The Growing Use of Plasma Medicine

Dr. S. S. Verma*

Abstract

Natural existence of plasma (a mixture of electrons, ions and neutral atoms) in the universe as a whole and its artificial generation on the earth in particular, has always been a subject of research interest. Plasma based technologies can offer enhanced quality of care at reduced cost and is going to be of immense societal and commercial value. Use of thermal and non-thermal (i.e. cold) plasmas with their exotic and reactive properties is expanding with applications in everyday life in the field of health science and technology, which is known as Plasma medicine. This use of plasma is totally different to blood plasma and convalescent plasma therapy. Understanding of various mechanisms by which plasma can be created artificially to interact with living systems, including effects of reactive oxygen species, reactive nitrogen species and charges, has begun to emerge recently. When therapeutic applications of plasma are already widely established in plasma medicine, efforts are towards using plasma medicine for bio-medical applications including wound healing, bacterial disinfection, and tissue engineering. A bright future for plasma medicine is emerging worldwide with many promising applications on the horizon.

Keywords: Cold plasma, plasma sources, plasma jets, sterilization, plasma medicine.

Introduction

We all know that from times immortal, the basic needs for living are: air, water, light, and food along with many other needs like cloth, transport, housing, medicine, etc. growing with time. In the present time, electricity, internet, entertainment and many more have also come up as basic needs towards human living. In this materialistic world, we are surrounded with matter in its three basic forms i.e., solid, liquid and gases, which human have always been exploiting for their living, needs and well-being. However, ninety-nine percent of all matter in the visible universe is in the state of plasma called as the fourth state of matter. Natural existence of plasma in the universe as a whole and its artificial generation on the earth in particular has always been a subject of research interest. After hot plasma, cold and low-pressure plasma can also be generated artificially. This kind of plasma is used in plasma medicine. Here we are discussing the plasma and its expanding applications in everyday life in the field of health science and technology called Plasma medicine. By adding energy to a gas, the electrons separate from the nucleus and move around freely producing plasma as a partially ionized gas, which shows, as an electro-conductive gas, a variety of interesting attributes. Plasma has already emerged as a very important tool in various fields of applications in industries. Some of the markets that have seen the most growth in application of Gas Plasma are aerospace, automotive, electronics, food packaging, glass, marine, medical, military, optics, packaging, paint, paper, plastics, and textiles.

Plasma Medicine

Providing healthcare at tolerable cost is one of the greatest challenges faced across the globe in present times. Technology has always played an important role in medicine and there are many medical applications of ionizing radiation, lasers, ultrasound, magnetic resonance and others. Technologies that may offer

*Department of Physics, S.L.I.E.T., Longowal, Distt.-Sangrur (Punjab)

enhanced quality of care at reduced cost, such as plasma technology, will be of immense societal and commercial value. Plasma is an ionized gas containing positive ions and negative ions or electrons, but is approximately charge neutral on the whole. Active plasma components, such as: molecules, atoms, ions, electrons and photons, reactive species, ultraviolet radiation, optical and infrared emission, and heat have the ability of activating, controlling and catalyzing reactions and complex biochemical procedures. Thermal and non-thermal (i.e. cold) plasmas - both already widely established in medicine - are used for various therapeutic applications.[1] Electrical power and discharges have been used for decades in electro-surgery for blood coagulation, tissue removal, etc. Plasma scientists have recently realized that low temperature plasmas are quite useful for various other medical treatments, including hand/skin sterilization, wound healing, cell apoptosis/regeneration, and so on.[1,2,3] These applications of low temperature plasmas represent an emerging and rapidly growing frontier in low temperature plasma science and technology. A deeper understanding of the nature of these phenomena is indispensable for future technological development. The recent tremendous progress in understanding physical plasma phenomenon, together with the development of new plasma sources has put growing focus on the application of plasmas in healthcare.

