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The Impact of Laser Technology in Cancer Treatment

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Annotation: Lasers are a unique and powerful tool extensively used in diagnosis and therapy of several medical conditions due to their non-contact and non-ionizing behavior. Lasers are also becoming increasingly more appreciated in oncology. Besides their use in photodynamic therapy, which is their most successful clinical application in cancer treatment, lasers have established other applications including activation of the immune system to target malignancies and improvement of the delivery and effectiveness of traditional cancer therapies. Furthermore, recent technological advents have opened new perspectives for the use of lasers as a powerful instrument in oncosurgery, namely through the control of the lesion's severity, location and extension during laser ablation surgical procedures. Presented with a laser of proper wavelength, intensity, and dose, a living tissue can show a selective light absorption, in such a way that depending on the chromophores, the temperature of the tissues can be raised enough to induce a thermally destructive effect.

Lasers are revolutionizing, or have

advent of surgery with high technology lasers is expected to have a similar impact. Despite of being a recent technology, laser therapy has been used with success in several types of surgical procedures and has demonstrated a high potential for the development of new procedures and substantial improvements on traditional ones. In oncology, lasers are now starting to become an important tool for a number of different applications both in preoperative preparation procedures and in surgery, including endoscopic and precise cutting, sculpting and vaporization of malignant tissues. Due to the high flexibility in the administering of laser radiation, and to the wide availability of commercial medical laser apparatus with a large range of wavelengths, temporal emission modalities and optical fibers, laser technological improvements are expected to further change the surgical scenario of cancer treatment. Over the years, through the pioneering clinical and preclinical work of several research groups, the use of the laser for the management of cancer has been a promising therapeutic approach. Despite this, the safety and the effectiveness of the therapy is still debated and it is clear that a great deal of study is required before its introduction as a routine clinical procedure, also in consideration of the tremendous amount of possible different intervention protocols possible using laser technology.

Keywords: Laser technology, cancer treatment, photodynamic therapy, oncosurgery, medical innovation, oncology.

1. Introduction

It is impossible to ignore the growing importance of laser technology in modern medicine today. In particular, the role of laser in cancer treatment has become more significant in the last few years. The use of laser technologies in the treatment of cancer has had a remarkably quick and impressive history of development. Since the first operation using a laser in medicine, there have been numerous developments and applications of lasers in this field. It has subsequently been suggested that the combination of laser technologies and other medical technologies could substantially improve and alter the diagnostic and treatment modalities for cancer. Throughout the historical development of lasers, a number of key milestones have been achieved [1].

The understanding of laser technologies and optical fibres has improved with the geometric dimensions of these fibres becoming smaller and the quality with which they could be reproduced improving hugely. Furthermore, it became possible within a few years to transmit

CO_2 laser light efficiently. There are different types of lasers utilised in oncology. Each type has specific types of tissue having main absorption abilities in relation to laser radiation. For each of the types of tissue, other types of tissues are considered as tissues having minimum absorption ability comparing with former one. This represents an ideal model illustrating how exactly light performs treatment tasks with appropriate lasers. It can be seen that layer by layer of tissue will be removed down to normal therefore.

This model has always been the ideal view of laser treatment in cancer. However, nowadays some of these expectations can be realised by using lasers and there are clinical data illustrating their success. The exponential increase in cancer incidence over the last few years became a driving force to develop investigation into alternative methods of treating this disease. It is very difficult to precisely understand the causes of this increase. Therefore, great importance should be addressed to prevention. However, there is still the necessity of finding more effective methods of cancer treatment. Most people believe that cancer cannot be conquered; however, it is nothing but a myth and recent technological developments in medicine have proved that it can be conquered. [2][3]

