THE CARBON DIOXIDE LASER SCALPEL

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ABSTRACT
The CO_2-laser is currently used as a scalpel by a large number of medical surgeons, but in the field of veterinary surgery, relatively little has been published on the subject. A review of the origin of medical lasers, the basic physics of laser energy production and the characteristics of laser light was therefore considered necessary. This review includes a discussion on how the optical radiation generated by the different lasers is absorbed, the cutting power of the CO_2-laser, and the effect on healing, tensile strength and haemostasis when used in the skin, *linea alba* and gastrointestinal tract.

Key words: CO_2-laser, physics, absorption, veterinary surgery, healing, tensile strength, haemostasis.

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INTRODUCTION
Albert Einstein developed the theory of stimulated emission of light which is the basis of what is known today as the laser. In 1950 the precursor of the modern-day lasers was assembled and named MASER (Microwave Amplification by Stimulated Emission of Radiation). In 1960, Maiman was the first scientist to build a laser from a rod of crystalline ruby[35]. The word LASER was created as an acronym for Light Amplification by Stimulated Emission of Radiation[4 20]. The two lasers used most commonly in the medical field, the carbon dioxide and neodymium-yttrium-aluminum-garnet (neodymium-YAG). lasers, were introduced in 1964[4].

Fisher[16] defined the laser as a generator of a unique form of light or electromagnetic waves, known as coherent radiation, which is not found in nature. This light can be produced by the excitation of a solid active medium (solid state lasers) or as gaseous medium (gas lasers), the latter being the type most commonly used in medicine and surgery. A gas laser is formed by a laser tube filled with a gas or laser medium (e.g. CO_2-laser). Two mirrors placed at both ends of the tube enclose the so-called optical resonator[47] (Fig. 1). Under normal circumstances of light generation, an atom absorbs a photon, and as a result the electrons move to higher energy orbits. Subsequently, the atom emits the photon and the electrons move back to their lower energy orbits, releasing in the process a disarranged form of energy termed "incoherent light". This is a spontaneous physical process. On the other hand, "coherent light" is only generated inside a laser tube during the process of amplification by stimulated emission. This is usually triggered by an electric discharge inside the optimal resonator (Fig. 1) that causes the excitation of a number of atoms of the laser medium. This discharge is larger than the discharge that occurs during the spontaneous process. The above-mentioned phenomenon is known as "population inversion"[47] because, under normal circumstances, most atoms are at rest. The laser medium is now excited and unstable and therefore the atoms begin to move to the lower energy level, each one releasing a photon in the process. When a photon, produced in this manner, strikes an excited atom, the atom moves to the low energy level, releasing an extra photon identical to the original one. In this way the process is "stimulated". The multiplication of photons has been called "light amplification" and the energy thus generated in known as "laser light"[23 47]. This is a cycle during which the atoms reaching the lower energy level are re-excited, producing a continuous flow of laser energy. The atoms leaving the higher energy level must reach and leave the lower energy level as fast as they arrive in order to accomplish their process of de-excitation. This is important because quick de-excitation contributes to the power of the laser output and secondly, only the atoms at rest are available for re-excitation.

Laser energy has 3 unique characteristics: coherence, monochromacity and collimation[23]. This means that laser waves travel in space in phase (coherence), as a beam formed by waves of the same length (monochromacity) and in almost parallel configuration (collimation). It is because of these particular properties that the laser beam can be transported by mirrors and lenses and focused in very small spots where the power density can be as high as 1 MW/cm[2 16]. At a distance of 30 m the energy beam still maintains almost the original cross-section and can be focussed upon a lens as small as 50 mm[16]. The scattering of laser energy increases with the decrease in wavelength. The gas used as laser medium determines the wavelength and therefore the light produced is either visible or invisible (infrared).

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ABSORPTION OF LASER ENERGY
Laser light is absorbed by living tissues and immediately converted into thermal energy, in a manner determined by the type of laser used (CO_2, neodymium-YAG, argon, etc.) and the wavelength. The termal effect of a surgical laser is essentially one of denaturation of the complex substances that form the different body tissues and with which the laser beam interacts. The absorption of laser energy is influenced mainly by 2 of the body's chromophores, namely water and haemoglobin[11]. It is also influenced by the scattering properties peculiar to a particular type of laser. Consequently, penetration may range from deep to superficial. Haemoglobin absorbs the light of some lasers, for example argon, rendering them ineffective as cutting tools unless the surgical field is completely free of blood. Otherwise the energy is absorbed entirely by this layer, causing its coagulation without having reached the tissues which it is meant to

