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Basic and Expermental Study

Physical vs Biological Effect of Silver and Copper Nanoparticles

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Abstract

The most common cause of cardiovascular disease in humans is valvular disorders which are commonly treated by heart valve replacement surgery. Mechanical valves mostly used for heart valve replacement surgery are made up of Pyrolytic Carbon. The major complications are thrombosis and microbial colonization. The main objective of this study is to define the physicochemical properties of Silver and Copper nanoparticles thin films coated on Pyrolytic carbon biomaterial by Pulsed Laser Deposition technique. In our previous work on application of nanoparticle to prevent clotting and microbial colonization on prosthetic heart valve, it was observed that there was a mismatch between the Nanoparticle number and the biological effect showed a linear increase in the number of nanoparticle and the biological effect upto12,500 pulse deposition of nanoparticle on the pyrolytic carbon surface of prosthetic valve. We tried to explain this mismatch with a physical model which is only a replica that substantiates our explanation for this mismatch. Review of the literature didn't show any explanation to this phenomenon.

Keywords: Nanoparticles, Pyrolytic carbon, Physical model, Heart valve, pulsed laser, Profilometry

Introduction

Heart valve diseases are one of the leading causes of cardiovascular mortality and morbidity. It leads to conditions such as incompetence and stenosis, where the valve does not close properly leading to regurgitation of blood and the valve leaflets becomes thickened or rigid leading to obstruction in the forward flow of blood respectively. Heart Valve replacement surgery is done for the above two conditions depending upon the severity and complications [1]. Heart Valve replacement surgery is done with two types of valves, namely mechanical and biological valves [2]. The mechanical valves are mostly made from Pyrolytic carbon. which has high durability but have risk of thromboembolism and microbial colonization. It is observed that the antimicrobial and anticoagulant effect of Silver and Copper nanoparticles thin films coated on Pyrolytic carbon biomaterial by Pulsed Laser Deposition technique was maximum at 10,000 ablation pulses. But the antimicrobial effect reaches a peak at 10,000 ablation pulses and decreases beyond that. We tried to explain this phenomenon by making a physical model of nanoparticle and the energy liberation.

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Materials and Methods

The main concept of this study is to elaborate the physicochemical effect of the Silver (Ag) and Copper (Cu) nanoparticles coated as thin film on the Pyrolytic Carbon by Pulsed Laser Deposition (PLD) method at optimum pulses from 10,000 to 15,000 pulses. We had attempted to draw a physical model to give a scientific explanation for the mismatch between the numbers of nanoparticles Vs the biological effects.

We have made a nanoparticle model as a cube; the physical model is made by fixing the nanoparticle model with interval from each other on the uncovered base layer. The length and the width of the uncovered base surface were taken as 28.5 cm and 17 cm respectively. The measurement of one side of a model nanoparticle cube was 3.5cm. The number of nanoparticle cube models taken were 18. While calculating the surface area of a single nanoparticle cube model, only five surfaces were taken into consideration. The sixth surface i.e., the surface fixed to the base was not taken for calculation. (Figure 1)

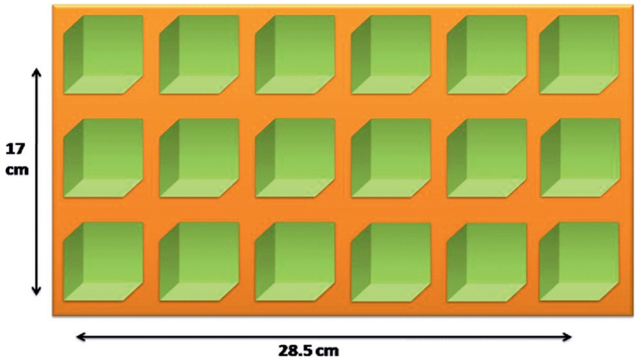

Figure 1: Size of each Squire is 3.5 (H) X 3.5 (W) X 3.5 (H)