Literature Review

2. Fundamentals of Laser Technology

An understanding of basic laser concepts is necessary to appreciate the complex issues involved in the utilization of lasers in the treatment of cancer. The fundamental principles of laser technology are discussed. The technology is described from its origin and the derivation of the term acronym LASER to a discussion of the specific types of lasers used in medicine today. A commonly used definition of a laser is: “Laser is an acronym for light amplification by stimulated emission of radiation” [4]. When an atom receives energy from an external source it may emit this energy as light. However, this light may be emitted in random directions with limited focus and over a wide range of wavelengths. The emission of light from an atom is called luminescence. Stimulated emission of light radiation can also take place. In this case an incoming photon of a particular wavelength interacts with an energized atom, causing it to emit a photon identical to the incoming one. The production of highly focused light in a tight beam with a narrow range of wavelengths is characteristic of laser light. The process of light amplification, monochromaticity, and coherence are described as they pertain to the operation of a laser. Many of the terms and concepts unique to the description of lasers are defined. These concepts include excitation, spontaneous emission, population inversion, resonator, threshold, Brewster window, output coupler, and power supply. Various types of lasers are used in medicine, but solid-state, gas, and dye are the most prevalent in oncology. Each of these lasers produce laser light by the same basic principles, but each is distinguished by unique characteristics that dictate how they are used. The most commonly used solid-state laser is the neodymium-YAG. Gas lasers produce laser light through the use of a high-voltage discharge or a radiofrequency discharge of a gas mixture. The argon laser and the carbon dioxide laser are the most common medical gas lasers. Dye lasers have become popular in laser medicine since their development in the mid 1970s. The parameters that are used to describe laser light in order to quantify the effects of its interaction with biological tissues include power (P) or intensity (I), energy (E), irradiance (P/A), fluence (E/A), and spectrum. Energy applied to a tissue by laser can create mechanical energy, thermal energy, or photochemical effects. The choice of laser for a specific clinical task is largely determined by the physical and optical properties of the tissue at the treatment site, and the biological response desired. The interaction of laser light with biological tissues is dependent upon the wavelength of the incident light and the physical and optical properties of the tissue. When light is absorbed by tissue, it may cause biological effects. Rightly, there is some concern regarding the undirected use or misuse of lasers on the skin by individuals who are not trained or qualified laser clinicians. Recent advances in computer technology have also contributed to the precision and ease of laser surgery. The high precision of the CO_2 laser beam has made it a workhorse in the operating room. Versatility of lasers used in different types of electrosurgical instruments, such as cutting, for percutaneous median rhizotomy and decompression of herniated lumbar disk. [5][6]

Materials and Methods

3. Applications of Laser Technology in Cancer Treatment

Laser technology revolutionized medicine and made a significant contribution to approaching a previously incurable disease. In the millennia, physicians resort to cautery to remove tumors, stop bleeding, and treat wounds. As a result, surgeons used a laser as a tool to remove or destroy malignant cells. Optimizing the combination of dielectrics in the light guide with a diode laser of the right wavelengths and powers allows conjugating thermotherapy of selectively accumulated tumor tissues with local drug delivery, reducing the systemic toxic effect of chemoradiotherapy on the patient's body. The former smoker became the first person diagnosed with non-small-cell lung cancer. Minimally invasive surgery for cancer is promising precisely because laser light sources are used for scans. The sequence of thermal coagulation of badly illustrative tissues, dissection of cope tissues, vessels and bronchi, and the final stage of formation of a durable solder seam due to laser welding of connective tissue are completed in a single program. The complex of research was to justify and investigate the possibility of multimodal diagnosis and treatment of cancer combining methods of spectral and laser-fluorescent diagnostics, as well as methods of photodynamic therapy and low-intensity laser radiation therapy using light guides for endoscopic and external exposure. Malignancies of the larynx are in one of the first places among the oncological pathologies of the ENT organ where 50% of the malignant tumors are of the glottis. [7][8]

3.1. Surgical Procedures

In the oncologic setting, there is a wide range of both surgical, hematological and pharmacological treatments for cancer. Beyond that, improvements continue: new treatments are developed, surgical techniques are refined and indeed the application of multimodal approaches is increasingly common. Laser is one very often used with other surgical procedures: associated with hemostatic techniques, diathermal scalpels, ultrasound and water-driven scalpels [9].

The advantages of the laser-assisted surgery are usually pointed out comparing it with steel scalpel-based techniques. Lasers sources are more precise in the target tissue removal, so the remaining tissues surrounding the surgical cutting channel remain unaffected. Other differences regard to the removing rate, that can be easily and precisely defined by the repetition rate of the Q-switch trigger. Leave of wounds and scabs, the minimization of post-surgery scars, control of superficial bacteriological skin contamination … are just some examples of additional benefits obtained when laser light systems are applied to medical treatments.

