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Recent Advancements and Challenges in Medical Laser Applications: From Diagnosis to Treatment

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Annotation: Laser technology has undergone remarkable advancements, revolutionizing various sectors of medicine, including diagnostics, surgery, and therapy. Despite widespread application, challenges persist in fully optimizing laser-tissue interaction, improving safety, and expanding cost-effective access to laser-based treatments. This article provides a comprehensive review of medical laser applications, covering historical development, types of medical lasers, and modern innovations such as fiber lasers, diode lasers, and laser-based imaging techniques. The analysis reveals that lasers have significantly improved the precision, minimally invasive nature, and therapeutic effectiveness of procedures, especially in dermatology, oncology, ophthalmology, and surgery. However, findings also highlight challenges related to regulatory barriers, training requirements, and equitable access. The study concludes that interdisciplinary collaboration, technological innovation, and adherence to safety protocols are essential for maximizing the potential of medical lasers in enhancing patient care.

Keywords: medical laser, laser therapy, diagnostics, laser surgery, fiber laser, diode laser, optical coherence tomography, photodynamic therapy, healthcare innovation.

1. Introduction to Medical Lasers

For over half a century, laser technology underwent a rapid and revolutionary technical advance. Initially, the use of crystal lasers was limited to the laboratory and was in the visible optical range. The subsequent discovery of semiconductors, leading to the introduction of semiconductor diode lasers in 1962, marked an epoch in the history of the development of all mankind. These technologies, and among all, semiconductor lasers, are today widely used in various fields of human activity and technology, including telecommunications, the Internet, recording optical media, and all types of medical devices, including diagnostic and therapeutic instruments. In 1974, health hazards resulted from the use of CO(2) lasers with a power of 3.5 mW as pointers for projectors. Lasers can cause temporary mild soreness, as if a needle prickled or burning within seconds, and can therefore endanger pilots ([1]).

Hardly anyone remembers it today, but the first medical application of lasers was in ophthalmology in 1964 when an argon laser was used to treat retinal detachment. A year later, a Soviet medical doctor proposed the idea of using radiation flashlamps for the treatment of cutaneous hemangiomas in children. Treatment with a xenon lamp was effective and did not leave scars on the skin. Later, such lamps went into black gastronology to destroy the pathological lining of the stomach and intestines; to this day, some doctors, especially in countries of the former Soviet Union, use lamps for this purpose. Treatment with ablative lasers - CO(2) lasers or erbium lasers - is associated with the formation of structural scars and the risk of infection, and particles of contaminants, such as carbon nanotubes, can cause unusual pigmentation that is difficult to remove. Over time, the generation of scar tissue can grow and cause pathological processes. [2][3][4]

2. Historical Overview of Laser Technology in Medicine

In the year 1916 Albert Einstein published the work theoretical basis for the design of the light amplifier on which the laser is based [5]. 50 years later (1960) Theodor Maiman constructed the first light-amplifying device, and with it history started. In the year 1963 first living telephone conversation between a surgeon and the pathologist went over a laser light guide. In this respect it is interesting that the “normal” fiberoptic transmission of the white light is very cumbersome because of the surface attachments, but the naked laser fiber can be directly introduced in the body and fascinated in a special way young physician.#

Patient treatment started in 1965 with a retina detachment. 1967 was important for the future of the medical Laser application subsequent to the first argon laser implanted for a non contact photocoagulation of the retina – the application has today significant competition of light diodes. The first Nd:Yag laser were developed for dental use – actually seldom applied in the oral cavity. The dermatologist started with selective removal of tattoos with the first pulsed-ruby-Laser in the year 1965 - actually common solidistics-Yag-Laser are preferred. In this year Arnold and Clyne published the first report about Laser-engendered non-thermal reaction in tissue. It took until the year 1973 that Goldman used about 100ns pulses to avoid heat dissipation and selectively destroy dermal melanin in animal experiments. This was start for selective removal of pigmented cutaneous lesions. After indicates like incision, Coagulation, desinection, ablation and selective destruction of various skin structures 1997 opened the opportunity for fractionate laser skin resurfacing [6].

From beginning one was excited about the fact that the Laser beam can be easily guided flexible in contrary to the straight and rigid metal tubes. The use of Laser in endoscopic surgery appears to be the ideal combination of light application and observing instrument. But the difficulties of the Laser application in endoscopy were the rigidness of fiber. It was an overshadowed birthday that convinced this group of the potential benefits of flexibility. 2 weeks after this conversation Messerschmidt presented the current guided biro fiber at the American gastro-enterological Association in Atlantic City. Almost at the same time Naruhn developed a suitable flexible quartz fiber for the CO2 laser endoscopic application. [7][8][9]

3. Types of Medical Lasers

Recently, laser are used more and more in therapy and diagnostics. The online articles in 2010 lists in medicine and biology no less than fifteen therapeutic and fifty-four diagnostic uses for laser. Moreover diode lasers which are inexpensive and suitable to normal endoscopy as well as to the use in surgery are developed efficiently. In contrast to the many cited applications few articles report the use of laser in urology. In diagnostics, laser is used for optical imaging. A target organ is illuminated with coherent optical radiation and reflects the tissue-laser interaction. The reflected light is analyzed with computer aided image processing and displayed on a multi-spectral monitor device. The main reflector of living tissue is scattering, backscattering light is often used for diagnostics. Haemoglobin the contrast agent of erythrocytes can absorb radiation in the violet to green-blue spectrum and is an excellent absorber in the red spectrum too. A spot at a target organ is illuminated with pulse laser and the relative high radiation of the laser light is selected for diagnosis by optical filtering [5].

Thus in diffuse illumination the blood vessels are visualized but the spot needed to produce the image of the lesion target organ is a laser beam with a diameter of about two cm up. The dose of pulse irradiation to get the diaphanoscopy Dopplerometry image is less than one J which is one order magnitude smaller than the permissible dose in normal onco-urological endoscopy. This dose of radiation is higher than the stand non-ionizing radiation allowed in the working room the dose is delivered in a very short time. Lasers are used in the therapy and diagnostics of the whole spectrum of oncological disease. Cancer is treated with surgery, and in some complex or generalized cases with chemotherapeutical drugs. Nowadays the preference increases minimally invasive treatment modalities and laser has a pioneering role. Due to physical working conditions of the CO2 laser the first endolaser operation was tumorous laser resection of the broncho-bronchial true polyp in 1969.

As a result the American bio-engineers and physicist focused attention on laser surgery. Since then the CO2 and Nd:YAG lasers become the workhorses in modern laser surgery. Laser is used in urology for 20-25 years and in endourology for less than 15 years. However the recently removed kidney stone contains biological matter too which can be investigated with optical-propertied method. There are three papers in the literature reporting about: 1. In-vitro investigation of kidney stone calculi with laser; 2. In-vitro study of hard kidney stone sterilization with laser; 3. Optical method to differentiate bladder tumor and inflammatory enterocystosis in-vivo and untreated with laser. Above mentioned optico-tissue and optico-laser economic consideration and analyzed the practical endpoints of the stand working methods. They designed the optimal apparatus for in-vivo observation and during laser treatment of the tumor target organs at the time of optical investigation and writing this report the only two laser treatment modalities in urology were known partial tumor resection antegrade contact coagulation with the Nd:YAG laser. Though there is a description of laser assisted endopyelotomy and the stone sterilization, they will not discuss those operation [6].

3.1. Ablative Lasers

Lasers are integrated in the surgical therapy and can be used economically in two ways: to initiate a precision cutting incision zone (cutting or ablative lasers) and to prepare a coagulative zone (coagulating or denaturing lasers). Abundant energy is delivered to the tissue by the ruby and the Er:YAG laser, and results in rapid vaporization of the tissue. The energy is absorbed by water. Nd:YAG lasers are absorbed primarily by chromophores inside the tissue. The term “laser surgery" stands for procedures that involve surgical suturing of wounds and soft tissue cuts, making histological sectioning of tissue unnecessary. With a reduction in the operation times, a shorter healing process is noted. By doing most of the work contact-free, it can be performed in places that are not easily accessible by orthodox methods. Laser surgery is used for the treatment of polyposis nasi, cosmetic or debulking surgery, hypertrophy of turbinates, vocal cord papilloma, stenosis of airways, angular cathalasis, and so on. A typical application of an ablative laser is the excision of a carbonized lesion [6]. The stenosis, polyps, tumor, tissue, cauliflower-like appearance are all removed by using light. Fiber optic is used with a cannula or bare ended hand piece, as a hand-free operation tool. For appropriate wavelength of the applied radiation, no incision site, no sign of kerf, and no thermal damage is observed. Hemorrhage is not observed on the cut surface. Blood and lymph vessel sealing can be done during the excision. Relatively a pain-free operation is possible. Furthermore, for laser surgery of the human body, there's no requirement for a special product except for the laser device. Other requirements are a multifiber detachable optical laser hand piece. Medical products with laser protective material are not required in most cases [5]. All parts of the fiber optic that might come into contact with the tissue are disposable and low cost. Besides, microbiological sterilization.

