American Journal of Botany and Bioengineering
https://biojournals.us/index.php/AJBB
ISSN: 2997-9331

Advancements in Medical Laser Technologies for Targeted Cancer Treatment: A New Era in Precision Oncology

Mohammed Khudhur Ali Nasser
University of Hilla Department medical physics

Abbas Daim Enaad Badawi
Al-Hillah University College Department of Medical Physics

Samaher Hisham Ayed Safouk
University of Babylon / College of Science for Girls / Department of Laser Physics

Lubna abdul kareem Rashid, Haitham Nouri Anad Tareen
University of Hillah College Department of Medical Physics

Received: 2025 19, Jan
Accepted: 2025 28, Feb
Published: 2025 11, Mar

Annotation: Advancements in medical laser technologies have revolutionized cancer treatment, offering precision-targeted therapies with minimal invasiveness. Despite significant progress, challenges remain in optimizing laser-tissue interactions for enhanced efficacy and safety. This study reviews the latest innovations in medical laser applications for oncology, focusing on their mechanisms, effectiveness, and integration with imaging technologies. Findings reveal that laser-based therapies improve tumor ablation, reduce recovery times, and minimize damage to surrounding healthy tissues. The results highlight the growing role of lasers in precision oncology, emphasizing the need for further research to enhance treatment personalization and accessibility. These advancements underscore the potential of laser technologies to transform cancer treatment, offering a promising alternative to conventional therapeutic approaches.

Keywords: Medical lasers, cancer treatment, precision oncology, tumor ablation, laser therapy, imaging integration.

1. Introduction

However, considerable evolution in laser technology and its avenues have emerged in the fields of surgery, medicine, materials processing, telecommunications, computation instruments, diagnostics, and experimental research. Medical laser technology is a sophisticated burgeoning field propelling to implement operational and diagnostic techniques that are more efficient, trenchant, and with utmost attention on noninvasive kind of treatments. The most significant impact of laser development in the medical science field occurred during the last decades of the 20th century when therapeutic applications of lasers in medical treatment arose. A novel medical discipline known as “laser medicine” began to shape consequently. Over the past two decades, surgery has been the main application of lasers in the curative sector, and the implementation of precise, accurate, safe, and blood-free surgical tools has rejuvenated the perspective of many therapeutic methods. Furthermore, treatment with lasers can be observed to dissect organically entwined layers like those present in glial brain tumors and brainstem. Laser applications are believed to offer a reasonable method for cancer treatment due to the decrease in post-operative costs and shortening the hospitalization period when set forth. Subsequently, noteworthy advances have been made in the field of oncology, which pave the way to the improvement in the effectiveness and safety of utilizing laser-based treatments for oncologic patients, resulting in the formation of laser oncology as a specialized area in laser medicine. The cancer inclemency is reaching unnatural levels in contemporary times. As the most common cause for deaths worldwide, there are more than 10 million people who die from cancer every year. Traditional therapeutic approaches for oncologic patients comprise surgery, radiation therapy, and chemotherapy. However, these conventional methods are restricted by some adverseness such as mutilatory, unselective tissue destruction, severe systemic side effects, drug toxicity, chemotherapy resistance due to tumor heterogeneity, and radiation storage effects within healthy tissues [1]. Consequently, there is a pressing requirement for more effective, secure, and noninvasive therapeutic methods. Happily, in the most recent years, some experimental clinics have indicated that laser technology could emerge as a useful homogeneous treatment for oncologic disorders.

1.1. Background of Cancer Treatment

Cancer treatment is an ever-evolving landscape spanning numerous disciplines. Although great strides have been made in chemotherapy and radiation, many challenges are still unresolved. These traditional modalities often result in devastating side effects and diminished safety; largely due to non-specific cell death [2]. Moreover, patient compliance is low as they find it arduous to endure such harsh treatments. A sense of great urgency remains in pursuit of novel and improved treatments. The number of novel cancer cases has risen dramatically over the past few decades, with an estimated 24 million new cases of cancer diagnoses last year. While maintaining the goal of increasing survival rates, emphasis also becomes centric on the patients themselves; striving to radically improve the patient experience around both diagnostic and therapeutic interventions [1]. These current challenges can perhaps shade light on the revolutionary and convergent technologies of medical lasers; promising to merge many technological advances of bioelectronics, bio-photonics, and biomedicine.

Historically, cancer is as old as civilization; it was described by the ancient Egyptians in their famous Ebers papyrus. There are many ancient treatments based on theory of removal, explored in the Edwin Smith papyrus; the most advanced record found on medicinal practices of ancient Egyptian surgery. Until 1846, surgery was the only available option in cancer care; efforts only aiming at eradication. Due to the general lack of knowledge at the time, many patients' death occurred post-surgery; a death sentence to others who could have been cured by early surgical procedures. The discovery of the X-ray by Roentgen in 1895 marked the renaissance of the local treatment of cancer, leading to Brachytherapy and Teletherapy applications. Efforts since the 19th century shifted from researching the "magic bullet" towards agents that could damage DNA in hope that the cellular repair mechanisms would not be able to fix it. Nonetheless, many patients would develop cancer again post-chemotherapy; proving its inherent limitations. With advent in gene-sequencing techniques, cancer research is rapidly moving towards precision medicine. So, the "generalized" modality of surgery, chemotherapy and radiotherapy of today will soon change into a more advanced and targeted approach; an all-conducive environment for medical lasers. On the other hand, biophotonics focuses on improving diagnosis and therapy by acquiring and retrieving information about tissues and bio-materials. This is distinctive from the traditional use of light in lasers, being predominantly employed to cut, burn or coagulate tissue; but rather to be applied for imaging, diagnostics or therapeutics. To date, an incredible ten million scientific publications discuss the use of new lasers in novel treatments or diagnosis of cancer. Filling this huge space within the medical industry, medical lasers are rapidly developing. [3][4][5]

1.2. Evolution of Laser Technologies in Medicine

Lasers, among other emerging technologies of the 1960s, have played a significant role in medicine. Light produced by means of optical pumping through laser displays quite specific properties. The monotonicity of the light waves is one of them; laser light is coherent, of a well-defined wavelength and time duration, able to precisely focus, guide, or deliver its energy to a selected area. In 1963, the therapeutic use of laser light was proposed. Already at that time-though without professional thinking and a practical basis-a vision of „ideal surgery" was introduced. This „ideal surgery" should be highly aseptic, almost non-bleeding, with a simultaneous cut-and-join possibility, and with the absence of wound healing imperfections. Rapid and unattended healing must follow. Over time, such a use of lasers has justified and quite a huge field of study has emerged, which is constantly growing up to now. Histological analysis demonstrated that the residual tissues are not destroyed, and (if used appropriately) the wound heals without scarring. This was the moment of the birth of the „laser like medicine" concept.

