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Polymeric Materials in Medicine

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Review Article

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Abstract: The development of methods for the synthesis and modification of medical polymers, as well as innovative technologies in medicine, allow us to proceed to the solution of the most important problems of theoretical and practical medicine. In the paper, the diversity directions questions of the polymers use in medicine and the characteristic properties of polymers as a main feature of their use are generalized. The characteristic fields of polymeric materials application in medicine are analyzed. The main elements of the medical services generalized classification with a description of the certain polymers application for specific fields of medicine with a direct indication of their name are considered. It is pointed out the importance of taking into account the physical and mechanical polymers properties as the basis for their application in medicine.
Keywords: Polymeric Materials, Cardiology, Nephrology, Oncology, Orthopedic Surgery, Ophthalmology, Dentistry.

INTRODUCTION

Polymer products and parts are indispensable in many areas of modern life. Virtually no area of human activity cannot do without the use of polymers for a wide variety of purposes. In medicine, as in other areas, polymers are also finding increasing use. Polymers possess the necessary physic mechanical properties, and their harmlessness for body tissues is the main advantage, which made them an indispensable material in the manufacture of medical devices parts and instruments, blood transfusion systems, syringes, care items, laboratory equipment, packaging, catheters, bougie, drainage tubes, probes, drug packaging, frames and lenses [1].

Polymers are economical and have a high degree of resistance to the negative effects of various media. Polymers properties can be adapted to meet specific needs by changing the "atomic composition" of the structure or molecular mass that repeats [1, 2]. An enormous role is also played by the possibility of performing natural polymers chemical modification [3-5].

Nevertheless, the specifics of the polymer products manufacture and the specifics of their use cause the need for detailed consideration of various issues relating to the direct use of polymeric materials in practical medicine.

The variety of directions in the use of polymers in medicine

The basis for considering the variety of directions for the use of polymeric materials in medicine can be considered various studies of individual authors. This allows us to make an appropriate small literature review on the use of polymers in medicine.

For example, Paoki addresses issues related to the use of polymers in: orthopedic surgery; ophthalmology; in tissue engineering; for surgery; dentistry; oncology; nephrology; cardiology [6]. Also in this paper, recent advances in hem compatible polymers for biomedical applications are considered. No less important are the questions of using polymers based on biosensors for medical applications.

In [7, 8], studies are made in the field of biomedical polymer materials. The polymers used for constructing artificial organs are described in detail. Presented are the latest data on promising polymers of biomedical use, methods of their investigation and processing into specialized products; results are given in the field of reconstructive surgery and the design of biotic organs.

Morelli and Piscioneri analyzed in detail the biomaterials for cellular engineering [9]. The study [10] is devoted to the use of new and known high-molecular compounds from polymers in the field of nanotechnology and nanomedicine.

In [11], the main types of polymeric materials used in medicine are considered. The requirements for medical polymers are formulated and the features of their application in various fields of medicine are indicated. The physical and technical characteristics of polymer materials and examples of their specific application in medical devices are presented. The issues of using biodegradable medicinal films, resorbable sutures, tissue gluing, microencapsulation and other applications of medical polymers are considered.

The most promising materials in medicine (smart polymers) are devoted to work [12]. In this paper, the types and preparation of smart polymers for medical devices are presented: polymers and their classification. Medical devices based on polymers with shape memory (SMPs) are also considered; biosensors for diagnostic medical devices.

At the same time, it should be noted that the development of science and technology leads to an ever wider introduction in medicine of high molecular weight synthetic compounds of synthetic as well as natural origin. The diversity of polymers, the wide variation in their stereo configuration and molecular weight, the possibility of obtaining composites in various combinations with various substances, all this is the basis for obtaining the widest range of new materials with new valuable properties. At the first stages of application, the role of polymers in medicine was reduced to improving the characteristics of the products used:

- containers of glass replaced with elastic and unbreakable vessels made of polyolefins;
- "non-woven" materials.

