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Review

Applications of biopolymer coatings in biomedical engineering

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Abstract

In this paper, a comprehensive overview of recent developments in the many different types of biopolymer coatings used in biomedical applications is presented. Biopolymer coatings have tremendous promise in various biological applications due to their adaptability. Polymer coatings may be used to improve surface qualities to fulfill certain criteria or to include extra capabilities for various biomedical applications. This analysis focuses mostly on certain polymers for usage in coating applications as well as a variety of polymer coatings that provide enhanced functionalization. The most recent findings from relevant research have been presented on using polymer coatings on nanoparticles for biological applications. Moreover, the latest research on biopolymer coatings for improved tissue engineering and drug delivery on various substrates and nanoparticles has been reported. Additionally, the most recent scientific breakthroughs have been compiled.

Keywords
Coatings methods; biomedical implants; tissue engineering

Introduction

Polymer coatings are gaining popularity in several industrial pplications and market areas across the world [1,2]. These polymer coatings provide powerful functions to the materials they are applied to, whether they are straightforward coatings or nanoparticle-incorporated, functionalized composite coatings. It has potential applications in a wide range of materials, including metals, ceramics, polymers, and nanoparticles, among others [3-10]. In the realm of biomedicine, polymeric coatings play an important part in the development of the future generation of biomaterials and equipment. They have a number of potential applications, including resistance to corrosion [7,8,11-13], functionalization of the surface [1,2], resistance to wear [14–20], enhancement of bioactivity [3,21,22], and even potential usage as switchable smart materials. The most recent development in the field of polymer coatings is the use of smart polymer coatings. According to a number of studies, polymers are intelligent and have the capacity to react in response to a wide variety of stimuli [23]. These stimuli include pH, temperature, electric field, light, and magnetic field. In the realm of medicine, the most common application for smart polymers is in drug delivery applications. In these applications, the pharmaceuticals may be loaded into the polymer coatings. Thus, they can be given at the desired site in response to an external stimulus. In addition, shape memory polymers are becoming increasingly popular and are emerging as potentially useful candidates for use in bone tissue engineering.

In tissue engineering, it is essential to supply suitable biointerfaces, comprehend the mechanism by which these biointerfaces integrate with tissues, and exercise control over the features of these biointerfaces [24-29]. This control is of utmost significance in the process of developing new methods for the delivery of drugs or biomolecules. It is possible to control over the delivery system by utilizing the appropriate mixtures of bioactive compounds and polymers. The significance of polymer matrices in hybrid biomaterials has come to be recognized over the course of the last few decades. This is due to the vast number of currently available options, which range from synthetic to natural biopolymers and possess desirable characteristics such as adaptability, biodegradability, mechanical properties that can be altered, bioactivity, and low toxicity. In addition, polymeric hybrid materials may be manufactured as "smart" materials, which means that functionality can be achieved utilizing them by responding to either physical, chemical, or biological stimuli. This can be done in a variety of ways [30,31].

However, the inquiry in tissue engineering incorporates elements of materials science, engineering, chemistry, biology, and medicine; as a result, this area of study may be categorized as an interdisciplinary subfield within the realm of scientific research [32]. There is not much room for adult tissue to regenerate when it has been damaged or has degenerated due to disease. Despite the fact that encouraging outcomes have been found in a few laboratory experiments, there has not been much progress made in clinical trials due to a number of obstacles. Therefore, in the field of tissue engineering, the most important principles for the creation of innovative materials are biointerface optimization and their incorporation with the tissues to which they belong and supremacy over the features of those tissues. There is a vast selection of polymers that are suitable for use in biomedical applications, and a variety of methods may be utilized to incorporate polymers into medical implants and devices. Applications for synthetic biodegradable polymers may be found in a variety of subfields within the biomedical industry. Biopolymers have favorable characteristics in terms of their bioactivity, bioresorbability, and lack of toxicity. To improve the usability of biopolymers in a variety of medical procedures and to enhance their usage as auspicious and diverse materials for coatings in biomedical applications, it is necessary to have a comprehensive grasp of the structure and characteristics of biopolymers.

The production of the composite with different types of polymers or inorganic compounds is yet another fascinating property of polymer coatings. The creation of composite materials based on polymers is one of the primary techniques that are being taken to resolve the issues related to the use of polymers in biomedical applications. Blending the polymers with other materials allows for the creation of substances with well-balanced physical, chemical, and biological characteristics. As a result of the development of nanotechnology, the insertion of nanoparticles into polymer basis materials has been shown to result in better functional features. In drug delivery, polymer-based nanocarriers show a lot of promise due to their capacity for encapsulating pharmaceuticals, controlled distribution, sustained release, and bioactivity [9]. Additionally, these nanocarriers are relatively easy to manufacture. Polymer nanocomposites can be created for a wide range of applications if formulated with the right nanofillers.

The purpose of the above literature is to provide an outline of the most recent developments in coatings and their applications in a number of biological sectors, to highlight the most significant findings in the survey, and to provide an overview of upcoming developments and perspectives. At first, a high-level review of the various polymer coatings and the processes used to create them is provided. Next, a concise review of the research pertaining to polymer coatings on metal surfaces is presented. In addition, several biopolymer coatings of varying types and their applications in biomedical domains are broken down individually.

