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Review

Cold atmospheric pressure plasma and decontamination. Can it contribute to preventing hospital-acquired infections?

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SUMMARY

Healthcare-associated infections (HCAIs) affect ~4.5 million patients in Europe alone annually. With the ever-increasing number of 'multi-resistant' micro-organisms, alternative and more effective methods of environmental decontamination are being sought as an important component of infection prevention and control. One of these is the use of cold atmospheric pressure plasma (CAPP) systems with clinical applications in healthcare facilities. CAPPs have been shown to demonstrate antimicrobial, antifungal and antiviral properties and have been adopted for other uses in clinical medicine over the past decade. CAPPs vary in their physical and chemical nature depending on the plasma-generating mechanism (e.g. plasma jet, dielectric barrier discharge, etc.). CAPP systems produce a 'cocktail' of species including positive and negative ions, reactive atoms and molecules (e.g. atomic oxygen, ozone, superoxide and oxides of nitrogen), intense electric fields, and ultraviolet radiation (UV). The effects of these ions have been studied on micro-organisms, skin, blood, and DNA; thus, a range of possible applications of CAPPs has been identified, including surface decontamination, wound healing, biofilm removal, and even cancer therapy. Here we evaluate plasma devices, their applications, mode of action and their potential role specifically in combating HCAIs on clinical surfaces.

Introduction

Healthcare-associated infections (HCAIs) present a serious risk to both patients and staff alike in clinical environments. The World Health Organization estimates that, per annum in Europe and the USA, approximately 4.5 million and 1.7 million patients, respectively, are affected by HCAIs, accounting for 100,000 and 37,000 deaths per annum.[1]

The hospital environment itself has been directly implicated in the transmission of HCAIs. High-touch surfaces may become contaminated with common HCAIs including meticillin-resistant *Staphylococcus aureus* (MRSA), *Clostridium difficile*, vancomycin-resistant *Enterococcus* spp. (VRE), and multi-resistant Gram-negative organisms such as *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and *Acinetobacter baumannii*.[2] These bacteria can survive in hospital environments for long periods in viable form; for example,

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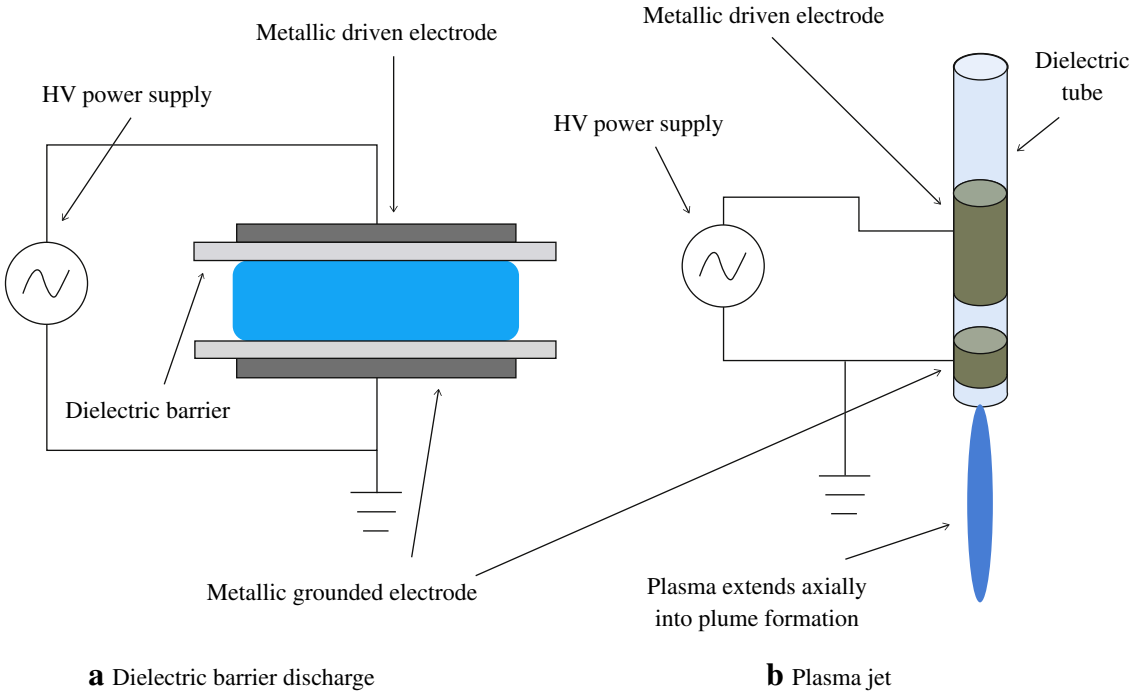

