Biodecontamination of Plastic and Dental Surfaces With Atmospheric Pressure Air DC Discharges

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***Abstract*—We present images of atmospheric pressure air dc discharges applied on plastic or dental (teeth) surfaces contaminated by bacterial spores (*Bacillus cereus*) and examine their biodecontamination effects. We found discharge regimes with good bactericidal effect and low energy requirements.**

***Index Terms*—Atmospheric-pressure plasmas, cells (biology), corona, dentistry, spark.**

SEARCHING FOR new options in the decontamination of heat-sensitive surfaces is crucial in medicine and food processing. Conventional techniques (dry heat and autoclave) cannot be applied for some plastic materials, such as polypropylene and polyethylene, as well as for human tissues. In addition, numerous bacterial strains become resistant against commonly used chemicals and antibiotics. Nonequilibrium (cold) air plasmas at atmospheric pressure represent an alternative with a great potential because they are efficient and do not cause the degradation of thermosensitive materials [1], [2]. Cold plasmas are capable to disinfect dental plaque and caries and so could become a good alternative to painful teeth drilling [3].

We used nonequilibrium air plasma at atmospheric pressure produced by dc discharges for the biodecontamination of plastic and dental surfaces with bacterial spores of *Bacillus cereus*. We tested the impact of corona discharge and transient spark in both polarities and the effect of moisture. A detailed description of our discharges used can be found in [4]. We treated spores on a smooth surface of polypropylene foil or on rough dental surfaces and in dental cavities of extracted human teeth, similar to [5].

Our discharge setup contains a hypodermic injection needle as a high-voltage electrode and a grounded copper plate. The gap between electrodes was typically 1 cm for the transient spark and 0.5 cm for the corona. A sterile circular plastic foil (2 cm in diameter) or a tooth, with a 20-μL spore suspension dropped on its surface, was placed on the surface of the plate electrode. A spore suspension contained around 10^6–10^7 colony-forming units per milliliter (CFU, every living bacteria or spore put on nutrient agar plate will reproduce and form a colony).

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Experiments with polypropylene plastic foils were made under moist or dry conditions; in both the positive and the negative corona, each discharge regime was applied to at least four samples in five series, and each sample was exposed to the discharge for 2 min. The positive corona was supplied with an HV of ~11 kV, and this formed streamers (current pulses) with a frequency of 7–12 kHz and a maximum amplitude of 30 mA. The negative pulsed corona was supplied with 8–9 kV. Its amplitude was ~0.3 mA, and its frequency was 1 MHz. When HV was further increased, the negative corona established a pulseless regime with a constant current of 0.22 mA and a constant voltage of 9.4 kV. Under physiological conditions, teeth surfaces are wet, and therefore, we treated the teeth as the moist plastic samples. So far, we did four experiments with eight dental samples. Teeth were exposed to the plasma for 3 min.

Fig. 1 shows the photographs taken by an Olympus E410 camera with long exposure times. Each picture was made from the side of the discharge. The photographs show discharges on plastic and teeth samples placed on the plate electrode and the needle (electrode above). The positive streamer corona apparently spreads on the dry plastic surface [see Fig. 1(a)] toward its edges to reach the plate electrode. It also partly spreads on moist teeth [see Fig. 1(d) and (g)], but the current is conducted through the thin layer of moisture on the tooth surface to the other side toward the plate where another discharge can be observed (1-D). The emission of negative coronas, either Trichel pulses [see Fig. 1(b), (e), and (h)] or pulseless [see Fig. 1(c)], is very strong at the needle tip and on the edges of the plastic or teeth. Despite that the negative corona does not visually fill the gap space, its decontaminating effects are evident. Transient spark, typical by visual appearance of a bunch of very luminous channels, was only applied on moist teeth [see Fig. 1(f) and (i)]. The current is also partly conducted through the moist layer on the tooth surface, but the spark channels seem to creep along the surface to reach the plate [see Fig. 1(i)]. In all cases, plastic foils or teeth represent dielectric barriers in the corona or spark pathway, so the resulting discharge has some of the properties of dielectric barrier discharges. This will be further investigated.

The results of the biodecontamination of the spores on plastic and teeth surfaces were the following (medians of efficiency and energy): The positive streamer corona was more efficient (83.2%) and more energetic (13.6 J) on dry plastics than on moist ones (76.7% and 4.9 J), whereas the negative pulse