Biopolymer coatings

Polymer coatings that contain a variety of inorganic ions have the potential to facilitate a variety of functionalities, like tissue development and repair, as well as cell generation and the transport of biomolecules. Growth factors, active compounds, antibacterial agents, and medicines are all included in this category. The process of the polymer coating is one method for changing the surface properties of an object in order to fulfill the criteria of a variety of different practical applications. It is a coating or paint that is made utilizing polymers that have superior qualities to those already available. Polymer coatings have found usage in a variety of applications, including adhesion, resistance to scratching and abrasion, resistance to corrosion, wettability, and bioactivity. It is generally agreed that polymer coatings are of great value in the field of biomedical applications. Because polymer coatings allow for a wide range of chemical groups to be bonded to surfaces, they are ideal for interactions between biomaterials and tissues. This is owing to their flexibility. In addition, the mechanical and elastic characteristics of these materials are quite similar to those of biological tissues. For the purpose of producing polymer coatings suitable for a variety of purposes, a number of alternative technologies have been developed and put into practice. A careful selection of the material, coating processes, and manufacturing conditions can result in the creation of coatings that are not only highly effective but also possess advanced characteristics. As a result of polymers' low hydrophobicity and small surface area, these materials have poor bioactivity and cannot be used in implants. This is one of the reasons why polymers are often used in composites instead of metals. Polymer-coated implants, on the other hand, can create biomimetic body surfaces [1,2]. Additionally, nanoparticles can be coated with polymers so that biomolecules and drugs can be transported more efficiently. Both the hardness adjustment and the component distribution processes can benefit from the use of polymer coatings.

Metal surfaces that have been coated with organic layers provide a variety of innovative properties that have a significant potential for usage in a number of different industrial applications. This method enables the modification of a wide variety of qualities, including elasticity, wettability, bioactivity, and adhesiveness [33]. Implants may be coated with biodegradable polymer coatings to prevent corrosion after implantation [1]. Liu and colleagues [34] used poly(2-methyl-2-oxazoline) to coat SS316L and improve its antimicrobial and corrosion resistance. Even though poly(2-methyl-2-oxazoline) has a low molecular weight and moderate hydrolysis, it has been shown to exhibit bioactivity and antifouling properties. In addition, they found that these coatings induced cell migration and proliferation, which bolstered their conclusions. Coatings are capable of changing the surface of 3D vascular stents, which might be useful in preventing late clotting and in-stent exacerbations [34]. Gnedenkov *et al.* [35] performed a super dispersed PTFE (polytetrafluoroethylene) treated polymer coatings on the magnesium alloy MA8 using a plasma electrolytic oxidation (PEO) technique. They found that the protective and antifriction properties of magnesium alloy surfaces were improved after this coating. In addition, the authors came to the conclusion that the increased thickness of this coating may be attributed to the SPTFE treatment that was performed on the PEO coating. A similar PEO-based approach was described by the same group for the preparation of hydroxyapatite-PTFE composite coating on the substrates of Mg–Mn–Ce alloys to be used in resorbable implants [36].

The elemental content, phase, shape, and multifunctional deterioration resistance of the different composites and coatings were described in this work, and it was proven that these characteristics confer bioactivity to magnesium implants. For magnesium's corrosion resistance and degradation time, Oosterbeek *et al.* [21] used polymer-bioceramics composite coatings as the first step in their research. The composite coating was created by a procedure consisting of two stages: first, a bioceramics coating was applied through immersion in the supersaturated $Ca_3(PO_4)_2$ solution. It was coated by $(C_3H_4O_2)_n$ coating utilizing a dip coating technique. They reported that coating developed through a hybrid technique exhibited stronger bonding strength and corrosion resistance than the polymer-bioceramics composite coating. This was the case despite the fact that both coatings were composed of the same material.

Researchers used calcium phosphate/collagen (CaP/Col) composite coatings to effectively increase the corrosion resistance and biological characteristics of Mg alloys for implant applications [37]. The CaP/Col coating was able to successfully slow down the pace at which magnesium alloys degraded, and it also enhanced osteoblast adhesion in the ideal microenvironment and interface that was produced.

Biopolymer coating methods

The literature provides a prosperity of information on the many different biopolymer coating materials that are currently accessible. Due to the fact that this analysis concentrates solely on polymer coatings, this part will offer a concise discussion of some of the most common coating processes that are utilized for biopolymer coatings. Layer by layer (LBL) [1,2], Langmuir-Blodgett (LB) [2,38,39], dip coatings, plasma-based coating technologies, polymer brushes, spin coatings, and hydrogels are some of the other ways that may be used to assemble polymer into coatings and films. During the LBL process, successive coatings of polyelectrolytes are applied that are positively and negatively charged. Producing LBL film and coatings requires the use of a variety of charged polyelectrolytes, all readily accessible. The versatility of the LBL method in terms of the production of polymer coatings is perhaps its most significant benefit [2,38]. Recent research conducted by Landry and colleagues examined the use of self-assembled layers and multilayer polymer coatings in tissue engineering applications [1]. Polymer brush is yet another common and fascinating technology for surface modification. In this method, a pliable substance is covalently anchored to the surface of the substrate [40], and the technique has the potential to be applied in a variety of different disciplines. Several researchers from a variety of institutions have analyzed the uses of polymer brushes in the biological sector [40-42]. Plasma-based polymer coatings offer excellent adherence to several substrates, including metals and ceramics. In addition, these plasma coatings make it possible to cover even intricate objects. Researchers from various institutions explored plasma-based polymer coatings and presented their findings [43]. In a similar fashion, polymer coatings may be applied using a wide variety of alternative processes, such as dipping or spinning. These procedures are easy to follow and economical, and the coating parameters may be modified with relative ease. A polymer coating solution is dipped into a substrate, then left in the solution for some time to allow the substrate to absorb the polymer molecules and complete the coating process. This technique is known as a dip coating. When that is complete, the substrate is removed from the solution and allowed to dry. This method of dip coating is capable of producing consistent coatings on even very large substrates. Several variables, including the viscosity of the solution, speed of drawing, dipping time, and exposed environment, are taken into consideration. During the process known as spin coating, the injection of a polymer solution is done in the middle of the stationary or slowly rotating substrate using the dropwise method. After that, the speed at which the substrate is being rotated is sped up to a high value in order to promote the uniform dispersion of the polymer solutions throughout the substrates by utilizing the synergistic effects of centrifugal force and surface tension. The rotating speed, the viscosity, and the surface tension all contributed to achieving the desired coating thickness here. Song *et al.* [44] conducted a review very recently on a variety of coating processes based on biopolymers.

