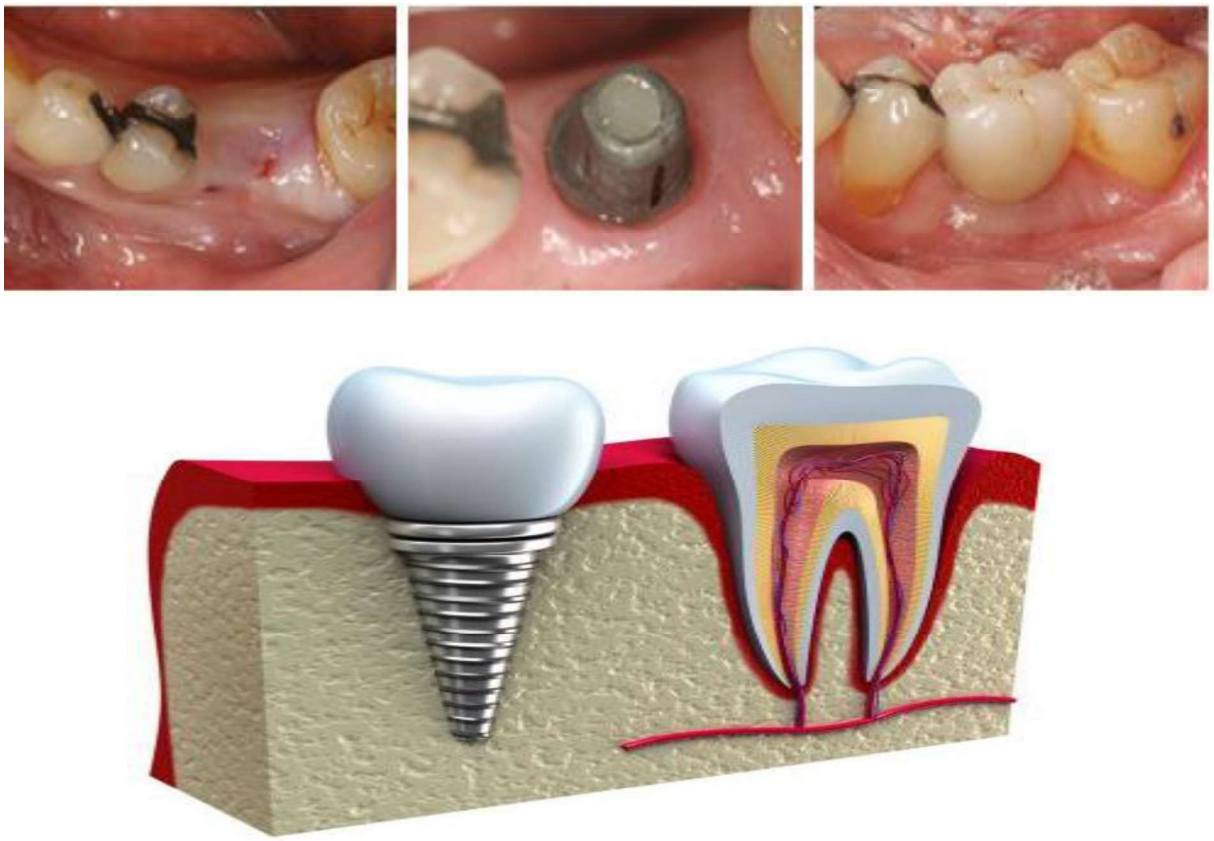


Fig. 6. Dental implants

In the extreme case, the damaged or condemned tooth is extracted and replaced with a dental implant. Dental implants are an artificial tooth roots that permanently replace missing teeth, and they are en alternative to bridges or false teeth. The dental implant may be designed to enter the jawbone or to fit on to the bone surface. The types of dental implants available are numerous. For example, certain root forms have threads, which facilitate to secure the root form into the jaw bone, whereas in some other designs, the surface is coated with porous bioactive materials, which allow bone growth and osseointegration. They are made of a wide range of materialssuch as metals(Co-Cr-Mo alloys, Ti alloys, stainless steel, platinum, silver), ceramics (zirconia, alumina, glass, and carbon), polymers(UHMPE,PMMA,PTFE,PS and PET), and composites (SiC/Carbon, and CF/carbon) [29,30]. Compared to ceramic and metal alloys, the outstanding properties of

composites are high or sufficient strength combined with low modulus. Such composite materials may offer protection against the alveolar bone resorption. Moreover fatigue properties of composites are far superior to the metal alloys and ceramics. The dental implants need to be designed to withstand extremely large and varying forces applied during mastication [1].

3. Soft-tissue applications

Many different types of implans are used in the surgery to correct soft tissue deformities or defects which can be congenital, developmental, or acquired defects, the last category usually being secondary to trauma or tumor excision. Depending on the intended application, the soft tissue implants perform various functions: fill the space from some defect; enclose, store, isolate, or transport something in the body; and mechanical support or serve as a scaffold for tissue growth[1].

The application of fibre reinforced composites to soft-tissue has, over the past two decades, proven to be difficult. Many kinds of soft-tissue, including skin, nerves, tendons, ligaments and vascular grafts, do not obey Hooke's law when subjected to a physiological load; instead, their stress–strain behavior is represented by a non-linear, convex, 'j-shaped' curve [3].

Composite materials to replace soft-tissue are generally founded on naturally occurring polymer-based systems such aspolysaccharide proteins [64]. Moreover, the intrinsic properties (molecular weight, charge, etc.) of the constituent parts areincreasingly important when developing these materials [64]. Inthe case of vascular grafts, for example, the optimisation of porosityplays an important role. Excessive porosity may lead to bloodleakage, but at the same time a certain threshold is required in orderto encourage tissue growth and acceptance by the host tissue [2].

4. Other biomedical applications



Fig. 7. Photograph of typical composite prosthetic legs [1, 2].

Initially artificial legs are designed primarily to restore walking of the amputes. They were made of wood or metallic materials. These materials are limited by their weight, and poor durability due to corrosion and moisture induced swelling. As a result the user is often restricted to slow and non-strenuous activities. Strenuous activities, such as playing ball games and running are not possible due to the weight of these devices and their poor elastic response during stance. The light weight, corrosion resistance, fatigue resistance, aesthetics, and ease of fabrication of polymer composite materials made them ideal choice for modern limbs systems [31]. Several designs of artificial limbs with different commercial names are available, thermoset polymer composites reinforced with glass, carbon or Kevlar fibers are widely used in these systems [1]. Less expensive polypropylene plastic and glass fibre/highdensity polyethylene (GF/HDPE) types have thus been derived at the expense of comfort, mechanical performance and manufacturing reliability [2]. A typical artificial leg system consist of three pars namely socket, shaft and foot (Fig. 7). The most highly customized and important part of the prosthesis is the socket, which has to be fabricated individually to the satisfaction of each amputee. The shaft is made of filament wound or laminated woven/braided fabric carbon fiber reinforced epoxy composites. It provides structural support and force trasmittance to mimic the skeleton [32]. In some design, the foot unit consist of heel and forefoot components, which are made of laminated CF/epoxy composites and are designed to serve as flat spring-like leaves so that the foot provides strong cushioning and energy storing effect [33].

4. Conclusions

The most important thing is health in our life that's why we should improve biomaterials. Owing to lots of biological and mechanical requirements, composite materials are most suitable biomaterials. In this respect, composite biomaterials are particularly attractive in manufacturing biomedical materials. The rate of advancement will, therefore, mainly depend on financial constraints and the concurrency of multidisciplinary efforts.

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