The control of the attainment of volumes during the surgical removal of tissues by means of the laser light sources has been one of the most studied fields in the last ten years. Advanced methodologies have been proposed and a good number of them have been demonstrated in the laboratory working on biological tissues and in-vitro experimental settings. However, clinical demonstrations are missing. The most relevant results were obtained with the Er:YAG type of laser in ophthalmologic microsurgery and recently tumoral models were obtained in liver. After this application, the laser type is mostly employed in oncology, the proliferative model and results coming from the in-vitro experiments are reviewed. The epidemiologic models of cancer are usually employed and within these types malignant neoplasms arising from epithelial cells are treated with excisional surgery. In this kind of procedures, the tumor, together with a surrounding margin of normal tissue is removed. Paraffin biopsies from the resected tissue in combination with conventional histopathological examination, allow to demonstrate if cancer cells reach the border of the removed material. If this is the case, new surgical procedures are carried out and vary depending on the kind of cancer and the variety of its spreading. In most cases, a new surgical intervention following curative intent is scheduled. Paraffin biopsies are employed to precisely identify remaining neoplasic cells in the border tissues, so called "positive margins.”

3.2. Photodynamic Therapy

Photodynamic therapy (PDT) is an important application of laser technology in cancer treatment. PDT is found to be a clinically approved, minimally invasive treatment that uses the combination of photosensitizing agents and light to specifically destroy cancerous cells when irradiated with light of a defined wavelength. The benefit of PDT is, in part, that it can be applied to a wide range of cancers and the technique can be used multiple times for the same patient and at different times during cancer progression. This is a significant advantage over many other therapeutic interventions. A key feature of PDT is that where the cells absorb light they become inactivated and destroyed. Thus, direct intravenous drug administration can result in high drug concentrations in the tumour which can absorb the therapeutic light whilst normal (non-cancerous) cells, which are not light-absorbing, will remain largely unaffected. From a clinical perspective, the treatment is attractive because it can be applied locally or systemically, and in highly focal-specific formulations, it is minimally invasive with low long-term toxicity for the patient. A topical drug application for skin cancer or in situ bladder cancer, or an implanted optical fibre irradiation for brain cancer, are common and widely used delivery systems.

PDT is based on the combination of a photosensitizer that preferentially accumulates in the tumour and light of a specific wavelength. When PS is activated by a light with a certain wavelength, ROS are generated. ROS are a group of reactive compounds including singlet oxygen that are able to kill cells. The cytotoxic effect is mainly produced immediately around the illuminating point, so that 1 mm2 of healthy tissue can be spared. These effects can be produced a specific number of times until the PS is completely extinguished, resulting in a high reproducibility along the treatment [10]. Until now, three dozen commercial photosensitizers with different properties have been developed for PDT, so that available in different wavelength of excitation, emission, and biocompatibility. Data on a clinical experience with over 41,000 patients among several types of neoplasms at different anatomic sites are given. Details on the light sources adopted and the treatments performed are reported. The overall complete response rate is equal to 72%. It has been found that PDT can eradicate completely tumours with a diameter <2 cm. Possible correlations between the treatment outcome and tumour size as well as photosensitizer properties are investigated. The rate of erythema and oedema in recurrent breast cancer was found higher than in primary lesions [11].

Results and Discussion

4. Advantages and Limitations of Laser Technology in Cancer Treatment

Introduction Laser technology has brought significant benefits to medical applications, including dermatology and surgery, as well as in diagnostic and imaging applications [10]. More recently, numerous variations of laser systems have been applied or proposed for cancer therapy. Currently, most new applications are at the experimental stage or are in preclinical trials. Nevertheless, research and development are active in the field; these activities involve many different photonic devices and methods, few of which share the same operating principle. The impact on cancer therapy of these evolving laser systems could be of key interest considering the trend toward personalized therapy and solving accessibility and compliance issues related to chemotherapy [12].