Different types of biopolymer coatings

Polyurethane (PU)

PU is only employed in a tiny proportion of the synthetic polymers used in medical applications, despite its applicability in a wide variety of sectors. There are important applications for PU coatings in a variety of sectors, including biological applications. Its primary use is in the medical industry, namely in the production of breast implant coatings, vascular devices, and pacemaker leads coatings. If the bio-PU is to be used in an implantable or non-implantable biomedical application (such as in Figure 1), its chemical structure, final form, and shape must be tailored to suit the specific needs of the application. Recent years have seen a surge in interest in polyurethane (PU) as a result of its bioactivity, biodegradability, and adaptability in terms of both its physical and chemical forms. In addition, its physicochemical and mechano-chemical properties are similar to real tissues [45,46].

PUs are made up of a series of hard and soft segments that alternate with one another (HS and SS). Stainless steels have an elastomeric quality, but the HS provides increased tensile strength due to the presence of hydrogen bonds within the urethane links [47,48]. Polyurethane's biodegradability, physical and chemical properties might be altered by changing the SS and HS ratio, the mix of chemicals, and the molar weight of PU [45,49]. Adding isopropyl myristate to polyurethane (PU) boosted its water resistance and bioactivity, but decreased its hydrophobicity, in another study [50]. This modification resulted in PU having a different chemical structure. The modified PU demonstrated much-decreased water permeability compared to the silicon packing materials already on the market. It is possible that this might be used as a suitable material for electronic implants. Roohpour *et al.* [51] synthesized bacterial resistance-PU coatings for medical device components. This was accomplished by encapsulating silver lactate and sulfadiazine in a polymer to prevent the growth of microbial films.

3D printing has recently been used to produce PUs for medical implants and equipment. Barrioni *et al.* [45] successfully produced new biodegradable catalyst-free PU films. Poly(caprolactone) triol and poly(ethylene glycol) (PEG) (lower mol.%) were combined to make an HS, while hexamethylene diisocyanate and glycerol were combined to create an SS. Both of these substances were used. In a similar vein, Wendels *et al.* [52] reported an overview of bio-PU for use in the biomedical field. In addition to conventional coatings, it has been shown that electrospun nanocomposite fibers based on polyurethane and graphene may boost electroconductivity, bioactivity, and mechanical qualities [53]. In more recent times, Non-isocyanate polyurethane (NIPU) fibers have also been effectively electrospun into a fibrous mat [52].

