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

Advancements in General and Medical Physics: The Role of Lasers in Modern Healthcare

Shahad Ali Abdulhussein Khalaf
Department of Medical Physics, of Science University: Al-Madina Al-Ilm University

Zahraa Laith Adham Aboub
University: Technological University Applied Sciences Laser Science and Technology

Mustafa Kazem AbisJafar
Karkh University of Science, Medical Physics Department

Abdullah laith adham abaob
Al-karkh University of Science College of science Department of Medical physics

Haider Adel Ward Radi
Technological University Department of Applied Sciences, Laser Science and Technology Branch

Received: 2024 19, Dec
Accepted: 2025 28, Jan
Published: 2025 22, Feb

Annotation: It is widely believed in the general public that the laser plays an important role in modern healthcare, and it is becoming increasingly common among medical professionals as well. For that reason, an investigation of laser web pages on popular science websites will result in articles such as ‘Benefits and risks of using laser therapy for varicose veins’. It is fair to conclude that the presence of laser medical devices in the form of muscle pain relief and tissue health promotion is becoming ubiquitous in the Western world. However, despite this familiarity, the physical principles that make laser use possible remain largely mysterious. This ‘scaling issue’ is made more serious by clinical data that suggest lasers in different wavelengths and pulse entangles have somewhat counterintuitive effects . Given the increased availability of these devices to individual consumers, a thorough campaign of education is warranted. Thus, the goal of this paper is to provide an introduction to the research; how lasers are used in modern medicine, and how they are implemented in medicine. The paper is geared towards a general audience with a background in physics: this includes medical professionals, commercial developers, scientists, and layman with a penchant for understanding new technologies. Regardless, a part is included which aims to quantitative argue how the parameters of a laser affect its effect on the body, even if it necessitates the application of physical principles beyond simple algebra. The semi-technical section endeavours to explain terms that are non-technical.

Keywords: Lasers, medical physics, laser-tissue interaction, healthcare technology, laser applications, medical treatment.

1. Introduction to General and Medical Physics

The role of lasers and laser systems is described, with specific applications in general physics. Lasers are an integral part of modern technology, and laser light is used in various fields today. Due to its properties, laser light is fundamentally different from natural light; its area of application is thus different. One of the features of laser radiation is its high directivity. Another feature of laser light is its monochromatism. The laser is used to achieve high light intensities due to the large number of photons. The possibility of generating laser light in a short pulse is emphasized on considering laser systems. Such pulses can have a duration of 10 ns. This new possibility allows the investigation of fast running processes on the nanosecond time scale in various fields. In ballistic physics, for example, this has made cutting processes possible, which thanks to the laser are particularly clean and precise [1].

The basic principles of general physics in modern healthcare are outlined. General physics is still an outstanding and one of the most comprehensive branches of natural sciences. It studies both the processes occurring in nature itself and the means of obtaining new knowledge, improving life and human activities. In view of the rapid advance of technology and science in recent decades, the demand for physicists in various fields has been very high. Such specialists are employed in industrial enterprises, research organizations and institutions, hospitals and schools. Medical physics is one of the fastest growing areas in physics. It examines and develops methods and devices for the treatment and diagnosis of various diseases (cancer, cerebral thrombosis, ulcer, schizophrenia, etc.). To achieve these aims, new physical devices are devised, based on the most advanced and sophisticated knowledge from various areas of physics, such as radiation physics, nuclear physics, and quantum mechanics. Only in the last two or three decades, however, has a very close collaboration between physicists and physicians plantargnosticians begun to bear fruits in industrial and technological applications [2].

1.1. Fundamental Principles of Physics

In order to fully comprehend the role of lasers in general and medical physics, it is important to first learn a bit more about lasers and how they work. Lasers are devices that emit light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term “laser” stands for Light Amplification through Stimulated Emission of Radiation. There are three primary components of a laser: energy source, gain medium, and mirrors. The gain medium is the core of the laser which is “excited” by the energy source. This could be done using electric current, or a flash lamp. Meanwhile, a laser cavity is formed by the two mirrors, one being fully reflective while the other is partially reflective. This way, most photons bounce back and forth between the mirrors, passing through the gain medium multiple times before being discharged in the form of a laser beam.

There is wide range of lasers in terms of wavelengths, power, and applications. For example, the visible red-light laser pointer that is commonly used for presentations operates at 1 mW. On the other hand, the most powerful laser in the world has an output power on the Petawatt scale with wavelengths in the ultra-violet part of the spectrum. In the past 5-10 years there have been substantial advances in the construction of high-power lasers, with numerous facilities worldwide that can deliver exawatt beams. Because “conventional” lasers are based on macroscopic optical systems, they are in the realm of General Physics. On the other hand, the ultrahigh-power lasers have enabled the study of extremely high-energy-density states, plasma systems with temperatures from 1eV-1GeVal and pressures of tens of Mbar. As these are extreme conditions, more generally speaking, evolution in laser technology will drive advancements in many fields of physics [3].

Literature Review

2. Introduction to Lasers

The laser has been an integral part of modern medicine for nearly 60 years. The numerous multidisciplinary applications include oncology, surgery, neurosurgery, general and ENT surgery, urology, gastroenterology, ophthalmology, dermatology, dentistry, therapy, diagnostics, and plastic, reconstructive and cosmetic procedures. Moreover, the developing laser-related technologies are increasingly used, e.g. in optochemistry, contactless welding of tissues, lithotripsy, photoactivation of drugs and bacteria, or as the light source in PDT which is used in the treatment of hard-to-heal chronic wounds and various infections. After several decades of development in the 21st century, the invention of the laser was rated by members of the American Physical Society as one of the ten most important discoveries in the time from 1899 to 1964. Since the patent application for the first pulsing laser was submitted in 1960, the range of applications has been constantly growing and is yet to be fully uncovered.

