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Air plasma gaseous reactive species determine the chemical properties and antimicrobial effects of plasma activated water

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Plasma activated water (PAW), i.e. water and aqueous solutions treated by cold atmospheric plasmas, demonstrates antimicrobial or cytotoxic effects that are of great interest for many applications in biomedicine, food processing and agriculture. Nonequilibrium air plasmas generate *reactive oxygen and nitrogen species* (RONS: O, N, OH, H_2O_2, NO, NO_2, O_3, O_2^-). They are transported from the gas phase into to the liquid and induce formation of secondary RONS in water, such as H_2O_2, NO_2^-/NO_3^-, peroxynitrites/peroxynitrous acid $ONOO^-$/ONOOH, superoxide O_2^-, or OH radical. This is typically accompanied by acidification of the solution and antimicrobial effects that can last for several hours/days after plasma treatment. [1-2]

Water can be activated by cold plasma discharges indirectly by blowing the discharge effluents onto its surface or by generating a discharge directly into the water surface. Even more efficient water activation is achieved with the water electrospray that drives the micrometric droplets directly through the active discharge region, which allows for very efficient mass transfer of plasma-generated reactive gaseous species into water [2-3]. We present self-pulsing DC-driven streamer corona (SC), transient spark (TS) and gliding arc (GA) discharges operated in air as non-thermal plasma sources [2-3]. Their physical properties can be controlled by the applied voltage and electric circuit parameters, which then affect the production of gaseous active species, such as O_3, NO, NO_2 and OH, and consequently the PAW properties. Low power SC generated dominantly O_3 and H_2O_2 similar to ozone-mode of the surface microdischarge (SMD) [4], while TS with higher current pulses, as well as GA, suppressed O_3 and enhanced NO_x formation, similar to the NO_x-mode of SMD [4]. The gas flow conditions influenced the gaseous species and the PAW properties: in the TS electrospray in a closed chamber, the NO_x generation was enhanced with respect to the open air system, resulting in higher NO_2^- and NO_3^- in the PAW.

Bactericidal effects induced in water activated by the SC, TS and GA air discharges were tested on *E. coli* bacteria in water and on biofilms on surfaces and correlated with the generation of RONS. NO_2^- interacts with H_2O_2 in acidic conditions and leads to peroxynitrites (detected by fluorescence spectroscopy) that were identified as the crucial bactericidal RONS agents in PAW [1-2]. Our preliminary results on antimicrobial effects of PAW show its great potential for some medical therapies of e.g. of periodontal biofilms, urinary tract infections, or open wounds.

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