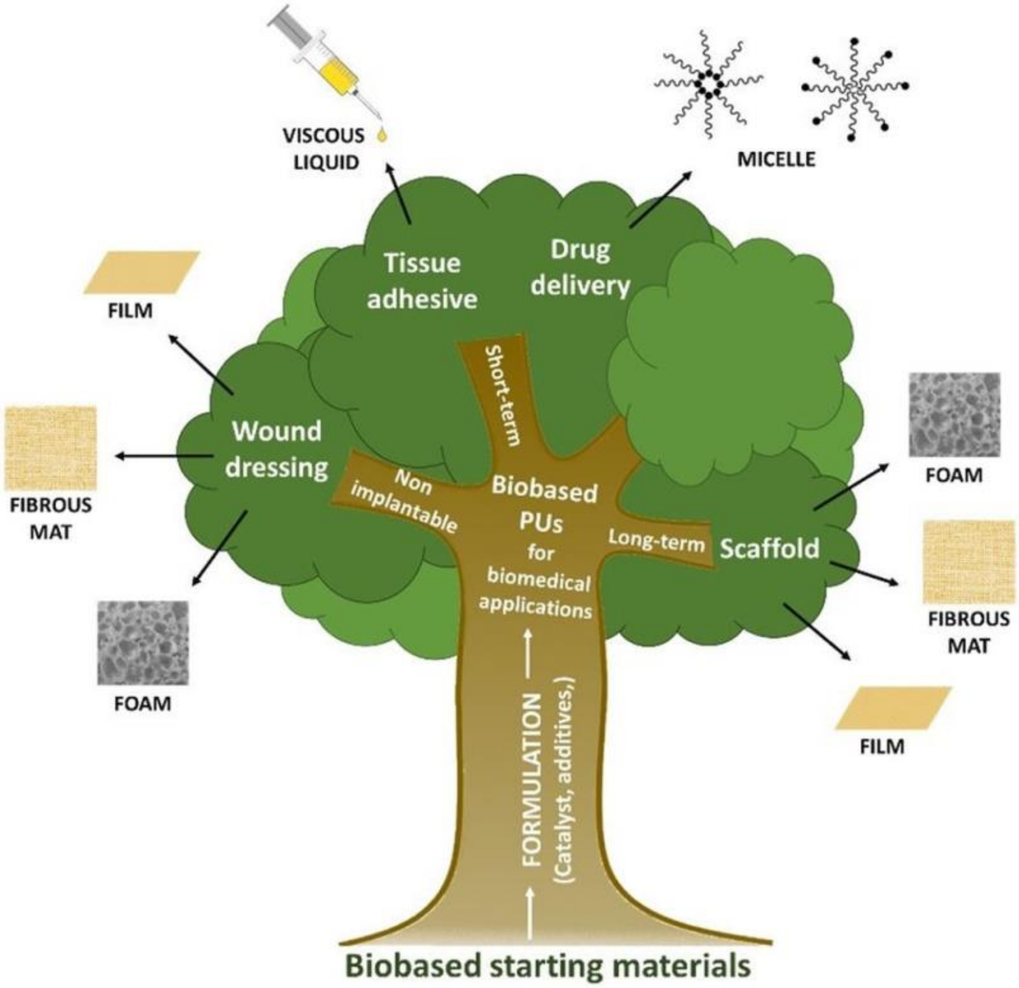

Figure 1. *Diagnostic equipment that makes use of polyurethane (PU) and biodegradable materials* [52]. *Permissions under Attribution 4.0 International (CC BY 4.0)*

The film-forming capability of the biodegradable polyurethanes that were produced and included functional chain extender PEG chains (GPU) and zwitterion PU was rather impressive [54]. The biodegradable Mg substrates may be coated with the GPUs and ZPUs utilizing the dip-coating procedure, which results in a continuous 4-micron thick homogeneous and non-porous coating. Adding GPU and zwitterion PU facilitates the improvement of the antibacterial adhesion characteristic of GPUs and ZPUs' coating, as expected. This is particularly notable [54]. Both of these characteristics are obviously advantageous to the magnesium implant materials. The cell cytotoxicity seen with the polyurethane materials used in this research may be easily remedied by constructing the polyurethanes without using any catalyst in the synthesis operations. It is well recognized that *P. aeruginosa* is a prevalent pathogenic bacteria in nosocomial infections and is particularly difficult to treat, mostly due to its powerful capacity to mutate [54]. There are fewer bacteria seen on GPU and ZPU surfaces when compared to the control group and PU-0, indicating that the functionalized polyurethanes may also limit *P. aeruginosa* attachment to surfaces. *P. aeruginosa* has a harder time adhering to PUs surfaces that have a higher content of PEG or zwitterion. This is mostly due to the hydration barriers generated by the PEG chain or the zwitterion group(s). *P. aeruginosa* is less likely to adhere to PU surfaces rich in PEG or zwitterion content. Similar types of results were found for dimethylolpropionic acid (DMPA) and L-Arg modified polyurethane by other researchers [55], as seen in Figure 2.

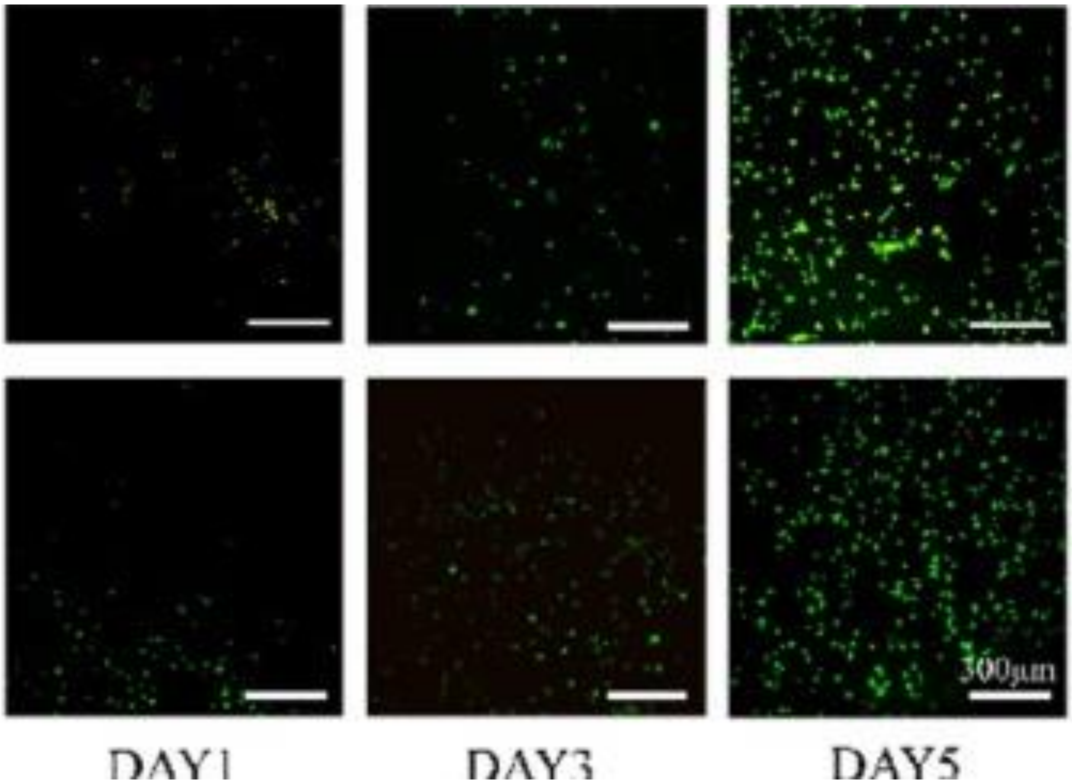

Figure 2. *Fluorescence micrographs of NHDF with live cells staining following proliferation on surfaces with DLPU and G-DLPU3 (DLPU and GelMA i.e. porous modified gelatin)* [55]*. Permissions under Attribution 4.0 International (CC BY 4.0)*

