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The Uses of Polymer in Biomedical Application

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Abstract: Nowadays, polymers are rapidly growing in many different fields, as polymers are inexpensive and less dense than metal. Polymers can also be said to be a cheaper material and can form a lighter product compared to other materials. However, many people opposed the use of polymers. It is because most of the polymers are non-biodegradable, as there are no polar bonds within the polymers. The non-biodegradable polymers might lead to plastic waste and bring negative effects on the environment, which involve choking marine wildlife, damaging soil, and poisoning groundwater. Nevertheless, advancements in the technology enable the production of materials with specific attributes, including mechanical strength, regulated degradation duration and rate, as well as antibacterial and antimicrobial qualities. The polymers enable the formation of materials in an infinite variety of shapes due to meticulous design. This article examined diverse literature regarding the application of polymers in medicine. This research identifies numerous applications of polymers in medical fields, including tissue engineering and medical devices.

Keywords: Polymers, biomedical application, tissue engineering, medical devices.

1. Introduction

Numerous fields are advancing rapidly in contemporary times. Among these, the field of biomaterials is paramount due to extensive research conducted on new generations of biomaterials. A biomaterial is a natural or manufactured substance that engages with biological systems for direct medical therapy [1]. Biomaterials are often categorized into three classes: metals, ceramics, and polymers. Polymers exhibit considerable variability in their physical and mechanical properties. The criteria for polymers in biomaterials are clear and mostly focused on patient safety. The criteria encompass the production process, appropriate material selection, and the consequences on and within the body.

To more effectively tackle the numerous challenges in biomaterial design and accelerate advancements, biomaterial scientists have radically altered their research methodology. A paradigm shift has occurred from independent scientists pursuing narrow research aims to collaborative teams addressing broader goals, particularly over the past decade. The integration of specialists specializing in chemistry, biology, materials science, engineering, and clinical practice has accelerated advancements in biomaterials research in recent years [2].

The polymers are widely used in medical applications: tissue engineering and generative medicine, cardiac surgery, dentistry, urology, controlled drug delivery systems and many others [3-7].

In this article, the author attempted to introduce the importance of the use of polymers in biomedical applications. Besides, polymeric bio-materials will also be discussed, since they are

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mainly chosen for the design and construction of scaffolds due to their wide range of properties, availability and lower cost compared to other materials. The content shown in the article is a small part of a very large amount of research around the world.

2. Polymers for tissue engineering

Following tissue injury due to an accident or sickness, complete recovery or immediate access to a donor may not always be feasible. Tissue engineering involves the utilization of engineering, medical, and physiological concepts to create novel tissues that mimic the functions and features of organic tissues, serving as substitutes for implantation to replace, repair, or enhance organ functionality. The fundamental categories of biomaterials utilized in tissue engineering can be roughly categorized as synthetic polymers, encompassing somewhat hydrophobic substances, naturally derived polymers, and inorganic materials. They are selected for scaffold design and construction because of their diverse features, accessibility, and affordability.

2.1. Polyglycolic acid (PGA)

PGA is a biodegradable thermoplastic polymer and the most basic linear aliphatic polyester. PGA is a hard substance with great crystallinity, rendering it insoluble in most organic solvents. PGA and its copolymers are extensively utilized in medical applications. Tissue engineering scaffolds composed of PGA are utilized in medical applications. A multitude of investigations have been conducted with PGA nanofibres in the domain of tissue engineering [8]. Kobayashi et al. have synthesized a nanocomposite by integrating PGA and collagen. Their findings on animal models demonstrated that the nanocomposites were fully populated and vascularized within five days post-implantation [9]. Patrascu et al. utilized PGA and hyaluronan to fabricate scaffolds that promote cartilage regeneration [10]. The mesenchymal stem cells were cultured on the scaffold. The results indicated that mesenchymal stem cell proliferation and differentiation were effective, hence demonstrating the scaffold's suitability for cartilage regeneration.