In the late 20th and early 21st centuries, a boom in the development and miniaturisation of opto-electronic systems was observed, leading to a significant increase in their presence in everyday life. Mass-manufactured components, which so far have been used mainly in telecommunications and the entertainment industry, have also been applied in medicine. Consequently, many laser instruments for home use have been created to support the procedures conducted in medical facilities and for cosmetic purposes, thus creating risks associated with uncontrolled use by individuals not entitled to carry out such procedures. Lasers are used mainly in diagnostics and therapy due to their high monochromaticity, coherence, low collimation error, minimal heat conduction, high concentration of energy in terms of heat and the ability to focus on small surfaces. Moreover, due to the amplification of light reaching the stimulated emission of photons in the same phase, it is used in optical communication to modulate digital signals. That is an application in the eye-safe radiation with a wavelength of 1.54 μm used in telecommunication networks; laser energy can also be used in a remote fusion reaction at a temperature of 107 K. [4][5][6]

2.1. History and Development of Lasers

This year, four groups of laureates are glorified by the award of one of the most prestigious awards in the world: The Nobel Prize. One of these awards, the prize in Physics, is shared by three scientists who have extensive experience in the field of physics and its underlying methodology. Changes in the field began with Einstein's quantum assumption in 1900 concerning the convolution of Planck's radiation law. Realizing that this, as expected, rekindled a debate about particle or wave theory, in 1905 Einstein wrote three publications illuminating the photoelectric effect. By empirically combining the corpuscular and wave properties of light, Einstein established firmly light's dual character as both particle-like and the wave-like condition which carries a frequency (ν), wavelength (λ), or propagation velocity (c) related to the particle energy (E = hf). Key to further advancement was the experimental demonstration that light, in practice, could be focused into an extremely intense, nearly monochromatic collimated beam. The laser has become an integral part of modern medicine and is hard to imagine surgery without this tool. In addition to surgical operations, procedures based on the use of lasers can be found in numerous medical disciplines, from dentistry and cosmetology to general and vascular surgery as well as neurology. Laser systems operated at various wavelengths and adjustable parameters provide extensive research opportunities. Laser light can be delivered in a perfect form in both spot and profile. Different wavelengths make it possible to work with tissues of various types and depths of treatment. With the right selection of parameters, it is possible to achieve very gentle tissue treatment, as exemplified by removal tattoos, varicose veins, or posterior capsules of cataract surgery. On the other hand, laser pulses allow for very precise treatments. Modern diagnostic apparatus such as computed tomography or confocal microscopy are also based on the principle of light amplification by stimulated emission of radiation. At the same time, both the diagnostic and therapeutic role in current medicine took the pada on much more diluted than ever before importance. Altered laser light can be very precisely manipulated in the sample, resulting in numerous research methods or diagnostic procedures. Similarly, the illuminating specimens will produce very good contrast of the image, which can help the diagnosis in combination with taking advantage of autofluorescence. [7][8][9]

3. Types of Lasers

The efficiency and precision of medical treatments have been greatly enhanced through novel developments in different technologies. A significant and innovative leap in medical treatments has been made through the development of lasers. In general terms, the laser can be characterized as a device producing a coherent beam of light, which allows laser cutting or laser cauterization. Due to the selection of different wavelengths of the laser, tissue can be cut with reduced bleeding. Since the discovery of the laser in 1960, the medical community has found many uses for these devices, from the intense ablation of tumors to the less aggressive anti-inflammatory treatments using low-intensity laser-energy sources. The laser has become an essential tool in modern medicine. In 2011, 76.51% of hospitals in Germany used lasers. In comparison to previous studies, these results show a significantly larger number of hospitals using lasers [1]. Thus, the medical sector has the highest application rate for lasers because biosafety and high-accuracy beam guidance are required to ensure safe application. Very little information is presently available on laser safety in hospitals. Although laser exposure limits have been established for different topographies, a detailed analysis of these thresholds in clinical settings has not yet been carried out. Lasers with different wavelengths could be used in hospitals, but there are no guidelines for hazard evaluation at specific wavelengths. In addition, most of the sources available focus on the safe use of a particular type of laser system.

3.1. Solid-state Lasers

The ruby laser was the first true laser when microwave energy was amplified by a ruby crystal to create a beam of red light travelling in a phase at a wavelength of 694 nm [10]. The ruby laser was followed shortly by the development of other solid laser systems such as the Nd:YAG 1064 nm. Despite this, lasers are still rarely used in medical practice as only about 700 lasers are in operation. The high cost of purchasing and maintaining a laser system has limited use to private practices and large hospitals. Surgery accounts for about 70% of laser use in medicine and is dominated by the CO2 10600 nm laser. Because of this, the Er:YAG has been shown to be effective in ablation and coagulation of soft and hard tissue, with a limited depth of thermal damage to the surrounding tissue. One of the more recently developed and promising applications for the Er:YAG is in bone surgery where early results show the potential it has due to efficient ablation of hard tissue in a minimally invasive way.

Coloring agents in the plasma membrane of red blood cells can absorb light and cause a temporary vasodilation of the capillary walls. Encrustations on the preferentially absorb. The holmium laser produces pulses of energy at a wavelength of 2100 nm that can be delivered with a flexible quartz fiber, thus allowing its use in endoscopic surgery. By constructing a histostat the surgeon can precisely control the pulse duration such that the desired ablative or cutting action occurs and not the mechanical effects which are largely responsible for the unwanted thermal damage commonly associated with laser surgery. One of the main reasons why the pulsed holmium laser has attracted significant interest is that the absorption of the 2100 nm radiation in the water is more than 10 times greater than in the near infrared spectrum of the Nd:YAG laser [1]. This makes it more efficient for cutting and ablating tissue as the collateral thermal damage is both predictable and minimal. As laser radiation increases in optical penetration depth, it has been suggested that the holmium laser may well be the optimal laser for intra-articular arthroscopic surgery. Plasma mediators are then released which causes neovascularisation of the subchondral bone and relief from symptoms.