Polyvinylidene fluoride (PVDF)

PVDF is a kind of polymer that is intensively researched due to its widespread usage in medical applications. It is an extremely non-reactive thermoplastic fluoropolymer and offers improved biological, textile, and piezoelectric characteristics [56,57]. Additionally, it is a thermoplastic fluoropolymer. Non-reactivity is necessary for the fabrication of surgical meshes and sutures, yet piezoelectricity is essential for wound-healing applications. As a result, this material is regarded as being appropriate for many biomedical applications, such as tissue engineering [24-29], detection of physiological signals [58-62], and the production of antibacterial and antifouling materials [63-68]. PVDF does not generate smoother films and problems of being adhesive with other substrates, which makes it challenging to employ in the production of coatings for use in the biomedical industry. Researchers have shown that using PVDF and its copolymers as the coating material results in successful coatings through the spin coating and Langmuir–Blodgett (LB) processes. A literature review by Yin *et al.* [69] was undertaken to examine the research that reported on the use of PVDF and its copolymer coatings by spin coating and layer-by-layer methods, respectively.

According to the findings of a number of researches [63-65,68], combining PVDF with other materials may result in composite materials that offer the benefits of both the individual and combined materials. Heart rate monitoring devices using wireless real-time pressure sensors include ZnO Nano-needles + PVDF films. These sensors are anticipated to be commercially available in the future [58]. Trung *et al.* [70] developed a temperature-sensing material that is quite similar to the one described above; it has good thermal conductivity as well as stability and repeatability.

In recent years, there have been just a few reports on their biological uses. According to recent findings, a piezoelectric sensor with polyaniline-coated PVDF natural fiber (NF) mats and piezoelectrically aligned PVDF nanofiber may operate independently of external power sources [71]. For assessing the health of people, this sensor turned mechanical energy into electrical power. It was very sensitive to the touch of a human finger (10 V under 10 kPa). For example, electrospinning PVDF and its copolymers and composites with a wide range of nanomaterials may be used to make use of the advantages afforded by both materials. Applications relating to energy harvesting and environmental remediation make up the vast majority of uses for these composites [72-75].

Polypropylene (PP)

The use of polypropylene in medical applications has become more common, particularly as a surgical mesh to reinforce damaged tissues. Polypropylene polymers are thermoplastics that come in a variety of densities and have the ability to be broken down into their constituent copolymer and homopolymer parts. Although it is low in weight, it has a unique set of features, including inertness, waterborne properties, and exceptional mechanical capabilities [76], PP mesh has found widespread use in the area of biomedicine, particularly in the fields of urogynecology [32] and hernia repair [76]. It also has uses in other fields of medicine, such as the restoration of breast tissue or as a blood oxygenator membrane and supporting soft tissue structure. In addition, research has shown that it has minimal potential for causing cancer in human bodies [77].

However, its usage is also connected with a number of potential problems, such as the creation of infections and inflammatory reactions inside the body, which may result in a prolonged process of healing, limited medication absorption, and an inadequate response from the immune system. Because of its high hydrophobicity, it may sometimes have negative effects on the human body, such as tissue damage and insertion resistance. These consequences can be expected. Therefore, despite the fact that PP is an excellent material, its use is restricted because of its low biological qualities it has. Because of this, a surface treatment that enhances PP's bioactivity is required before it can be used in medicinal applications inside the human body. Steinmetz *et al.* [78] used UV curing to apply cross-linked poly(styryl bisphosphonate) (poly(StBP))-6 thin coatings on corona-treated PP films for tissue engineering in bones. The coatings had thicknesses of 163±8 and 175±7 nm. The first step included the preparation of poly(StBP) nanoparticles, which were then combined with poly(ethylene glycol) dimethacrylate and a photo-initiator. After that, PP film coating was done on them and UV light was used to cure them. Because poly(StBP) has a significant affinity for calcium ions, scientists noticed that the poly(StBP) nanoparticle-enhanced coating encouraged apatite crystal formation [78]. This was due to the fact that poly(StBP) was embedded inside the coating. In addition to these qualities, the coating had optical characteristics and was long-lasting. According to scientists, this coating approach can potentially be beneficial in various applications involving bone tissue engineering. A typical BT *i.e.* barium titanate BT piezoelectric ceramic coating was used to improve the bioactivity of MC3T3-E1 cells on titanium alloy, as shown in Figure 3 [79].

Polydimethylsiloxane (PDMS)

Bioactivity, increased adaptability, simplicity of manufacturing and features like oxygen permeability, optical clarity and low toxicity are just some of the many advantages this material offers [30,31]. Many biomedical devices rely on synthetic materials like PDMS, which is utilized in various applications like surgical implants and catheters as well as biosensors [78]. It is also used in drug delivery and DNA sequencing. In addition, it is an excellent organ-on-chip substrate that may be utilized to investigate the behavior of stem cells [80]. Figure 4 shows the cytotoxicity of human mesenchymal stem cell (hMSCs) grown on aligned and flat PDMS substrates by live dead staining [81]. Because of its properties, this material is an excellent option for the investigation of cell activities, including mechanical and electrical stimulations, as well as topographical and stretching, which are all necessary for the development of materials for use in tissue engineering applications [30]. A typical polymerization process of PU-modified PDMS coating was performed in the study [82]. PDMS only has a limited ability to interact with cells, which means that the surface features of the material need to be modified to attain the attributes sought [82]. To change the surface of PDMS in a manner similar to that of PP, plasma treatments may be used to bring about the formation of hydroxyl groups. Modifying the surface of the PDMS with a composite made of PDA and hyaluronic acid (HA/PDA) led to the development of a material with improved hemocompatibility that may be used in medical implants or devices [83].

