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Chapter 1 : Laser Safety Standards and Measurements of Hazard Parameters for Medical Lasers

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Introduction In recent years the use of laser sources have gained attention for an increasing number of new techniques for various applications, including material characterization, quality control of industrial products, study of hybrid systems, sensing, up to medical applications, thanks to the significant advancements in laser source and detector technology and in optical fiber and sample preparation techniques also including novel nano-object fabrication methods []. Among these applications those in medicine are particularly attractive since they are opening the route to new diagnosis or pathology follow up methods along with new surgical procedures[]. Nowadays, lasers are used in surgery, dermatology, gynecology, cardiology, otology, ophthalmology, angioplasty, photodynamic therapy PDT , and in imaging for diagnostic purposes, just to name some applications. As a consequence of their increasing popularity, laser systems are now highly widespread in medical environment, where they are used also by personnel not highly specialized in optics and laser source management and in the presence of patients. This has greatly boosted the attention towards laser safety issues related to exposure to laser beams and to strictly assess the values of well defined laser radiation standard parameters characterizing the level of hazard of laser sources[]. Special care has to be taken when considering laser safety in research environment, where lasers are often used in not standard working conditions. In general, to make laser source users aware of laser hazards is crucial for a proper application of rules and safe behaviours even when the working conditions change. The main hazard due to accidental exposures regards eye injury but it is well known that skin injuries can also occur when high power laser beams are used[]. Safety legislations in Europe and USA take into account non ionizing radiations and laser radiation sources of hazard for human health deriving from physical agents. Laser safety standards are aimed at: Laser safety standards comprise 3 parameters for hazard characterization: The present paper reports on experimental measurements of two parameters, Maximum Permissible Exposure MPE and Nominal Ocular Hazard Distance NOHD , performed with well assessed methods described in the safety regulation and standards for some of the laser sources mostly employed in medicine. The results are compared with data elaborated from standards in order to single out safe and comfortable working conditions. In the photothermal interaction, the absorbed energy of the electromagnetic field is quickly transferred to the molecules thus inducing an increase of the local temperature. When a photochemical effect occurs, the laser radiation makes the structure of molecules vary or form one new molecular specie, or induces a transfer of the energy to another molecule. A photomechanical effect occurs when high-power short pulses are used and produce shock waves that damage tissues during their propagation. These effects mainly depend on the temporal duration of the exposure to radiation along with the temporal regime of the laser pulsed or continuous , the radiation wavelength and power, and the energy absorbed per surface unit and on the characteristics of the target. The organs mainly exposed to laser radiation are eyes and skin. The ultraviolet radiation nm - nm has a photochemical prevailing action causing inflammation of the conjunctiva or, in deeper penetration, cataract. In the skin, dermatitis with possible mutagen effects can occur as a consequence of exposure to high energies. The entity of the damage is determined by exposure time duration and total dose, that is by the absorbed energy per surface unit. Visible nm - nm and infrared nm - 1 mm radiation have a thermal prevailing action; the damage derives from the increase of temperature induced in the tissue that can lead, for exposure lasting enough, to protein denaturation. Its entity is therefore determined by the incident radiation power, its duration and the ability of tissue to disperse heat by conduction. For its anatomical configuration the eye is highly vulnerable to the laser light. The ocular damage is particularly elevated when radiation with wavelengths between nm and nm visible-VIS and near infrared-NIR are used since the eye focuses VIS and NIR radiation on the retina, increasing the power or energy density of one hundred thousand times with respect to incident radiation on the cornea. In medium and far infrared nm - 1 mm regions, the thermal effect is limited to the external surface without affecting the retina. Laser Safety Standards and Hazard Parameters Laser safety standards are usually divided in two parts: The AEL indicates the maximum accessible emission level allowed and it is used to categorize laser sources in classes. The classification is strictly necessary for safety standards since lasers sources can present hazard levels strongly varying with emitted radiation characteristics, such as wavelength, power and temporal behaviour continuous wave emission, pulsed emission , repetition rate, etc.. Such classification is carried out considering the power level of emission and the wavelength of laser radiation. The manufacturer must consider all the working possibilities of the laser system and adopt the appropriate classification. Hence, since FDA has