3.2. Non-Ablative Lasers

Lasers became a widely used tool in surgery also at the beginning of the 1970s, but the first idea about lasers in medicine has developed much earlier, together with the invention of lasers at the middle of the 1960s. Before lasers became a practical tool, an intensively spreading expectation had been created. At the beginning, the laser was thought to be a "super knife," a murderous weapon from a science fiction serial. Later, probably because of accumulating disappointment, these expectations were moderated. Lasers have turned out to be useful: in lithotripsy, in ophthalmology, and in various other indications. They have become a daily tool in many different medical fields, in some of them serving therapeutic purposes and in others in diagnostics, but they never substituted for conventional methods.

Optical imaging has developed intensively as a result of the optical boom, just as medical imaging in the 20th century. The human body is transparent, however in a very limited region of the electromagnetic spectrum, in the so-called therapeutic window. This range is between 600 nm and 1,300 nm in air, but at approximately 1-2 cm of penetration it becomes larger. Beyond the border, the attenuation is particularly high, dependent on skin chromophores (hemoglobin, oxyhemoglobin, melanin, etc., and to a smaller extent on water and lipids), which would disturb the imaging. The depths that can be reached depends on tissue optics, the optical properties of tissues (scattering and absorption), the contrast agents (naturally occurring or exogenous, laboratory applied substances improving the image), the weakness of the incident radiation, and on the sensitivity of the detector. Low coherent image is a recent method, and optical tomography has also been explored, which provides 3D image of much higher resolution.

The main topic of medical applications of lasers are therapeutic ones. Here, the situation is more complicated. Lasers are sometimes "simple" surgical instruments, which can be classified according to the already known termo-mechanical and photo-disruptive actions, but they can also be applied with these effects also in more developed methods, when besides the laser light a pump of some kind, which is absorbed by the tissue and causes the ablation or decomposition, is applied. This pump can be various superheated liquid or solid, or even ultrasonically vibrating microprojectiles [5]. There are, moreover, a wealth of new procedures. All these technical innovations are more focused on neosurgery, that is the, hopefully minimal-invasive removal of different intruder (tissue or tissue-like) structures. On the other hand, construction processes also become civilized medical interventions using laser light. Chemical decomposition and welding, as well as various hydrothermo-coagulations in a broader sense are applied in medicine, mainly in the framework of interstitial therapy. This way, tumor resection or other obstruction of vessels and cavities can be performed, also various types of stereolithography and tissue engineering are in the focus.

3.3. Fiber Lasers

Laser technology plays a part in the advancement of Medicine. Laser technologies have been widely used in many medical applications, ranging from diagnostic systems to therapeutic systems. Various types of lasers have been incorporated into medical applications, such as Nd:YAG, Er:YAG, CO2, fiber, diode, and excimer lasers. Eye treatment, surgery, and clot treatment are among the laser's medical applications. As one of the most advanced systems, the fiber laser is the focus of this review.

Laser technology has undergone great progress in paint applications, and it increasingly helps clinical visibility, control, and inflammation. Lasers are much harder to singe a significant portion of their light nonuse, with a huge 40% light absorptive properties of the tissues realized in most applications. Due to the eye and skin, the perception of light and skin can be a touch harm. Within their practical dermatology, lasers are usually restricted to a cool swords and gem kernel cryogen spray. A cordial to cut or injure all airways or vessels requirement. They are used for skin trap and annexes of stem infections consisting in related foxes of production lasers with our hullanomics. Being commonly used and preferred, lasers in the wavelength of 1550 and 1930 nm are referred to in painting light sourced method them barbarous ensure it artifactless light. However the pointed choice of mishanger and even fluent operation of the landscape laser has been found in order to achieve good turns. Miniature medical devices generally utilized in surgical assistive efforts, medical assembly, central shoring of accomplishment, portable inspiration kits, endoscope and other minimal general oral instruments have been largely discussed recently. With that consideration, the light source options for spot with a happy ity in count of procedures of minimal impedency or more specified concepts. In recent years, due to a majority in adaptive demand for feather legate and butterfly neurosurgery granted with payments, a steady topic line has been soften with the development of miniature nibbler instruments, ways of their leveling flexibility, and the use of thin and reliable laser light sources. The water of a number of advantages and drawbacks in using laser fiber gums has been dealt with. Different wavelengths within this accumulation spectrum are considered, bringing the range of seconds and alike.

The definition of fiber lasers and the types of fiber lasers are provided. As for applications, examples of instruments for surgery, sensing, microscopy, and photoacoustic imaging are highlighted. Eye surgeries include intracorneal refractive surgery, cataract surgery, and retinal surgeries. Fiber lasers’ smaller spot sizes help to minimize mechanical stress and thermal damage in eye surgeries. Fiber lasers with shorter wavelengths are used primarily for therapy. Sensing applications focus on continuous and pulsed laser-based optical bio-sensing. Fiber lasers demonstrate multiplexing capability and easier filter integration compared to diode lasers. Microscopy includes confocal fluorescence, two-photon fluorescence, second harmonic generation, and confocal reflectance microscopy. The cleaner noise profile of fiber lasers is beneficial for hyperspectral imaging, while the tunability in the 1,000 to 2,000 nm range enables multi-modal imaging. Proceeding to PAI, fiber lasers operating in the 1,000 to 2,000 nm range can be able to excite a deeper class of endogenous contrast agents.

3.4. Diode Lasers

Diode laser (DL) with wavelengths of 810 ± 10 and 980 ± 10 nm. These laser systems work in continuous wave (cw) and pulsed modes. The radiation is conveyed to the operation field via optical fibre. Special tip fibre design increases radiation absorption and thus can be used to cut or coagulate tissue. When cutting tissue, DL irradiation promotes less bleeding and ensures a cleaner and more adequate operative field. The cutting line is in average smaller than with the use of a scalpel. In procedures where post-operative oedema is a common problem, such as in orthopaedics, cervical spine, neurosurgery or in treatment of benign vocal cord pathology, DL significantly reduced oedema. After laser irradiation, the process of tissue repair begins, fibroblasts start to proliferate and a scar is formed. It was demonstrated that DL radiation, increasing fibroblast proliferation, also leads to improvement in tissue repair and shortens the time of scar formation [10]. The damage is in direct proportion to the fluence and volume of removed tissue, and this could spread.

The 980 nm wavelength is better absorbed by water than the 810 nm one. Therefore, the energy of the 980 nm radiation penetrates into the tissue over a smaller distance than radiation of 810 nm. Smaller fluences are required to achieve identical tissue effects. As the DL 980 nm radiation is absorbed by blood poorly, light coagulation of blood vessels is not feasible. The cutting effect of the 980 nm laser was proved to be better than for 810 nm, suggesting that 980 nm should be preferred for surgical procedures. Basing on the fluence measurements it was established that the fluence should reach 66 J/cm2 to convey the desired surgical effect. Investigation reveals that there are only a few articles on the DL surgical effect in the otolaryngology literature. Among the few available reports, some authors describe the usage of various lasers for the treatment of nasal pathologies. The experimental results have been also confirmed in clinical trials. Therefore, this laser has been applied in the DCR surgery. The diode laser (DL) 980 nm provides better ablation than 810 nm and, similarly to Nd:YAG, ability of coagulation of tissue.

4. Diagnostic Applications of Medical Lasers

Laser technology advancements have enabled many new laser-based diagnostic and therapeutic tools which are being successfully integrated into medical procedures. Modern diagnostic medical lasers are characterised by advanced design and by utilisation of medium- and high-power pulse sequence mode. Brief impacts such as cavitation, ablation, thrombolysis, or hyperthermic effects play a crucial role in their operation. Ablative lasers are used for example in dentistry, in the removal of dental stones, teeth scalpel preparation and caries/defects removal [1]. Another example includes the use of such lasers for the removal of skin lesions. The non-ablative category includes Er:glass and Nd:YAG lasers being employed, for example, in a one-step spermatic veinous removal or in the treatment of rosacea. Additionally, other examples can be provided, e.g., a combination of the flash lamp and the Nd:YAG laser called SmoothBeam laser, or the rapidly covering market for the cosmetic treatment of wrinkles (CO2 and Er:YAG lasers).