When calculated the surface area of the uncovered base layer without the nanoparticle cube model was found to be 484.5 sq. cm, which is an empirical representation of the surface area of a normal Pyrolytic Carbon mechanical valve used for valve replacement surgery. Secondly, we calculated the surface area of a single Nanoparticle cube model with its five exposed surfaces only because the sixth surface was fixed to the uncovered base. The surface area of five surfaces of single nano particle cube model was 61.25 sq. cm. The total surface area of the 18 Nanoparticle models coated was 1102.5 sq. cm [3]. The surface area of the intervals between the nanoparticle cube models was calculated as follows:

The surface area of the uncovered base layer = 484.5 sq. cms. The area of the sixth surface fixed to the uncovered base layer- 3.5x3.5= 12.25 sq. cms. The area of the sixth surface of all the 18 nanoparticle cube models- 12.25x18=220.5 sq. cms. Hence, the surface area of the intervals between the nanoparticle cube models - 484.5-220.5= 264 sq. cms. Therefore, the total surface area of the nanoparticle cube models fixed on the uncovered surface- 1102.5+264=1366.5 sq.cms. i.e., nearly 3 times greater than the uncovered base layer's surface area. Thus, the surface area of the mechanical valve made from Pyrolytic carbon will be increased when the surface is coated by silver or copper nanoparticle thin films by Pulsed Laser Deposition technique. This suggests that there will be increase in the physicochemical effect which will lead to the increase in antibacterial, antifungal and anticoagulant effects of the mechanical valve used for heart valve replacement surgery.

The characteristics of silver nanoparticles and copper nanoparticles deposited by pulsed laser deposition technique at various ablation pulses were studied by the following techniques: surface profilometry, Scanning Electron Microscopy Energy Dispersive X - ray analysis (EDXA) and Atomic Force Microscopy (AFM). The parameters which were studied in these processes were structure, morphology and composition of the silver nanoparticles and copper nanoparticles thin film coatings [4]. The thickness of the surface was measured by the Surface Profilometry which showed that the increase in the number of ablation pulses increases the thickness of silver nanoparticles and copper nanoparticles thin films. The scanning electron microscopy was mainly used to measure the surface morphology and particle size. Scanning electron microscopy study revealed that there was an increase in the mean size and the shape was changed from spherical to large islands at 15000 ablation pulses. The Energy Dispersive X-ray analysis measured the elemental composition and confirms that the nanoparticles deposited by pulsed laser deposition on the pyrolytic carbon material was mainly composed of silver and copper nanoparticles thin films without any impurities. The roughness of the silver and copper nanoparticles thin films was studied by using atomic force microscope at various ablation pulses. The threshold pulse for an optimum surface characteristic of Silver Nanoparticles and Copper Nanoparticles thin films were ranging from 10,000 -15,000 pulses. Incongruity of the physical Number of nanoparticles Vs the biological effects, the anticoagulant and antimicrobial effect reached a peak at 10,000 ablation pulses. After that the anticoagulant effect reduces when the ablation pulses are increased to 12,500 and attains a plateau thereafter. The antimicrobial effect decreases after 10,000 ablation pulses and reduces thereafter [5]. This has been demonstrated with graphs using the data obtained from our previous work [6].

Results and Discussion

From the work done by our previous research candidate, the antibacterial, antifungal and anticoagulant activity was significantly increased after the coating of both Silver Nanoparticles and Copper Nanoparticles thin films on Pyrolytic Carbon materials at various ablation pulses. The Silver Nanoparticles and Copper Nanoparticles thin films will have optimum thickness, mean particle size, elemental composition and roughness when deposited up to 15,000 ablation pulses which will be favorable for preventing microbial infections and thromboembolism. Unlike the anticoagulant effect which reaches a peak at 10,000 ablation pulses and reduces at 12,500 ablation pulses maintaining a plateau thereafter, the anti-microbial effect reaches a peak at 10,000ablation pulses, reduces to an extent at 12,500 ablation pulses and reduces with further increase in ablation pulses. Comparing both the Silver Nanoparticles and Copper Nanoparticles thin films coated on Pyrolytic Carbon material, Silver Nanoparticles thin films showed better antibacterial, antifungal and anticoagulant activity than Copper Nanoparticles thin films.