accepted the new classification labelling. The AEL is usually a maximum power in W or energy in J that can be emitted in a well defined spectral range and exposure time that passes through a specific aperture set at a specific distance. The MPE represents the radiation level to which people can be exposed without suffering harmful effects, i. It can be expressed as radiant exposure H J mâ€"2 or irradiance E W mâ€"2. The MPE value is fixed by the International Commission on Non Ionizing Radiation Protection, ICNIRP[16,19], and represents the maximum level of irradiance for a given type of laser source to which eye or skin may be exposed without suffering short or long term damages. Since the damage depends on optical and thermal properties of the material hit by radiation skin or eye which, in turn, are different depending on the radiation wavelength, MPE table values specific for eye and skin are defined. To refer to these two tables is absolutely mandatory in the spectral region of retinal damage â€" nm []. Additionally, the level of damage depends on the exposure time. In this frame, the use of radiant exposure or irradiance represents the best choice for evaluating the hazard of a laser source, a very simple relationship between E and H holding: Therefore, somebody staying at distances from the source greater than the NOHD is in a low risk zone, where the radiation turns out to be equal or smaller than the admitted MPE limit. Conversely, an operator staying at distances less than the NOHD is in a dangerous zone, sometimes called nominal hazard zone. To calculate the NOHD is obviously meaningful only when the laser irradiance or power is higher than the MPE, in order to define a safe region. To understand how to calculate the NOHD it could be useful to recall that the irradiance E at a given distance R from a laser source is given by the following expression: P0 is the maximum power for a laser emitting a continuous wave radiation or the averaged power for a pulsed laser. In practice, some approximations have to be considered. The hypothesis of a Gaussian beam is strictly verified only for gas lasers; in the other cases multi-mode beam structures have to be taken into account. At this aim, if considerations are done about the laser power, P0 is usually increased by a multiplicative factor 2. R can represent 1 the distance between the apparent source and either the observer or 2 the entrance aperture of the measurement system or the distance between the apparent source and the diffusing target. In our analysis we will keep the latter term and neglect the exponential one. When a lens is used to focus the laser beam and is considered as an internal part of the laser system, the NOHD has to be evaluated by using the following expression instead of the one given in Eq. Materials and Methods In this study we focused the attention on the most popular continuous-CW and pulsed-PL lasers used for medical applications. Er-YAG laser is used for laser resurfacing of human skin, for removing warts and in oral surgery, dentistry, implant dentistry, and otolaryngology. Main Characteristics of the Investigated Laser Sources The experimental setup employed for the measurements shown in Fig. It was mainly composed by the laser source under investigation, a circular diaphragm that simulates the pupil or a portion of the skin, a detector power meter Model 3A, Ophir Optronics, Israel to measure the power of the portion of the beam passing through the diaphragm and by a focalization lens to use when the spot emerging from the diaphragm is greater than the diameter of the detector opening window[]. The minimal distance adopted for irradiance measurements was kept equal to the accommodation distance for human eyes that is nearly equal to 10 cm. The diaphragm diameters can be set in the range from 1 to 11 mm depending on the wavelength and the tissues. Given these characteristics, diaphragm diameter aperture A values were selected for each laser and operating condition, according to the safety standards, in order to perform measurements for evaluating the hazard level for eye Aeye and for skin Askin. Experimental apparatus for irradiance measurements. Under the safety regulations, a laser is considered to work in continuous emission CW regime when it emits continuously for a duration equal to or greater than 0. Accordingly, in our calculations an emission duration of 0. For lasers that emit outside the visible spectrum, an emission duration of 10 s was considered to be potentially dangerous. According to regulations, for lasers operating in pulsed regime PL the MPE value was calculated by considering the most restrictive among the following conditions: In mathematical terms, this becomes: This correction factor is only applicable when the pulse duration is less than 0. Performing calculations for all the PL lasers and all the conditions, it came out that the most restrictive criterion is the one adopting the exposure to a train of pulses with a total exposure equal to 10 s. In the presently examined cases we considered the direct exposure to the laser beam without considering the occurrence of extended source viewing conditions, given the characteristics of laser sources here analysed. After the numerical evaluation of the MPE values, the beam power was measured for each laser source and operating conditions at specific distance D and for a proper value of w0 by employing the set-up shown in Fig. For all the sources allowing two operating conditions, both CW and PL regime were considered. Additionally, in order to account for the