2.2. Polylactic acid (PLA)

PLA is a thermoplastic polymer made from sustainable organic materials, including corn starch and sugar cane. The utilization of biomass resources distinguishes PLA production from the majority of plastics, which are manufactured from fossil fuels via the distillation and polymerization of petroleum. Additionally, PLA is both biodegradable and bioabsorbable. PLA can be synthesized from lactide using ring-opening polymerization. PLA is commonly utilized in a diverse array of consumer products, including disposable dinnerware, cutlery, and casings for kitchen appliances and electronic equipment including as laptops and handheld gadgets. Nonetheless, PLA is applicable in medical contexts. Chang examines one of the applications of PLA in the medical field. In his research, PLA has been utilized as a semipermeable microcapsule for encapsulating hormones, vaccines, enzymes, and various biological products. PLA is biodegradable and generates harmless metabolites within the body upon degradation. Consequently, PLA functions as a semipermeable microcapsule. Conversely, PLA is utilized as a biodegradable and biocompatible substance in the field of tissue engineering. Hao-Yang Mi and colleagues fabricated composite scaffolds for tissue engineering using polylactic acid (PLA) and thermoplastic polyurethane (TPU) in varying proportions. Their findings demonstrated that the nanocomposite had a rough surface, biocompatibility, and mechanical qualities. These characteristics indicate that the nanocomposite may serve as synthetic scaffolds in the field of tissue engineering [11]. In a separate investigation within tissue engineering, Lin et al. synthesized hydroxyapatite (HA) calcified on chitosan-coated PLA nanofibers for osseous regeneration. The results indicated that this composite possesses analogous combinations, as well as structural and biological activities, to those of real bone. Consequently, this composite may serve as an excellent option for bone regeneration [12]. These results indicate that PLA can serve as scaffolds for bone and other tissue regeneration.

2.3. Polycaprolactone (PCL)

PCL is a biodegradable and biocompatible polyester characterized by a low melting point. PCL is a synthetic thermoplastic polyester utilized in biomedical applications such as sutures and medication delivery systems. PCL is utilized in dental splints, medical implants, and tissue engineering. Zheng R et al. have fabricated electrospun membranes with varying proportions of gelatin (GT) and polycaprolactone (PCL). The results indicate that three types of membranes, characterized by different GT and PCL ratios, exhibit biocompatibility with chondrocytes. The findings indicate that the membrane with a high PCL ratio was detrimental to 3D cartilage formation. Studies indicate that electrospun GT and PCL are promising candidates for cartilage and other tissue regeneration [13]. Uma Mateshwari et al. developed a polymer-ceramic bilayer nanocomposite scaffold utilizing electrospun polyvinyl alcohol (PVA) and PCL bilayer nanofibers incorporated with hydroxyapatite nanoparticles for bone regeneration [14]. The results indicate that the nanofibers serve as biocompatible scaffolds for applications in bone tissue engineering. These investigations demonstrated that PCL is a biocompatible scaffold suitable for cartilage and bone regeneration.

2.4. Poly (lactic-co-glycolic acid)

Poly(lactic-co-glycolic acid), commonly referred to as PLGA, is a copolymer utilized in numerous Food and Drug Administration (FDA) approved medicinal devices, due to its biodegradability and biocompatibility. PLGA is produced through the ring-opening copolymerization of two distinct monomers, specifically the cyclic dimers of glycolic acid and lactic acid. PLGA is utilized in tissue engineering. Junmin Qian and colleagues produced PLGA and nano-hydroxyapatite (nHA) scaffolds. The findings indicate that the crystallinity of PLGA diminishes in the presence of nHA. The findings also indicate a substantial improvement in the compaction modulus of biomorphic scaffolds. PLGA and nHA nanocomposites are advantageous for bone tissue engineering [15].

3. Polymers for medical devices

The advancement of plastics during the 1930s, 1940s, and 1950s facilitated the creation of medical gadgets that supplanted traditional materials with superior alternatives such as polyvinyl chloride (PVC) for tubing and polyolefin for trays and bottles. The majority of polymers utilized in medical applications are thermoplastic and thermosetting polymers. These polymers have supplanted metal and glass in medical applications. Nonetheless, there exists a paramount rationale for the use of these polymers in medicinal applications. These polymers exhibit significant adaptability, facilitating the design and production of a wide array of products to satisfy diverse application needs.

3.1. Poly Vinyl Alcohol (PVA)

PVA is utilized in medical devices due to its biocompatibility, swelling qualities, nontoxicity, and bioadhesive attributes. PVA composites, including PVA gels, are utilized in artificial heart surgery, wound dressings, and medication delivery systems. Additionally, PVA is applicable in three-dimensional (3D) printing. 3D printing is the fabrication of a three-dimensional object derived from a computer-aided design (CAD) model or a digital model. The 3D printed product is composed of PVA. PVA is utilized in 3D printing due to its soft, biodegradable nature and great sensitivity to moisture. PVA dissolves upon exposure to water. PVA serves as an exceptionally beneficial support material for 3D printing.