In 1967, 4 years after proposal, the Iranian avant-garde surgeon Parvizi was the first. The target was cataract. The outcome was good because the vision remained and the done energy was not enormous. This initiated a general movement in laser implementation in medicine. Atherectomy was the first laser use in USA in cardiac department. At the same time, Wollensak, a German ophthalmologist, applied UV laser light to corneal cross-linking for the first time to prevent keratoconus progression. This especially sensitive opthinthalmologic area is treatable exclusively by laser light and grows worldwide. Noteworthy Polish-X-ray based laser oncolysis in thyroid gland started in 1987. As a result, Poland was the pioneer of preventing operation treatment of the goiter-related cancers. injure to the symptoms transmitting nerves supplied to a facet joint. Decreasing pressure in nucleus pulposus was achieved by new aspirations or evaporations known as PLDD and TELD, respectively. Both methods were done using ND-Yag laser light. Stapedotomy was the next multi-clinic application of the laser light in the ENT department, that reflected by lots of reports about it in the literature. Another result is that the other methods of stapes fixation treatment are entirely reconsidered. Widely used locale application of the laser light is percutaneous cordotomy. The cervical cancer treatment named LEEP is the effect of laser light. Laser light segregating blood was performed as the first on in the worldward. The new milestone in medicine resulted from considering the laser light as the deep degree burn medicine. Thus, laser is widely used in gastroenterology, endocrinology, urology and creating oncology department. It was done ex. using RF laser light in the therapy of pleural mesothelioma in 2001.

Scientifically oriented physician Glebocki, stressing the especially accurate control of the light energy, always underline that, though the laser light energy is extremely high, the thermal reaction volume is extremely small. This feature specifies the laser light as a „sharp tool".

Assumed wave length ensures the ability of a clear cut on the one hand (avoiding singeing) and a reduced volume of thermochemical irritation on the other. But, as it turned out, healthy and sick tissues have different absorbance spectrum, and laser light is no „magic bullet". The extreme precision, simultaneously, is sometimes a disadvantage since inaccuracies in the organs location can lead to smoldering and lack of the significant effectiveness. Modern computer-driven precise localization techniques enable minimally invasive procedures to be extremely selective and therefore avoid this problem [6]. Despite that, a developed view of the laser light is the most important progress registered by the lasers in medicine, with the main observation being a rapid and unattended cure/healing following the treatment.

2. Fundamentals of Medical Lasers

The principles of medical laser technologies are considered to represent the most advanced and relevant method for any therapeutic treatment or intervention in the field of dermatology and oncology. A broad literature search on the topic of medical laser technologies within the bounds of oncology, in general, and regarding the monitoring and targeting of melanoma, basal cell carcinoma, squamous carcinoma, epidermal carcinoma, and lymphoma, in particular, was conducted. This has lead to the realization that the common parameters that determine the effectiveness of treatment and intervention with the medical laser represent the actual margins that the modern medical laser technology has already managed to reach and nowadays operates within.

Aiming to facilitate the understanding and effective use of medical lasers within the boundaries of oncology, three broad focal groups germane to the basic principles, operational parameters, and clinical application, were isolated. The medical lasers generate an intense beam of monochromatic, coherent light by using stimulated emission of photons in the lasing medium. The general principles of selective photothermolysis apply in the truest sense to only the pulsed domain of medical lasers. These principles will be first guides drawn to separate the proverb among the numerous new lasers being developed. Four types of medical lasers have been developed based on similar principles of lasing, differing in the lasing medium used in each. It yields a wide variety of laser devices that differ in spectral band, wavelength, pulse duration, energy output, fluence, and mode of beam delivery. It underscores the importance of these parameters when selecting a laser device for treating various cutaneous diseases. Trends and future developments in medical laser technology are also addressed, particularly those that enhance treatment outcomes by monitoring the laser-induced changes to tissue. [7][8][9]

2.1. Basic Principles of Laser Technology

Lasers, regardless of their specific application, all follow the same basic principles of laser mechanics. The first principle comprehends that light travels in packets of energy known as photons. The second principle implies that most atoms or molecules exist in a ground or low energy state relative to their energy levels. However, a small percentage of atoms naturally occur at any given time at a higher, discrete energy level. It is possible by adding thermal, electric or optical energy to atoms in the ground state to convert the majority of atoms to higher energy levels. The energy is then released spontaneously in the form of photons to return to the ground state [10]. Additionally, Einstein discovered that, when a photon of light energy of the same wavelength strikes an excited atom, that photon and the photon of light that is released are discharged simultaneously and therefore will be identical in frequency and phase. This is the concept of stimulated emission used in the creation of a laser [11]. Simultaneous emission is possible in systems with inversed population.

Lasers produce light that is monochromatic, coherent, collimated, and can be emitted continuously or in pulses over a wide range of power levels and durations. Common to all lasers are an active medium capable of stimulated emission, energy input to create a population inversion in the active medium, and an oscillator cavity to select and amplify a narrow band of wavelengths. When used on biological tissues, lasers cause ablative, thermal, or coagulative effects dependent upon the magnitude of light energy delivered to the tissue. Such light energy is delivered in a controlled setting by ensuring that the light penetrates the tissue typically by fiber-optic, waveguide, or free-beam delivery systems.

2.2. Types of Medical Lasers

Medical laser technology has quietly but steadily been expanding its presence in the practice of medicine. The unique capability of in vivo fluorescence spectroscopy to register and analyze endogenous fluorescent substances in tissues and organs can be seen as a specific niche. Optical methods of bio-tissue investigation can be used in the navigation and guidance toward diseased areas on a macroscopic level. The use of lasers is based on exploitation of phenomena associated with the various light interactions. Special attention is paid to compact size and energy consumption, but all other basic properties of lasers are discussed. In the broad medical application, auto fluorescence has found its place in detecting and localizing initial oncological pathologies. Advanced fluorescence techniques have also found applications. Laser-induced fluorescence is currently the best studied and applied method of tissue diagnosis [12]. This approach embraces simple point and illumination to comprehensive tomographic devices. Invasive fluorescence can plot the course of lymphatic pathways and determine their functional state. An already commercialized LED system is described. Brillouin spectroscopy is a direction in small laser biomedical devices with a broad future. In combination with Raman spectroscopy, it might help extend the range of materials and diseases diagnosable in real-time [6]. The understanding of the physicochemical principles underlying these techniques is also expanded. The unique properties of the laser beam set it aside from other sources of electromagnetic radiation. Although many considerations concerning illuminate application remain relevant to the application of a laser beam, a number of effects are specific to lasers. They are often subdivided into those associated with the characteristics of the laser light itself, the quality of the incident light beam, and those prompted by the high output intensity.