At present, polymers receive the widest range of medical devices and devices. This portable equipment for medical and procedural use, clinical equipment and tools, sanitation and hygiene items, medical analytics equipment, artificial organs (kidneys, blood vessels, valves, pacemakers, heart-lung devices, and dental materials, etc.).

Characteristic polymers properties as the main feature of their use in medicine

To date, there are a huge number of polymers used in medicine, but there is no single accepted classification of the polymers used as well as their use in medicine. For example, polymers can be considered in terms of biodegradable [1, 2, 6]. In general, biodegradable natural polymers are classified into: natural polymers of plant origin; natural polymers of animal origin; natural polymers of microbial origin.

In turn, natural polymers of plant origin includes: polysaccharides (cyclodextrins, cellulose, hemicellulose, starch, inulin, pectin, glucontannan, guar gum, arahinogalactan, carragccnan); proteins (soy protein); polyesters (from higher plants).

Natural polymers of animal origin contains: polysaccharides (chitosan, hyaluronan, chondroitin sulphate); proteins (collagen, gelatin, albumin, fibrin, silk fibmin); resin (shellac).

Natural polymers of microbial origin are: polysaccharides (alginate, dextran); polyesters (PHAs); polyamides (poly-y-glutamate); polyanhydrides (polyphosphate).

At the same time, there are classifications of polymers from the view point of the physico-mechanical properties and methods for their preparation, etc.

Nevertheless, polymers are an irreplaceable material in medicine, as they possess a number of properties. Properties of polymeric materials are determined by their chemical structure, macro- and micromolecular structure. The study of the basic polymers properties is carried out using a complex of physical and physico-chemical methods, including spectroscopy, X-ray diffraction analysis, differential thermal analysis, electron microscopy, etc.

Any material intended for biomedical purposes must first of all be characterized by harmlessness to the body and functionality. The complex of necessary mechanically-physical and biocompatible properties that polymers of medical purpose must possess varies quite widely depending on the specific functions or material, the place of its implantation, the service life, etc. [9]. In relation to the body, for example, the implantable material must meet the following basic requirements: not to cause poisoning of the body and not to be an allergen, not to injure living tissue, not to be carcinogenic, do not cause antigenic action, do not cause destruction and decomposition of proteins and enzymes, do not disturb electrolyte balance, do not cause abnormalities in metabolic systems.

The most important characteristics of polymers are the molecular weight and the degree of polymerisability. Polymerization reactions lead to the distribution of chain lengths in the polymer and to the distribution of molar mass (M_W). The value of the polymer average molecular weight is determined by the method by which the molecules are counted [8, 11]:

$$M_n = \Sigma N_i \frac{M_i}{N}, \quad (1)$$

where N_i – number of molecules mass I; N – total number of molecules; M_i – mass of molecules length I.

The weight of the average molar mass of the polymer is found as follows:

$$M_W = \Sigma w_i M_i, \quad (2)$$

where w_i – mass fraction,

$$w_i = \frac{N_i M_i}{\Sigma(N_i M_i)}. \quad (3)$$

The degree of polymerization shows the average number of monomer units per chain. This value can be determined from the view point of the average number, or from the view point of the average weight [8, 11]:

$$N = \frac{M_w}{M_{mer}} = \frac{M_n}{M_{mer}}. \quad (4)$$

Polydispersion [8, 11]:

$$N = \frac{M_w}{M_n}. \quad (5)$$

In relation to products made of polymeric materials used in modern medicine, a number of criteria are necessary for monitoring in terms of their biological safety. In general, the system of corresponding tests includes a series of successive stages, differing in both methods and objects of research [13].