4. Laser-Tissue Interaction

In general, lasers can be used in medicine for the treatment of ablation, incision, excision, and coagulation of biological tissues. Various laser types with different wavelengths, such as CO2, Er:YAG or diode lasers with 650–1500 nm wavelengths, are suitable for these purposes. By the choice of parameters (power densities, exposure times, etc.), these lasers guarantee treatments that are bloodless or that have limited bleeding [11]. In dentistry, different laser types are used mainly on oral hard tissue and soft tissue. In surgery, Nd:YAG, CO2, diode, and Er:YAG lasers are used on soft oral tissue.

The acids formed in the decay soften and decalcify the enamel, so the hard tissue has to be removed effectively. High-speed drilling is typically used for this, yet it can be very uncomfortable and scary for patients due to its noise and vibration. This effect can be avoided when using laser treatment. Drilling with lasers is practically noiseless. Hard-tissue lasers also require local anesthesia only in relatively few cases, so the patient is not exposed to the chemical burden of widespread occlusive anesthesia. Due to these advantages, these types of lasers may be successful competitors of the conventional dental drill in the near future.

4.1. Absorption, Scattering, and Transmission

The complex nature of oral and dental tissues are due to the variation in composition and behaviour of its constituents. Of key importance to laser–tissue interactions are demands for the clinician to understand the varying compositions of host tissues, and subsequent how these may to be managed and manipulated using laser energy without unwanted damaging effects [11]. In particular, this salient adaptation of various techniques in the ultrastructure of dental enamel, the high mineralisation and subsequent transparency of dentine, the physicochemical considerations of hard tissues (which may lend themselves to differences in laser interaction dynamics), and the exponential contrasts in optical absorption coefficients between whole soft tissue and its components have led to aspects of the oral cavity serving as a testing ground for lasers and their potential utility. While examination of the scientific literature will show a wealth of investigation of laser–biological effects, with a bias towards in vitro studies, the clinical significance and practice of how these may be applied may be lacking.

Exposing oral and dental tissues to photonic energy has enabled a transformation of how both the assessment of oral health and the modality for treating disease can be effectively achieved. Essentially, following appropriate codes of good practice with respect to the illuminating source will enable control and direction of the angle of light incidence, a principle defined by both Fresnel reflection and the more well-known Brewster’s angle laws. Concern continues to be expressed over the lack of complete and comprehensive laser operating parameters in published literature to enable the clinician (and most notably the non-scientist) to use laser therapy in order to optimise a desired clinical outcome. To perhaps obtain the best results important considerations include the method of ancillary cooling, the extent of light scatter, the mode and frequency of laser delivery, and importantly the temporal effect of super-pulse operation in comparison to more traditional continuous wave delivery modes. Further, excessive application of incident power may cause overheating of the target material and carbonisation, and it is of note that suggested that despite the use of diffuser devices designed to homogenise radiant power, the delivered energy may become increasingly focussed and form hotspots, leading to aberrant interactive effects.

5. Applications of Lasers in Medicine

The complex idea of light as therapeutic instrument is possible with the advent of Alfred Nobel's invention. Up to the early 90s, the first practical straightforward malleonetion laser had been a truly revolution and challenge regarding its application in medicine. The astonishment of early users is understandable easily when one might remember the few words of confessions of H. Maiman himself on the historical occasion of 33 January 1960: "I told all my superiors at Hughes that this would be of absolutely no use to anyone but the organization, but I based that statement on my complete lack of knowledge of biology and medicine. I was mainly interested in the feasibility of producing a new type of device possessing very unusual and non-intuitive characteristics".

6.1.1 Wound healing Larger wounds created by cold lances or by scalpels and radiant energy are characterized by different healing kinetics. According to IR analysis the phase II (deposit of endogenous nitrogen) is much shorter in laser treated wounds (1 week) compared to scalpel wounds (1 month). The second phase is characterized by the production of extracellular matrix. Due to this finding healing of laser treated wounds is much faster. It is reported that wound healing is improved and accelerated by laser. Recent experimental work and its interpretation are presented and may open a pathway for understanding these findings. Ruby laser burns reveal a zone of reversible and irreversible damage both in vitro and in vivo.

6.2 Photodynamic therapy Possibility of light killing whole organisms was demonstrated by [1] and by Kärreman in 1920. The enormous development of the laser might now provide a new base for light killing. The CO2 - laser was tried with success on alcohol instilled urinary bladder of rabbits. The reduction of viable area is conceivably dependent on the distribution of the photosensitizer and wavelength. Long term studies of survivors were carried out. Arrays of necrotic areas with random occurrence of helatinized squares due to laser application were found.

6.3 Interpretation of results The incomparable increase in plasma generation as compared with the life microscope confocal microscope findings may be due to the different time delay between the end of laser impulse and the beginning of monitoring. After Nd YAG laser exposure a gas bubble is generally created immediately or within the first few μ sec and collapses with intense shock wave generation. The cessation of the first medium here impulse is provided by the opaque surface layer of the specimen that forms within the first 10–100 ns. Due to relative slow growth of plasma the corresponding electromagnetic signal may come later and is not registered by the LSM. A light transmission microscopy visualization of the plasma generation reveals numerous channels on the specimen surface before lift-off. Even the movement of erythrocytes prior to the channel growth is detected.