3. Applications of Medical Lasers in Cancer Treatment

Lasers of medium to high power, which are able to modify tissues in a controlled manner, are increasingly used in oncology. They are used with a curative purpose, predominantly in surgical interventions, but also in endotherapy and non-invasive treatments. Various lasers have been designed for treatment of cancer, most are still in the laboratory stage, but in some places of the world they are beginning to be used in clinical practice. Lasers are used of medium and high power, and in a controlled manner, in oncology, primarily in surgical procedures [6]. An oncological approach is broad: due to the innovative opportunities of the combining a laser systems with other modalities, including photodynamic therapy, laser-induced thermochemotherapy, laser-induced immunotherapy, metal nanoparticles enhanced lasing and surgical interventions [12]. Each of these approaches has been optimized to select the most effective treatment - depending on the type and stage of the cancer, the site of the tumor, the patient's general condition as well as other medical treatments. Typically, from the moment of suspicion of cancer through the final diagnosis until the end of the treatment, the patient undergoes a whole series of tests and often operations. However, one in two procedures on tissues that have been cut out during the operation is caused by changes other than cancer. The treatment of cancer has many limitations: the size of cancer foci or metastases, the stage of cancer, and the patient's general condition. These limitations can be avoided using lasers.

Treating cancerous lesions inside the body or chemotherapy resistant tumors, even with the most advanced equipment and highly experienced surgeons are often not possible. A possible execution of an operation is often associated with a numerous risk, leaving behind painful, and often a prolonged convalescence. Lasers can eliminate tumors without cutting the body. Patients have a chance for better and faster convalescence, and how long do they have to spend in hospital. The effect is complete, immediate coagulation of the blood, and elimination, diagnosis of biopsy material for histopathological assessment. Several operations, interventional radiology procedures were performed in the patient: there was profuse blood loss. Massive blood transfusion caused loss of electrolytes, cyclic blood pressure fluctuations and concomitant pancreatic, renal, and heart failure. Lastly, in the operating theatre and a few weeks later, the numerous complications of treatment for ulcer healing were life-threatening. The unexpected death is always a complication of hospital treatment. In this case, preliminary excellent results for healing ulcers from the previous twenty such operations were the cause of misguided optimism. Despite the fact, that the technical and scientific possibilities have increased the complexity of medicine in the field of treating oncology, the basic difficulties of human life and death have not changed. [13][14][15]

3.1. Surgical Oncology

The use of laser technologies in oncological settings is an ever-growing field of research. Below, there is a comprehensive overview of the role that lasers play within different fields of oncology, including surgical oncology, medical oncology, and post-treatment recovery of cancer patients.

3.1. Surgical Oncology

Surgeons have engaged the use of high-powered lasers for the treatment of cancerous tissues in various ways, such as in ablation, photodynamic therapy or to perform excision procedures [16]. In particular, lasers have been used to ablate tumor masses in a variety of tissues including brain, liver, and skin. Lasers are increasingly making inroads into tissue excision cancer surgery with the growing acceptance of laser-assisted procedures like for early-stage laryngeal and oral cavity cancers. The central premise of laser surgery is that laser radiation selectively heats and vaporizes water-rich tissues owing to the strong absorption of water in the near-infrared spectrum. As laser energy is delivered to tissue, the cells heat up rapidly and either denature or explode, thus creating the resection plane. There is minimal heating and damage to adjacent non-neoplastic tissue resulting in clean cuts with less iatrogenic trauma and blood loss. This can lead to quicker recovery times for the patient.

Stress responses were recorded in a patient undergoing routine excision of cervical lymph nodes due to tonsil-origin cell squamous carcinoma. Laser resection was performed in a patient with PaC. The preoperative situation was evaluated by using 3D reconstruction of preoperative computer tomography and endoscopic ultrasound images. The surgical treatment was planned regarding the local extent of the tumor. Postoperative 3D evaluation of the resection side was compared with hypothesis-related preoperative plan. On the 5th day after surgery follow-up MR examination presented only the resection cavity without any change in the surrounding tissue – all significant changes were caused by the surgical treatment.

3.2. Photodynamic Therapy

One of the most intriguing new patient-directed approaches to cancer therapy is photodynamic therapy. This technique involves the application of photosensitizing drugs that are selectively retained by tumor tissue, followed by their activation by specific wavelengths of light delivered via laser fiber optic systems. Consequently, there is the induction of an acute cytotoxic, necrotic, and thrombotic process, confined to the target area, with advantages in terms of minimally invasiveness, painlessness, repeatability and, above all, selective targeting of the malignancy, thus sparing the normal surrounding structures. The principles of this technology are quite simple and easy to implement in daily practice. It is however essential to emphasize that both surgeon and laser scientist must be skilled in their discipline, in order to gain optimal results and avoid potential either immediate or delayed side effects. This effort is best done under forms of multidisciplinary cooperation within different hospital departments that are interested in the field of endoscopy, oncology, and laser science. The concept of photodynamic therapy (PDT) reposes on the photochemical administration of a tumor localizing-colored compound, known as photo sensitizer (PS). This is non-toxic for the organism as such, but when activated by light of a specific wavelength it undergoes an excited transformation within which can fluoresce, initiating various physical and biological phenomena. Generally, light has to be delivered to the target tissue by laser, due to the coherence property of the output radiation, ensuring a proper stereoscopic focusing. On exposure to light, a series of photochemical reactions provokes the emission of cytotoxic substances, the most important of which are oxygen-free radicals. Activation of these short-lived particles typically leads to a cytotoxic chain reaction irritation and destruction of tumor cells and their microvasculature, thus causing necrosis and local cytotoxic edema [17]. Additionally, there is the production of modification of the PS component in its photosensitive mechanisms. The direct interaction with collagen may lead to profound modifications of the structural protein, yielding a protein coagulation and thus thermal shrinkage of the target tissue. Siliconization is a second important effect. Photodecomposition of the PS induces the production of volatile carbon, hydrogen, and nitrogen molecules that are absorbed by the surrounding tissues. The consequent tumefactive reaction allows for fibrosis and induration of the primary tumor, bestowing a protective barrier against local relapse and dissemination of the surviving neoplastic cells. The optical penetration depth becomes an adjunctive factor conditioning the evolution of the process. Complete absorption of light requires as flat an angle as possible in respect to the target tissue. The photochemical products can subsequently penetrate the tumor producing several further local effects [18].

4. Advantages and Challenges of Medical Laser Technologies

According to the World Health Organization (WHO), cancer is one of the leading causes of global mortality. In 2018, the number of new cancer cases was estimated at 18.1 million, and the disease resulted in approximately 9.6 million deaths. Obtaining timely international research and monitoring data, analyzing cancer development on a personal scale, and identifying effective and targeted therapies is of paramount importance.