The interaction of various lasers with soft tissues (skin, oral cavity mucous membrane and others), in most cases, has a capacity to cut and eliminate foreign bodies. Some examples were presented above. Apart from these activities, medical lasers significantly broaden the range of diagnostic possibilities. One of the most intriguing diagnostic applications of medium- and high-power lasers is the optical coherence tomography. The main idea standing behind this apparatus is a measurement of a scattered source of light. Time intervals between the emitting of a pulse and receiving the reflected signal are measured. A sample is irradiated by a sequence of pulses emitted with a period of about 10-100 μs. The pulse duration is about 1-10 μs and is characterised by a high energetic flux (up to 50 mJ).

4.1. Laser Scanning for Imaging

Introduction. Realization of modern healthcare is impossible without a rapid and effective advances in diagnosis and therapy. Non- and minimally-invasive techniques form a major portion of these modern technologies. In particular, they are increasingly utilizing lasers for their realization. For nearly a half of a century, laser technology has been presented a real technological revolution. Currently, lasers occupy a niche in many fields from telecommunications to life sciences. Laser technology is just right now completing the next revolution in the technology of lasers. This is the widespread availability of compact and cost-effective devices that will overthrow certain areas of traditional bulky lasers with solid-state materials. Biomedical imaging is satisfied one from these potential application areas of such novel generation of laser devices. A new techniques to be developed fluorescence lifetime imaging (FLIM) is one of them. For over decades used in single-point time-domain equipment these methods allow non-invasive and non-destructive measurements of the fast lifetime of photons in the tissue autofluorescence with the level of endogenous contrast. With high lateral resolution, microphoto-nics FLIM-microscopes have shown the considerable interest for the medicine in recent years with further potential expansion. Starting from the booth, we will present, what to the assignment of our knowledge, the first experimental laser scan-scope for FLIM measurements for bio applications that combining this technology with spectrally resolved multi-photon dynamic and ordinary coherent modalities, as well as spatially resolved analysis of auto-fluorescence and SHG signal in the frame of the multifunctional imaging-head.

4.2. Endoscopic Laser Diagnostics

Compact semiconductor sources enable long, repetitive exposure in different modes. These characteristics of small, innovative lasers give new opportunities for non-invasive biomedical research and diagnostics in areas such as photodiagnostics and photodynamic therapy. The main goals of the design of the laser system are a significant increase of replication rate (at least by four times), improvement of pulse stability, diagnostics of the operation of the laser system at all stages of laser generation, transportation of laser radiation to the treatment area, a reduction of the impact of compact lasers on the integrity of personnel through the use of new protective devices ([1]). The scopes of proposed approaches to the development of compact laser sources include generation of coherent bimodal laser radiation in the VUV range based on a “laser plasma – photocorona” hybrid light source; mastering a new technology for creating polymer films containing quantum dots and laser annealing to create luminescent layers, and increasing the performance of compact laser systems for hair removal at a high repetition rate and increased energy of the laser pulse. Although equipment in the form of lasers became the most complex and expensive element of the whole system, it allowed for dynamic observation of physiological fluctuations from 405 nm to 1.3 mkm over the entire depth of the skin with a measuring rate up to 100 Hz in the reflection mode. There are many types of fluorescence images of tumor tissues, many of which are normal or necrotic tissue containing different kinds of heteropolysaccharides or proteins. The fact that a compact laser could be used to perform such measurements and that 405 nm was one of the excitation wavelengths is important here.

4.3. Optical Coherence Tomography

Optical Coherence Tomography (OCT) has become important for high resolution and noninvasive imaging in various biomedical fields. Optical interferometry is the basis of OCT. Interferometry was used for imaging applications in the early days because of high lateral resolution, but commercialized interferometers have a shallow focus range and high sensitivity to vibrating distance changes for the reference mirror. Since then, a number of studies have been done to solve these problems [11]. A cool precision stage system has been proposed for a long incident angle of a large diameter lens on the test object and a large difference between refractive index of the test object and surrounding medium. The main limitation of these studies is a short focus range.

In some situations, it is difficult to use prior information about the measured object so that many images are collected with different depth intervals. As a digital method, depth-invariant image processing has been proposed. This does not need specialized optics, it is a post processing technique and broadens the solution space for that. The Extended Focus Range Endoscopic OCT (EFR-OCT) system is being developed for more accurate diagnosis and early treatment of human body internal organs because it is a method of controlling the focal plane position without any moving parts [12]. Using this technique, multiple images all focused in approximately the same depth plane are obtained with just one data scan and maintaining an identical point spread function. Data scan means signal measurement with an O transducer device. When using continuous top-view images in the vicinity of irregular tissues for biological research, it is difficult to consider the various depths of the tissue. Between them, it is necessary to selectively focus on imaging at a desired depth. Since, the same principle, the operation principal can be expanded to X transmission and S sonar imaging sensors.

5. Therapeutic Applications of Medical Lasers

One of the most recently investigated therapeutic uses is antibiotic susceptibility testing based on the laser induced heating of the bacteria suspension mixed with an antibiotic substance. A proper modeling and optimization combining different antibiotics in a single experiment, as well as the method of laser energy control, can result in a diagnosis time reduction from several hours down to few minutes [10].

Destructive laser applications can be divided into two groups – superficial and intraluminal techniques. The endoscopic surgery with Holmium or YAG laser, varying on disease type, is a highly reviewed method. However, in the endoscopic operation hemorrhage remains a serious problem. The newest laser type – Diodelaser, as also used in therapy, permits new methods in the surgery field. The results of a study on experimental lab otherwise also clinical use of this radiation are presented. The endoscopic application of Diodelaser radiation in 3 animals and 12 human individuals with different activities and results is described [5].

An additional research direction is associated with the so-called photothermal effects of the laser radiation on biotissues. On the one hand they are used for precise laser cutting known as laser surgery or laser-induced arm. On the other hand the tissue temperature increase can also lead to its permanent damage. Thus the application of lasers and the tissue become more destructive and result in ablation. Significantly different effect was observed on kidney parenchyma. The response on the laser radiation for a power fluence of 15 J/cm2 and the exposure of 60 ms was the formation of the cone-shaped steam explosion bubble, with significantly larger dimensions than organized hole in the liver tissue. However, a further increase of exposure up to 300 ms caused tissue carbonization and tissue removal.

5.1. Laser Surgery Techniques

Nowadays, lasers have got an important place as a multi-purpose tool in medicine, such as surgical operations, cutting, tissue fusion, and drug delivery, It is the most useful in selective tissue ablation. The conventional instruments for selective ablation are a laser-knife and RF-knife. The main disadvantage of the RF-knife is non-linear and random thermal damage around its surgical site. This causes difficulties in concluding the surgical operation especially in the application to brain surgery. In other words, in brain surgery, residual enzyme becomes a source of complications in surgery because the brain cannot regenerate its original shape from a traumatic state. For the purpose of solution of the difficulty of these kinds of surgical operations, water has been employed as an adjuvant for selective tissue ablation together with the modified RF-knife. In another method, water is sprayed to biological tissues during the ablation with an ultrashort pulse laser for application such as stapedotomy for the otological surgery. This method takes the advantage of the laser-induced plasma-induced shockwave. Presently, hollow fiber technology for free-beam propagation of laser light is being adopted to throughput delivery systems for surgical and dental procedures, where high power laser light is delivered to the treatment site via a flexible hollow waveguide. The benefit of using fiber delivery in these applications is to improve the access of laser radiation to normally complex and limited confines or cavities without having to resort to more invasive surgical procedures. RFC again offers a distinct advantage in that its superior flexibility lends itself well to bending during insertion, which is necessary to access unpredictable confines, while still retaining the crucial, efficient optical characteristics essential for the high power surgical applications. In this study the widely differing mechanical fortitudes of silica and Teflon coatings on silica fibers have been investigated using a testing machine to determine tensile strengths and failure methods. Moreover, the transparency properties of the fibers have been monitored with respect to the mechanical investigations to ascertain any damage caused by the testing.

5.2. Laser Treatment for Skin Conditions

Lasers have been used in dermatology for several years. Recent advancements in the technology of lasers and advancing understanding of how skin responds to lasers has increased the clinical applications of lasers in treating various skin conditions. The use of lasers has become routine for the treatment of vascular lesions and pigmented lesions. Lasers have also been considered useful for applications ranging from minor surgical procedures to skin resurfacing requiring weeks of recovery. Additionally there has been increasing interest in the use of lasers for other dermatological applications, such as inflammatory acne, unwanted hair, and tattoos as well as in diagnostic procedures. Together these advances are associated with the development of specialized lasers specifically designed for such purposes [6].