Advantages of Laser Technology - Lower side effects and quicker recovery: Minimally invasive laser therapy enables localized efficient destruction of the tumor/tissue, causing much less damage to surrounding areas. This type of therapy is often performed on an outpatient basis. Substantially less repair and regrowth are required, and in consequence, wound recovery is substantially quicker compared with traditional surgery or chemoradiation. Patients report substantially lower physical fatigue and psychological distress. - Precision: Localized, extremely precise treatment is possible using specific PS, particularly for superficial cases. A great variety is available, each absorbing light at a well-defined wavelength and each may be linked to the specific pathology. Light can be delivered directly to the tumor tissue or photoactivated in vivo. The ability to deliver light through endoscopes allows the treatment of small or distant tissue without causing damage to neighboring healthy tissue. This feature is particularly useful for cases where the tumor is close to fragile vital structures. Light can also be delivered through thin fiber optic needles that have been implanted directly into the target area. Lasers, like photons, are monochromatic and collimated. The monochromatic emission can be matched with the absorption spectrum of the PS, hence the laser platforms generating the required wavelengths constitute an efficient light source for a specific drug-tumor system. Considering the required power density is extremely low, and based on the behavior of light, a highly collimated laser beam will be transmit and deliver a substantial amount of light to the target. - Multipurpose: Highly versatile laser applications are possible depending on the selected therapy. PDT can be used as a stand-alone treatment in the early stages of the disease or after surgery or as a palliative treatment. PDT can also be used concurrently with surgery. In this case, the PS would not just destroy the tumor but also act as a tracking tool. In addition, PDT can activate the PS and ablate any residual or microscopically scattered diseased tissue hence fulfilling the purpose of adjuvant therapy. PDT can also be used after radiation therapy, simultaneously with it or during the recovery time, if required. On the other hand, the possibility of applying the laser beams in a scanning, raster, or volumetric converging scheme has a range of potential medical applications. The technology can be applied for the ‘sculpting’ or debulking of tumors in surgery or for the selective ablation of pathological tissues in internal organs, where it is difficult to intervene with conventional surgery methods. Laser can also act as a ‘virtual knife’, opening up the potential for surgical procedures in MRI/PET imaging. The multipurpose aspect can be greatly enhanced if synchronized beams are exploited. A great potential at the clinical level, to investigate possible combinations of laser beams in the 600–1100-nm wavelength and sources of UV, X-rays, or charged particles beyond classic PDT. In the case of charge particles, the impact on the tissue could be monitored via secondary prompt radiation so that the colorimetry technique could be implemented for very precise, selective, and real-time dosimetric purposes. [13][14]

5. Future Directions and Emerging Technologies

This article underscores the bright future of a laser regarding the technological development and cancer treatment. It explores various laser applications and potential avenues to address cancer. Among them, promising therapies are discussed including photodynamic therapy, laser thermoablation, laser-induced immunotherapy, laser-induced drug delivery, and laser particle delivery. Several novel laser applications are also presented. With the rapid advance of light sources and delivery devices, lasers have become key tools in photomedicine and photobiology. The implementation of laser systems allows precise delivery of laser light to the target tissue and cells. Combination of lasers with photosensitizers improves the effectiveness of photodynamic therapy. Lasers also induce heating and cooling of the tissue, facilitating surgical treatment. Besides, with rapidly developing biophotonics techniques, lasers provide a useful tool for a wide range of biological, biochemical, and clinical applications. Given the wide range of laser applications, a multidisciplinary approach shows how the close collaboration of chemists, physicists, biologists, technologists, engineers, and medical professionals opens up new avenues for treating cancer with the bright future of laser technology.

In recent years, great attention has been paid to the use of light technologies in the treatment of cancer. The most dynamically developing trend is laser therapy, which is used as an independent therapeutic method or as an element of various therapeutic approaches. The rapid progress in the development of laser technology results in the implementation of innovative coherent light sources with a wide range of parameters. This review presents discussion on laser engineering, including their construction and characteristics, as well as a list and description of types and properties of lasers used in oncodermatology. [15][16]

6. Conclusion

In the world of medicine, lasers have brought about a variety of techniques that have fundamentally changed the way surgery is performed and patients are treated, and they have created an alternative method for drug delivery. Aside from cutting and coagulating tissue, lasers are now commonly used in oncology to treat patients suffering from a range of cancers. One common procedure for the treatment of cancer is surgery. The removal of tissue is performed by cutting it open and excising it. Excising tissue results in a mechanical damage along the cutting edge of the treated tissue. The scissors, knives, or lasers can be used to cut this tissue.

A variety of studies have shown that lasers are just as good as knives for cutting with respect to pain experienced by the patient during surgery. Of the various lasers and other light sources available, not all are equally effective for every medical treatment. An illustrative example of the use of lasers for cancer treatment is photodynamic therapy. Photodynamic therapy is a treatment where a patient is given an intravenous injection of an organic compound called a photosensitizer. The photosensitizer accumulates preferentially in cancerous cells. The tumor is made light sensitive by the photosensitizer, and light is used as an external or internal source of energy to selectively destroy the tumor.

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