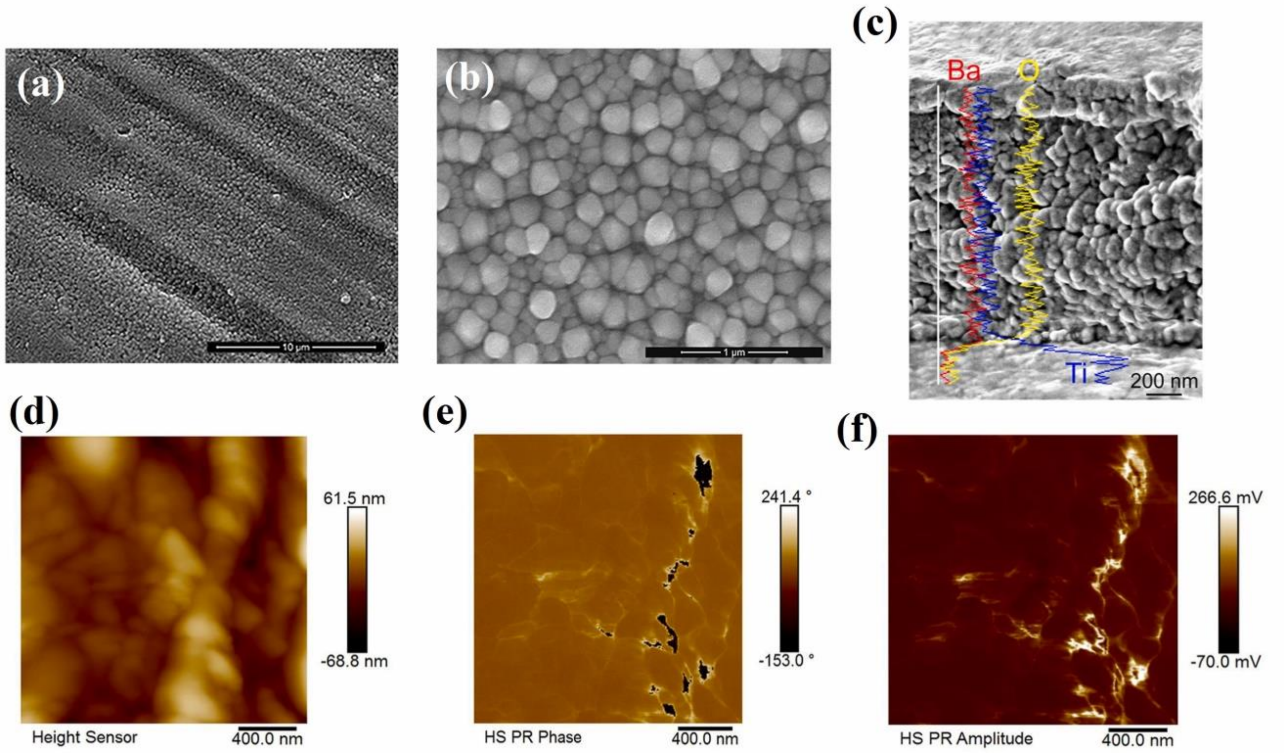

Figure 3. *BT coating characteristics.* ***(a, b)*** *Surface SEM images of BT/TC4 materials.* ***(c)*** *Cross-section SEM-EDS picture of BT/TC4 material.* ***(d)*** *AFM topography.* ***(e)*** *PFM phase.* ***(f)*** *PFM amplitude* [79]. *Permissions under Attribution 4.0 International (CC BY 4.0)*

Polymethyl methacrylate (PMMA)

PMMA polymer is a synthetic and lightweight polymer that is simple to manipulate, cost-efficient, and includes small inconspicuous components; these features make it appropriate for use in applications that involve the medical field. Numerous medical applications, such as the administration of drugs, as well as instruments, such as bone cement and microsensors, make extensive use of the substance [84]. Denture foundations, orthodontic braces, and implants are all made from PMMA, the dentistry industry's preferred material [84]. A ZnO plasma-treated PMMA surfaces behave well against the antibacterial activity of *E. coli*, as shown in Figure 5. It is inert and has high mechanical qualities, a moderate disintegration rate, a low toxicity level, and low toxicity. Because of these qualities, it is often used in the surgical replacement of hip joints.