5.1. Surgical Applications

Lasers have firmly established themselves as an intensive tool in medicine. Current properties, possible applications as well as compatible combinations of lasers with so-called Doppler devices are highlighted and illustrated through illustrative examples. Lasers are used since several decades as standard tools in a multitude of applications. Today's laser technology is characterized by a broad selection of different types and the associated, adaptable instruments. Laser systems have historically only been operated with a fixed output wavelength. Today, broadband emitters are in use. Current developments have advanced towards the continuous adjustment of the output wavelength or the simple exchange of a corresponding emitter while maintaining the fundamental components. The laser power can be selected within wide limits or even changed during operation. Thus, the tissue can be treated with different energy levels. Furthermore, it is possible to continuously influence the output power. This can be achieved by digital regulation of the pump power or other components. Concomitant effects of this regulation are the change in pulse duration or the emission of specific pulse patterns. Some types of lasers work with an accordingly intense broadband em wave that can be adapted to the interaction with the tissue. A broad spectrum of such lasers is available for medical purposes. These can be selected within a large spectrum that spans from the ultraviolet to the infrared range. Also, the multiplicative capability of different types of laser sources is in use. Different types of lasers are combined in only one device. In parallel, such systems allow to use the applied laser source individually. The individual laser systems and the power output of these are switched on or off in an adjustable pattern. Thus, tissue treatment can be performed gradually and in a controlled manner. However, any combination of the available laser sources and other integrated components of the device can be applied. This facilitates the implementation of surgical or diagnostic applications. One of the basic interests with using a laser light is the aspect of tissue ablation. Today, lasers have become a standard tool in a variety of surgical applications [1]. In particular, different types of lasers are used that run on different tissues and interactions with these. Then there is laser surgery that offers an advantage in the precise removal of tissue. Furthermore, the coagulation of biological tissue often appears as a parallel effect. Thus, laser surgery can reduce postoperative blood loss. However, the depth of penetration of the laser light can be altered by adaptation to the thermal parameters. Moreover, other bioeffects can be specifically used. Liposomes are an example for biological markers that are effectively destructed using a very special laser. Also, photosensitizers can be introduced into the body which accumulate in the disease-tissue and strongly increase the effect of irradiation due to laser light - Photo dynamic Therapy can take place.

6. Laser Therapies in Dermatology

Lasers and light sources have revolutionised the interventional dermatology field over the last two decades [10]. A multitude of dermatologic conditions that were previously untreatable are now treated with a variety of lasers and lights. The large number of laser systems coupled with advances in the technologies associated with laser application have in turn expanded the applications of lasers for dermatologic conditions including but not limited to acne, scars, birth marks, wrinkles, tattoo removal, pigmentation, photorejuvenation, hair removal, melasma, conditions causing cutaneous pigmentation such as naevi, and many more. Applicability of the laser for any indication is dependent on the laser tissue interaction which is well documented. However, there are several types of lasers and wavelengths that can target the desired chromophore resulting in the required effect. For a successful outcome with laser therapy, the right end point of the desired successful treatment has to be achieved. Like many other critical treatments in therapeutic fields, the right parameters and end points for laser therapy are industry and indication specific. As dermoscopy has found its place in many other dermatologic diagnoses and procedures, the use of dermoscopy both before, during, and after laser therapy in various indications has recently been documented. There are few reports on the standard use and benefits of dermoscopy before lasers or lights used in all response types. In this study, application of dermoscopy before, during and after laser therapy is reviewed. Use of dermoscopy before, during and after laser therapies is an invaluable non-invasive tool that can predict the right indication and laser response. Dermoscopy could be utilised to initiate the appropriate priming before any lasers or lights in melanocytic lesions. With the expansion of medical technology and changes in the pace of life of the population, dermatoscopy is increasingly being used in a variety of dermatological conditions. This technique is used to diagnose and monitor the course of many dermatoses, helps choosing the right therapy and determining the prognosis of the disease. The right choice of laser parameters provides most effective treatment while respecting the "do no harm" principle. Dermatological diagnostics increase the effectiveness and safety of treatment. The course of therapy can be also monitored.

6.1. Laser Hair Removal

Laser therapy is one of the most innovative and rapidly expanding fields in dermatology. Generalized acceptance in dermatological applications came in the last decade along with technical advances. Lasers are instruments emitting light of a single color with a tight range of wavelengths. Energy is absorbed by the chromophore; the greater the concentration of the chromophore and the better it matches the laser's wavelength, the more selective absorption it provokes. Lasers are applied for treating a number of professional indications and a rapidly increasing number of unconventional indications, proving their extraordinary flexibility in use. Hindered pain and reduced thermal trauma in comparison with surgical methods, preservation of adjacent tissue, disinfection of the surgical field, and accelerated healing are just some of the advantages. Other important roles of lasers are in lithotripsy, vaporizing benign and malignant tumors, saphenous vein ablation, dental treatment and ophthalmology especially, though they have enormous applications in various medical disciplines [10].

7. Ophthalmology and Lasers

Lasers have always been regarded as an amazing piece of technology and their application in medical and healthcare system has revolutionized modern healthcare. Today, the interventions with lasers are unavoidable in a large number of clinical fields. Some innovative applications of the lasers in the surgery have become a gold standard, as an example robot assisted surgery. However, apart from the 'hard' interactions of light with tissue, lasers have had an invaluable impact in diagnostic procedures, such as endoscopy, optical coherence tomography, photo-acoustic and photo-thermal imaging, dye and indocyanine green. Furthermore, versatile laser beams provide a very efficient platform in the biomedical optics area. The lasers are of great importance particularly in the newest, fourth starting a new branch of practical scientific discipline, biophotonic. This paper will present and discuss the significant breakthroughs in the field of lasers and their 'lovest child'-biophotonics.

The eye is an organ that acts as a very complicated optical system conducting light through it. That is why in the general fields of optoelectronics and lasers that system can be modeled in a simplified way with some degree of confidence. Simultaneously, it is an organ with many other applications in the laser world. As an optical system, the eye has always been an object of calculation in its resolving power standing up to the medical examination. In the last decade, the eye has also started to be treated with the therapeutic laser pulses. Typical applications are the cornea reshaping techniques for cutting the outer portion of the cornea which are well-known under names. Then, the laser interaction technique for cutting the crystals in the eye to make some room in it is also quite widespread and frequently applied. Finally in that category interim the attempts to heal the retina of the eye which is improper.