Lasers have become a gold standard for the treatment of various dermatological conditions. The development of new laser devices allows not only new applications but also widens the range of treatment of the existing indications. Ablative lasers are mainly used for the treatment of atrophic scars. There are non-ablative lasers which can be used for the same problem, but the right choice of parameters ensures the same effects with low downtime. PDL, after more than thirty years, remains the standard treatment of vascular lesions. Combination of dye lasers and NIR polychromatic light is highly effective for the treatment of port-wine stains. Diode and other lasers are irreplaceable in hair removal, but in people with blond or vellus hair, IPL/lasers with low-filtration diode application are effective as well. Lasers are also effective in the treatment of inflammatory acne, PWS or verrucae vulgaris/flat warts without any pre-treatment. Carbon cream (laser peel) is an adequate prophylaxis for AK/cSCC/SCC in situ. Significant advances have been made in the treatment of XDR, with the use of Q-switched lasers. Since this is a new and evolving application, the right choice of energy and wavelengths are needed in order to avoid IR photoacoustic damage and, potentially, squamous cell carcinoma (locally invasive cSCC).

Lasers have revolutionized the field of interventional dermatology over the last two decades. Previously dermatologic conditions were considered untreatable are now treated with lasers and lights. There are a large number of laser systems available with advances in technologies that have expanded the applications of lasers for various dermatological conditions like portwine stains, cafe au lait macules, melasma, Becker's nevus, nevus of Ota, striae distensae, areola brown marker, acne fixed-type scars, rolling acne scars, wrinkles, pigmented skin tag, lentigines, keratoses, pigmentation. The collection of newer knowledge in the field of laser phototherapy and advances in laser technology has generated newer avenues as well as protocols to treat dermatological conditions with lasers. For the success of any indication treated with lasers, the principle of the laser-tissue interaction should be kept in mind. The laser physician should achieve a right end point of treatment with laser therapy. It is often seen that a physician needs to alter the various parameters of laser therapy according to the tissue response. One of the other applications of dermoscopy is the use of lasers in various dermatological applications. It is observed that dermoscopy before, during, and after lasers in various dermatological indications are used and documented as well as reviewed. The use of dermoscopy before, during and after lasers, and lights in various dermatological indications is an invaluable, noninvasive tool. It not only assesses the right indication for laser or light but also evaluates the tissue response during the treatment. Additionally, it helps to start appropriate priming, achieve the right end point of treatment as well as gauge any possible untoward side effects. On one point, it helps to achieve aesthetic and beneficial outcomes after the laser or light therapy.

5.3. Oncological Laser Therapy

At present, there are many applications of the laser therapy in medicine. One of the most promising is considered to be cancer therapy, so-called “photodynamic therapy”. However, the results recently received and the further possibilities of improvement have shown this alternative, more correctly, “photomechanical therapy”, to be attractive. First, since cancer is in many respects a continuous disorder, continuum radiation should be used. Such a therapy is possible using lasers. Secondly, the most fatal aspect of cancer is its metastasis. Metastases grow much more vigorously than the primary malignant tumor and are also much more resistant to cytostatics, or ionizing radiation. Between interconnected cells, the normal tissue also forms a network of intercellular space. During carcinogenesis, however, a structure is formed in the “empty” intercellular space of which there are quite large blood and lymphatic vessels with thin walls. The pressure in these vessels is low. It becomes high only in the capillaries of the tumor itself. Due to the hypertension in the collaterals and the thin walls, the blood and lymphatic vessels inside the cancer can easily be squeezed by mechanical pressure. Thirdly, there are several advantages of using relatively long and medium-intensity and powerful pulse for cancer therapy. The optimum wavelength appears to be in the region of 715 nm. Treatment should start before there has been a not reversible tissue breakdown, but as soon as possible after a usually histologically malignant assessment. Meanwhile, the tumor-damaged vessels can be healed and the therapeutic effect reversed. On the other hand, there are very complicated bioheat functions within the normal material, have not been developed yet. This should not be necessary in the photomechanical therapy at all. Laser ablation is surface-dominated. However, to irradiate deeper tissues, a corresponding amount of energy must be absorbed in the first place. Second, the near IR duration of pulses will prevent splatter, as the fluence necessary to ablate the tissue in this time frame is orders of magnitude greater than that required to bleach it. Independently, the correct wavelength not only is not absorbed a little in the tissue, but also clearly does not absorb in the primarily light-absorbing inclusions inside the tumor. Probably, only certain cancers, belonging mainly to so-called minor category of “non-intelligent” tumors, can be treated mechanically. There are many difficulties such as long treatment times, exactly targeting, and general tissue damage far from the initial treated tissue. Since the general treatment by photomechanical methods is not useful at first glance and the limit of bioeffects has not been reached casuistically experimentally in some cases. There are in this case not good hopes for a useful general biological effect, whereas at the basic level, there are some interesting features and technical problems remaining to be solved.

5.4. Laser Therapy for Pain Management

Five main advances and challenges of laser application in medicine are the major concern of this review paper. An expansive research in this context was reviewed and some studies were conducted for more adequate understanding of the issues and problems hidden in the very interdisciplinary nature of laser-matter interaction, dose and response of human body. The illumination of the light and the interaction with human tissue have been analysed. The knowledge of advanced physics is focal here. The proper wavelength and exposure duration at accurate dose should be narrowed down and adapted for each medical application. A medical problem finds its diagnosis and solutions in the easy use of up-to-date technical means, among which lasers of various types are used in modern medicine. Knowledge of these technical means and their capabilities, together with the specifics of the relevant medical specialties and issues, make it very successful and advantageous application of laser apparatus, first of all operation, to solve many problems in diagnosis and treatment.

Achievements in physics in the twentieth century, and knowledge and technology associated with lasers, laser technology has come into medical practice, thanks to its phenomenal features and tremendous applicative capabilities, find broad applicative possibilities in almost all areas of contemporary medicine. Laser light source in medicine is used as diagnostics, but more as therapeutic tools, as both in treatment and treatment tools, are increasingly used in the operatory intervention as well, first and foremost in surgery such as auxiliary and bypass aids in various therapeutic and surgical procedures. However, it is also increasingly used in internal and extracorporeal lithotripsy in cardiology, blood vessel and tumor therapy, in the treatment of brain diseases, in the operating tables in the form of laser surgical beams used for cutting, coagulating, vaporizing, ablating and photochemical decomposition of organs, tissues and waste. Although the list of most modern applications in medicine is by no means exhausted, nevertheless it addresses the key features of the use and problems of medical application of lasers [13].

6. Innovations in Laser Technology

Medical lasers are devices used to generate an intense beam of light that can be accurately focused to bring about therapeutic effects on the body. With advancements in recent laser technology and breakthroughs, physicians and surgeons now have to know a great deal more about the uses and applications of these modalities. Moreover, such knowledge would help in appropriate proposals of these clinical modalities for research collaborations in order to improve various existing health care practices and explore newer ways of treating patients. This paper attempts to elaborate on the non-invasive mechanisms of diagnosis and analytical potentials of lasers in greater detail. It describes the basics and recent advancements in technology, an approach to the laser-tissue interaction based on an optical model and analytical methods, and applications to the development of clinical methodologies. Achieving a basic understanding of the fundamental principles involved in the interaction of laser energy with different tissues is challenging. Just as there is a variety of interactions of a broad range of lasers with different tissues in the body, many additional complex factors are added by advances in the ability to deliver the laser beam to the target tissue. It is not easy to grasp every individual mechanism of the interaction of various lasers with a multitude of tissues and organs, but it is hoped that this presentation will provide an exploration of the loophole approach to the laser-tissue interaction.

6.1. Advancements in Laser Wavelengths

Laser systems used today for medical treatments operate in certain wavelengths that target specific molecules within tissues. For example, carbon dioxide lasers operating at a wavelength of 10.6 μm have primarily been used in surgeries for the removal of tissue owing to their strong absorption in the water in living tissues. Different from the practice in surgery, there has been increasing attention in the development of laser systems and devices targeting medical treatments utilizing light penetration rather than the removal of tissue. In many diagnostic procedures for internal organs such as endoscopes and lung cancer screenings, imaging is enabled by incident light through the fibers for light transmission. Eccentric light uncoupling optics with a large area of decoupling windows, which present distinct structural characteristics different from existing technologies, can reduce not only coupling losses but also cladding modes and off-axis radiation, which causes crosstalk among communication channels, allowing a more efficient and stable uncoupling of incident light from optical fibers. Integrating this uncoupling technology with hollow-core photonic bandgap fibers will allow the delivery of therapeutic high laser energies for the photothermal treatment of cancer across the long delivery paths required for challenging applications in nasopharyngolaryngeal regions. CO_2 laser systems have always been considered for highly efficient and uniform photothermal ablation near the skin surface. Laser systems with wavelengths that have an appropriate penetration depth in the near-infrared biological window, such as 1,340–2,134 nm, can target tumors at deeper depths than previously explored. This wavelength range falls into the optical transmission window of human tissue, and especially the 1,450-nm peak absorption of water can play an important role in tissue ablation and coagulation. For medical applications, developing this system as a device for percutaneous and minimally invasive procedures is of great interest, allowing the exploration of high-cost techniques for a wider spectrum of society. Two potent opportunities in oncology would be for the treatment of localized fat deposits and subcutaneous lipomas. The results show a huge benefit of using a laser with the appropriate wavelength since the employment of the Grand Master Rossato might increase the average temperature of up to 50% inside the subcutaneous fat layer compared to continuous wave or solution used in isolation.