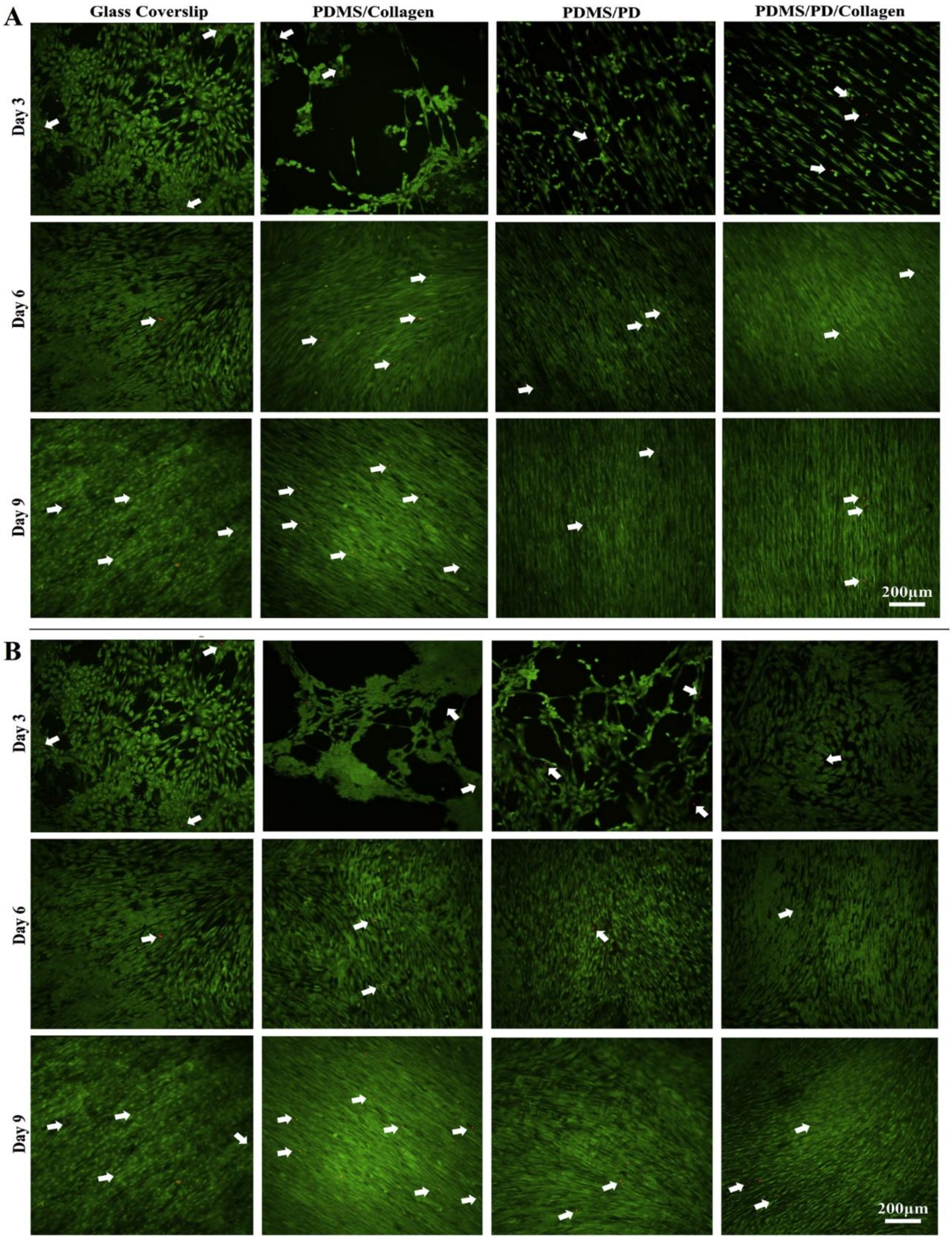

Figure 4. *Cytotoxicity of hMSCs grown on* ***(a)*** *aligned and* ***(b)*** *flat PDMS substrates by live dead staining* [81]*. Permissions under Attribution 4.0 International (CC BY 4.0)*

Because it is non-biodegradable, it may be utilized in building structures that are intended to be permanent and mechanically durable [85]. One example of this kind of structure is employed in bone tissue engineering. The poor adhesion between these two components is one of the problems that might arise when organic materials are coated on metal surfaces. In order to circumvent this issue, polymers may be covalently attached to the surface of the substrate in order to provide an adhesive interlayer. Alkali activation of the Ti surface resulted in incorporating a 1–2 m PMMA layer [86]. In further research, the same approach was used to create a sandwich construction composed of titanium, PMMA, and titanium to investigate the adhesion and formability of these materials. We were successful in achieving both a high bonding strength and excellent formability. According to the findings, the interfaces between the titanium and the PMMA did not degrade or delaminate. Because of this, the implementation of this technique of coating and adhesion can be beneficial in the forthcoming biomedical technology. Nanoindentation and a variety of atomic force microscopy (AFM) methods were adopted to mechanically characterize the thick PMMA layers grown on top of Ti substrates [33]. Each of these techniques indicates the material's mechanical characteristics at a unique scale.

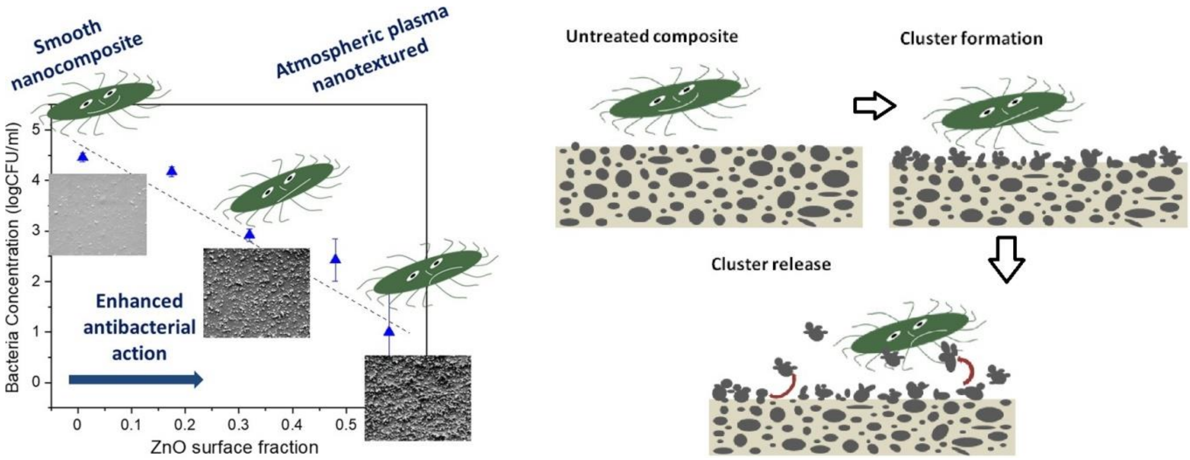

Figure 5. *ZnO plasma-treated PMMA surfaces against the antibacterial activity of E.coli* [87]. *Permissions under Attribution 4.0 International (CC BY 4.0)*

