Basics of Lasers in Dermatology

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Lasers have become a critical part of the dermatologist's armamentarium for modulating cutaneous biology, both in treating skin disorders and providing tangible cosmetic alterations to the skin. Although modern lasers are relatively straightforward to use, they are powerful tools that are capable of considerable damage when used incorrectly. Developing an understanding of how these lasers function is essential to their safe and responsible use. This article will discuss the fundamental concepts of lasers in dermatology and the cutaneous interactions they cause.

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Lasers have become a critical part of the dermatologist's armamentarium for modulating cutaneous biology, both in treating skin disorders and providing tangible cosmetic alterations to the skin. Although advances in technology and convenient user interfaces have made modern lasers relatively straightforward to use, they are in fact quite complex and powerful instruments that are capable of considerable damage if not used correctly. Thus it is necessary to establish a framework for the safe and responsible use of lasers in dermatology; fundamental to this tenet is an understanding of the development and physics of lasers. In this article, the fundamental concepts of lasers as well as their interactions with the skin will be discussed to impart a working knowledge of lasers to allow for better, safer use of these important tools.

Development of Lasers

The term *laser* is an acronym for "light amplification by the stimulated emission of radiation." Albert Einstein established the framework for the functioning of lasers in his seminal work, "On the Quantum Theory of Radiation,"[1] in which he described how an electron in an atom in an excited state can return to a lower state by emitting energy in the form of a photon of light. Light comprises a portion of the electromagnetic spectrum, ranging from UV (200–400 nm) to visible (400 to about 700 nm) to infrared light (about 700 to >3000 nm). The unique properties of light that affect the function of lasers include reflection (eg, seeing a mirror image of a mountain on the surface of a still lake) and refraction (eg, your hand looking larger under the surface of a pool of water).

Despite early theories on lasers, it was not until the late 1950s that the technology finally started to catch up to the science. Researchers experimenting with microwave fields were able to generate a beam of excited ammonia molecules through a resonant cavity, resulting in a uniform (albeit low power) emission of radiation.[2] Maiman[3] expounded on this development by building the first working prototype of a device that radiated light without the use of a microwave. So how exactly do lasers work?

Basic Physics of Lasers

To understand how lasers work, one must have a rudimentary understanding of quantum mechanics. Bohr[4] revealed that an atom is comprised of a nucleus

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that is orbited by electrons at discrete distances (ie, only at specific radii), which have corresponding energy levels that increase as the distance from the nucleus increases. With the application of energy, an electron may be excited to a higher energy level, thus increasing its distance from the nucleus, but will then spontaneously return to the lower energy level. By the law of conservation of energy, the excess energy is released as a photon. Although this small amount of energy would not be of much interest at the single particle level, Einstein and Bose discovered that photons were uniquely "gregarious" with the tendency to join together in a common state, leading to the ability to generate a coherent beam of light by simultaneously exciting multiple atoms and their electrons, whereby the return of one electron to a lower energy state generated a chain reaction among the other excited electrons, subsequently prompting the release of photons with the same characteristics as the initial incident photon and returning to a lower energy state.[5] This process requires several steps to occur in order. First, absorption of energy has to occur among a population of atoms, thus exciting the electrons to higher energy states. When one of the electrons returns to a lower energy level, spontaneous emission will occur with the release of a photon of light. The photon has a certain probability of colliding with other atoms, thereby causing their electrons to return to a lower energy state and release additional photons of light with the same wavelength and in the same direction as the incident photon in a process that is referred to as stimulated emission.[6] When this process occurs in a cavity with a large number of atoms, the result may lead to a high-energy beam of photons, which becomes the laser beam.

There are some caveats to consider regarding electron population dynamics as outlined by the Boltzmann principle whereby only a small proportion of molecules are in the first excited state and the vast majority are in the ground state (lowest energy) at any given time, but the details of higher-energy transitions in quantum mechanics are beyond the scope of this article.[7] Primarily, it is important to understand that the ultimate power of a laser's output depends largely on the population of electrons that are residing at a higher energy state at any given point in time, and the goal of many types of lasers is to achieve a large number of electrons in a high-energy state as opposed to their usual ground state, a process known as population inversion.[8]

This process leads to the fundamental construction of a laser: a population of atoms in a resonant cavity flanked by reflectors that are exposed to some sort of excitation mechanism (known as the pump) with an output mechanism for the laser beam to exit. In practice, the material used to supply the atoms (known as the gain medium) varies and also determines the wavelength and properties of the laser beam due to differences in the discrete energy states of orbiting electrons. Whatever the gain medium being used, the important properties of a laser resulting from these principles is that the beam is monochromatic (consisting of a single wavelength or a very narrow band), coherent (the light is emitted in the same phase and direction), collimated (a narrow beam diameter with limited divergence), and intense (high power per unit area). Consider the differences between a laser pointer and a flashlight; from across the room, the laser pointer output is a small spot of light on the wall whereas the flashlight has long dispersed to a weak, broad swath of light.