dependence of the parameter on the laser power, measurements at different powers have been carried out for the Argon laser. Results and Discussion The MPE values as calculated from both eye and skin safety tables MPEeye and MPEskin, respectively for the properly selected diaphragm aperture A Aeye and Askin, respectively are shown in Table 2 along with the hazard class of each laser source. Nearly the same happens for Ti: All these lasers can be responsible for damage to retina. The highest MPEeye value is obtained for Er: YAG laser indicating that this is the less dangerous laser for eyes since its radiation is mainly absorbed by the cornea and the vitreous humour and does not reach the retina. On the other hand this laser is the most dangerous one for the skin since the emitted radiation is absorbed by skin external layers causing a relevant thermal damage. This results in its MPEskin value, which is the lowest one. For these peculiar characteristics the Er: For the other lasers the radiation deeply penetrates the skin and thus undergoes a larger thermal dispersion. By doing the comparison, it comes out that Eeye experimental values are greater than MPEeye values for all the investigated lasers except for SSSC one. Sa, Argon and Er: YAG lasers has been calculated by using Eq. The obtained NOHD values see Table 3 greatly differ from one laser to another, confirming that information provided by manufacturers is not enough to define the hazard level of the laser source and measurements of the main safety parameters are required. This evidence confirms the hazard level associated to the use of laser sources belonging to class 4. In the case of an Er: YAG laser source used in working conditions including the use of a collimating lens proper to dentistry applications, the NOHD is about 40 cm notwithstanding this source belongs to class 4; this is mainly due to the use of the collimating lens placed at the end of the bundle. If operators and patients are in this zone, no safety prescriptions are given. An important characteristics of the goggles is their Optical Density OD. The corresponding values are reported in Table 3. They fall in a wide range 0. From this comparison it is evident that Argon, Ti: YAG laser sources, all belonging to class 4, are dangerous for skin. In fact, at the measuring conditions here considered see Table 2 all the measured Eskin values are higher than the MPEskin ones and hence the use of protective devices is mandatory to work in these conditions. For such lasers some cautions have to be taken also in presence of ignitable materials to avoid fire. Conclusions In the present paper the safety standards for non ionizing radiation have been applied to evaluate the hazard level related to laser sources widely used in medicine. In particular, the accidental exposure to direct radiation has been considered and the MPE values have been calculated using the tables that are available in the safety standards for eye and skin. The radiant exposure has been experimentally measured for different kinds of lasers belonging to class 1, 3 and 4. Well assessed methods described in safety regulations and standards have been used to underline the efficacy of such methods in safety issues. The results have shown that information provided by manufacturers is not enough to define the hazard level of the laser source and measurements of the main safety parameters are required.

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By Allen Cary, Director of Marketing, Ophir-Spiricon Measuring the propagation parameters of a laser beam is an important method of understanding the quality of the laser beam and predicting its performance for various laser applications. For this reason, it is one of the major specifications required by laser users and reported by laser manufacturers. Ophir-Spiricon has been a leader in providing instruments dedicated to this important measurement. There are currently three different instruments available under the Spiricon and Photon brands, and in this article we will explain the differences between them and the reasons for these different approaches to making this measurement. Hopefully, this will assist you in deciding which approach is best for your laser and laser application. At least 5 beam measurements are made at the waist and 5 more at the far field positions. ISO Standard Method. What does this mean? When one is focusing a laser beam with a lens, the minimum beam waist achievable is called the diffraction limited beam waist. This waist size is dependent on several factors and can be described by the following formula: This instrument allows an instantaneous measurement of the entire caustic at the frame rate of the camera. This makes it very popular with laser manufacturers doing the same measurement on similar lasers. It provides consistent results in a final test environment. There are some shortcomings though. It is also not too good for the lower UV range below nm because continuous use in this range tends to destroy the CCD imager relatively rapidly. For this reason, the NanoModeScan may be a better choice for this as well as for infrared sources above nm. Because the NanoScan is available with silicon, germanium or pyroelectric detectors, the NanoModeScan can be used with any wavelength. Additionally the very wide dynamic range of the slit scanning beam profiler, there is no need for the adjustable attenuation. The NanoModeScan does this by moving the scanhead itself though the beam caustic. In either case the process consists of multiple beam measurements over a