The program of testing medical products according to the standard consists of four stages, each of which includes a specific process:

I stage – characterization and raw materials testing. At this stage, rapid assessment of chemical, physical and biological (cytotoxicity, hemolysis in vitro) before and after technological operations (pressing, extrusion, etc.) is carried out;

II stage – research of biocompatible products components properties with the purpose of an estimation of a separate product components biological safety;

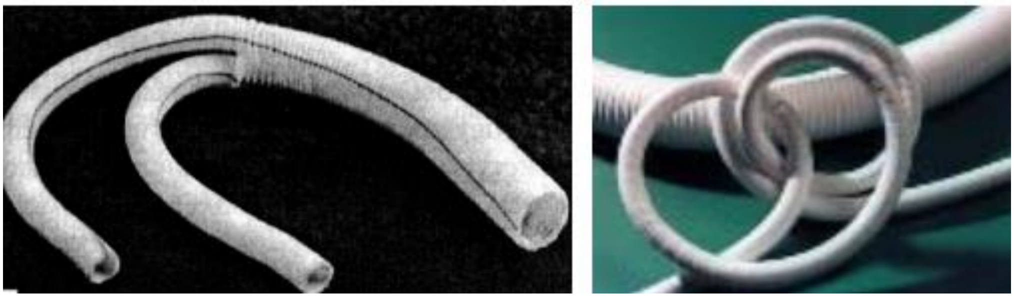
III stage – an estimation of quality and efficiency of the control on manufacture. Certification of industrial premises is carried out (control system of initial raw materials and final product is estimated);

IV stage – quality control of the final product. It is necessary to check the raw materials and the final product for compliance with the passport data and the required medical and technical properties.

Typical applications of polymeric materials in medicine

Today the development of new medical materials intended for contact with the environment of a living organism is a high complexity task. At the same time, new medical categories are also rapidly and widely disseminated. Therefore, in order to analyze the characteristic fields of polymers application in medicine, it is necessary to start from a generalized classification of medical services. Given this fact, the use of polymers in the following medicine fields is considered promising: cardiology; nephrology; oncology; orthopedic surgery; ophthalmology; dentistry; surgery.

In cardiology, polymers are used as [6, 11]: structural materials for extracorporeal devices (for example, acrylates); heart valves and artificial heart elements (for example, epoxy compounds, polyimides, polysulfones); prostheses of blood vessels, catheter covers (for example, fluorocarbons, polytetrafluoroethylene epoxy compounds) (Figure 1); suture threads (for example, polyamides); structural materials for extracorporeal devices (for example, polycarbonates); catheters, artificial heart (for example, polyurethanes).



a) Denture from the mesh b) corrugated shape prosthesis

Fig-1: Prostheses of blood vessels from polytetrafluorethylene

In nephrology, polymers are used as membranes for hemodialysis (for example, acetate and cellulose hydrate, polyacrylonitrile, polynephron, plexiglas).

In orthopedics, polymers are used as [6, 11]: bone cements (for example, polymethylmethacrylate); bearing surfaces in artificial joints (for example, ultra-high molecular weight polyethylene); artificial arteries (for example, polyethylene terephthalate); finger joints (for example, polypropylene); fastening elements (Figure 2).

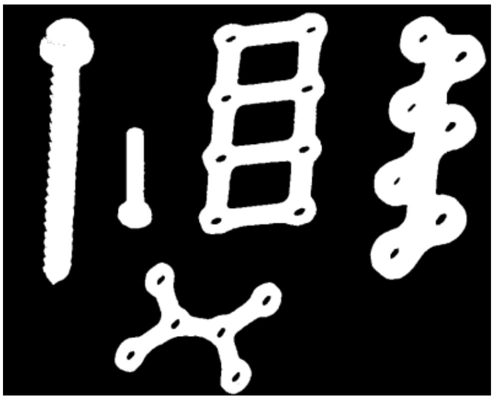


Fig-2: Fastening elements for fixing bone fragments, Made of polylactide and hydroxyapatite

In ophthalmology, polymers are used as [6, 11]: solid contact lenses, intraocular lenses (for example, polymethylmethacrylate); soft contact lenses (for example, polyhydroxylethyl methacrylate). In dentistry, polymers are used as the basis of dentures (for example, polymethylmethacrylate).