Types of Lasers

Different gain media have been used to create a variety of lasers with different properties. In general, lasers fall into 1 of 4 categories: gas discharge, diode, dye, and solid-state lasers.[9]

Although a gas discharge laser theoretically is the simplest laser, whereby a gas is excited by an electric discharge and the excited particles of gas create the laser beam, there are practical considerations such as excessive heat production, which may necessitate the use of cooling coils or some other method for heat dispersion. The excimer laser is a specific type of gas discharge laser in which a noble gas is mixed with halogen and high-current pulses are used to generate excited dimers, hence the term *excimer*. The excited dimers consisting of 1 halogen molecule and 1 noble gas molecule are only linked in the excited state, thus allowing for more stability in the excited state and enabling a higher proportion of molecules to be in that state at any given time, which increases population inversion and thus helps to maximize the output energy.

Diode lasers employ the use of diodes, or semiconductors that allow current to flow in one direction but not the other (theoretically with infinite resistance in one direction and no resistance in the other direction), thus creating a downstream method to achieve a high-power laser output; however, despite its theoretical efficiency, the use of diode lasers has been limited due to practical considerations of the divergence and quality of the output.

Dye lasers consist of a liquid solution of organic dye in a solvent that is pumped by an optical source. While gas discharge lasers involve excitation of a gas, there is a clear corollary with dye lasers with liquid taking the place of the gas; however, this modality has certain limitations, including the use of toxic materials that degrade naturally; the need to switch cuvettes when changing gain media, which serve as the lasing medium; and a relatively low-power output. One benefit of the dye laser, as alluded to above, is the operator's capability to switch out cuvettes containing different dyes, thus using one machine to generate widely varying laser beams.

Solid-state lasers are most often used in dermatology. These devices utilize a conducting medium (eg, garnet, sapphire, ruby) doped with trivalent rare-earth ions or transition metal ions (eg, neodymium, ytterbium, erbium, titanium, chromium). This process is a relatively reliable and flexible methodology for generating stable lasers, thus explaining its widespread use. Additionally, these solid-state lasers are particularly amenable to modifications (eg, Q-switching).

Considerations for Lasers

Quality switching (known as Q-switching) is a method used to generate a shorter burst of a higher-power laser output.[10] The longer the electrons have to become excited within a resonant cavity, the higher the number that may end up in an excited state, thus allowing for a higher ultimate energy output to a certain point. The quality of a medium, in general, refers to the ability of light exiting a medium to return. Within a cavity, the ability of light to go back and forth through the lasing medium is critical in achieving stimulated emission and thus laser beam output; however, in a low-quality medium, population inversion can still occur to allow a greater proportion of electrons to reside in a higher energy state. There are multiple mechanisms to switch the quality of a medium, but the ultimate result always is for the quality to be switched to high so that the light beams can immediately start achieving stimulated emission of a "primed" population of high-energy, population-inverted electrons, resulting in a much higher output power.

Selective thermolysis is critical for understanding modern laser use. To fully comprehend its meaning, one must first understand that the interaction of a laser with the skin depends on a number of factors, including the power density of the laser itself (the beam characteristics), the length of time of exposure, and the physical properties of the targeted molecules. Although there is some modulation of laser function via the wavelength of the laser (eg, higher wavelengths penetrate deeper), the properties of the target molecule can allow for precise control of the laser's action. The framework for understanding this principle was outlined by Anderson and Parrish[11] in 1983. Fundamentally, a laser causes damage to a target molecule via application of large amounts of energy; however, the laser beam does not discriminate between different molecules in its path. Rather the size and other properties of the molecule play a critical role in determining the amount of energy it is able to absorb before dissipating the excess energy as heat. This excess heat energy is what causes damage to surrounding tissues, or collateral damage. Conceptually, being able to target a molecule without damaging surrounding tissues is our goal as practitioners when using lasers in dermatology. It is accomplished by heating a molecule to just under its thermal relaxation time (ie, the time needed for a molecule to dissipate half of the energy applied), thus allowing for acceptable results with regard to efficacy balanced with side effects.[12]

Conclusion

Lasers are an important treatment modality, and their use in dermatology is becoming widespread for many possible indications; however, lasers are complex mechanical devices that have the potential to cause great harm when used incorrectly. By gaining a thorough understanding of the basic physics of lasers, the different types of lasers that are available, and critical concepts regarding the cutaneous application of lasers, physicians can better understand these devices and approach their use confidently and safely.

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