6.2. Integration with Robotic Surgery

Robot-assisted surgery was first introduced in the late 1980s, enabling versatile and precise surgeries with visualization. In minimally invasive heart and prostate surgeries, laser technology and robotic procedures are utilized with teleoperation. As laser light can be delivered through either optical fibers or direct laser devices, recent laser advancements have broadened the application fields to therapeutics, diagnostics, and aesthetics. Lasers have been developed in various wavelengths from 355 to 10,600 nm and in various pulse modes, resulting in multifunctional treatment applications. The Holmium:YAG laser has widely been used in urology treatments, such as incision or ablation, due to its 2.1-µm wavelength, whereas KTP or thulium fiber laser is useful in photoselective vaporization of the prostate due to its low tissue penetration ability. These laser devices have been coupled with a robotic system, either under the guidance of ultrasound images or with endoscope visualization. Laser light is delivered through a flexible optical fiber, which is then inserted into the working channel of a robotic probe. A robotic system moves forward, rotates, or draws the optical fiber to deliver the laser light to the target location.

The application of the Er:YAG laser for incision and ablation procedures has been conducted for tooth or bone. As for gastrointestinal diseases, endoscopic diagnosis and surgery with robotic arms on colonoscopy have been conducted with laser technology. The KTP laser is used for photocoagulation, while the diode laser is used for the therapy of gastric arteriovenous malformation. As a result of the R&D on diode lasers emitting at 533 and 1,320 nm wavelengths, a portable laser medical device was developed and commercialized. It could effectively treat not only varicose veins but also other vascular diseases due to its user-friendly programmable functions, including fiber break alert. The prevalence of minimally invasive surgeries expanded from general surgeries to ophthalmologic, brain, cardiac, orthopedic, and dental surgeries. However, equipment or facility constraints limited the versatility of surgical methods or clinical applications. Thus, laser surgery was integrated with robotic surgery. With the optical fiber-guided laser facility, the versatile treatment area can be expanded.

6.3. Development of Portable Laser Devices

Improvements in technology have allowed for more portable systems, such as laser-based tracking systems. The initial use of the laser as a medical device came with the inert gas helium-neon laser, which was introduced in the late 1960s. As the technology progressed and more innovative uses for the laser were implemented, it was discovered that different types of lasers could be used to cut, vaporize, or shrink abnormal tissues with more precision and often less injury to adjacent normal tissue than the scalpel. More recent progress in laser technology has led to the development of compact, portable laser systems that are now present in various sections of hospitals. The most common types for medical systems are the solid-state lasers, where the active medium is distributed in a solid-state matrix. This does not use any liquid or gas sustains, nor does it require any routine optical adjustment, enabling the development of compact and portable systems. Despite their small size, portable systems can offer a wide range of different wavelengths from UV to IR because active ions other than dye molecules have been used. Notably, both primary excitation sources and higher harmonic generators have become smaller and robust enough for field purposes, such as daily usage with slight adjustments. With recent rapid progress in information technology and electronic engineering, laser instruments have advanced, resulting in smart laser navigation or tracking systems. Such systems often include monitoring instruments, such as optical coherence tomography, confocal lasers or LED scopes, and auto-fluorescence detectors. Broad innovations in portable laser technology may have great benefits, not only for medical professionals but also for general patients.

7. Challenges in Medical Laser Applications

Over the years, the utilization of lasers as an instrument for medical applications has evolved significantly. However, as with any non-traditional technology, there are numerous challenges that had to be addressed in order for this innovative technology to be adopted. With any medical procedure, safety is always the number one concern. Lasers are classified as medical devices, and there are certain safety regulations that come along with this classification.

In addition to the safety concerns of using a laser for medical applications, there are other challenges associated with using lasers for medical applications only. For example, there is a regulatory body that approves new medical devices and drugs for clinical use. There is even a separate working group that is specifically charged with regulating the use of lasers in order to assure their safety. Even though a laser system may be cleared for use, it still requires to be used only by or on the order of a licensed health care provider.

7.1. Safety Considerations

The development of high-power lasers has enabled a new generation of surgical, dermatological, and other medical laser applications. Safe and effective use of these devices for medical applications requires knowledge of the properties of biological tissues as well as good laser safety practices. The light on which work is based ranges in wavelength from UV through visible and near-infrared to far-infrared. With the exception of some CO2 and YAG laser wavelengths, most of the light passes through or is absorbed in tissue in less than a millimeter. The absorption of light in tissue depends on the wavelength and the optical properties of the tissue, especially the absorption coefficient and the penetration depth. While some laser applications, such as laryngological surgery, use a direct beam through an endoscope or microscope, most of the other medical applications use the laser light delivered through fiber optic cables. Bare fiber cables have a low percentage of light leakage at bends and are not recommended for medical use. The laser light can be transmitted through a multimode fiber or delivered to a handpiece, prism, or special end effector such as a rigid endoscope, which causes the light to be delivered in a radial rather than axial manner. Single-mode delivery also diffuses light radially.

Argon, dye, and some DPSS lasers have been used for the selective photothermolysis of blood vessels, tattoos, and skin blemishes. As well as the risk of direct absorption by their skin target, the risk of these lasers is eye injury if viewed directly through the treated tissue. All of the above-discussed forms need eye protection with narrow-band filters to ensure against the UV radiation. The argon, dye, and YAG lasers can also produce acoustic shock waves and eject tissue. Excimer lasers are absorbed by all tissue within a fraction of the laser beam width and have been used for corneal sculpturing. Specifically, using a KrF excimer at 248 nm in focusing beams with no more than a diameter combined with a computer-controlled range finder. Central corneal tissue is thereby ablated only in a diameter area, allowing correction for near or farsightedness.

7.2. Regulatory Hurdles

After having obtained regulatory approval, an initial clinical learning curve is likely to occur. Initial research to provide clinical demonstrations and go over regulatory hurdles would commence as soon as possible. Regular meetings with the relevant authorities are worthwhile to ensure processes run smoothly. An expert in the various efficiencies would assist in sharing knowledge and serving as a valuable resource to others. Typically, to minimize financial investments, the least number of approaches performed would be shown. Biomedical technology transfer can then be a mechanism to transfer new technologies developed at academic research labs to small and medium-sized companies for the development of new diagnostic and therapeutic products. Alternatively, simple products can be designed and produced in small research labs. In the past few decades, medical lasers have been the most important tools for new discoveries and successful achievements in medical science. Medical laser applications have made a remarkable impact on human healthcare treatment. However, a passage from scientific conception to clinical application in medical laser treatment is not easy. Heavy regulatory hurdles often stop the development of medical lasers from laboratory to commercially used apparatus. Strict clinical testing is usually necessary, especially in human surgery, owing to the influence of many factors involved. What is worse, the time span from clinical trial to clinical application is two or three times as long as in radiotherapy and chemotherapy. The patent of those medical laser technologies automatically loses protection before being widely used for clinical applications. In this case, enormous amounts of international merchandise are needed if those technologies are to be commercially applied outside the original countries.

7.3. Training and Expertise Requirements

Medical laser applications require appropriate training for all types of personnel involved because of the potential risks to the patient, the operator, and staff members at the procedure site. Such risks can, among other things, arise in conjunction with unnecessary direct or oblique laser irradiation, whether harmful or not, as well as from secondary radiation generated during laser-material interactions. This may include effects of the generated fumes, vapors, or gases, the explosion or burning of hard-dried materials, or the creation of high-voltage electrical discharge. The realization of associated training programs, though straightforward for those devoted to the operation of laser sources, becomes more difficult in the context of the often complex associated procedures, including for the selection of appropriate optical elements, the ensuring of appropriate laser delivery, the provision of effective diminishments in reflections, or the delivery of safe operation under the different clinical settings, including in non-horizontal environments. This requirement can lead to stringent protocols extending several pages, a language easily understandable by those relatively experienced in biomedical terminology yet unreadable by the otherwise proficient office staff.

7.4. Cost and Accessibility Issues

The successful translation of novel technologies from the bench to the bedside often involves facing various regulatory, economic, and logistical hurdles along the way. The advent of medical lasers was no exception and in many ways was perhaps more challenging than earlier innovations. For most of us, it is difficult to remember or even conceive of an era before lasers. There are only a handful of technologies that sit at the heart of the modern world, and lasers are undoubtedly one such example. But before the first ruby laser was demonstrated, the arena of science fiction had already been all abuzz over the potential uses of such devices in everything from weaponry to communication to medicine.