In surgery, polymers are used as [6, 11]: implants facial devices (for example, silicone); biodegradable suture material (for example, polyglycolide, polylactide); artificial liver (for example, a synthetic component – a polymeric capsule); an artificial esophagus (for example, a synthetic component – a silicone tube).

At present, a sufficient number of enterprises and organizations are engaged in the development and medical products production. Therefore, in the medical products production, polymer materials are also becoming particularly relevant. Under the broad notion of "medical products" is meant a whole range of objects that it is advisable to structure in the form of a materials number and products. For example, the products include: medical equipment and care items. Medical equipment is a technical means used in the medical-diagnostic process. Medical equipment includes: appliances; apparatuses; equipment; instruments; consumables. The subjects of care for patients include: syringes; medical utensils; mittens; plasters; dressing.

Generalized classification of polymeric materials in medicine

Based on the possible structuring of medical materials and products, the following hierarchy of polymeric materials in medicine can be proposed. Such hierarchy of polymeric materials in medicine is shown in Figure 3.

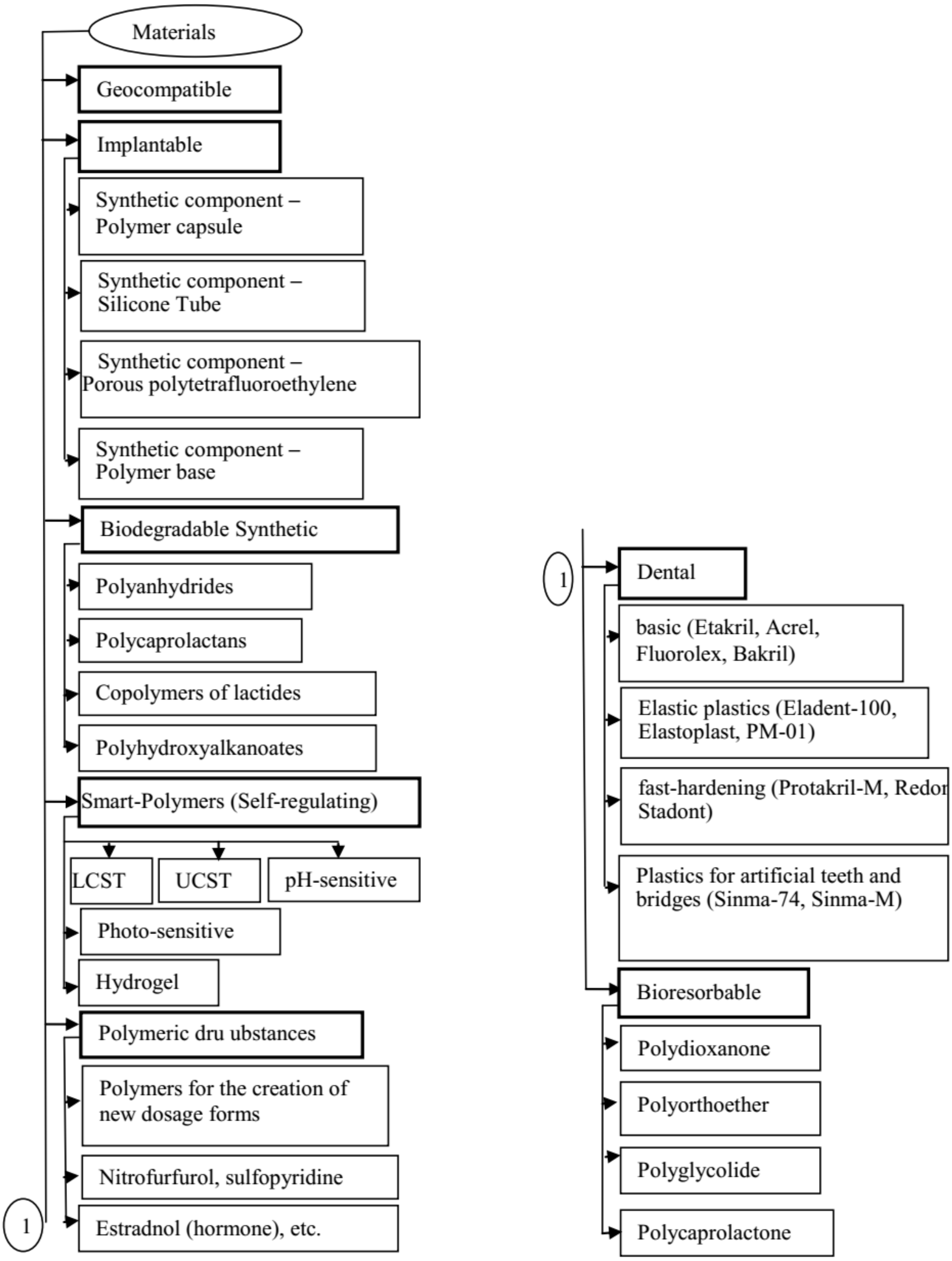


Fig-3: Generalized classification of polymers in medicine

In Figure 3, geocompatible materials are highlighted in the first category, since they are the most important aspect of biomaterials biological compatibility. The requirements for biological properties of materials and products that are intended for contact with blood can be formulated as follows: hemocompatible medical products should not have toxic, allergic and inflammatory effects; activate enzyme systems; to have a negative effect on protein and uniform elements of blood, as well as organs and tissues.

The second material in Figure 3 is implantable materials as the reconstructive technologies to date, the level of science and technology can offer several alternative ways to restore or replace damaged or damaged tissues and organs: transplantation; implantation; tissue engineering.

The third category is biodegradable synthetics – a number of synthetic polymers are exposed to liquids and swell or dissolve. Studies of such materials are most relevant and in demand at the present time. A special and significant problem is the need to create biodegradable materials and capable of simulating the biological structures properties. This is due to the revolutionary changes that are currently taking place in medicine in connection with the emergence and development of new works in the transplantology field and artificial organs, based on a fundamentally new approach to the restoration of vital organs functions.