The increase in the ablation pulses i.e., at 12,500 and above led to the increased deposition of the number of nanoparticles

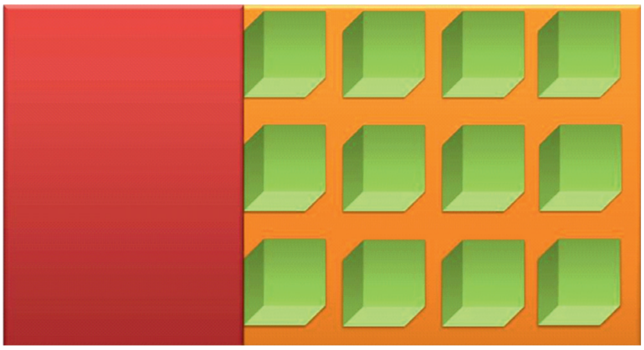

Figure 2: Number of nanoparticles completely filled up the base and the biological effects plateau

which resulted in the occupation of the intervals. This led to the decrease in the surface area of the Pyrolytic carbon mechanical valve which resulted in the reduction of the biological effects of the Silver and Copper nanoparticle thin films coated on the pyrolytic carbon biomaterial. The plateau phenomenon of the anticoagulant effect is due to the reason that only some intervals are occupied by the increased number of nanoparticles at increased ablation pulses, but the remaining Surface area will have the same intervals between the nanoparticles which were present at the initial deposition at 10,000 ablation pulses (Figure 2). Thus, the remaining number of nanoparticles with the normal intervals maintain the constant biological effect which explains the formation of the plateau in the graph. The antimicrobial effect which reaches a peak at 10,000 ablation pulses and decreases with further increase in the ablation pulses can be hypothesized due to the destruction of the microbes at a peak of 10,000 ablation pulses that leads to the reduction in the microbial load.

This hypothesis thus explains the reduction in the antimicrobial effect with increased ablation pulses unlike the anticoagulation effect which attains a plateau after an initial decrease. Also the surface area of the normal mechanical valve will be increased 3 times greater when the Silver Nanoparticles or Copper Nanoparticles are deposited by Pulsed Laser Deposition technique on the Pyrolytic Carbon mechanical heart valve [7,8]. Thus, the surface area of the total Silver Nanoparticles and Copper Nanoparticles coated on Pyrolytic carbon increases when they are deposited with intervals between them on the Pyrolytic Carbon mechanical heart valve up to a particular ablation pulse i.e., 10,000 ablation pulses. Further, the nanoparticles are deposited in such a manner, that the electro chemical energy produced around the nanoparticles surface are spread throughout the interval. This in turn increases the antibacterial, antifungal and anticoagulant effects of the Pyrolytic carbon mechanical heart valve coated by silver and copper nanoparticle thin films during the heart valve replacement surgery [9].

Conclusion

Therefore, the physicochemical effect exerted by the copper nanoparticles and silver nanoparticles on the pyrolytic carbon coated on the mechanical heart valve was increased with increased surface area of the nanoparticles when deposited with intervals between each other on the surface at 10,000 ablation pulses. The further increase in pulses led to an initial decrease in the anticoagulant effect which attained a constant after 12,500 ablation pulses corresponding to the plateau phenomenon. Whereas, with increased ablation pulses, the antimicrobial effect shows a constant decrease after a peak of effect at 10,000 ablation pulses. Both the antimicrobial and anticoagulant effects were increased when compared to a normal non-coated pyrolytic carbon mechanical heart valve used for the heart valve replacement surgery.

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