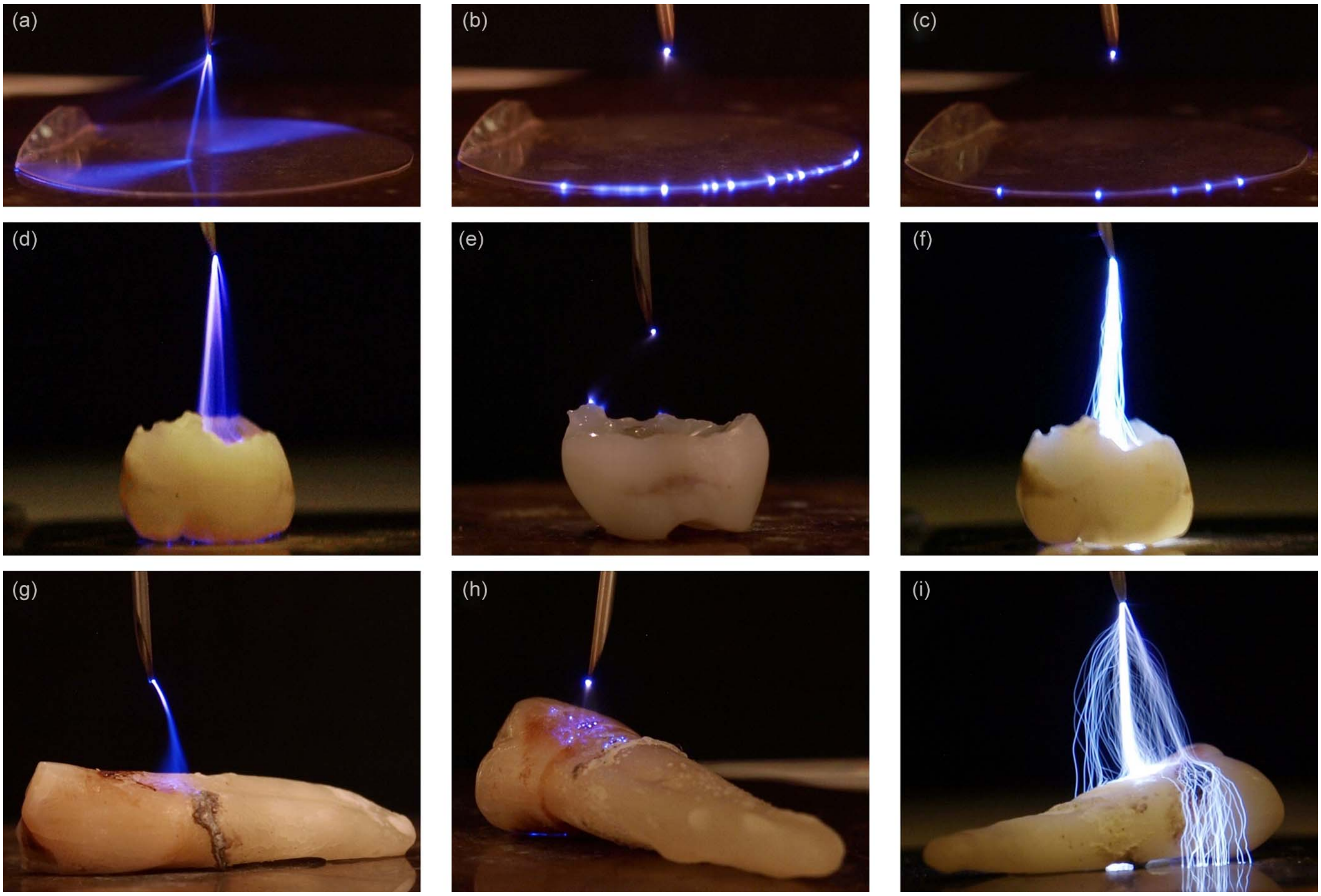

Fig. 1. Photographs of contaminated (a–c) plastic and (d–i) tooth samples with atmospheric pressure air dc discharges. (a, d, and g) First column—positive streamer corona. (b, e, and h) Second column—Trichel pulses (negative corona). (c) Pulseless negative corona. (f and i) Positive transient spark. (Exposure times (in seconds): (a) 5, (b) 3.2, (c) 5, (d) 1/2, (e) 1.3, (f) 1/2, (g) 2, (h) 2.5, and (i) 1/1.6.)

corona was more efficient on moist ones (82.8% and 17.2 J) with about the same energy consumption (15.5 J) but had the worse efficiency (79.4%) on dry samples. The negative pulseless corona was largely more energetic (274 J) and so is not so useful for biodecontamination. The first few experiments on moist teeth surfaces showed that the positive streamer corona was the most efficient (96.4% and 43.5 J) and the negative Trichel pulse corona was slightly less efficient (87.7%) but less energetic (19 J). Transient spark on moist teeth was more than ten times more energetic (831 J) but not more efficient (87.5%). It seems that it is not convenient for rough surface decontamination, which is in contrast with our previous results on the decontamination of water [6].

Our results from the decontamination of bacterial spores on both plastic and dental surfaces are satisfying, taking into account that spores are extremely resistant to adverse conditions. The next step will be the treatment of real dental surfaces contaminated by *Streptococcus mutans* biofilms in tooth cavities representing a dental plaque.

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