Other coatings

Universally, many biomedical applications rely on the use of biopolymers and natural polymers such as collagen and chitosan. The most frequently used biopolymers are poly(lactide-co-glycolic), polycaprolactone, poly(lactic acid), and polyethylene for Mg (AZ31) alloy. There are several uses of poly(lactic acid) in the biomedical field, like tissue engineering, medication delivery, and 3D printing scaffolds [88]. As a result of this, medical devices also make use of it. Poly(lactic acid) contains the zinc oxide (ZnO) nanoparticles. These particles are helpful in controlling the degradation and enhancing antibacterial activity. It is possible to alter the surface topography and the rate at which magnesium is broken down by including ZnO into PLA matrix. PLLA (poly(l-lactide)) solution on PDMS generates the PLLA microchambers, which facilitates the drug loading and sealing resulting in improvement of the drug delivery [89]. As a smart polymer, it is conceivable to use it to deliver medication based on external inputs.

Coatings made of natural polymers, like collagen and chitosan, were also utilized in the process of improving the functions of biomaterials. There are a variety of reports available regarding the chitosan coatings that have been used in biomedical applications. Electrophoretic deposition is one of the methods that may be used to coat. Recent research published in a variety of journals offers an overview of this coating approach to metals, alloys, and glasses [90-93]. Recently, Avcu *et al.* [93] conducted a review on the chitosan-based composite coatings that are used in biomedical applications. Frank *et al.* [94] present a detailed study regarding chitosan coatings on nanoparticles in a paper that was published quite recently. Chitosan coatings for nanoparticles may be created in one of two ways. Firstly, the nanoparticles themselves are first prepared, and a chitosan solution is added to the nanoparticles. Secondly, chitosan is added while the nanoparticles are still in the process of being prepared.

Coatings on nanoparticles

Optimization of the nanoparticle's surface is required in order to make nanoparticles usable for therapeutic applications in a realistic setting within a nanoparticle system. Functional coatings on nanoparticles can be extremely appreciated in systematic drug delivery systems for modifying the discrimination of nanoparticles during the delivery process. This helps to develop a system that has the potential to deliver drugs more precisely to their intended sites of action. Because surface modification may, in certain instances, change the characteristics of nanoparticles, As a consequence, the choice of coating material is critical in biomedical applications due to its performance in clinical settings. This is due to the fact that surface modification can occur. Magnetic nanoparticles are a good example (MNPs), since some coatings have the potential to alter the magnetic properties of these particles. In medical applications, bioactivity, toxic effect, resilience, and support for the embedding of other functional groups are all important considerations when designing these coatings, which may perform many functions simultaneously. When it comes to biomedical applications, the universal polymer coating is a beneficial technique since it can be applied to a wide range of material surfaces and does not need any specific substrate parameters, such as stiffness or topography [95]. In order to put MNPs to use in the applications described above, it is necessary to guarantee that they do not clump together as a result of the colloidal or magnetic forces present in the medium. Coating MNPs with substances that promote their solubilization in a medium may be an effective strategy for addressing these difficulties. Because of their bioactivity and propensity to biodegrade, biopolymers have the potential to fulfill these criteria [96]. Marins *et al.* [96] performed an investigation to improve the colloidal stability of iron oxide nano-rods in an aqueous environment by coating them with polymers. For biomedical applications, total colloidal stability is a need, and this method may be able to improve the stability of rod-like nanoparticles.

Conclusion and future perspective

Biomaterials utilized in tissue engineering applications are becoming more popular due to advances in polymer-based hybrid materials and novel imaging and characterization tools. New materials and combinations might also be helpful. Among the many ways available for surface modification, the modification of the surface with appropriate polymeric materials is one that may be effectively employed for real biomedical purposes. Although, it is crucial to select the proper substrate, coating process, and polymer, which can be significantly utilized in clinical applications. This is because clinical applications need a certain region of the material. As a result, it is necessary to understand the underlying mechanism, and it is recommended that theoretical techniques be used in the creation of such coatings.

In a similar vein, nanoparticles can be employed as the potentially useful candidates for biological applications; however, there are several criteria that must be taken into consideration. Coatings made of polymers may be applied to these materials in order to help solve several problems, including the quick absorption of proteins and the uptake of macrophages. Several distinct nanoparticles that can be changed by applying a variety of polymer coatings in various ways have been produced and tested. These nanoparticles have a significant potential for use in biological applications.

The majority of the outcomes that were described above were reported from laboratory investigations, and it has not yet been fully implemented that coatings and sophisticated structures be developed for biomedical applications on a broad level. The developments that have taken place in this area have opened the path for the creation of polymer coverings that have multifunctional properties in order to meet typical issues that are encountered in tissue engineering. Biomedical coatings must be shown to work optimally in biological contexts before they can be authorized for use in clinical settings. This is the case even though other industrial applications have been successfully implemented. Because of this, there is still a significant obstacle in the way of breakthroughs in this area, and there is a need for qualitative study and development.

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