Helium atmospheric pressure plasma jet: Diagnostics and application for burned wounds healing

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Résumé

A new field of plasma applications developed in the last years, with the short title plasma medicine, focused the attention of many peoples from plasma community on biology and medicine. Subjects that involve plasma physics and technology (e.g. living tissue treatment or wound healing, cancer cell apoptosis, blood coagulation, sterilization and decontamination) are nowadays in study in many laboratories. In this paper we present results on optical and electrical diagnosis of a helium atmospheric pressure plasma jet. This type of plasma jet was used for modification of wound healing process and we obtained an acceleration of the process with 50% against control group. Data from biochemistry and histology tests are presented and commented.

Introduction

The growing importance of plasma technologies in medicine, biology and health care is a fact reflected by the increasing number of scientific publications or reports on this subject [1]. For many applications low pressure plasma sources have several drawbacks and their potential use in medicine is limited. In contrast, atmospheric pressure plasma sources are presented in literature as good candidates for medical use. They are labeled in different ways, well known names being plasma needle, plasma pencil, plasma gun or atmospheric pressure plasma jet (APPJ). Plasma is generated in these sources using various geometries and working gases, using the principles of corona discharge, dielectric barrier discharge and microdischarges. Parameters of these plasma sources (e.g. temperature and concentration of charged species, gas temperature, concentration and distribution of reactive species) are spread over large domains of values. Having this in mind, standardization of operational parameters of atmospheric pressure plasma sources represents a necessity before any large medical use and remains an open challenge. Parameters like maximum current value, charge, power density, repetition rate, applied voltage can be used to achieve this goal.

Helium APPJ

The helium APPJ, designed in our laboratory, is generated in a dielectric barrier discharge configuration. Aluminum tape electrodes are wrapped on a quartz tube, 4 mm inner diameter and separated by 10 mm space. Helium is flowing trough this quartz tube with a flow rate of few liters/min. High voltage monopolar square pulses are applied on powered electrode with a repetition rate between 0.5 to 4 kHz, with variable amplitude and pulse width. The signals of discharge current and applied voltage are monitored using probes and digital scope (TDS5034, Tektronix). Images of our plasma jet in the nanoseconds range are obtained using a Hamamatsu C8484-05G camera (Fig. 1).

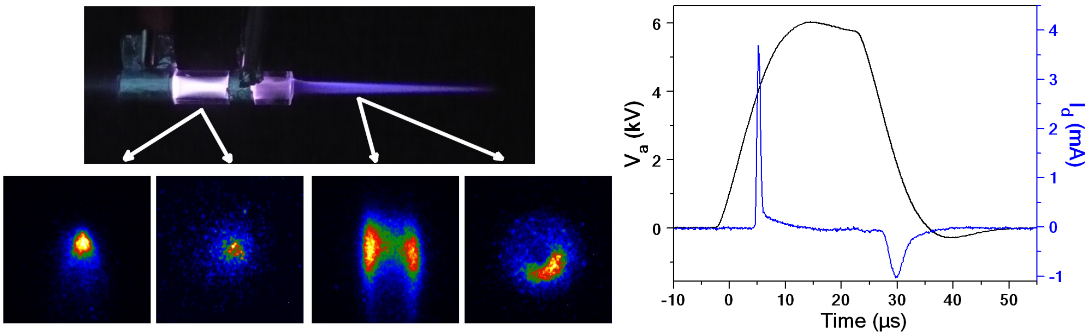

Fig. 1: The appearance of our helium atmospheric pressure plasma jet (top left, image taken with an usual camera and bottom left, 30 ns exposure time images taken with an ICCD camera, side view and on-axis view) and typical voltage-current waveforms.

The length of plasma jet is mainly controlled by the helium flow rate, having values from few mm to around 5 cm (flow rate: 4 L/min). The current is characterized by two sharp peaks, which correspond to primary and secondary discharges. The amplitude of these peaks, as well the values of charge, peak power and average pulse power are function of the amplitude of the applied voltage pulse, on its width and the repetition rate. For an amplitude of the applied voltage pulse from 3 to 8 kV (width 30 μs, repetition rate of 2 kHz, flow rate 3 L/min), the primary current peak value increases from 1 mA to 2.5 mA, the charge from 1.8 nC to 4.7 nC, the power peak from to 3 to 20 W and the average pulse power from 0.5 to 2.5 W.

Regarding the propagation mechanism we found for this type of plasma jet two very different types of plasma bullets: homogenous ones inside the quartz tube and non-homogenous ones outside the tube, where the air surrounds the plasma jet. In cross section, the light emitted from these bullets has a non-homogenous intensity [2]. The speeds of these luminous structures are as follow: the homogenous bullet starts with a speed around 6.5 km/s and the speed increases in the vicinity the ground electrode to 22 km/s, while the non-homogenous bullets present at the beginning a speed of 6 km/s and increases up to 14 km/s.

Application for wound healing

The above presented helium atmospheric pressure plasma jet was used to compare spontaneous reepithelization versus plasma-assisted reepithelization (40s daily treatment). Reproducible burned wounds were produced on the back skin of Wistar rats. The protocol for the animal experiments has been approved by the Ethics Committee of „Grigore T. Popa" University of Iasi. Hematological, biochemical and histological data were measured at different time intervals to monitor the evolution of systemic and local effects.

After 21 days, the hematological and biochemical data showed no differences between normal values compared to control group. However, the histological images showed that subjacent dermis regenerates for the plasma treated group of wounds (Fig. 2). For these plasma treated wounds, it is worth to mention that we found significant differences in the values of local oxidative stress markers.

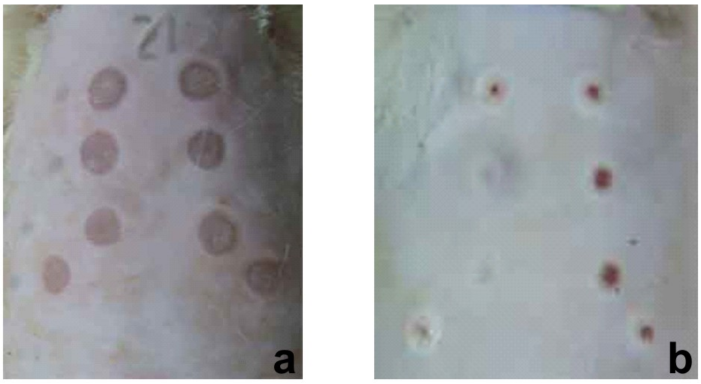

Fig. 2: Typical clinical appearance of (a) fresh wounds and (b) after 21 days: left side, daily plasma treatment for 40s and right side control group.

Conclusion and perspectives

Helium atmospheric pressure plasma jet represents a good candidate of plasma source for medical applications. Its operation is reproducible and can be standardized, while the economic aspects can be adjusted to obtain a profitable system. This type of plasma jet was used to accelerate the wound healing process and the results are promising.

For a better understanding of mechanism that are behind the benefic effects in plasma medicine, experiments regarding plasma effects on supramolecular biological systems like proteins are carried now our group. Plasma effects on protein structure and structure to function relationships are investigated. Time dependence of plasma effects on biological molecules is also an important part of our studies.

References

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