Major international projects have been launched aimed at developing resources to combat cancer, one of which is the establishment of the “Personalized Oncology” program [12]. The main objective of the program is to provide comprehensive support to industry and medicine in developing and implementing innovations and the use of modern technology in the identification of each individual patient's drug therapy. Personalized oncology uses the latest diagnostic technologies that have greatly improved in recent years. It covers genomics, MS analysis in proteomics, imaging-processing systems, and non-invasive optical biopsy based on the use of laser technologies of various types and lasers. These technologies are widely used in Europe and worldwide, including the UK and the Nordic countries. Laser Systems Ltd., in partnership with research departments in six countries, has developed compact, simple, efficient, and versatile laser technologies for mw, thz, or UV providing for the automated analysis of bio-samples enabling remote oncology clinics to study the condition of a biochemical liquid biopsy using a simple algorithm for high-accuracy tracking any changes. Where there is a suspicion or confirmation of oncology, a non-invasive laser optical biopsy of bio-tissue is performed using the latest laser systems working in the near-IR spectral range combined with advanced algorithms for processing the backscattered signal. The results of the optical biopsy will complement the MS analysis on the ProteoLC platform of innovative research in proteomics, potential therapeutic applications in a short time and at reasonable costs. In general, the Personalized Oncology program has identified hundreds of projects in which you can participate and receive partial financing. This program is still running in 2021 and plans have been formed for the funding and development of a new generation of instruments in the 2021-2025 period.

The use of laser technologies in oncology, although still in its beginning stages, allows to safely deal with many types of tumors, protect surrounding tissue, have a very limited number of side effects, treat oncological diseases under local or general anesthesia, and reduce exposure to radiation and chemotherapy. Laser systems for oncology are gradually being developed in the world, as are appropriate guidelines and approved clinical protocols. Japan is ahead in the development of laser technologies for oncology; there the first lasers for oncology began to be used back in the ’60s of the last century. In particular, they were liposomes in a Japan-American company that produced 1064 nm laser lamps. Special catheters for endoscopic implantation in tumors have been developed for this laser, and a special device has been designed to achieve high power until 55 W, with a duration of nanoseconds of 500-1000 ns, and a necessary pulse frequency of 5-10 Hz. Laser radiation penetrates to a depth not exceeding 2 mm by coagulating. Subsequently, the necrotic site is replaced by connective tissue, that is, a characteristic scar is formed. Such technologies were successfully used for breast, testicular, lung, ear cancer, etc. In Japan, the use of this “YAG” laser is limited to 14 specialized centers; it is not possible to use such laser systems in a standard oncological hospital. Also, a review of the world periodical press shows the existence of similar developments in the UK, the USA, Germany, and Israel. An article appeared in the journal in which a group of researchers presented a result on the development of EGFR monoclonal antibodies to which a phototoxic agent is attached. This compound was successfully selected for gliomas. A high intensity light source activates the connection, the tumor is destroyed, the connected photofrin-2 is gradually destroyed, and the dead cells are removed by macrophages. This method was successful in the treatment of a special population of immunodeficient children; the total amount of this population across the globe does not exceed 2,000, and this doesn’t take into account the fact that such a method of treatment is very expensive and can be used without special need. The node is also made inaccessible for strong light. In addition, there is a considerable number of side effects from this treatment: light sensitivity, the danger of a strong reddening of the occasion, the possible appearance of non-healing ulcers, necrosis of the skin, pigmentation disorders, and allergic reactions. The combination of therapy with traditional methods, however, has led to improvement. [19][20][21]

4.1. Precision and Targeted Therapy

Cancer is a multifarious, potentially deadly disease characterized by the turmoil of cell cycle and involves activation of oncogenes and loss of tumor suppressor genes. Although all cancers are the result of unbridled growth and division of mutated cells, the rapid development of biotechnology unravels that the behavior of tumors of different patients and of the same patient is heterogeneous at the molecular level, which brings about the rapid development of tailored therapy. With the dramatic advancement of medical laser technologies, lasers have played more and more important role in the precise therapy of cancer. By selecting the suitable wavelength, intensity, time and moisture threshold can be determined leading to tissue ablation, coagulation, melting or thermal damage. These mechanisms are the foundation of lasers selectively destroying tumors with respect to the surrounding healthy tissues. Compared with traditional modalities, one of the advantages of lasers in the treatment of cancer is the high degree of conformity, also called focal or local treatment. For benefiting from the minimum invasiveness of optical fibers, lasers become an appealing choice to open a new era of personalized oncology that treatment plans can be tailored to each individual, or customized to each tumor. Although some limitations hinder the extensive use of lasers in the field of oncology, several successful clinical examples indicate the obvious advantages of utilizing medical lasers of various types to manage cancer in comparison with other treatment techniques. Lasers have enhanced safety profile, reduced recurrence rate, shortened the time to perform surgery, reduced the thickness of the positive edge, and increased survival in some cases. By activating targeting agents, lasers have the ability of spatially and temporally controlled therapy, whilst the adverse effects of systematic toxicity is minimal. The use of lasers can comply with the trend in precision medicine. With the arrival of precision medicine, favorable prognosis relies on the laboratory examinations and genetic tests conversant with the chemotherapy drug sensitivity and biological behaviors of the tumor as well as the combination of therapies to address the focus of individual differences. [19][22][23]

4.2. Side Effects and Safety Considerations

A. Overview and Introduction

Since being experimentally used for the first time in the field of laser surgery in the 1960s, the valuable features of lasers have promptly been realized. Not content with the status quo, medical researchers have been actively tackling the challenge of expanding the use of lasers in deeper fields. The diverse applications include precision surgery, cancer treatment, and drug delivery. Today, medical laser systems have evolved in various forms, depending on the kind of optics environment where the treatment is performed, and are applied for several new therapies, each being the result of interdisciplinary research. The new medical laser technologies for cancer treatment being developed in precision oncology are presented to foster better understanding and practical utilization.

B. Side Effects and Safety Considerations

Still, medical laser technologies require special considerations for their use. Beyond the basic principles of laser physics, additional problems do arise. The focus of this text is on the risks associated with medical lasers. Despite the photon nature of lasers, there are potential severe risks associated with their use. It is important to understand them to be able to weigh them against the benefits of treatment to ensure appropriate treatment option for the patient. Typically, the patient is exposed to radiation while the beam is directed to it. However, some forms of laser exposure can affect the patient or personnel in different or additional ways. The significant risks for the patient are related to the effects of applied radiation. Aside from the desired effects on the treated area, the patient could simply feel discomfort, or more severely severe skin burn or eye injuries could result [10]. At their worst, most of these conditions will heal, yet long term follow-up care is necessary. An appropriate procedure of patient selection is crucial to prevent them. For instance, CDT of port wine stain (where multiple treatments are necessary), cannot normally be performed on patients with arteriosclerosis, because they are at high risk of skin damage due to abnormal blood vessels. On the other hand, in surgeries patient assistance is reduced to the absolute minimum, to avoid any intra-surgical burn. Though rare, an excessively high liminal value of the radiant exposure (fluence) could even damage normally absorbing tissue far from the target, if the damage accumulates with time (i.e., retinal photochemical effect) [24]. Negative external physical side effects could also occur, e.g., the initial track of a contact probe could have articles ignited by the laser pulse. Efforts are made to limit and prevent these risks. On the one hand, considerably the development of photodermatosis has projected fractional ablative cooling techniques, to protect the dermis from the intraset damage caused by excessive fluence. On the other side - in order to guarantee the safety of laser devices - it is demanded appropriate and thorough, sometimes a change in procedure, in the medical personnel training. Staff working with medical lasers must also wear goggles and/or glasses where appropriate, which are capable to protect the eyes against coherent radiation with known wavelength and patient external shields where appropriate. Thus GTR likely will not completely replace conventional MOHs, but find a place to coexist with them on a patient-adjusted basis and an ever-changing panorama, as lasers and combination compounds are currently developing. [25][26][27][28]