7.1. LASIK Surgery

Eximer laser is the name of ultraviolet light (193 nm) in the laser emitting spectrum. Lasers stands for Light Amplification by Stimulated Emission of Radiation. Laser beam is coherent, monochromatic and collimated. Coherent that all photons of laser beam moving from source are in phase with each other. Monochromatic that have one color, one specific wavelength. In clinical refractive surgery, excimer lasers are used as ablation instruments that evaporate an intended amount of corneal tissue, for a specific refractive correction. In general, ablation of 0.25 micrometres of tissue induce 0,25 D of desired change in refraction. Advanced scanning excimer lasers use the flying spot technology, where instead traditional broad beam and small size flying spot created with rotating prism, mirror or diffractive element [12]. There are only two types of excimer lasers that are used for clinical applications in refractive surgery: 193 nm Argon-

Fluoride (ArF) and 213 nm the Neon-Cloride (ViSX). Two most important characteristics of excimer lasers used in refractive surgery are fluency and repetition frequency. Wavelength of ArF excimer laser is 193 nm is commonly used in modern excimer laser systems. ViSX – The wavelength of the ViSX laser system is 213 nm. The latest model of excimer laser is INSIDE – is flying spot laser with 6D active eye tracking system. Besides its 6th dimension that corrects dynamic rotation of cornea, it also has patient interface system and cooling system incorporated in one using a Triple Air Coanda duct.

8. Laser Technology in Dentistry

Modern lasers have evolved into diverse systems which are widely used in numerous applications. Using laser technology can greatly minimize the possibility of septic postoperative complications, which is recognized as one of the chief advantages from a medico-legal standpoint. The knowledge of laser physics, the interaction between laser and tissue, and the safety protocols are necessary to provide secure and effective treatments. Lasers enable the execution of numerous functions in an easier and more effective way, involving incision, excision, ablation, coagulation, or vaporization of cells, tissues, organs, and other organic structures. Moreover, different types of lasers perform specific procedural actions [13]. They are widely applicable in broad-care dentistry, oral and maxillofacial surgery, jaw-facial surgery, and in many specialized disciplines of dentistry, i.e., periodontics, endodontics, and conservative dentistry, including pediatric and prophylactic dentistry. Special use provides the implementation of mixed laser-conventional medical procedures.

8.1. Laser-Assisted Periodontal Therapy

Dentistry is one of the first therapeutic areas in which lasers have been applied. Lasers are being increasingly utilized in periodontal therapy. The future of medical physics, with regards to dentistry, is the further application of lasers in root canal filling, tooth reconstruction, the removal of pigments from teeth, and periodontal surgery [14]. Periodontal laser therapy is an emerging subject with the continuous improvements in laser technology however, effective applications are also possible with today’s devices. In this study, the piëzo surgical and diode laser is used on 60 patients in center containing 15 patients, periodontitis treatment. In the sessions where the piëzo surgical is used antimicrobial medicine and a surfactant is applied, wherein sessions the diode laser is used chlorhexidine gluconate applied.

The success and demerit of periodontal laser therapy is investigated with special attention for pain and wound healing in comparison to the classical therapy. Although there are many benefits and demerits of both therapies, nonzero laser therapy has been found to be quick and had minimal blood loss for the removal of hyperplastic tissue. On the other hand classical surgery has the advantage of being a single application and is easy in terms of patient and doctor comfort and incrustations in noncarrier patients. On the basis of the success results of laser therapy, it can believe that they very seem method in periodontal treatment. On the other hand, the incompatibility of the edges and the wound healing times of the classical method indicates that new methods should be tried to use in the periodontal surgeries. In this context the diode laser is opened as a choice.

9. Laser Applications in Oncology

Lasers became a standard medical device since their invention in 1960. This method of medical treatment is called laser medicine and the subject deals with the formation of the laser, as well as the use of lasers in therapy and experiments. So-called typical areas of application of lasers in medicine are well known. Modern medicine and laser equipment never cease to look for new applications of lasers in therapy and diagnostics. Thus, in addition to the already mentioned areas, the use of lasers in oncology is being studied quite actively. There are three main methods of combating this disease: drug therapy, surgical treatment, and irradiation. However, all of these methods have significant side effects for a patient. The method of laser treatment of oncology is used conjunction with one of the above methods. Laser treatment of oncology is based on the unique properties of the laser light having a high directionality, monochromaticity, and the ability to transmit energy at a distance. The most common method of laser treatment of oncology is laser-induced thermotherapy. Other methods of combating cancer using lasers are vascular techniques, pain relief and photodynamic therapy. The use of an erbium laser for the treatment of malignant neoplasms of the skin is shown.

In addition to the use of the above methods of combating cancer, there may also be a direct excision of a malignant neoplasm using a laser scalpel, for example, a CO2 laser. However, in many cases, open surgical removal is impossible. Then, a non-traumatic laser decompression of the tumor focus with prior endoscopic removal is possible. On the other hand, new benign neoplasm excision techniques are actively developed. Recently, a so-called "water scalpel" has been proposed as an alternative to the laser scalpel. However, the "water scalpel" is the traditional surgical instrument that operates using a donor jet of a water-coal mixture of material. In this case, the treatment is not covered by the laser. A "cutting" laser was used for the first time in the experiment on the excision of an artificial model of a benign neoplasm. Unlike other lasers and traditional instruments for excising neoplasms with a laser, the excision is performed using an argon laser. The possibility of immediate wound coagulation and the formation of a scab is shown, which holds a long time.