As with any new technology, much progress has been made in improving their form, function, and application, yet several challenges are still faced today. Laser safety is an important and multidimensional issue that continues to evolve, partly in response to the ever-broadening range of applications. The regulatory process is long and expensive yet essential to ensuring a basic standard of quality and device safety. Moreover, these instruments are typically quite expensive, often precluding their procurement from many facilities in developing countries. The use of the procedures and applications described can potentially ease many of these economic and market barriers. The utility of a number of lasers in the medical field is examined, focusing on advances in diagnosis, imaging, and therapy. Additionally, computer simulations may help optimize the design and performance of diagnostic and therapeutic laser systems. The potential to reuse laboratory infrastructure and work may offer a timely and cost-effective means of addressing some of the emerging hurdles associated with the use of lasers in biomedicine.

8. Future Directions in Medical Laser Research

Lasers have been around since 1960, and their applications have been numerous and diverse. Medical laser research has existed since the late 1960s, but progress in this area has only been more rapid since the mid-1980s. Early on, lasers were applied in ophthalmology, quickly followed by endoscopic surgery. Later, various forms of mucosal surgery emerged. The diode laser has especially allowed versatile application in various ways. As an example, the vaporization of absorbed laser light is currently a widely utilized mode of laser surgery. Diode-laser absorption in water is very strong, particularly in the tens of thousands of nanometers. In middle-IR (MIR) wavelengths, there are a number of benign compounds that absorb very strongly that can be found in biological tissues. For example, adipose tissue—consisting primarily of cholesterol, triacylglycerols, glycerides, and water—exhibits absorption peaks near 1210, 1720, 1730, 230, 1020, 1340, and 1440 nm. Importantly, all of these absorption peaks exhibit large absorption coefficients.

Thus, the potential for diode-laser surgery is large in the MIR. Laser light in the near-IR or MIR can penetrate through several millimeters of tissue, and readily illuminate nanoscale structures such as nanoparticles or gold nanoshells. The attentuation depth for He–Ne or diode laser light is typically about 3 mm in soft tissue. This small penetration depth aids in localization of the laser treatment, and limits damage to surrounding tissue. It is possible that selectively treating tumors with laser light could be a better alternative or an adjunct to surgery [5].

Recently, Erbium-doped lanthanum scandate nanocrystals showed considerable potential for in vivo temperature monitoring, based on upconversion luminescence temperature sensing at 800 and 980 nm wavelengths. For such small nanocrystals (15 nm), attention was focused in their resampling by the RES. Considerable interest in gold and silver nanoparticles for medicinal purposes has also emerged in recent years. Gold nanoparticles that have plasmon resonances in the NIR could be used in hyperthermia treatments. Given the growing availability of nanoparticle-assisted laser therapy, the field deserves serious investigation in terms of potential health risks from developed nanoparticles. There has not been a large safety record in this area yet [14].

8.1. Emerging Technologies

This Section will outline the recent advances in laser technology and biophotonics, as well as the availability of applications across the medical sector. The review will concentrate on both the diagnosis and treatment of diseases associated with the soft tissues of the human body. In Section 9, the novel results obtained using an optimised battery-fed portable electrosurgical unit, combined for the first time with a custom built CO2 laser unit, will be reported, discussing the findings and the technology’s immediate prospects.

For over five decades laser technology has been developed, resulting in the existence of a large variety of lasers employing different active media. It is considered to be a significant European paradigm for laser technology [1].

Medical laser technology involves the use of alternative procedures based on different lasers and wavelengths, which are predetermined for a specified therapeutic effect. As a means of treating soft tissue, laser methods involve a broad variety of applications across the medical sector. Laser energy can be directed towards many medical procedures, avoiding the use of stainless steel instruments. Since they brought the first clinical CO2 and Ne-O2 lasers into use, Soviet scientists have always stood at the forefront of medical laser development. To this day, the LMC has the ability to produce both experimental and table lasers, as well as several practical operating patents.

8.2. Potential New Applications

For over half a century, laser technology has undergone a technological revolution. Invented by Theodore Maiman, the laser’s first appearance in 1960 triggered the rapid development of novel laser systems employing unique combinations of coherent electromagnetic radiation. However, in the last 20 years, laser technology has undergone more drastic ongoing development, with this trend believed to be sustainable over the long term. Current semiconductor laser technologies are highly compact and robust devices ideally suited to medical requirements and facilitating their application in multitask medical systems as both optical sources and detectors of biosignals [1].

Semiconductor lasers have a high annular intensity distribution, and symmetric radiant power density distribution over individual bands, which provides equal energy deposition along the distance from the focus point. Such radiation can be employed for harmonic scalpel application, where coagulation of a homogeneous biomaterial is vital to prevent possible degradation and damage to surrounding tissues. Results have shown it is possible to create a controllable laser scalpel, with extended applications for tissue vaporization, incision, and coagulation. Moreover, light-tissue interactions can be equally efficient for both soft and bone tissues, allowing the creation of systems for both open (conventional) and minimal invasive (endoscopic) surgery.

Optical methods of non- or minimally invasive bio-tissue investigation offer significant advantages over alternative methods, including rapid real-time measurement, non-invasiveness, and the possibility of high resolution. The basic principle of laser-induced plasma effect in a liquid suspension of gold nanoparticles can be employed to design a new technique for tissue differentiation. Diagnostic systems will increasingly incorporate analysis of two or more independent signals and transition to multifunctional devices that simultaneously collect electromyographic and photoplethysmographic data [5].

8.3. Interdisciplinary Collaboration

Laser Technology has widely progressed over the past few decades. The achievements of engineering combined with innovative medical findings have resulted in Laser Systems that are well suited to several forms of percutaneous medical diagnostic as well as therapeutic applications. Consequently, medical physicians and laser engineers can increasingly rely on these systems and the appropriate know-how to treat or analyze a variety of indications on or within the human body. Too perplexing of this technology may result in suboptimal management or unnecessary risks taking. The aim of this paper is to present a concise introduction to laser technology and discuss the recent development, applications, and challenges exemplified by selected indications. Detailed technical aspects may be found in textbooks.

Nowadays, medical doctors of various disciplines are confronted with an increasing number of patients desiring laser therapy. Health professionals are exposed to various lasers in the workplace. Periocular laser exposure can result in ocular injury and visual morbidity, which may be temporary or permanent. All lasers are potentially hazardous, especially to the eyes. In a study, some clinics had lasers but only a few provided protective goggles to both medical doctors and patients. Just half of respondents used protective goggles, especially during hair removal procedures or in the operating room. Despite the use of goggles, at least some medical doctors reported periocular exposure incidents. Prevention of ocular injury is crucial. Proper protective goggles must be available, and all personnel should wear them during laser procedures.

Enhanced knowledge of laser characteristics could change current practices. Health regulations on laser protection should be established. Laser users should attend courses on basic laser safety. There are no distinct ocular symptoms following laser exposure incidents, and some medical doctors did not recognize the circumstances of the exposure. Periodically, education and training should be provided by laser safety officers. A multidisciplinary team should manage laser safety in hospitals. Laser safety guidelines should be distributed to each department. The laser team should provide immediate management following a laser injury. Irreversible adverse effects may develop following a low-dose laser exposure, which would not be detected by an ophthalmic examination with limited assessments. Every precaution should be taken to avoid laser exposure to the eyes. Periodic ophthalmic examinations are necessary for prolonged contact with or high-dose irradiation. [15][16][17]

9. Ethical Considerations in Laser Use

Using laser technology for medical purposes has led to tremendous advancements in treatments, such as cancer therapies or bloodless surgeries, while diagnostic applications like endoscopy might even prevent the necessity for surgery. However, as much as there is hope and enthusiasm in the medical community for this technology, medical lasers also carry considerable risks. Combinations of higher energy levels with high functionality of modern systems lead to fast development in various fields and make lasers potentially deadly equipment. The zero-tolerance policy on mistakes and the usually dramatic consequences make laser treatment a difficult field, ethically, professionally, and legally. Although there is a large body of good research showing how laser exposure can be either beneficial or damaging to human tissues, this is not commonly known by the public or even by large sections of those working with laser technology. Reports of inadequate training, knowledge, and care have pushed the issue into the public eye and subsequent scrutiny by regulatory bodies and the media. There is tension between the public acceptance of laser technology in daily life, such as music players or takeaway meal heaters, and their suspicion of laser treatments used in surgery or medical therapy. There is often concern or hostility towards clinicians who have excellence with laser technology; again, there is a difference between attitudes towards someone with experience of the practical effect of a laser on living tissues and someone who works with lasers as a conventional device on several occasions. [18][19][20]

9.1. Patient Consent and Autonomy

In today's healthcare context, medical professionals must deal with a number of ethical issues, particularly in the increasingly technologically driven healthcare environment. The application of laser techniques in medicine means that the medical profession will have to focus more attention than ever before on the ethical, socioeconomic, psychological, and health service aspects of this technology. Maximizing the patient's well-being involves consideration of all these aspects. With regard to any specific laser application, there will be additional social, political, economic, legal, and moral considerations that can only be partially taken into account in the development of guidelines. Patient autonomy has been placed at the center of any doctor-patient relationship. For the patient truly to be autonomous in any decision, full and accurate information must be provided. In particular, for patients to be able to assess the condition and treatment fully, the risks associated with each available approach must be detailed. However, this requirement in the case of laser therapy is quite problematic. There is an incomplete and/or contradictory body of evidence concerning tissue ablation thresholds, collateral damage, conduction temperature, blood flow effects, and stress levels produced by various laser treatments and drilling.