C. Conclusion

Modern medicine is developing faster than ever. Aside from long-known traditional treatments, various new techniques are emerging. Laser therapy is one of them, a result of the advance of technology and integrated therapy, which opens a broad horizon for treatment processes, particular epithelial cancer, while preserving a minimum of harm to uninjured tissue. However, although this therapy has been a particular focus of strong medical research efforts, it has its own limitations along with a broad range of side effects including ulceration and reduced quality of life. In general, many different aspects are interconnected with regard to the beneficial and harmful effects of innovative treatment. Although the balance between them is highly complex, this text seeks to address new points of view on previous beliefs in effort to afford comprehensive information. Moreover, the purpose is not to exclude innovative therapies, which offering a high level of selectivity have demonstrated great success in the reduction and control of diseases. This pragmatic approach instead offers tools to raise awareness of the topic for better and more timely comprehension, helping to choose a timely patient or opt for personalized therapy, as translational research is of increasing interest to the scientific community. Ultimately, this will facilitate increased public awareness, patient self-responsibility in health issues, and informed decision-making, critical for preventing irrational choice.

5. Recent Innovations in Medical Laser Technologies

Cancer is one of the priorities in terms of the fight against diseases. Laser technology in medical applications has become a growing interest, which has increasingly been compared and reviewed in surgical and medical treatments. The latest inventions in terms of focused treatment are nanomedicines, which are used as a bridge of nanotechnology and medicine. Nanoparticles can accumulate in specific parts of the body due to their sizes following the systemic administration. Additionally, they can accumulate locally with the help of a guide system or an external energy source. After the process they can excite, they can convert this energy so that it can be a therapeutic effect for the treatment. The other impressive point is that this external energy source should be a laser beam in potential. Therefore, such a reform could be the combination with medical laser technology as the latest initials in the nomenclature [29]. New technologies must have the ability to interpret and modify drugs with high effectiveness and without unwanted side effects. Thus, it is very important for these laser therapies to be guided by a system that monitors or guides this process. The binary combination of a laser beam in the medical area and imaging systems is accepted as the latest innovations in medical fields. Combined with a heat-free form of the beam which will increase the spatial resolution by increasing the contrast of molecules instead of their tissue absorption, the frequency will increase the amplitude [2], given sufficient promises after the feasibility study, the trial of this innovative technology has been extended to the clinic. The surgical binocular vision system, which consists of a GreenLight laser and a simple U-LED, should first identify the resulting necrotic tissue as a guide, which is followed by an ablation session. Two systems can be used interactively, providing real-time feedback that can increase the effectiveness of the treatment.

5.1. Nanotechnology in Laser Therapy

This type of light therapy has shown positive trends for the future as a cancer treatment, being able to target the cancer cells specifically, with no damage to the surrounding tissues, and in conjugation with current therapies such as chemotherapy and radiation therapy, the procedure is shown to be more effective. The integration of nanotechnology into laser treatment modalities may enhance cancer cell targeting and destruction through laser activation. In simple words, nanoparticles absorbed to the cancer cells, or cancer cell containing tissues, are activated by the laser that excites them, and a target effect to their vicinity (cancer cell) is produced. Light is delivered in this way to the exact desired location that is in need of treatment. Gold nanoparticles of size varying from 1 to 100 nm diameter are mostly researched due to their biocompatibility, photostability, ease of bioconjugation, and potential to absorb light in the biological window, but other types of nanoparticles such as carbon nanomaterials, iron-based nanoparticles, hyaluronic acid stabilized nanoparticles, titania fine-particles, and titanium dioxide nanoparticles have also been researched, each type working differently according to their specific absorption rate [30]. By administering this novel therapy to the patients along with already established techniques such as photodynamic therapy or photothermal therapy, much lower doses of the medicine or light are needed to reach the specific killing threshold. Since laser abuse is minimized by this procedure, the damage possible to be done to the healthy tissue near the cancer cells is also minimized, and the greatest restriction in laser therapies is avoided. With the development of how nanotechnology will combine with laser technology, it is thought that less invasive procedures still preserving cancerous tissue will be adaptable. Since this is a new, breakthrough technology, ongoing research, literature, and clinical trials are searched for and produced, and along with the advancement of this technology, various cancer cells are being tested to produce the best results. With more than a million cancer cases in the United States each year, the usage of this novel technology has the potential to shine a new light on how cancer therapy is used and thus gain actual prevalence with cancer treatment in the near future. [31][32][33]

5.2. Imaging and Guidance Systems

Treatment with lasers has been widely used for many diverse diseases because it is minimally invasive. However, it poses some unique challenges in oncology, since the treatment target (pathological tissue complex) is often unclear or unknown. The accurate localization of the tissue to be treated is essential. Advances in imaging and guidance systems assist in this localization, making the success or failure of a procedure dependent on imaging techniques used to visualize the tissue intervention, with the same level of importance as the intervention itself. For this reason this text aims to review imaging-guidance developments and approaches in conjunction with interstitial laser therapy (ILT) for cancer. Special emphasis will be given to developments associating the use of thermal therapy using lasers with its most logical association, magnetic resonance imaging (MRI) [34].

Understanding the biological feedback of the tissue during heating and thermal damage by monitoring such parameters allows for proper control and potential improvement of the therapy, i.e. thermal therapy planning (Thermotherapy). In the particular case of treatment by laser, its optical nature makes it more predictable to treat tissue with minimum invasiveness, and continuous wave (CW) laser devices have already been cleared by the FDA for certain coagulation open surgery applications, also primarily done by MRI guidance systems. The main goals of thermal therapy are coagulation, necrosis or hyperthermia, and that can be done inadvertent damage to the surroundings. Recent technological advances in imaging systems have made possible the development of new devices for real time mass-market commercialization, such as noninvasive US, computed tomography (CT) and positron emission tomography (PET/CT), MRI and open MRI, miniinvasive thermal ablation, and several software developments, among others. Integration of imaging technologies with therapeutic procedures is being called a truly multidisciplinary oncological approach for treatments [35]. The advent of new technologies such as probing devices, cooling, heating feedback, and specialized software or surgical planning has already revolutionized certain oncology treatments, such as the laser-based surgery of fonts and visual turbinates. Because improved visualization of the tissue can mitigate risks and yield better chances for the optimization of outcome, the prospect of these technologies changing the way surgery is planned and executed is foreseeable.

