Advancements in Plasma-Activated Liquids: System Development, Characterization, and Biomedical Applications

F. S. Miranda[1], V. K. F. Tavares[1], N. F. Azevedo Neto[2], R. S. Pessoa[2], C. Y. Koga-Ito[1]
[1]*Institute of Science and Technology, São Paulo State University (UNESP), São José dos Campos, Brazil*
[2]*Technological Institute of Aeronautics, São José dos Campos, Brazil*

Abstract: This work highlights the scientific and technological advancements achieved by our research group in developing and applying Plasma-Activated Liquids for biomedical purposes. By establishing safe, effective, and scalable solutions, this research line underscores the transformative potential of PAL, aiming to revolutionize healthcare through cutting-edge plasma-based applications.

1. Introduction

Plasma-activated liquids (PAL), such as water and saline solutions, have emerged as valuable tools in biomedical sciences. Enriched with reactive oxygen and nitrogen species (RONS) and generated through plasma discharge techniques, PAL offer potent antimicrobial properties, anti-inflammatory effects, and the ability to stimulate tissue regeneration [1–3].

This work highlights the advancements in PAL technologies developed by our research group, emphasizing their ability to address critical biomedical challenges. By combining innovative system designs with comprehensive plasma characterization, we have established a transformative approach for PAL production. These systems offer safe, efficient, and scalable solutions for current and emerging medical applications. A notable achievement is the development of systems that enable real-time production of activated liquids, a capability particularly valuable in high-demand settings, such as hospitals and dental clinics.

2. Methods

Plasma-activated liquids (PAL), enriched with reactive oxygen and nitrogen species (RONS), were synthesized through different plasma systems, including dielectric barrier discharge (DBD), gliding arc plasma jet (GAPJ), pin-to-water, and other configurations. Each system is designed to optimize RONS generation, tailoring PAL properties for specific applications. Comprehensive plasma characterization, employing advanced techniques such as UV-Vis, Raman, and optical emission spectroscopy, has provided critical insights into the chemical and physical mechanisms driving reactive species production. These findings have enabled fine-tuning operational parameters, including gas selection, activation duration, and liquid flow rates, ensuring safe and effective PAL generation.

3. Results and Discussion

This meticulous approach has elevated the quality and consistency of PAL, broadening its applicability in biomedical contexts. PAL demonstrates exceptional antimicrobial efficacy (Fig.1), achieving up to 99.99% reduction of pathogens such as *Staphylococcus aureus* and *Escherichia coli*. Moreover, PAL showed low cytotoxicity. The development of continuous activation systems, such as a DBD reactors, marks a significant leap forward, enabling real-time PAL production for immediate use in clinical settings. Hybrid systems, integrating DBD and gliding arc technologies, have further enhanced RONS generation in saline solution, paving the way for advanced therapeutic applications.

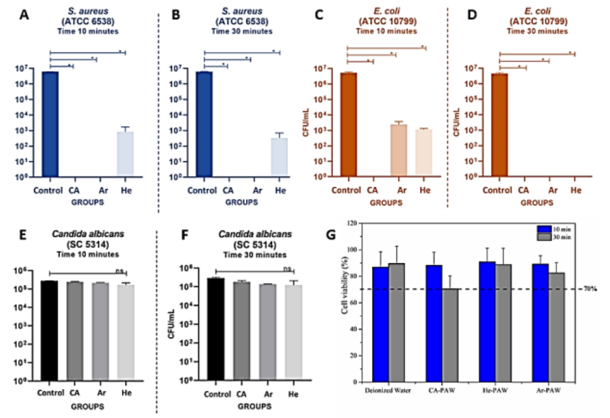

Fig. 1. Reduction of *S. aureus*, *E. coli*, and *C. albicans* following exposure time of 10 and 30 min to PAW produced with different gases (air, helium, and argon).

4. Conclusion

These contributions reflect a transformative evolution in plasma technologies, combining system innovation with robust characterization to address critical biomedical challenges. By establishing safe, effective, and scalable solutions, this research line underscores the transformative potential of PAL, aiming to revolutionize healthcare through cutting-edge plasma-based applications.

Acknowledgement

Authors acknowledge São Paulo Research Foundation (FAPESP), 2021/14181-3 (FSM), 2023/02268-2 (NFAN) and 2019/05856-7.

References

[1] C. Bradu et al., J Phys D Appl Phys **53**, 223001 (2020).
[2] W. Chiappim et al. Water, **13**, 207841 (2021).
[3] F.S. Miranda et al. Plasma Chem. Proc., **44**, 1713-33 (2024).