period of time from 20 seconds to several minutes. This requires that the beam be completely stable or the results will be meaningless. In this system the beam caustic is divided into 10 "slices" and simultaneously measured on the CCD. This means that even an unstable beam, or one in the midst of being adjusted can be measured with direct and immediate feedback. Laser beam waist size and location Divergence angle Rayleigh range How do they work? This successively focuses different positions in the beam caustic onto the CCD, making the beam size measurements. From these beam measurements the propagation parameters are determined using a fit algorithm. The Photon NanoModeScan uses a similar measurement technique by moving the scanhead successive to positions along the Z-axis of the caustic formed by the test lens. Again, the propagation parameters are reported by the dedicated NanoModeScan software interface. NanoModeScan measurement screen showing beam caustic measurements. Because the NanoModeScan can be fitted with any of the NanoScan beam profilers, it is not limited to any wavelength range. It can be used from UV to far infrared by selecting the proper NanoScan detector type: By using 10 reflective surfaces provided by precisely aligned quartz wedges, the beam caustic is divided into ten slices and simultaneously focused on the CCD detector. The CCD sensor is divided into 10 sectors, and the beam is aligned to put each beam measurement position into one of these boxes. Once aligned, the software reports the parameters for each frame the CCD acquires. This makes it possible to make real-time adjustments to the laser and watch the results as direct feedback. Two Rayleigh ranges would be the point at which the beam is 2.

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However, if the beam sizes are large enough or the pulse rates are fast enough, the measurement can be sped up by increasing the scan speed to 2. The NanoScan software will generate a warning if the scan rate is set too high for the pulse rate or beam size. This warning algorithm is based on having at least 15 pulses across the beam to provide a minimum of 2 percent accuracy. Calculations Table 1 lists calculated minimum beam diameters at a given pulse frequency for each of the drum sizes and for a desired number of pulses per profile. The more pulses per profile, the more accurate the measurement is likely to be. The formula is fairly simple. The larger drum used in the large-aperture and high-power versions of the NanoScan causes the slits to move faster at any given rotation rate because of the larger circumference. For this reason, the minimum beam sizes are larger for the large drum. The peak-connect algorithm finds the highest peak pulse. Using the frequency value entered by the operator, it finds the other peaks and connects them to generate a smooth beam profile. It is important that the exact pulse frequency be entered into pulse acquisition parameters. The earlier instruments only allowed the measurement of pulsed beams with the pyroelectric detector. NanoScan provides this capability with all scanheads and detectors. Beams with average powers that were too low to be measured with the pyroelectric detector can now be profiled using silicon or germanium scanheads. At very high laser repetition rates e. If inconsistent results are seen with a high-repetition-rate laser, it may be advisable to try the measurement both ways. Q-switched lasers Another type of pulsed laser, operating in the kilohertz pulse rate regime, is the Q-switched laser. These use the pulsing to increase, rather than decrease, their effective power. Because the laser power is concentrated into a short pulse, the peak power of each pulse increases while maintaining a low average power. In order to measure these lasers, the same mathematical relationship of pulse rate to beam diameter applies, but there is an additional complication; the peak power of the pulses may exceed the damage thresholds of the NanoScan even though the average power remains within the operating space. CW beams are measured as power P in watts; pulsed beams as energy E in joules. Therefore a beam with an average power of W with a pulse frequency of 8 kHz will have energy as follows: This is also important in understanding the potential damage to the profiler. Taking the above example, if the pulse duration is 1 ms, then: Pico- and femtosecond lasers When the pulse duration of the laser becomes very short, such as with pico- and femtosecond lasers, the peak power of the pulses can become very large. This creates some added complications when determining the type of scanhead that can safely measure these beams. In addition to the average power of the beam, which is used to determine the proper operating space of a given scanhead, it is important to know the energy density of the pulses. The energy density must be below the damage threshold for the aperture material, and the average power must fall within the operating space of the scanhead for it to be possible to measure the beam without additional attenuation. To determine the energy density, first use the above formula for Epulse: Most pico- and femtosecond lasers have both a high repetition rate and a fairly low average power. They use the short pulse duration to amplify the effective power of the laser beam. A typical laser that one might encounter would have an average power of 1. For this laser the Epulse would be: Using this value, calculate the energy density for a given beam diameter by the following formula. Note that the energy