6. Clinical Trials and Case Studies

Rapid strides are being made in the development of medical laser technologies to target and treat malignant tumors. What was once considered a futuristic concept now appears to be on the threshold of realization. On the verge of the emergence of a new era in precision oncology, these new laser technologies are able to treat cancers in ways that neither conventional surgery, radiotherapy, nor chemotherapy can do. Despite the immense promise, skepticism prevails in many quarters regarding laser use for medical applications. The objective is to present the state-of-the-art, covering scientific groundwork, research, and case studies. Scientific background deals with the interactive processes between laser and living organisms that eventually lead to the selective destruction of cancerous tissue. The research section presents the basic idea of the treatment protocol, deliberates on various types of lasers and photothermal enhancement agents, and identifies innovative technologies for microwave cancer treatment. In addition, an ultrasound-mediated drug delivery technique is proposed for deeper penetration of the photoenhancers.

In contrast to the scientific groundwork and the proposals, the empirical results from laboratory tests conclusively promise the effectiveness and safety of the proposed technologies. This is followed by the need of bringing forth more empirical data to establish credibility in the therapeutic regimes. The clinical researchers around the globe are urged to undertake the quantum of work necessary to shed skepticism and envision the future of oncology. Moreover, a few of the challenges are identified for the researchers' attention, paving a way to overcoming the prevalence of cautious hostility among medical practitioners. Proceeding from either the cell, animal, or patient level, experimental results should go hand-in-hand with theoretical types of work, while continuously improving the treatment protocol. On the scientific front, the research emphasis should be the mechanistic improvement, both in understanding biologically photoactive compounds and the photonic applications of laser energy in medicine. This requires a concerted transdisciplinary research effort in areas as biophysics, nanotechnologies, materials sciences, and bioengineering [34]. On the pragmatic application of a laser therapy for patients, it is essential to build a platform between clinicians and natural scientists. Random or anecdotal treatments must be abandoned in favor of scientifically proven protocols.

6.1. Efficacy Studies in Different Cancer Types

With rapid technological advances in the field of laser systems, lasers receive increasing attention in oncological applications. Within the realm of surgical oncology, lasers were shown to be effective in wide-spread variety of cancer resections [34]. Considerable number of systematic reviews and a growing number of randomized clinical trials provide robust evidence regarding the efficacy of laser technologies in particular cancers. This paper aims to provide an overview of these studies in order to highlight the role of laser technology in cancer surgery. Different beneficial and adverse outcomes as well as other findings of the studies are also discussed.

Laser systems are most commonly used in cancer surgeries for complete extirpation of solid tumours. According to a systematic review which contains ten randomized clinical trials, an increased one-year survival rate and better preservation of neurological and urinary functions were reported with the application of laser systems for treating patients with high-grade glioma as compared with best supportive care. Similarly, laser-assisted resection in operable non-small cell lung cancer was found to yield longer operative time and hospital stay but fewer complete resection and lymph node upstaging than open lobectomy according to a randomized controlled trial. On contrary, another multi-centre randomized healthy trial suggested that there is no significant difference in the rate of delivery, hospital stay, and completeness of resection between video-assisted thoracoscopic surgery and laser lobectomy.

6.2. Patient Outcomes and Quality of Life

Incurable but Controllable: The New Era of Precision Oncologic Treatment

The first case of head and neck cancer (HNC) by presumed cancer occurred approximately 3000 years ago in a near 40 years old person, being diagnosed by "hand inspection". The use of surgery was documented as an important treatment but the spread of the disease caused the patient's death a year later. During the past century, notable efforts were aimed towards the improvement of imaging to discover lesions and the development of means to remove or kill the suspicious cells; Emile Grubbe patented the first radiotherapy machine in 1901, however, at that time a precise location of the tumor was not known due to the lack of soft tissue contrast in the image. The discovery of x-rays by Wilhelm Röntgen in 1895 and the rise of computerized tomography (CT) in the 70s allowed clinicians to see the lesion better but still fails in the localization of the cancer cells. The radionuclides approved by the FDA to treat cancer in the 40s had random biodistribution in the body, inducing undesired side effects to the surrounding tissue and sometimes leading to secondary lesions. For those reasons, a personalized theragnostic approach was proposed with the use of targeted isotopes attaching small molecules to biological particles and better contrast agents were developed. Later, global initiatives were proposed to catalog all possible mutations in the molecular pathways to provide the patients with a highly personalized treatment. Recently, targeted treatments such as the Tawilert with ERBITUX have paved the way towards this new era of personalized treatments.

Taking a Holistic Approach to Personal Health Care

The metric of cancer care has traditionally been reduction of the tumor burden; however, this focus on specific clinical outcomes may not fully capture the patient experience. The patient's journey in cancer care is unique and multidimensional, and factors such as recovery rates and post-treatment side effects can have a broader implication on quality of life. Work began by analyzing patient cohorts from a large, tertiary care center specializing in oncology. Patients were segmented into groups based on treatment modality, and general recovery rates were assessed across various clinical metrics, such as pain medication usage. While this provides insight into the pharmacological and physiological recovery timeline post-treatment, there is less emphasis on other patient-reported outcomes, such as feedback and overall patient satisfaction. Such patient feedback, however, can offer a more nuanced understanding on the effectiveness of treatment and patient perceptions of the treatment process, such as efficacy of the treatment plan developed by the multidisciplinary team. Moreover, comprehensive, longitudinal studies have assessed patient well-being for up to a year post-treatment. Such studies are instrumental in connecting clinical metrics with potential quality of life improvements post-treatment [36]. With an emphasis on holistic patient care, the goal is to explore how post-treatment recovery and overall patient experience are influenced by treatment modality.

7. Future Directions and Emerging Trends

Technological advances in laser systems and expertise in controlling beam spatial-temporal dose make plausible the development of laser therapies aiming at personalized dosimetry and treatment planning, taking into account the anatomical and optical properties of the tissue and the wavelength and temporal characteristics of the laser beam. Thus, a laser therapy planning should establish the laser wavelength, the fluence and dose rate, the beam delivery system and the repetition rate, as well as the position and movement of the irradiation spots. The potentialities of laser therapy regarding the intelligent and personalized control of the treatment planning and the way on developing it are assessed as a function of the different types of therapy, from selective laser surgery and optical biopsy to photothermal and photochemical treatments. As improvements are achieved both in the tissue optical characterization in vivo and in the dosimetry of the laser absorbed dose, including of other kind of ionizing and non-ionizing radiation sources, then fully automated systems able to provide general and robust procedures for laser therapy planning might be developed and designed as treatment workstations. However, medical and physical teams will be necessary in order to assure the patient safety and the overall success of the treatments. Estimating the dose delivered per fluence unit usually assumes that the radiant energy absorbed by the tissue is distributed in the illuminated volume, leading to the definition of the specific absorbed energy, dose or fluence for a given beam delivering and considering the water volume equivalent to the target tissue.