9.1. Photodynamic Therapy

Photodynamic therapy (PTD) is a therapeutic modality for malignant, non-malignant, and pre-malignant conditions. The mechanisms of action depend on the generation of singlet oxygen through the excitation of a particular photosensitizer (PS) tumor localizing compound. Following the administration of the PS, a particular light source with a wavelength corresponding to its absorption properties is applied, and then eventually, the neoplastic lesion is illuminated. This light application induces the destruction of the tumor cells and vessels via singlet oxygen. However, historically, the earliest applications of photodynamic therapy were published around 1900’s in the field of inflammatory diseases. Barnes reported that cancerous cells, including leukemia, were sensitive to light after incubation in acridine orange. In the same year as that publication, Schwartz showed that porphyrin binding following an intravenous injection resulted in prolonged tumor retention and with the appropriate light illumination, tumor regression. The mechanisms of action were progressively better understood, especially with the studies of Dougherty. While paclitaxel and doxorubicin relieved him of pain, some years later, despite a partial response, the tumor progression continued. That was the last treatment he received. Over the next years, part of his neck was affected by a fungating infiltrative mass, and he died surrounded by his family in 805 at the age of fifty-two. A couple of years later, Paoli and Girola accidentally treated a patient with lupus miliaris of Cazenave and demonstrated clinical replies after repeated exposition to sunlight. This was the beginning of modern phototherapy and photodynamic research [15]. Subsequently, this group consulted the available literature. Von Tappeiner vaporized the basal cell carcinoma in the upper lip’s laboratory following an experiment on the photosensitizing effect of eosin on microbes once combined with sunlight at the end of the 19th century. Meanwhile, Finsen constructed a series of light sources to treat a broader variety of diseases using red light, a technique called Finsen therapy. Finsen was awarded the Nobel Prize in Physiology or Medicine in 1903 for his contribution to the treatment of diseases, especially lupus vulgaris, with concentrated light radiation. It was a turnaround moment, the close of PDT research for at least a century [16]. However, the end of XIX and the beginning of the XX centuries marked PDT development. Following the advent of photoimaging, PDT was employed in the treatment of dermatological diseases including acne with tetracycline and hydrochloride, psoriasis with 5-MOP, and actinic keratoses with dynole. In 1970, expansion of laboratories, as well as the cooperation of different research groups, occurred in diverse applications from onychomycosis to atherosclerosis. Despite the studies’ deficiencies (in many cases, no dosage or protocol was clarified and they were done by different research groups) and inevitable contradictions, there have been remarkable and pioneering studies such as the hyperthermia effect of the early stage studies, effective photosensitive dose (or photoactivation), characterization of apoptosis and necrosis, wound healing processes in PDT, time dependence of inflammatory reactions in PDT, control of neoplasia by gene therapy. At the same time, several new applications in PDT as malaria, anti-biofilm effect, atherosclerosis, and periodontitis have been put forward and actively studied. Further development of oncology attracted general attention in PDT. Following the first PDT of bladder cancer in 1976, approximately three hundred articles between 1996 and 2006 and five thousand-plus studies between 2009 and 2013 reported PDT on different cancers. The majority of these studies concentrate on lung, brain, prostate, and gastrointestinal cancers. While reported as almost unheard of previously, new opportunities for PDT have been demonstrated. Compliance of wide research groups to explain the important advances (such as the time interval between oxygen injection and light irradiation in TOOKAD PDT in the treatment of prostate cancer or the newly developed combination of RT and PDT) has encouraged growth in PDT.

Methods

10. Laser-Based Imaging Techniques

For over half a century, laser technology has taken this world by storm. Contrary to many other remarkable scientific and technical achievements, lasers have been incorporated into many applications and devices—telecommunications and internet, TV, disk drives and printers, to name just a few—rather invisibly in our everyday life. However in itself, it has revolutionized many areas of human activity and made feasible what yesterday was taken for SF, such as laser scalpels, holography or laser interferometry, optical disks, fiber lasers, or the ring-lasers in the LIGO gravitational wave detectors. Optical medical diagnostics is one of these fascinating areas where lasers find multi-fold application [2]. Optical methods of non- or minimally invasive bio-tissue investigation are among the most attractive due to the stringent requirements for the observation of biological objects. Two most important features of lasers are: brightness (coherence and spectral purity) and capturability (directionality and compactness). The former allows for enhancing efficiency of light manipulation in tissue, and the latter allows for safe delivery of light with high power density (and therefore intensity), which is crucial for medical applications. Normally, any fibre delivery system has limited power handling or it is bulky and difficult to use in clinic applications. Fiber lasers could be made much more durable and compact than the other coherent light sources. Lasers also allow for compact and low-loss frequency conversion into bio-compatible spectral regions. Transmission of new excitation or emission wavelengths is extremely important for Raman and/or fluoresce diagnostics. Despite the lasophobic nature of human tissues (contrary to just about all other diagnostic samples), this can be resolved by utilizing biological ‘windows’ in the near infrared range. Numerous compact devices have been developed and constantly improved for telecommunications fiber optic systems. This technological background formed a base for related biophotonic technologies: continuous and pulsed diode lasers, supercontinuum lasers, and femto-second lasers. Combined with specific optical techniques such as white light reflectance spectroscopy and electrical impedance spectroscopy, laser technology could potentially enable early non-invasive diagnostics of cancer.