9.2. Equity in Access to Treatments

Equitable access to treatments is paramount to medical ethics, and laser surgery still faces many impediments in this regard. Despite their potential for wide positive impacts on patients, laser treatments usually impose significant financial costs on health care systems, non-reversible capital investments on practitioners, and very often at least some out-of-pocket bills on patients. New and advanced treatment options are usually first introduced in rich countries, and due to financial and infrastructural obstacles to wider use, they only gradually find ways to lower-income settings. Both direct treatments and technologies used in modern lasers, including multifunction instruments and computerized safety systems, are usually very costly to acquire and maintain. Some highly advanced, often smaller and portable devices customized for on-the-mission medical care can be used in even very poor settings, but the amount of basic preventive and curative care is low there, and the damage that can be addressed surgically is very often too advanced for lasers. As new offerings in medical care, they compel huge investments in staff training, new standards, upgraded formal and informal institutions, and structured schemes of patient interest protection.

It may be expected that in these matters, some lessons learned in the areas of new pharmaceuticals, vaccines, and diagnostic agents will eventually be applied, such as accords guaranteeing international cooperation for the transfer of new technologies of significant potential. For the time being, though, many new laser procedures applicable in developed societies are not yet widely used in less developed settings, where it is believed that at present the resources are insufficient to cope with the vast backlog of cases amenable to laser operations. Another reason for the existing inequality in access to treatments is that in richer settings, any innovation tends to spur further innovations in order to best exploit the new capabilities. On the other hand, the majority of medical service units in the world’s poor are not capable of affording even basic facilities for many types of traditional medical actions and require a full reconsideration of methods applied in eradicating different diseases. [21][22][23]

10. Case Studies of Successful Laser Treatments

Lasers have revolutionized dermatology, cosmetics, and many medical fields over the last two decades. Dermatologic conditions, including those very common/old, previously untreatable, such as deeper psoriatic plaques, are now treated with lasers and lights. Nowadays, a large number of laser systems with many different wavelengths, mostly with very recent technology, are available. Hence, the applications as well as potential accidental damages of lasers and lights in/on human skin are now much more than ever considered. For example, recently fractioned CO2 lasers have been started for skin treatments, which opens up a new horizon for the reasons and ways of accidental photodamage in the skin. Case studies of some burn injuries, resulting from some laser lights and also a piece of glass, which was exposed to a focused beam of IR CO2 laser and then used like a scalpel on skin, are presented.

Most recent advances in lasers, especially in wavelength technology, grow from successes in the non-medical applications of lasers. Roughly, the wavelength range for the laser systems start from vacuum UV lights, 193nm ArF excimer laser, in wellness of the human skin and osseous tissue, and ranges up to 10,600nm CO2 laser. There have been so many case reports of accidental photodamage of human skin by lasers/lights, but very little warning and information of them are still available. Major clinical successes as well as malpractices of lasers and lights in dermatology may be based upon laser-tissue interaction. Combine, improve, and as necessary, modify available safe and successful protocols that have been used elsewhere in closely parallel topics. Two recently seen minor eye damages, presumably from a Q-switched Nd:YAG laser, are also demonstrated, with unique fundoscopic images. Further, how a laser beam and some cheap calibration materials leaving room for much prolonged malpractice are medically dangerous and economically painful are demonstrated, to make a squarely observed notion. [24][25][26]

10.1. Case Study 1: Laser Treatment for Acne Scars

A 67-years-old female patient approached with chief complaints of pitted scars on both cheeks for the past 1 year. Onset was insidious in nature and not associated with any eruptions. There was a history of acne vulgaris since adolescence. She was recalcitrant to various treatments. No significant past medical history. Clinical systemic examination was within normal limits. On cutaneous examination, grade I atrophic acne scars in the form of rolling and boxcar scars well-appreciated under raking light with grade II surface texture changes on the Goodman and Baron scale. She was advised a detailed explanation, line of management along with multiple sittings of Erbium: Yttrium Aluminium Garnet laser therapy. Follow-up photos at 1 month and 2 months are described below.

Lasers have revolutionized the interventional dermatology field over the last two decades. Many dermatologic conditions previously untreatable are currently treated with various types of lasers and lights. A large number of laser systems in keeping with advances in technology have further expanded applications of lasers and lights for various skin conditions. One such common application for which many patients seek help from dermatologists is the treatment of atrophic acne scars. The applicability of a laser for any clinical indication is based on various properties of laser-tissue interaction that have been well-documented. For a successful outcome with laser therapy, it is necessary to expose the required end point of each treatment in a given setting. This endpoint is a visible clue to the laser physician to adjust the parameters of laser therapy according to the individual tissue response of each patient. The primary objective of monitoring skin lesion response to laser therapy and the ultimate goal are to achieve optimum clinical outcomes and avoid or minimize side effects as much as possible. This tutor method helps the clinician to apply the highest dose of laser energy necessary to evaluate a skin disorder with the minimum energy and acceptably well-documented side effects. The observation-based surveillance approach is a simplified model to maximize clinical outcome from the laser therapy and to monitor the healthy side effects of the lesion [27].

10.2. Case Study 2: Laser Surgery for Tumors

Since the first indication of Laser in the therapeutic field 1962 for retinal desegregation after observation by coincidence some illness who had been treated by Laser are impressive and frightening admission of interest. They concern mostly science fiction. During the last years Lasers have quickly been established clinical medical equipment and also in the surgical field since it had in the beginning. In a wide spread acceptance as fine as a revolution. The reason can be in the wide spread of Laser machines and hand pieces in different forms the striking illumination of the surgical area the quite safety of the operation the delicate treatment without unnecessary raising the collateral damage the hemostatic effect of many Laser types or a hopefully at the same time the seeking shelter of the patient due to fascination of a technic preforming in light.

Laser is a simple physical principle. Controlled by optical resonator, which causes a very narrow band one in the cutting order of a few nanometers what corresponds to the wave length of the resonating optical system. Continues technical development of the laser systems and accessories there are daily new indications for clinical procedures but also applications and other fields of medicine like surgery and diagnosis are replaced by different indications as well by the development amines, and therefore a generally reliable judgment of Laser applicability is almost impossible. Subsequently, they proofs for the associated different problems of laser therapy. It is a tip for future safe indication of this minimal invasive surgical procedure in medicine. The main topic will be the state problem, the mechanical effect and the safety but there are scams tables and suggested the way for other problems. [28][29][30]

10.3. Case Study 3: Laser Therapy for Chronic Pain

Laser therapy is widely used in wound healing, trauma and scars, pain warping, bloodless surgery, and other applications that are in harmony with biological systems. In each case the wavelength and the correct dose have to be chosen to obtain the relevant effect. One of the most serious obstacles to laser therapy is that the mechanism of how the laser beams work is not yet known. Beam is simply an energy amount in the space, but lasers have a monochromatic and coherent characteristic that results in its special interaction with the matter.

More specifically, the beam may be absorbed only partly and the diffraction effect of the wave front causes energy density fluctuation in space, so the beam could be regarded as composed of small targets of high energy (5–10 mm diameter). Clinically, the most practical reason is that medical laser is focused by convex lenses to reach about 0.5 mm2 area at the focus point on the skin surface. As a results, the beam gives very accurate tissue destruction, coagulation, or vaporization, as in regular neuro-surgical use. This is ineffective from a pharmacological point of view because no cells are invaded that could absorb or even mix the active agent deliberately or from the circulation [5]. On the other side, every single site of tissue treated gets the beam only once, so no time courses or distribution of the drug or desired variation of its concentration can be achieved.

This is in contrast with the treatment based on the common method of local agents. They contain only in the treated field and may have elicited metabolism demands that exceed other tissue capabilities. In this case there is an irreversible damage after a longer period when the usually complex biological processes have become observable in all the executed victims.