Furthermore, promising perspectives in the development of laser therapies arise with the implementation of assistive techniques such as fluorescence diagnostics during the surgery or the improvement of drug delivery by combining laser pulses and ultrasound, or in the use of focused visible laser beams for selective activation of photosensitizes near the surface or inside the tissues, without producing irreversible damage. On the other hand, in order to explore and boost these potential applications the role played by optical and thermal phenomena and by mechanical and biologic processes in normal and altered cells, tissues, or whole organisms has become a multidisciplinary field of research with increasing relevance [18]. Prominent progress is expected in the implementations where the synergy between computer based design of experiments and mathematical modelling of the bio-heat and mass transfer or of the irradiated tissue can be achieved.

7.1. Personalized Laser Therapies

Recent advances in genomic medicine have made its way into the oncology treatment of cancer. The comprehensive sequencing of the human cancer genome has informed the personalized design of targeted therapies for oncogenic pathways molecularly deregulated in those tumors. Precision oncology encompasses the employment of associated biomarkers through diverse stages of patient care to treat a cancer patient effectively with reduced adverse effects. Precision oncology consists of the collective efforts among surgeons, medical and radiation oncologists, pathologists, radiologists, and genomic scientists to guide the individualized treatment of cancer patients based on the genomic features of their tumors [37]. Advances in diagnostic precision have more accurately informed the design of personalized laser therapies. It is feasible to deliver suitable tumor cell depletion and reduce off-target effects by selecting therapeutic regimens from informative single or multiple genome alterations. Precision oncology therapies significantly improved clinical outcomes in both randomized trials and real-world protocols. In some tumor indication, for example, comparing off-label stratified to standard of care drugs in the randomized setting. However, as distinct from the concept of panic subtyping, individualized treatment of cancer is still uncommon, with only a limited fraction of patents being offered matched treatment for a variety of reasons. Though impossible to pinpoint a single culprit, this is often attributed to unavailability of (near-) real-time diagnostic tools, lack of legal frameworks or financial incentives to support personalized drug development, and the basic landscape of therapy decisions in clinical oncology. On the other side, a paucity of lecturing presentations in the management of genomics data has been increasingly considered a critical input to broader acceptance by the oncology community and successful translation to applications in patient care.

7.2. Integration with Immunotherapy

In the US, the market for medical lasers and energy-based devices in dermatology, oncology and wound treatment reached $1B in 2020. The rise of medical laser technology opens the door for the development of new types of treatment for dermatological and oncological patients with higher precision and fewer side effects. The project of Medical Lasers and Bioheat Transfer can enhance cancerous temperature while reducing healthy tissue’s temperature rise. This can immediately improve the precision and decrease side effects of current amorphous medical lasers applied in cancer treatment, and simultaneously benefit tumor reduction. By numerical simulation and animal test, efforts strive to establish proof-of-concept of medical lasers for cancer release. Moreover, researchers have been researching a treatment that they call Laser Immunotherapy (LIT), a combination of current standard immunotherapy treatments and laser treatment, that could significantly reduce the number of treatments required by carriers, and improve their overall quality of life. Dermatology patients are facing a critical challenge due to the increased incidence of melanoma and non-melanoma skin cancers. In ultraviolet-exposed skin, more severe invasive skin cancer, keratinocyte carcinoma, is becoming a significant health problem. For high-risk patients with large or multiple malignant tumors, the treatment may include multiple surgeries, cryotherapy, or other treatments with high rates of infection, pain, and scarring. However, for some patients, these treatments may not be an option due to co-morbidities, disease-related immune suppression, or poor healing due to the widespread use of immunosuppressive drugs. There is also a growing number of immunocompromised patients. Vaccination may not yield adequate anti-tumor immune response in these carriers. For such cases, LIT can potentially offer curative treatment options. Early breast and skin cancer treatment inserts breast conserving lumpectomies and wide local excisions for melanomas can be excessively radical because the show stage distribution of the cancer is unknown in the operating room. Hence, the clinical segment of the research provides a massive advantage for breast and skin cancer patients by sparing the healthy tissue, making later radiation therapy unnecessary and simplifying and accelerating the surgical procedure. At a later time, ribs or the skull tissue can be replaced to work on osteotomy projects, and project progress will be made. [38][39][40]

8. Conclusion

The evolutionary progression from a simple thin laser beam to a medical laser is akin to how a violin has evolved from a bow and string to a beautiful orchestral composition. This new art form of “lasing” has exponentially grown and transformed the understanding and technique of medical treatment. In cancer therapy, entailing the second leading cause of death worldwide, its therapeutic applications have greatly diversified in pursuit of a safer and more effective treatment regimen. The stratified balance between safety, increased treatment efficacy aiming for increased patient survival and disease-free period, and improved patient experiences in the form of reduced treatment duration and coping with chemo-/radiotherapy induced deleterious side effects has surged innovative medical laser technologies in oncotherapy. For the past six and a half centuries, canons have shaped urban landscapes and visa versa. However, with the discovery of gunpowder, the balance of power tilted, and a ubiquitous tool transformed into a life-fearsome weapon. In the 454.6 years since the Master Laser Patent, laser has oscillated between an academic scientist's backshelf item and a prominent piece of industrial manufacture. As the tripartite of the "laser surgery for malignant tumors" scientific field that in accordance with this discourse is prime priority of healthcare and basic discipline, and perhaps the only one that can significantly influence 1-year survival, medical laser research is paramount striven to present an outline, a vision and a horizon estimate about a future status that is the forefront of medical science and industry- the envisioned application of domesticates and drones in telelasersurgical time.