3.2. Poly vinyl chloride (PVC)

PVC is a crucial polymer utilized in various applications, from packaging toys to medical gadgets. PVC is available in both rigid and flexible variants. Rigid PVC is utilized in the fabrication of doors and windows, as well as in the production of plastic bottles and packaging materials. The incorporation of plasticizers renders PVC more pliable and flexible. Soft PVC is applicable in plumbing, electrical wire insulation, and inflatable items. Nonetheless, PVC is utilized in medical gadgets, such as flexible containers and tubing. Flexible containers, encompassing blood, urine, osmotic products, and intravenous solution administration sets. PVC's superior water and chemical resistance contributes to the maintenance of solution sterility. PVC is the sole material capable of fulfilling the specifications for blood bags, which include a minimum storage duration of 42 days for red blood cells. Moreover, standard specifications for medical tubing encompass transparency, flexibility, resistance to kinking and scratching, durability, and compatibility with sterilization processes. Researchers attempted to utilize alternative thermoplastics as substitutes for PVC; however, none have succeeded in replicating the performance and benefits offered by PVC. Specifically, achieving the optimal equilibrium between kink resistance and cost-effectiveness in PVC medical tubing [16].

3.3. Polycarbonate (PC)

Polycarbonate is a transparent thermoplastic. Its considerable strength renders it resistant to impact and fracture. Its lightweight nature makes it a great substitute for glass. Polycarbonate is melted and subjected to high pressure within a mold to achieve the required shape, hence providing design flexibility. The primary rationale for the utilization of polycarbonate in medical devices is its ability to endure gamma radiation, hence enabling the effective sterilization of medical housings and equipment to safeguard patient health. PC is utilized in the neonatal unit as well. A transparent, lightweight polycarbonate shield serves as a protective barrier for infants in incubators, enabling medical staff to monitor their condition effectively. Polycarbonate (PC) can offer durable, transparent material for the exterior of the incubator, as well as the housing for heating lamps and their supporting framework [17]. Additionally, PC is utilized in pharmaceuticals and medical, particularly in the manufacture of drug-delivery systems due to its ease of sterilization and durability. PC offers essential advantages by enabling devices like medical injection pumps to operate evenly and consistently, allowing patients to self-administer drugs with precise dose. These pumps are capable of administering several medications, including chemotherapy, analgesics, and antibiotics, and must be robust enough to endure daily use and occasional drops.

4. Discussion

The emergence of polymers helped a lot in the field of medical applications, thanks to their versatile properties and capacity to be engineered for specific functions. These synthetic or natural polymers are now integral to various medical applications, from tissue engineering to medical devices, and their role continues to expand as technology and material science are still progressing.

Polymers are prominently utilized in the medical profession for tissue engineering, serving as essential scaffolding materials that facilitate cell proliferation and tissue regeneration. Biocompatible polymers, like polycaprolactone (PCL) and polylactic acid (PLA), are utilized to fabricate structures that replicate the extracellular matrix, offering a scaffold for tissue regeneration. These materials are

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designed to be biodegradable, allowing for their gradual substitution by natural tissues during the healing process.

Medical devices have also benefited from the advancement of polymer technology. Polymers like polycarbonate (PC) are used in safety barriers as it is rigid and strong enough to protect infants in incubators. Polyvinyl chloride (PVC) is also used in medical devices like flexible containers or flexible tubing because PVC has excellent water and chemical resistance, thus it can ensure the solution is sterile.

Despite these advancements, challenges remain in the development of medical polymers. Ensuring long-term biocompatibility and preventing the body's immune response are ongoing concerns. Researchers are also exploring the development of smart polymers that can respond to environmental stimuli, such as pH or temperature changes, opening new possibilities for personalized medicine.

5. Conclusion

Numerous types of polymers are currently used in medical applications. Currently, various polymer-based medical devices have received approval for clinical testing. This article exclusively examines certain polymers and their particular applications. Numerous more polymers are utilized in various domains.

At the same time, selecting a good polymer used in medical applications is critical, as the polymeric composite must fulfill the requirement and has special properties in their own areas. For instance, some polymers are biocompatibility and non-toxic, and some can form material which is flexible and chemical resistant. This is why many scientists are searching for new polymers that can promote their functions in specific areas.

Notwithstanding significant progress in this field, researchers continue to encounter numerous challenges and inquiries, prompting ongoing endeavors to enhance the application of polymers in medicine. For instance, efforts are focused on augmenting the mechanical properties of scaffolds to elevate the success rate of commercial and clinical trials. Attaining this objective necessitates extensive scientific investigation and sustained interdisciplinary collaboration.

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