density is presented as joules per square centimeter; therefore the beam area needs to be converted to centimeters in the formula. Unless the beam is wildly different from round, it is easiest to consider that the area will be that of a circle: Once the energy density is calculated, it can be compared with the damage threshold for the aperture type and the wavelength range for the aperture material. For this reason, scanheads intended for use with these pico- and femtosecond lasers should have the reflective slits, regardless of the detector type or the average power of the lasers. The wavelength of the laser also influences the energy density that the aperture material can withstand. For high-power copper slits, the values are 2. Copper slits are not recommended for use below nm. However, in some experiments we have seen better performance in the UV at nm from copper slits. This may be attributed to the better heat dissipation of the copper material or the fact that the copper aperture material is thicker than the nickel alloy. Damage threshold curves showing a comparison of energy per pulse at a given beam diameter with the appropriate threshold line for the aperture material and wavelength of use. Figure 1 can be used in lieu of the calculation to compare the energy per pulse at a given beam diameter with the appropriate threshold line for the aperture material and wavelength of use. For the above case, These estimates of damage threshold are primarily based on the relative reflectivity of the slit material. There are many other factors that may influence interaction of the laser beam and the aperture. At some level of power and pulse duration, this interaction may become nonlinear. In addition, surface finish, roughness, contamination, tarnish or oxidation can also affect the reflectivity of the materials. For this reason, these damage threshold values can only serve as a guideline, not an absolute guarantee. Use caution when measuring any new or unfamiliar laser system.

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Non coherent Therapy Lasers have several common characteristics which are summarised below. The mean power of such devices is generally low mW , though the peak power may be much higher than this. The treatment device may be a single emitter or a cluster of several emitters, though it is common for most emitters in a cluster to be non laser type devices. A cluster probe will usually incorporate both higher and lower power emitters of different wavelengths. The output may be continuous or pulsed, with narrow pulse widths in the nano or micro second ranges and a wide variety of pulse repetition rates from 2Hz up to several thousand Hz. It is difficult to identify the evidence for the use of pulsing from the research literature, though it would appear to be a general trend that the lower puling rates are more effective in the acute conditions whilst higher pulse rates work better in more chronic conditions. There is a growing body of support that suggests that the pulsing settings are of secondary importance in terms of clinical doses. Light Absorption in the Tissues As with any form of energy used in electrotherapy, the energy must be absorbed by the tissues in order to have some effect. If exactly the same amount of energy left the tissues which was introduced into them, it is difficult to rationalise what kind of effect might have been achieved. The band between i. Although much of the applied laser light is absorbed in the superficial tissues, it is proposed that deeper or more distant effects can be achieved, probably as a secondary consequence via some chemical mediator or second messenger systems, though there is limited evidence to fully support this contention. The fact that the polarisation appears to be lost in the tissues, as is much, if not all of the coherence, will result in a shallower penetration. King cites a more realistic penetration depth for nm light to be mm, whilst at nm one could expect penetration depths of mm. Laser - Tissue Interaction As with many other forms of energy delivered to the patient under the umbrella of electrotherapy, the primary effects are divided into thermal and non thermal. LLLT is generally considered to be a non thermal energy application, though one must be careful to appreciate that delivery and absorption of any energy to the body will result in the development of heat to some extent. Non thermal in this context really relates to the non accumulative nature of the thermal energy. Photobioactivation is a commonly used phrase in connection with LILT - meaning the stimulation of various biological events using light energy but without significant temperature changes. Much, if not all the cited work on therapeutic laser consider these photobioactivation effects. Some authors have proposed that there are other terms which are preferable to photobioactivation including photobiostimulation and photobiomodulation. It provides for a great semantic argument, but assume at this point that therms are generally interchangeable. She notes in her paper that some biomolecules DNA, RNA change their activity in response to irradiation with low intensity visible light, but that these molecules do not appear to absorb the light directly. The laser light irradiation of the tissues is seen then as a trigger for the alteration of cell metabolic processes, via a process of photosignal transduction. The often cited Arndt-Schults Law supports this proposal.

Chapter 5 : Dr. Mani Subramanian: Publications

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