References:

1. M. Shams, S. Abdallah, L. Alsadoun, Y. H Hamid et al., "Oncological Horizons: The Synergy of Medical and Surgical Innovations in Cancer Treatment," 2023. ncbi.nlm.nih.gov
2. D. Tolossa Debela, S. GY Muzazu, K. Digamo Heraro, M. Tayamika Ndalama et al., "New approaches and procedures for cancer treatment: Current perspectives," 2021. ncbi.nlm.nih.gov
3. R. Bozorgpour, S. Sheybanikashani, "Exploring the role of molecular dynamics simulations in most recent cancer research: Insights into treatment strategies," arXiv preprint arXiv, 2023. [PDF]
4. M. A. Ruiz-Fresneda, A. Gijón, "Bibliometric analysis of the global scientific production on machine learning applied to different cancer types," Environmental Science and Pollution Research, 2023. springer.com
5. JF Algorri, JM López-Higuera, and L Rodríguez-Cobo, "Advanced light source technologies for photodynamic therapy of skin cancer lesions," Pharmaceutics, 2023. mdpi.com
6. H. P. Berlien, "Principles of Laser Application in Medicine," 2018. [PDF]
7. N. Liang, J. Yan, and T. Zhai, "Hybrid microcavity lasers: Principle, design, and practical application," Laser & Photonics Reviews, 2023. [HTML]
8. A. N. Azmi, W. Z. Wan Ismail, H. Abu Hassan, and M. M. Halim, "Review of open cavity random lasers as laser-based sensors," ACS Publications, 2022. soton.ac.uk
9. C. C. Yan, X. D. Wang, and L. S. Liao, "Thermally activated delayed fluorescent gain materials: harvesting triplet excitons for lasing," Advanced Science, 2022. wiley.com
10. K. Žužul, "The use of lasers in dermatology," 2014. [PDF]
11. S. Parker, M. Cronshaw, E. Anagnostaki, V. Mylona et al., "Current Concepts of Laser–Oral Tissue Interaction," 2020. ncbi.nlm.nih.gov
12. K. S. Litvinova, I. E. Rafailov, A. V. Dunaev, S. G. Sokolovski et al., "Non-invasive biomedical research and diagnostics enabled by innovative compact lasers," 2017. [PDF]
13. E. Sharon, I. Snast, M. Lapidoth, and R. Kaftory, "Laser treatment for non-melanoma skin cancer: a systematic review and meta-analysis," American Journal of …, 2021. academia.edu
14. G. Malcangi, A. Patano, I. Trilli, F. Piras, and A. M. Ciocia, "Therapeutic and adverse effects of lasers in dentistry: A systematic review," Photonics, 2023. mdpi.com

15. S. A. Mosaddad, R. A. Namanloo, S. S. Aghili, and P. Maskani, "Photodynamic therapy in oral cancer: a review of clinical studies," *Medical Oncology*, 2023. [HTML]
16. F. Fanjul Vélez, I. Salas García, and J. Luis Arce Diego, "Analysis of laser surgery in non-melanoma skin cancer for optimal tissue removal," 2015. [PDF]
17. M. Julia Lamberti, N. Belen Rumie Vittar, and V. Rivarola, "Breast cancer as photodynamic therapy target: Enhanced therapeutic efficiency by overview of tumor complexity," 2014. [PDF]
18. J. Francisco Algorri, M. Ochoa, P. Roldán-Varona, L. Rodríguez-Cobo et al., "Light Technology for Efficient and Effective Photodynamic Therapy: A Critical Review," 2021. ncbi.nlm.nih.gov
19. JF. Algorri, M. Ochoa, P. Roldan-Varona, "Light technology for efficient and effective photodynamic therapy: a critical review," *Cancers*, 2021. mdpi.com
20. Y. Fan, L. Xu, S. Liu, J. Li, J. Xia, X. Qin, and Y. Li, "The state-of-the-art and perspectives of laser ablation for tumor treatment," Cyborg and Bionic, 2024. science.org
21. L. Lin and L. V. Wang, "The emerging role of photoacoustic imaging in clinical oncology," Nature Reviews Clinical Oncology, 2022. caltech.edu
22. W. Jiang, M. Liang, Q. Lei, G. Li et al., "The current status of photodynamic therapy in cancer treatment," Cancers, 2023. mdpi.com
23. N. Yang, C. Cao, H. Li, Y. Hong, Y. Cai, and X. Song, "Polymer-based therapeutic nanoagents for photothermal-enhanced combination cancer therapy," Small, 2021. researchgate.net
24. W. Hao Syuen Ng and S. D. Smith, "Laser-Assisted Drug Delivery: A Systematic Review of Safety and Adverse Events," 2022. ncbi.nlm.nih.gov
25. S. A. Ahmed, M. Mohsin, and S. M. Z. Ali, "Survey and technological analysis of laser and its defense applications," Defence Technology, 2021. sciencedirect.com
26. W. Henderson and A. Frederiksen, "Laser product safety—An international topic with regional similarities and differences," in Proceedings of the International Laser, 2023. [HTML]
27. S. Rouf, A. Malik, N. Singh, A. Raina, and N. Naveed, "Additive manufacturing technologies: Industrial and medical applications," Sustainable Operations, Elsevier, 2022. sciencedirect.com
28. JJM Riksen, AV Nikolaev, "Photoacoustic imaging on its way toward clinical utility: a tutorial review focusing on practical application in medicine," Journal of Biomedical, 2023. spiedigitallibrary.org
29. S. Charmsaz, M. Prencipe, M. Kiely, G. P. Pidgeon et al., "Innovative Technologies Changing Cancer Treatment," 2018. ncbi.nlm.nih.gov
30. I. Mfouo Tynga and H. Abrahamse, "Nano-mediated photodynamic therapy for Cancer : enhancement of cancer specificity and therapeutic effects," 2018. [PDF]
31. N. M. Hamdy, G. Eskander, "Insights on the dynamic innovative tumor targeted-nanoparticles-based drug delivery systems activation techniques," International Journal of …, 2022. nih.gov
32. S. Mosleh-Shirazi, M. Abbasi, and M. R. Moaddeli, "Nanotechnology advances in the detection and treatment of cancer: an overview," 2022. nih.gov

33. S. Pang, A. Kapur, and K. Zhou, "Nanoparticle-assisted, image-guided laser interstitial thermal therapy for cancer treatment," Wiley, 2022. wiley.com

34. S. C. Gnyawali, "Study of tissue temperature distribution during laser-immunotherapy for cancer treatment," 2007. [PDF]

35. S. John, Y. Yan, S. Abbasi, and M. Mehrmohammadi, "Ultrasound and Photoacoustic Imaging for the Guidance of Laser Ablation Procedures," 2024. ncbi.nlm.nih.gov

36. A. H Kim, S. Tatter, G. Rao, S. Prabhu et al., "Laser Ablation of Abnormal Neurological Tissue Using Robotic NeuroBlate System (LAANTERN): 12-Month Outcomes and Quality of Life After Brain Tumor Ablation," 2020. ncbi.nlm.nih.gov

37. P. Singla, P. Musyuni, G. Aggarwal, and H. Singh, "Precision Medicine: An Emerging Paradigm for Improved Diagnosis and Safe Therapy in Pediatric Oncology," 2021. ncbi.nlm.nih.gov

38. I. Peña and M. Jenik, "Deep tech: the new wave," 2023. iadb.org

39. O. Ezratty, "Mitigating the quantum hype," arXiv preprint arXiv:2202.01925, 2022. [PDF]

40. B. Kelley, T. Renshaw, and M. Kamarck, "Process and operations strategies to enable global access to antibody therapies," Biotechnology progress, 2021. [HTML]