Figure 1. Main configurations of cold atmospheric pressure plasma sources: (a) dielectric barrier discharge; (b) cold plasma jet. HV, high voltage.

MRSA can persist on objects for up to seven months.[3] Surfaces frequently implicated in contamination include floors, bedrails and linen, mattresses, patients' gowns and clothing, curtains, over-bed tables, call buttons, computer keyboards, and even ambulance equipment.[4–10] Microbes may become airborne and recirculate within wards due to the physical movement of infected or colonized individuals, e.g. making up a bed and/or moving the patient.[11,12] The persistence of microbes causing HCAIs in the environment poses a risk of transmission between patients and healthcare workers due to physical contact with organisms or by virtue of airborne contaminants.[13,14]

Decontaminating surfaces involves the use primarily of water containing liquid detergents. Disinfectants such as chlorine-based fluids, quaternary ammonium-based compounds, phenolics, and, more recently, dissolved hydrogen peroxide can remove these organisms from the environment to a certain degree but not completely. The frequency of use and the reapplication is also a significant consideration.[15,16] Some high-risk medical equipment and instruments may be decontaminated using steam, ethylene oxide gas, and/or ozone sterilizers.[17–19] However, the current approaches to decontamination have certain drawbacks as some of the chemical agents pose hazards to the health of patients and staff. In addition, decontaminating soft furnishings, bed linen, curtains, mattresses, and upholstered furniture may not be possible with these liquids. Clinical downtime is also an issue incurred by the use of complex decontamination approaches such as H_2O_2 gas and UV radiation, where both procedures require the vacation of patients and healthcare staff from the treatment area.[20–22] This may pose logistical challenges for hospitals operating at maximum capacity.

As described, the use of fluid disinfectants remains the standard for surface decontamination. However, complex objects such as bed frames, lockers, and call buttons may not achieve the level of cleaning required using these procedures. Therefore, new approaches that would combine safety and efficiency in terms of minimal disruption and antimicrobial efficacy in clinical areas are being investigated. CAPP systems have been reported widely in recent times due to the development of plasma medicine. A range of novel biomedical applications has been identified, chiefly due to antimicrobial properties of CAPP systems. In addition, CAPP systems can be engineered as hand-held devices that have the flexibility of decontaminating complex geometric surfaces and materials. Here we evaluate the novel use of CAPP for surface decontamination in the hospital environment.

Cold atmospheric pressure plasma

To fully understand the use and applications of CAPPs, their characteristics and their individual effects on cells and cellular components such as DNA must be considered. CAPP is an electrically conducting quasi-neutral 'sea' of electrons, ions, and reactive and neutral molecules. The electronic/ionic component of the CAPP state is generally of the order of one millionth that of the background gas.[23–25] The electrons, because of their small mass, respond to applied electric fields more readily and so the application of electric fields to such a medium results in the electrons acquiring energies far greater than the ions and neutrals of the surrounding 'gas'.[24–26] In this way, a non-equilibrium state is achieved in which the mean energies of the electrons (some tens of thousands of Kelvin when measured on a temperature scale) are far greater than those of the neutrals, ions and radicals, which remain close to room temperature. This non-equilibrium nature of CAPP