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Investigation on the effects of simultaneous adding of α -tocopherol (vitamin E) and Multi-walled carbon nanotubes (MWCNT) on the mechanical properties and biocompatibility of the ultra-high molecular weight polyethylene polymer matrix (UHMWPE) in joint replacements

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Introduction

Ultra-high molecular weight polyethylene (UHMWPE) is well known for its successful performance over the last three decades as the material of choice for use as a joint replacement. However, the wear of the UHMWPE is considered a major problem, which leads to osteolysis (bone destruction) and limits the lifespan of this prosthesis. It has been shown that oxidation in UHMWPE increases the wear rate of the polymer and makes a large amount of wear debris around the prosthesis. Therefore, there is a fundamental need to improve the oxidation resistance and mechanical properties of UHMWPE in joint replacements. One of the effective methods to prevent oxidation is the use of vitamin E (α-tocopherol) in the UHMWPE matrix. vitamin E prevents the oxidation degradation of UHMWPE and increases its oxidation resistance. One of the most popular fillers in polymers is multi-walled carbon nanotubes (MWCNT). This filler is notable for its exceptional properties such as high elastic modulus, tensile strength, fracture toughness, and excellent surface-to-volume ratio.

The purpose of this article was to investigate the effects of adding vitamin E as an antioxidant filler and multi-walled carbon nanotubes as a reinforcement, on the mechanical properties and biocompatibility of the polymer matrix to improve its lifespan. To compare and investigate the effects of adding carbon nanotubes, another composite containing vitamin E was produced and the results of the two composites were compared.

Materials & Methods

To produce composites, 0.5 percent by weight of multi-walled carbon nanotube powder was mixed with 50 ml of organic solvent (pure ethanol 99.9%), then for obtaining a homogeneous and well-dispersed carbon nanotube, the solution was ultrasonicated for 15 minutes. In the next step, 0.25 percent by weight of vitamin E was added to the ultrasonicated liquid, stirring the solution for 30 minutes with a magnetic stirrer. Afterward, the obtained solution was mixed with 30 grams of pure UHMWPE powder and ball milled for two hours. Next, the obtained slurry was placed in an oven for 24 hours at a temperature of 60 °C to evaporate the excess solvent. Finally, the obtained powder was molded and pressed using a pressure molding machine at a temperature of 190 ℃ and under a pressure of 5 MPa. The samples were produced in round-shaped tablets with a diameter of about 7 cm and a thickness of 2 mm.

Results & Discussion

Various studies have shown that the combination of vitamin E with UHMWPE polymer can protect the polymer from oxidation in the long term, On the other hand, the use of vitamin E in the UHMWPE matrix reduces the mechanical resistance of the polymer. In this regard, various research has been conducted to improve the mechanical properties of UHMWPE polymer by adding graphene nanotubes, diamonds, etc. In this research, multi-walled carbon nanotubes were used as a reinforcement to improve the mechanical properties of UHMWPE /vitamin E composite (for orthopedic applications and the replacement of artificial joints). Two composites, one containing vitamin E and the other containing vitamin E and carbon nanotubes (simultaneously), were produced by the wet mixing method and pressure molding (with temperature). The FTIR spectra of both composites showed characteristic peaks of UHMWPE polymer. Moreover, all characteristic peaks of the PE-E/CNT composite experienced a significant increase compared to the PE-E composite. These results confirmed the homogeneous and successful dispersion of carbon nanotubes within the UHMWPE matrix. X-ray diffraction (XRD) analysis in semi-crystalline polymers provides details about crystallinity, composition’s phase, etc. According to the results, the intensity of UHMWPE crystal phases (orthorhombic and hexagonal) increased in carbon composite compared to vitamin E, So we can expect better performance for this composite in bearing surface of artificial joint replacements. XRD also showed similar results. The DSC results showed a 7% increase in the crystallinity of the PE-E/CNT composite compared to the PE-E, which reduces the chain mobility and consequently reduces the plastic deformation of the composite. It was also shown that the addition of carbon nanotubes had no noticeable effect on the melting temperature of the composite. The results of the DMTA test also showed a decrease in the loss modulus or viscous properties in the PE-E/CNT composite compared to the PE-E. On the other hand, the storage modulus (elasticity) of the PE-E/CNT composite showed a significant increase compared to the PE-E composite. Since this research was carried out with the aim of orthopedic application and joint bearing surface, according to the results, it is expected that carbon nao-tube composite can withstand the frequent and abrasive forces as a joint prosthesis. Finally, via cell culture and cytotoxicity test, the viability percentage of the fibroblast cells that were in contact with the extracts of the samples was calculated, and the results showed complete biocompatibility of the produced composites.

Conclusion

This research was conducted with the approach of increasing the mechanical properties and biocompatibility of the polymer component of joint replacement prostheses, and the results showed the improvement of the mechanical properties of the polymer in the simultaneous presence of vitamin E and carbon nanotubes.

Keywords*:* Artificial joints, UHMWPE/Vitamin E composite, UHMWPE base composite, UHMWPE/Vitamin E/MWCNT composite

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Declaration of conflict of interest

The authors declare that there is no conflict of interest.