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An overview of Polypyrrole (PPy) and PPy-based Composites and their Biomedical Applications

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Abstract: *The employment of metals and alloys in the biomedical field is one of the most challenging approach and shows immense applications for improvement human life. Basically, the materials used for metallic biomedical applications, particularly those are implanted in vivo, provide appropriate mechanical and biological properties that allow them to accomplish the purpose for which they are used. This article shows the latest developments in the preparation of conductive polymers including polypyrrole and its composites to enhance mechanical properties, biocompatibility and most importantly corrosion protection performance of metallic implants.*

Keywords: *Biocompatibility, Composites, Conducting Polymers, Coating, Corrosion, Metallic Implants*.

I. Introduction:

Metallic materials have an essential role to play as biomaterials due to the fact that they can replace or regenerate the damaged tissue and some of the body parts. [1-3]. The exploitation of implantable medical devices and orthopaedic implant is being growing recently in which the orthopaedic biomaterial market recorded more than one third of the total biomaterial products market [4]. The metallic materials that have been broadly utilised as metallic implants are 316L stainless steel (316L SS), pure titanium (Ti) and Ti alloys, and cobalt-chromium alloys (Co-Cr). Generally, the biocompatibility, high mechanical strength and corrosion resistance of these metallic materials have promoted their use in biomedical applications, particularly in orthopaedic and orthodontic implants.

In the last few decades, the interest in using polymers has increased remarkably in various biomedical fields such as tissue engineering [5-6], drug delivery [7-8] and dental technology [9-10]. Among the different types of polymers, there is a class, which is called conductive polymers or conducting polymers (CPs), has some unique characteristics allowing it for use in distinctive applications that conventional polymers may not be able to achieve. The electrical conductivity in CPs is attributed to π- electron backbone; single and double bonds alternate all over the polymer chain [11].

Polypyrrole (PPy) and PPy-based Composites

PPy has high electrical conductivity and can be easily fabricated and modified. Besides, it has good biocompatibility with mammalian cells; therefore, it is alleged to be the most examined conductive polymer for biomedical applications [12-14]. PPy has the capability to promote cell adhesion and ingrowth of various cell types [15-17]. The biocompatibility of PPy film coated implants has been confirmed in a variety of studies both in vitro and in vivo [18-19]. Along with the biocompatibility and because of the stability of PPy, which preclude the electron exchange between the metallic material and the biological materials, PPy coating has an exceptional corrosion resistance [19]. PPy has been employed for several biomedical applications such as tissue engineering [12], drug delivery [20], and biosensors [21]. PPy can straightforwardly be produced in large quantities in different solvents [22].

The enhancement of corrosion resistance and biocompatibility is being considerably crucial in recent implant technology. Improving surface properties for biomedical implants can be successfully achieved using biocompatible nanocomposite coatings where hybrid implant coatings with various chemistry, functionality, and biocompatibility components have been drawn remarkable attention in a variety of biomedical applications. Cyclic votametric technique was used to prepare PPy/zirconia nanoparticles (ZrO_2) nanocomposite coatings electrochemically on 316L SS in aqueous solution of oxalic acid for orthopaedic implants. Owing to their hydrophilic, smooth, compact and less porous surface morphology compared to nanoparticles-free PPy coatings, the PPy/ZrO_2 coatings had superior biocompatibility and reduced corrosion rate on 316L SS [23]. PPy was also strengthened with functionalised multi-wall carbon nanotubes (CNTs) that was deposited on 316L SS by means of electrochemical method. 316L SS coated with PPy plus CNTs displayed corrosion potential better than uncoated 316L SS when both alloys placed in simulated body fluid (SBF) [23]. Kumar et al. fabricated PPy/graphene oxide (GO) nanocomposites by electropolymerisation to be applied on 316L SS implants. Dispersion of the GO nanosheets within the PPy matrix was verified, and enhancements in surface protective and biocompatibility of MG-63 human osteoblast cells of PPy/GO coatings on 316L SS implants were clearly achieved [24]. Bilayer coatings by electropolymerisation of PPy on 316L SS followed by the electrodeposition of porous strontium hydroxyapatite (Sr-HA) were successfully developed. The PPy/Sr-HA bilayer coated 316L SS could have the highest Rp value, and could reduce both the release of metal ions and corrosion rate for the implant for a longer period. Besides, owing to their chemical and biological resemblance to the bone tissue, and the presence of pores that can promote cell proliferation and differentiation, the porous coating may stimulate fixation of implants to host bone [25]. In order to increase biocompatibility and corrosion resistance of 316L SS for orthopaedic and dental applications, the substituted hydroxyapatite (I-HAp)/silica nanotube (SiNTs)/PPy coating on 316L SS was formed by electrophoretic deposition procedure. An efficient anticorrosion rate in SBF solution of this alloy by this bilayer composite coating was verified. The IHAp plus SiNTs coating diminished metal ions dissolution ratio. Good mechanical properties of the composite were obtained due to the presence of SiNTs while the I-HAp improved the formation of apatite that was confirmed in the SBF for different time points of incubation. In vitro MG-63 cells attachment and viability were higher for the IHAp/SiNTs/PPy compared to that ppy-coated free substrates [4]. In another work, coatings of PPy and TiO_2 were electrochemically produced on 316L SS in oxalic acid solution. 316L SS coated with PPy/TiO_2 nanocomposite displayed greater biocompatibility and improved corrosion performance compared to the alloy coated with pristine PPy coatings. In a study by Kumar et al., PPy/$Nb2O_5$ nanoparticles composite coating was synthesised and coated on 316L SS by electrochemical deposition. The existence of these nanoparticles was shown to strongly influence the surface nature of the nanocomposite coated 316L SS along with improving its microhardness. The electrochemical and biocompatibility studies in SBF and on MG63 osteoblasts, respectively indicated that the coatings displayed proper corrosion protection and biocompatibility by contrast with PPy modified 316L SS [23].

II. Conclusion:

The use of metals and alloys in biomedical applications has been witnessing a great deal of interest due to what these vital materials can provide in terms of replacing and renewing organs and tissues, especially with the increase in people life span and the rise in accidents worldwide. Therefore, abundant studies have been conducting to enhance these properties through a wide range of techniques, perhaps the most important of which is coating these materials with CPs especially PPy and its composites. This type of coating has been observed to greatly develop biocompatibility and corrosion resistance, especially by using CP-based composites that are reinforced with nanomaterials such as ZnO, ZnO_2, TiO_2, Nb_2O_5. The high surface area of nano-additives for the dopant release, and the promotion of barrier effect against diffusion are achievable with these composite biomaterials. It is expected that numerous further research will be conducted in the future to develop composite biomaterials based on CPs for the purpose of improving the performance of the devices currently used in implantation.

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