Impact of plasma discharge pressure on implant surface properties

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Abstract: This study investigates the effect of reduced gas pressure on plasma properties, implant surface characteristics, and biological outcomes. Results indicate that the 5 Torr operational condition effectively removes hydrocarbon impurities and enhances protein adsorption, improving cell adhesion, proliferation, and differentiation, while providing a more stable plasma environment compared to the 16 Torr condition.

1. Introduction

Low-temperature plasma has been widely used in various biomedical fields. Specifically, plasma has been applied for treatment of medical implants surface to enhance their biocompatibility and osseointegration [1-3]. However, atmospheric pressure plasma faces challenges like limited plasma uniformity and sensitivity to ambient conditions, often necessitating noble gases. Reduced gas pressure plasma devices offer a promising alternative, enabling stable plasma generation and improved implant surface treatment, as demonstrated in studies showing enhanced bone-to-implant contact [4].

This study investigates the relationship between plasma discharge conditions and biological outcomes, finding that optimizing gas pressure improves surface modification, osteoblast activity, and implant performance.

2. Methods

Our plasma module consists of two electrodes, an implant, a fixture driver and holder, and a quartz tube, based on the ACTILINK system, an implant surface treatment device (Plasmapp Co., Ltd). A high-voltage power supply applied a 3 kVpp, 100 kHz sinusoidal waveform to the top electrode. To evacuate gas from the quartz-enclosed chamber, a diaphragm vacuum pump (N 84.3 ANDC, KNF) was connected to the module with a pressure gauge installed to monitor the pressure level.

This study utilized a commercial implant (SLA, #SFR4008NS, Hoowon) with dimensions of 4.0 mm in diameter and 8.5 mm in length. Plasma treatment was performed for 10 seconds following pumping periods of 10 or 20 seconds, achieving pressures of approximately 16 Torr and 5 Torr, respectively. Plasma emission spectra were acquired using a monochromator (Dongwoo MonoRa 500i) paired with an ICCD camera (Andor iStar 340T) to analyze the temporal change in the N_2^+ first negative and N_2 second positive systems.

3. Results and Discussion

Using optical emission spectroscopy, we demonstrated that the emission intensity in the plasma at the implant surface declined significantly under the 16 Torr condition. In contrast, under the 5 Torr condition, the emission intensity decreased only slightly, by approximately 14%, and remained relatively stable due to the consistent gas pressure. Consequently, the emission light intensity immediately after plasma ignition was greater in the 16 Torr case. However, after 3 seconds of breakdown, the overall emission intensity was greater under the 5 Torr condition, likely due to the more stable plasma environment and generation of excited nitrogen species.

We then assessed surface hydrophilicity, chemical composition, protein adsorption, and osteoblast activities on plasma-treated implants compared to untreated controls. Our results indicate that the 20-second pre-pumping condition significantly improves hydrocarbon-based impurity removal and protein adsorption, leading to enhanced cell adhesion, proliferation, and differentiation.

4. Conclusion

In conclusion, our study demonstrates that the 5 Torr plasma treatment condition significantly enhances the biological performance of implant surfaces due to the stable generation of excited nitrogen species, which leads to beneficial modifications in surface chemistry. These findings suggest that excited nitrogen radicals in plasma may play a key role in overall surface modification, including hydrocarbon decomposition, and further enhance the biocompatibility of implant surfaces.

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References

[1] M. C. Kim et al., Surf. Coat. Technol. **174**, 839–844 (2003).
[2] L. Bónová et al., Appl. Surf. Sci. **331**, 79–86 (2015).
[3] E. Gonzalez 2nd et al., Langmuir **26**, 3710–3719 (2010).
[4] H. Lee et al., Biomed. Eng. Lett. **12**, 421–432 (2022)