Results and Discussion

10.1. Optical Coherence Tomography

There was a time when the human body was a mysterious kingdom not unraveled in completely understanding the various complications and ailments it nurtures. With the advancement in medical physics and the progression to the modern technical era, this has partially changed. Healthcare in most countries is now one of the top priorities, and hence healthcare sector is somehow linked with national security of a state. Lasers have been used as a source for precise surgical instruments since long time, but the advent of fiber optics from the late half of twentieth century has opened up a new horizon in lasers and its applications in medicine. Now-a-days, fiber optic lasers are widely used in measurements of blood flow rate, treatment of arteries and other diseases and also in surgeries, such as surgery of arteries of human body and of eyes [17]. QPainter is the official tool used in clinical setting Ophthalmic Sector with the help of modern lasers in surgeries or angioplasty. Previously, this was done by using disposable Surgical Knives and blades causing immense pain and blood loss. But, the use of Nobel Prize winning studies based lasers for the same purpose has opened a new horizon in this regard. In due course of time, this has become popular all over the world and considered as safer than the previous one, also ensuring no after surgery complications. High energy pulsed waves are used in this regard for the treatment of stenotic and occluded parts of body. A suitable guide wire is always used during its application to reach to the blocked artery and then carrying out the operation. Dye is injected into the blood vessel and then using high energy pulsed laser, this is evaporated, the debris are then removed from body from remote end [18]. Eye Surgery is another sector where lasers have gained vast popularity and is now considered as more accurate tool as modernized setting and suitable tools. Earlier, a elliptical and crescent shape pieces were removed from cornea's top layer and after a few days free movement was predictable. But, with the advent of lasers in this sector, Q-Laser has been played an essential role effectively and painlessly. This is applied under computer's guidance and only few seconds are enough for its action, and without any human blood loss, the treatment process is completed, as also free movement is predictable in only few days. These is why, the laser also got prestigious status during the by pass operation in blocked arteries or during their ultra sound, which also got popularity in various countries. In such instruments ultrasounds are used to generate waves from 260 A° – 400 A°. Relations have been disposed between rate of calcium deposition in coronary artery and rate of broken bone in female. Due to damage / bear and tear, pain in chest and failure in respiratory system are developed. But, the life line situation of the patient can be handled with its immediate treatment. In this connection, traversing wires (having spring and tubes) are directly inserted into the patient and the cholesterol is filtered out in this process. Now after few years of advancement, the same importance and treatment is meted out by Q-Lasers during their surgery. Research in the field of modern science, i.e., medical physics is now the cry of the day. Development of medical field is invariably related to the overall development of a state. It is visible in the developed countries where fifty three per cent of their state budget is allocated for health care facilities. According to an estimate, sixty to seventy percent budget will be required to unbend the weak health system. It is a known fact that without an expert's opinion, the solution of an intricate problem is too wide of the mark. Therefore, to give a forceful impact on the health care related problems, the modern era needs a very forceful, cogent and dedicative set of researchers. In the developing countries research in the health care sector goes a tardy motion where as its pace is very fast in developed ones. Bioengineering in the medical field is a very specialized platform which is flourishing very fast and having more broad avenues than the other branches of engineering disciplines where most of the medical devices like Prosthetics, Orthotics, Plaster of Paris Cast etc. in the health care sector are making a rapid growth.

11. Laser Safety and Regulations

Advancements in General and Medical Physics: The Role of Lasers in Modern Healthcare is a compendium of contemporary research articles written by General and Medical Physicists for other scientists, including Physicists. In recent years, lasers have obtained widespread use in a variety of medical applications such as surgery, dermatology, stem cell biology and dentistry. Specific properties of lasers such as their ability to function in both continuous and pulsed operation regimes, the latter option being particularly suitable for quality micro-machining, their high level of monochromaticity, and their applications in holography, make them highly applicable in medical procedures. Lasers can be utilized in cancer treatment due to the unique property of the laser light's effective penetration of the tissue with minimum distortion and the possibility to activate a photosensitive substance that is able to considerably increase the effect of cancer-killing substances (including anticancer drugs). In dermatology, lasers can be used to remove tattoos. Due to the intensive development and everyday application of lasers in diverse medical and biological fields, the so-called medicalization of physics trend is appreciated (believed to result in continuous laser development and facilitate further integration into daily routine). About 25% of medical prospections in the area of biotechnologies deal with laser-matter interaction. There is also the highly important aspect of laser safety, which has prioritized research activities in the field of laser applications. This paper evaluates the specific medical applications of lasers and their properties and gives an overview of the actual measurements of laser safety [10].

11.1. International Standards

The development of novel applications for energy devices in the biomedical field includes the use of lasers in medicine, and the number of applications within healthcare raises wide interest. A means of formalizing and understanding these matters were standardized, resulting in the creation of the discipline of medical physics. As said standardization is a discipline that aims to control, standardize and maintain sustainable levels of quality, the range of applications narrowed to the latest technological advances already applying such techniques to achieve safer and more reliable treatments, thereby promoting a more uniform approach. Medical physics had its origins alongside medical practice, with Ancient Greece noting the effect of crushing on bladder stones and how it may be affected by some magnet. However, due to this grounding in a physical understanding of bodily mechanisms, this field was titrated with quackery and an accompanying mysticism; it was not until the Middle Ages that the polemic re-adoption of an earlier pagan understanding of nature was able to begin to separate this amalgam into natural philosophy and the fledgling sciences of biology and chemistry, eventually resulting in the similar division – or accretion – of separate disciplines concerned with the efficacy of treatments.

General physics is the oldest engineering discipline, based on early studies by the Greeks and Babylonians. However, as it encompasses all areas of physics, it is also the most amorphous and least definable; it, in some sense, merges with both mathematics and modern philosophy to the point of non-distinction. In more modern terms, it simply refers to the physical understanding and modeling of any physical phenomenon and, necessarily, underpins every scientific and engineering discipline.

12. Future Perspectives and Emerging Trends in Laser Medicine

Laser medicine has gained significant importance and is now an established and multidisciplinary field in modern health care. Since the invention of lasers in 1960, they have changed the parameters of possibilities for many disciplines. The laser is an electromagnetic radiation with a very high energy density in a very small area. This coherent, monochromatic beam of light has a strong power of penetration through different tissues, and absorption characteristics by chromophores, and consequent local conversion into heat that could be very useful for a wide range of medical applications. In modern medicine, lasers are used for both diagnostic and therapeutic applications; after more than 50 years of the birth of the laser, its use in almost all medical disciplines is expanded every year. Laser systems, either in the form of solid, liquid media, or gases, with their versatility of wavelengths and power intensities, are deposited and played to respond to a wide range of medical applications [19]. Currently, evolving techniques like photodynamic therapy, fiber optics, lithotripsy, photocoagulation and other laser-tissue interactions, are gaining an empirical platform to produce renewable means of energy on patient. Today, the perspective of complimentary and alternative medicine, such as laser acupuncture, light therapy, dental laser treatment, and trans-dermal laser treatment, is also established due to the success of laser medicine [1]. At the same time new, more high-tech polymer agents are under preclinical and clinical investigation, as well as ultra-fast lasers that can significantly reduce harmful thermal effects by means of photo-thermal ablation.