The fourth category – Smart-polymers or "self-regulating" – is one of the most promising materials in medicine, as "smart" materials or "intelligent" materials belong to the nanomaterials category. The scope of such materials is quite wide. These are transdermal or implantable devices with controlled and controlled output of biologically active substances for drug, cell and gene therapy; products with "shape memory" for orthopedics and cardiovascular surgery; biosensors; biodegradable products for reconstructive surgery; biotechnological devices for separation, purification and identification of biological structures at the molecular and cellular levels, etc. LCST – temperature-sensitive polymers present low critical solution temperature. UCST – upper critical solution temperature [12].

The fifth category – polymeric medicinal substances (pharmacology).

The sixth category is "dental" polymers. These materials, which are based on polymers that are in the period of molding in a viscous or highly elastic, and when used in a glassy or crystalline state.

The seventh category of polymers is bioresorbable polymers. The development and mastery of new materials, in addition to biocompatibility and functionality, as well as in vivo degradability, is a specialized problem that is substantially more complex than the difficulties encountered in the materials construction and systems of long-term and permanent functioning in vivo. The application areas of resorbable materials are quite wide today.

CONCLUSION

As a review result of the polymeric materials use in medicine, it is determined that this is an indispensable material in all fields of medicine.

Based on the modern medical services analysis, the generalized classification elements of medical devices are considered, which will allow determining the basic polymers types used in each of the medical fields. The proposed classification differs from existing ones in that it takes into account "self-regulating" and bioresorbable polymers, since they are modern materials of the latest generation and possess the most important high physical and mechanical characteristics. This in turn makes it possible to determine the main characteristics that affect the quality of medical products. The main trend in the use of polymers in medicine is their physical and mechanical properties.

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