Application of atmospheric plasma to disinfection of chronic wounds

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A large opening microwave plasma torch has been developed for the purpose of 'in vivo' bacterial disinfection. Using 2.2 slm of Ar gas flow and 85 W of microwave power at atmospheric pressure, we obtained a plasma with suitable characteristics for medical applications and treatment. Test with cultures of *E. coli* (and others) showed a bactericidal effect. The UV light from the plasma is one important agent for killing bacteria in our study, however there are other mechanisms, e.g. reactive species and charged particles.

Introduction

Study in the field of atmospheric plasma is quite active because it can combine many advantages, e.g. low cost, simple design, easy handling, and treating substances which are not resistant to vacuum. It is a potential tool for surface sterilization even on living tissues since non-thermal atmospheric plasma sources were developed. A contact-free treatment can be achieved without heating. Moreover, many chemical reactions are expected because of high energy electrons that are produced even in a very low gas temperature plasma. Due to these reasons, many low gas temperature plasma devices at atmosphere were developed for different medical purposes. An overview of the studies in this field is given in the paper by E. Stoffels [1].

In our group, a plasma device (a microwave plasma torch) at atmosphere has been developed and tested with a view to applying the plasma to a therapy of chronic foot and leg ulcers [2]. We already conducted a phase I study which examined the effect of the plasma treatment on bacteria and healthy human skins. For bacteria cultures, a bactericidal effect was observed and no visible structural changes occurred on the human skins. We have also begun a phase II study, which reviews the efficiency of bactericidal effects by the plasma treatment on wounds.

In this abstract, basic device characteristics and measurements of plasma effects on bacteria cultures are discussed.

Experimental setup and results

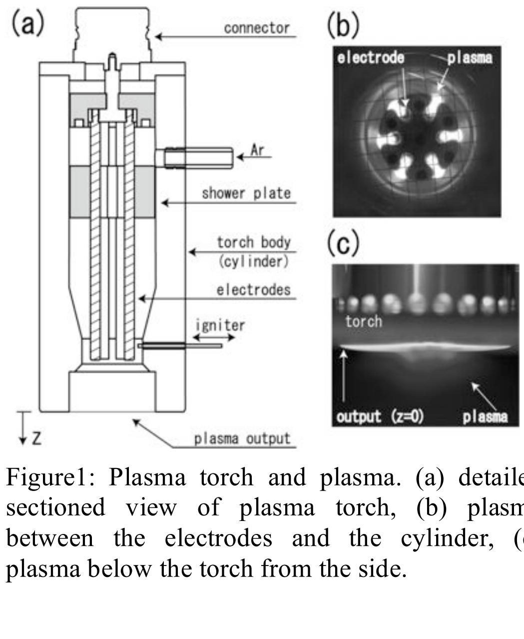

Figure1: Plasma torch and plasma. (a) detailed sectioned view of plasma torch, (b) plasma between the electrodes and the cylinder, (c) plasma below the torch from the side.

Figure 1 (a) shows a detailed view of the plasma torch. It has 6 stainless steel electrodes placed inside an aluminum cylinder of 135 mm in length. The opening of the torch is 35 mm in diameter. The centers of the 6 electrodes are distributed equally at a distance of 6 mm from the inner surface of the cylinder as shown in fig. 1 (b). In this study, Ar gas (purity 99.998%) of 2.2 slm is used to produce plasma. Microwave power at 2.45 GHz in frequency is applied to the electrodes through coaxial cables of 2 m in length via a 2 stub tuner. The microwave power is 85 W. Six plasmas are produced between each of the electrode's tips and the inner surface of the cylinder as shown in fig. 1 (b). Figure 1 (c) shows a side view of the plasma flow below the torch (the exposure time of the photo is 30 s).

We observed the plasma exposure effect on bacteria. For example, when an *Escherichia coli* culture (ATCC No. 9637) was placed 20 mm away from the output of the torch for 2 minutes, a clearly visible bactericidal effect can be found in a circle of 40 mm in diameter as shown in fig. 2. At the position, the gas temperature was below 300 K, low enough for ‘in vivo’ application.

We already tested our plasma torch for other kinds of bacteria relevant to wound healing. Clear bactericidal effects were observed after two minutes of plasma treatment [3].

From the plasma, charged particles, ROS, RNS, UV light, heat, etc. can affect bacteria. The UV light is one of the important agents for the bactericidal effect by our plasma torch. However there are other mechanisms, e.g. charged particles [4,5] in the plasma and reactive species [5,6] which are produced in the air.

We consider that this technique could be used for different medical applications, in particular wound healing, and have started a clinical study for the therapy of chronic foot and leg ulcers.

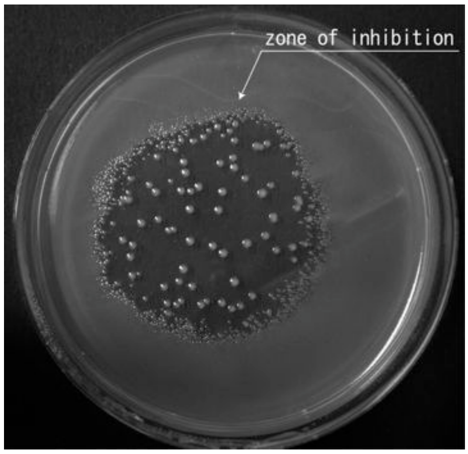

Figure 2: *E. coli* culture on an agar plate after plasma treatment. This image was taken after 16 hours of incubation.

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