Plasma technology is a relative newcomer to the field of medicine but is emerging as a field that combines plasma physics, life sciences and clinical medicine. Plasma medicine uses plasma for bio-medical applications including wound healing, bacterial disinfection, and tissue engineering. The term plasma medicine refers to the direct treatment of human cells with plasma. Because of the potential-free nature of plasma energy, it is principally suitable for the treatment of human skin. Researchers have pioneered work on the use of atmospheric plasma systems to treat the skin by examining the impact of most varied direct and indirect applications of plasma to human skin.[4] In the process, researchers also discovered a synergetic relationship between bacteria reduction through the application of plasma (plasma disinfection) and wound healing. Plasma treatment has great use in the area of disinfection of technical surfaces in medicine, known as plasma sterilization.[5] Open air plasma jets are extremely effective in treating surfaces in continuous operation. Extensive verification and further development of jet technology are required to get to the point of using it in human medical applications. Experimental work conducted at several major universities, research centers and companies around the world over recent decades demonstrates that plasma can be used in variety of medical applications.[6] It is already widely used in surgeries and endoscopic procedures. It has been shown to control properties of cellular and tissue matrices, including biocompatibility of various substrates. Non-thermal plasma has been demonstrated to deactivate dangerous pathogens and to stop bleeding without damaging healthy tissue.[7] Further, it can be used to promote wound healing and to treat cancer. Particularly in dermatology, plasma applications hold big potential, for example, in wound healing, such as efficient disinfection or sterilization, therapy of various skin infections or tissue regeneration. Plasma Medicine has seen an enormous growth in recent years for sterilizing surfaces, but a fundamental understanding of the mode of action of the plasma in wound healing or in cancer treatment for example is still unclear due to the complex integration of plasma and biological systems. However, the development of systems for controlled medical plasma treatments presents tremendous opportunities for the future.

Plasma medicine is not to be confused with convalescent plasma therapy. The idea behind convalescent plasma therapy is that immunity can be transferred from a healthy person to a sick, using blood plasma. Convalescent plasma refers to the liquid part of the blood from recovered patients. So in this therapy, blood from recovered patients, which is rich with antibodies, is used to treat other sick people.

Growing Use of Plasma Medicine

Understanding of various mechanisms by which plasma can interact with living systems, including effects of reactive oxygen species, reactive nitrogen species and charges, has begun to emerge recently. In plasma medicine, non-equilibrium plasmas are shown to be able to initiate, promote, control, and catalyze various complex behaviors and responses in biological systems. More importantly, plasma can be tuned to achieve the desired medical effect, especially in medical sterilization and treatment of different kind of skin diseases.[8,9] Wound healing and tissue regeneration can be achieved following various types of plasma treatment in a multitude of wound pathologies. Non-equilibrium plasmas will be shown to be non-destructive to tissue, safe, and effective in inactivation of various parasites and foreign organisms. The general aim of plasma medicine is to introduce physical plasma into clinical practice. Plasma medicine can be subdivided into three main fields:

- Plasma modification of biomedical surfaces
- Plasma based decontamination/sterilization
- Direct therapeutic plasma application
- Precision is working in all three areas

Biomedical applications: Plasma energy contains free energy carriers, i.e. ions and electrons that are neither bound to atoms or molecules nor to active radicals. These free carriers include reactive nitrogen species and reactive oxygen species that can activate important mechanisms in the body. Specific molecules can be targeted as prothrombin for blood coagulation, cytokines for killing bacteria, and angiogenesis for tissue regeneration. These ions were responsible for turning these things on and off but now are able to create and control it, which have never been able to do before. Because plasma energy can allow us to control bodily mechanisms such as wound healing, in the future, healing a wound could be as simple as exposing the area to a plasma energy light. Plasma is proposed to be used in the area of surface treatment of biomedical devices using low-temperature, non-thermal atmospheric pressure plasmas, in the surface treatment of these devices.[8]

Decontamination/sterilization: Preventing and reducing healthcare-associated infections includes the effective decontamination or cleaning of the physical environment.[9] A number of causes of reducing healthcare-associated infections such as Methicillin-resistant Staphylococcus aureus and Clostridium difficile can survive for considerable periods in the hospital environment such as on hospital beds. However, many items of medical equipment are either difficulty to treat because of their physical configuration or are heat sensitive. Furthermore, many current chemical disinfectants are potentially toxic to some materials and surfaces. Gas plasma is being explored for use as a gas decontaminant in this area.[10]

Direct therapeutic application: The use of atmospheric plasmas to deposit functional coatings on medical devices is closely related to the rapidly developing area known as plasma medicine. In this area, the focus is on the use of plasmas in therapeutic applications, such as in wound care and dentistry.[1] Cold atmospheric plasmas can be applied on living tissue due to their non-equilibrium property. As a result, the plasma can be controlled so as not to cause thermal damage to heat-sensitive biological systems such as cells and living tissue.