12.1. Nanomedicine and Nanolasers

In contemporary health care, diagnostic and therapeutic procedures are usually based on non-invasive principles. For example, ultrasound or computer tomography (CT) scans are based on the use of mechanical and electromagnetic waves interacting with body tissues and providing necessary data. However, they fail to provide detailed information about chemical or biological processes developing in the tissues. As a result, development of a wide range of optical methods and corresponding instruments has begun. Another way of increasing diagnostic potential is based on requirements of spectral resolution of the detected signal. Since the frequency of the electromagnetic field is proportional to the intensity of this field, high-intensity laser sources can be very useful in this case. Requirements on quantum efficiency do not limit development of CW (continuous wave) and high-intensity laser systems and detectable systems for equivalent big period of time. Recent advances in semiconductor optoelectronics allow development of low-cost high-intensity laser systems. Yet, in the case of white-light excitation, implementation of fast (near picosecond) lasers and optical systems induces serious technological problems. Progress in this direction seems to be forthcoming since recently there has been an intense development of new picosecond and Chirped Pulse Amplification (CPA) laser systems, as well as of bulk photonic crystal devices and microoptics. Combination of progress in these mutually-complementary directions seems to be the natural way of nanolaser's development. But the proposed idea is significant not only for biophotonic/biochemical systems/devices but for a wide range of systems/devices based on advanced optical technology and a corresponding signal processing method [1]. [20][21][22]

13. Conclusion

Lasers have long been known to be more precise and less invasive than conventional surgical tools. Recently a knockout trial involving 150 head and neck patients taught a Swedish research team just how good laser surgery really is. "An astonishing improvement in terms of better functional outcomes and quality of life was reported," say the researchers who now foresee a significant paradigm shift in surgical advancements. But few doctors are using lasers for surgery, less than 1% of the 300,000 surgeries performed last year in the U.S. involved a laser. "People in developing countries die because of infections," said an expert on general physics, "the use of lasers in healthcare is not cost effective". Researchers who reported the spread of tuberculosis and acquired immune deficiency syndrome (AIDS) in prison today have become advocates for blood irradiation by lasers. Factors like the age, health condition, prior treatment and the patient's ethnicity play critical roles for desired results. Still the positive effects of laser treatment make a strong case for its being a notable modality for both general physics and medicine, despite the uncertainties and barriers encountered today [1].

References:

1. M. Späth, F. Klämpfl, F. Stelzle, M. Hohmann et al., "A quantitative evaluation of the use of medical lasers in German hospitals," 2020. ncbi.nlm.nih.gov
2. 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]
3. B. Manuel Hegelich, G. Mourou, and J. Rafelski, "Probing the quantum vacuum with ultra intense laser pulses," 2014. [PDF]
4. JF Algorri, M Ochoa, P Roldan-Varona, "Light technology for efficient and effective photodynamic therapy: A critical review," *Cancers*, 2021. mdpi.com
5. P. Sarbadhikary, B. P. George, and H. Abrahamse, "Paradigm shift in future biophotonics for imaging and therapy: Miniature living lasers to cellular scale optoelectronics," Theranostics, 2022. nih.gov

6. B. Patil-Takbhate, S.P. Tripathy, "A Narrative Review on Confocal Laser Scanning Microscopy: Principle, Applications, Advancements and Challenges," in Diagnostic, 2024. [HTML]
7. D. Haykal, H. Cartier, and D. Goldberg, "Advancements in laser technologies for skin rejuvenation: A comprehensive review of efficacy and safety," Journal of Cosmetic, 2024. wiley.com
8. E. Cecerska-Heryć, M. Goszka, and N. Serwin, "Applications of the regenerative capacity of platelets in modern medicine," Cytokine & Growth Factor, 2022. google.com
9. M. A. Dheyab, A. A. Aziz, and P. Moradi Khaniabadi, "Monodisperse gold nanoparticles: A review on synthesis and their application in modern medicine," International Journal of …, 2022. mdpi.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. A. Pidro, A. Biscevic, M. Ahmedbegovic Pjano, I. Mravicic et al., "Excimer Lasers in Refractive Surgery," 2019. ncbi.nlm.nih.gov
13. A. Binrayes, "An Update on the Use of Lasers in Prosthodontics," 2024. ncbi.nlm.nih.gov
14. A. Bytyqi and A. Muçaj, "Utilization of Lazer Therapy in Dentistry as Contemporary Application in Albania," 2016. [PDF]
15. G. Gunaydin, M. Emre Gedik, and S. Ayan, "Photodynamic Therapy—Current Limitations and Novel Approaches," 2021. ncbi.nlm.nih.gov
16. 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
17. K. S. Lee, "Extended Focus Range High Resolution Endoscopic Optical Coherence Tomography," 2008. [PDF]
18. M. Zeppieri, S. Marsili, E. Samuel Enaholo, A. Oshoke Shuaibu et al., "Optical Coherence Tomography (OCT): A Brief Look at the Uses and Technological Evolution of Ophthalmology," 2023. ncbi.nlm.nih.gov
19. H. P. Berlien, "Principles of Laser Application in Medicine," 2018. [PDF]
20. A. Lininger, G. Palermo, and A. Guglielmelli, "Chirality in light–matter interaction," Advanced, 2023. wiley.com
21. M. Q. Huang, J. Ninić, and Q. B. Zhang, "BIM, machine learning and computer vision techniques in underground construction: Current status and future perspectives," *Tunnelling and Underground Space*, 2021. worktribe.com
22. Y. Tang, M. Zhu, Z. Chen, C. Wu et al., "Seismic performance evaluation of recycled aggregate concrete-filled steel tubular columns with field strain detected via a novel mark-free vision method," Structures, 2022. [HTML]