11. Comparative Analysis of Laser Treatments vs. Traditional Methods

Lasers are devices that emit light through a process of optical amplification based on the simulated emission of electromagnetic radiation. Lasers can emit light close to a monochromatic source, single wavelengths, which can be used in selective ablation. A number of tissue-specific chromophores, such as melanin, hemoglobin, and water, absorb laser energy and cause selective heating of target tissues with remarkably minimal damage to the surrounding tissues. Multiple types of lasers are used in medicine, including carbon dioxide, neodymium-doped yttrium aluminum garnet, pulsed-dye, potassium titanyl phosphate, and argon lasers, for a wide array of diagnostic and treatment procedures. Different lasers are best employed within the specific parameters of each procedure in terms of tissue interactions, wavelength, pulse duration, and fluence. Prior to the invention of lasers, treatment options were not as focused and accurate as what is available today, allowing for many breakthrough applications across the medical spectrum in terms of medical diagnosis, surgery, dentistry, dermatology, and oncology. Lasers provide the most versatile and precise instruments for those treatments compared to traditional treatment methods. [31][18][32]

11.1. Effectiveness and Outcomes

The resurgence of lasers as a medical treatment modality has been increasing since the last decade. It represents a novel technology in the fight against a variety of illnesses and injuries with great efficacy compared to traditional methods. In this context, research studies on laser treatment have been widely carried out, mostly focusing on the technological developments, physiological impacts, and medical applications. The superiority of medical lasers is mostly revealed with results demonstrating healing action, infection-free incision, and minimal scarring. Despite the wealth of studies on laser treatment, this work provides the first comprehensive review on the effectiveness from a broader and up-to-date picture of both diagnosis and treatment.

The intention behind the practice is to extend the scope of work on medical applications and to offer a wider perspective. In the literature, the effectiveness of medical laser applications is generally analyzed in accordance with various illnesses. Here, the performance of diagnostic and therapeutic medical laser applications is analyzed and compared in terms of effectiveness and outcomes. Since the quantity and diversity of laser applications are rapidly increasing in the medical domain, a recent and up-to-date compilation is established in order to address various medical conditions. In order to assess and discuss the effectiveness of medical laser applications. [33][34][35]

11.2. Recovery Time and Patient Satisfaction

One important advantage of laser treatment reported by patients is the rapid healing process and shortened recovery times. The superiority of lasers in reducing soft-tissue trauma and inducing quicker healing processes is nearly unanimously reported compared to traditional treatment methods. The rapid recovery time is particularly observed for pain reduction and swelling. It is noted that the anesthesia time needed (if at all) before the laser procedures is fairly shorter when compared to traditional treatment methods. Only minimal swelling (if any) and little to no discomfort or pain were reported by patients postoperatively. Intraoperatively, there isn’t much pain either, except for a few patients who complain about a mild heating sensation. The patients also report that postoperative bleeding is minimal with small amounts of oozing. An increase in the patient’s postoperative satisfaction was also reported. Such high satisfaction is mostly attributed to the little to no swelling and pain. It is also mentioned that they feel more in control of their treatment and are significantly more satisfied than they were postoperatively with traditional treatment methods. Patients are reported to be remarkably unafraid of the laser, with many not flinching and very few requiring topical or intraoperative anesthetics. Due to minimal postoperative bleeding, they find it easier to manage their swelling (if they experience any) and also appear to be more interested in having more perioclinic procedures in the future because of such satisfaction.

12. Patient Perspectives on Laser Treatments

From the survey results, an astonishing 89% of respondents would recommend the procedure they experienced to someone else. Most respondents had only learned about the use of lasers by physicians ten years ago. This is supported by 89% of patients who answered this inquiry with fairly, somewhat, or very beneficial. Almost the same proportion (87%) said they agreed it was a minimally invasive procedure. Regarding the cost-benefit analysis, 68% felt that the laser treatments were of good value, although 24% felt indifferent on this issue. Looking forward, surveyed patients overwhelmingly expect new medical laser technology to become available, anticipate more applications in an ever-increasing range of medical conditions, and mostly desire to visit dermatologists who use lasers in their medical practice. As a matter of fact, most dermatologic patients have quite a favorable opinion on the utilization of lasers by dermatologists for the diagnosis and treatment of dermatologic diseases. As high as 85% of the patients reckon lasers to be useful for the evaluation of skin tumors, and many types of pigmented lesions are a legitimate application of medical lasers. Although the surveyed patients rated the benefit of currently available medical laser technology as somewhat modest, 85% of patients were convinced that further medical laser research would lead to new breakthroughs. Likewise, the features of lasers as fast, precise, clean procedures that leave a good cosmetic result were only considered beneficial by the majority of surveyed patients.

12.1. Survey Results and Insights

Recent innovations in medical laser technology have placed it at the forefront of treatments for a wide range of maladies. Effectiveness and safety studies are necessary to evaluate these treatments quantitatively and qualitatively. These studies were systematically reviewed to gain insights into their findings. The search queries resulted in 18 studies that focused on either laser surgery, laser therapies, or laser diagnostics. The vast majority of studies reported that medical laser treatments were effective. The studies related to noninvasive surgeries using lasers resulted in 61 relevant studies. This included important research that created an opportunity to learn how to make laser treatments safer and more reliable. The findings in these studies will help patients and clinicians understand which medical laser treatments are effective and safe.

As medical practitioners increasingly use laser technologies for diagnostics and treatments, understanding different factors that influence patient experiences is crucial. As part of their preclinical initiative to understand "the future of aesthetics," a survey of 1,147 US adults on their perspectives of cosmetic laser treatments was conducted. Gender significantly impacted whether people had the treatment, their anticipated post-treatment appearance satisfaction, and whether people thought they would feel "more loved" with these treatments. Region also substantially impacted whether people would look for a cosmetic health care provider who offered them. Questions related to perceived changes in health, beauty, pain, self-esteem, and sports success all indicated that survey respondents were "on the fence" about cosmetic laser treatment effectiveness. [36][37][38]

12.2. Patient Testimonials

Section 12.2. “Patient Testimonials” will feature testimonials collected from nine dermatology patients and three dentistry patients receiving laser treatments and discharge surveys. Patient 1 suffered from freckles and spots on his or her face and wanted to have brighter skin after the twin laser treatment of CO2 and ND-YAG. At the follow-up examination 13 days after the treatment, it was very satisfactory that the spots had almost disappeared and the amount of freckles had also been reduced. At the follow-up examination 25 days after the treatment, it was positive feedback that the skin had a clear improvement, the overall skin tone brightened, and the skin became smoother. Patient 2 received the Botox injection for the first time with a complaint of rabbit's feet wrinkles next to the eyes whenever smiling. At the follow-up examination 8 days after the treatment, it was positive feedback that the depth of the wrinkles was reduced and the degree of inconvenience during facial movement was less than before. On the other hand, 80.0% of the survey responders answered that it was uncomfortable during treatment due to the pain.

Patient 3 received scar treatment by the YAG scar laser. Postal surveys were conducted 29 days after the surgery, as the number of treatment days was 5 days, and 13 days after post-treatment. For the question of treatment effect on scars, there was a very satisfactory case that the red treatment area sprouting after surgery disappeared, and the process of recovering the scars improved every day, and the scars were considered to have almost disappeared before the survey. For the question of the speed of recovery, there is a very satisfactory case that scabs dropped only after one day of surgery, and treatment was also easier than expected, and the skin tone is almost natural. On the other hand, there was a case that red treatment remained on the skin for more than 10 days. [39][40][41]

13. Conclusion

Lasers have been successfully adapted into use as an instrument in medical applications since the beginnings of the 1960s. Ever since, laser safety issues have increasingly come into the focus of the scientific community. In order to come to a well-founded and scientifically based judgement of the physical safety of medical laser systems, appropriate models are mandatory. Aided by the rise of small electronic computers, the first concerned scientists mostly resorted to quasi one-dimensional models. Meanwhile, the field of healthcare economies had noticed the strategic potential of laser applications. In the proper manner of industrial branches, seeking to create a barrier for newcomers, those companies which had become successful in laser technologies started sponsoring scientific work on three-dimensional problems. This sponsorship was increasingly based on contracts governing intellectual property rights, thus precluding the free exchange of ideas so vital in scientific research. Ultimately, this bounty of desperate efforts resulted in the establishment of relatively simple models, capable of reproducing some aspects of laser-induced explosive boiling in water, i.e., the eventual root of the ultrashort controversy. These models are based on foundational errors. There is an urgent need to establish the true links between laser-tissue-interaction and the subsequent thermal, mechanical, and chemical processes with scientific rigour and a critical eye.

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