Plasma Sources

The plasma sources used for plasma medicine are generally low temperature plasmas, and they generate ions, chemically reactive atoms and molecules, and UV-photons. These plasma-generated active species are useful for several bio-medical applications such as sterilization of implants and surgical instruments as well as modifying biomaterial surface properties.[11,12] Sensitive applications of plasma, like subjecting human body or internal organs to plasma treatment for medical purposes, are also possible. In this context, low temperature refers to temperatures similar to room temperature, usually slightly above. There is a strict upper limit of 50°C when treating tissue to avoid burns. A broad spectrum of plasma sources, dedicated to biomedical applications, has been reported during recent years, mainly two basic principles of plasma sources used are:

Dielectric-barrier discharges (DBD): A type of plasma source that limits the current using a dielectric that covers one or both electrodes. A conventional DBD device comprises two planar electrodes with at least one of them covered with a dielectric material and the electrodes are separated by a small gap which is called the discharge gap. DBDs are usually driven by high AC voltages with frequencies in the kHz range. In order to use DC and 50/60 Hz power sources investigators developed the Resistive Barrier Discharge (RBD). However, for medical application of DBD devices, the human body itself can serve as one of the two electrodes making it sufficient to devise plasma sources that consist of only one electrode covered with a dielectric such as alumina or quartz. DBD for medical applications such as for the inactivation of bacteria, for treatment of skin diseases and wounds, tumor treatment and disinfection of skin surface are currently under investigation. The treatment usually takes place in the room air. They are generally powered by several kilovolt biases using either AC or pulsed power supplies.

Atmospheric pressure plasma jets: A collection of plasma sources use a gas flow to deliver reactive species generated in plasma to the tissue or sample. The gas used is usually helium or argon, sometimes with a small amount (< 5%) of O_2, H_2O or N_2 mixed in to increase the production of chemically reactive atoms and molecules. The use of a noble gas keeps temperatures low, and makes it simpler to produce a stable discharge. The gas flow also serves to generate a region where room air is in contact with and diffusing in to the noble gas, which is where much of the reactive species are produced. There is a large variety in jet designs used in experiments. Many such systems use a dielectric to limit current, just like in a DBD, but not all do. Those that use a dielectric to limit current usually consists of a tube made of quartz or alumina, with a high voltage electrode wrapped around the outside. There can also be a grounded electrode wrapped around the outside of the dielectric tube. Designs that do not use a dielectric to limit the current use a high voltage pin electrode at the center of the quartz tube. These devices all generate ionization waves that begin inside the jet and propagate out to mix with the ambient air. Even though the plasma may look continuous, it is actually a series of ionization waves or 'plasma bullets'. Direct contact of the plasma with the tissue or sample can result in dramatically larger amounts of reactive species, charged species, and photons being delivered to the sample.

Conclusion

A bright future for plasma medicine is emerging worldwide and some promising applications are on the horizon. The general aim of plasma medicine is to introduce physical plasma into clinical practice. Direct therapeutic plasma applications as the central element of plasma medicine will bring physical plasmas directly on or in the human (or animal) body. The bases for these treatments are plasma generating devices specially developed to be applied in medical practices and hospitals. Even though initial plasma source characterization and optimization lie within the main responsibility of plasma physicists and engineers, potential users from the biomedical field are integrated at a very early stage in order to consider special needs and constraints for specific applications. This multidisciplinary research cooperation among plasma scientists and engineers on one side, and life scientists and clinicians on the other, is one of the main characteristics of plasma medicine field.

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