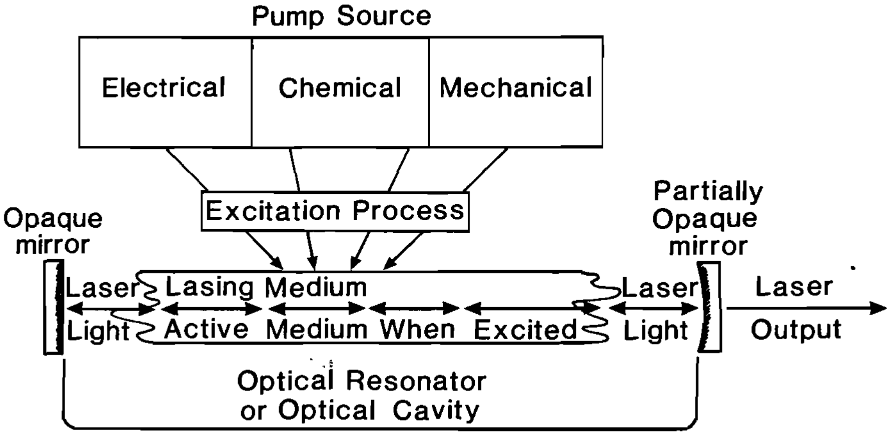

Fig. 1:**Mechanism of laser light production (modified from Bailin et al.[4])**

incise. The energy generated by the neodymium-YAG laser is poorly absorbed by water and haemoglobin, and thus, penetrates deeply into the tissues. The CO_2-laser is almost completely absorbed by water and as a result only penetrates the tissues superficially, with little scattering[6 26 27]. Heat conduction will determine the volume of tissue beyond the incision line which will be affected by the thermal energy. The temperature generated in a tissue exposed to the laser beam is determined by its water content. Tissue water acts as a buffer, maintaining the temperature in the interaction site at 100°C[16 27]. Once the water in the tisue has evaporated, the buffer effect will disappear and the temperature will increase substantially. If irradiation is prolonged, carbonisation may occur[36]. The temperature at an impact site in tissues with very low water content, such as bone, can reach 1 000°C.

ORIGIN AND DEVELOPMENT OF MEDICAL LASERS

After the creation of the ruby laser, medical researchers spent a great deal of time investigating the potential applications of lasers in the medical field. The first experiments were done with the ruby laser and later the neodymium laser in areas such as oncology, dermatology and ophthalmology[40]. The energy produced by these lasers was delivered in the form of short pulses. Therefore the excision of even small tumours was extremely impractical, since only a minute amount of tissue could be destroyed with every pulse. The high-energy pulsed ruby and neodymium lasers that appeared later were more effective, but it was soon discovered that their effect on tisues was very turbulent. This was probably due to shock waves produced by the sudden formation of steam deep down in the tissue. This in turn can be explained by the deep penetration of the beam at the impact site due to the reduced absorption of these types of laser energy by the body tissues[56]. For this reason pulsed ruby and neodymium lasers were not suitable for surgical use. In 1970 a CO_2-laser for surgical purposes was introduced and its potential medical applications were discussed[49].

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The CO_2-laser light is emitted in the infrared region at a wavelength of 10,6 nm. It is well absored by all the body tissues, with the exception of bone. This tissue has a very low water content which causes the laser energy to generate very high temperatures, leading to carbonisation and thermal necrosis. In contrast with the lasers emitted in the visible region of the light spectrum, the absorption coefficient of CO_2-laser light is not affected by the colour of the tissue it penetrates[1 55].

The ability of this laser to incise or vaporise a tissue is determined by the instantaneous transformation into heat of the absorbed light within a depth of about 0,2 mm[22]. The effect of this thermal interaction is determined by the energy density[26]. The depth of the incision, therefore depends primarily on both the power used and on the speed at which the beam is swept across the area. The light of a CO_2-laser can be delivered to the surface of a tissue in 2 ways. Firstly, the beam may be focussed on a very small spot causing the division of the tissues. Secondly, the beam may be unfocussed by withdrawing the handpiece from the target so that it enlarges its diameter. This results in the vaporisation of a large area. When the focussed beam of the CO_2-laser reaches the tissue, division occurs due to cell vaporisation[1 9 24]. The high-power of the beam determines a sudden increase in the temperature of the exposed area that causes the inter- and intracellular water to boil voilently (100°C). This process results in the disintegration of the cells due to the expansion of steam and the ejection of the cell's solid components[27]. This cellular debris is heated further to the point of combustion as it moves through the beam's path, resulting in a thick plume of smoke. At the same time, part of this carbonised material is deposited along the wound edges giving the erroneous impression that the incision of the tissue is due to burning[24]. A photographic study of laser wounds has shown that burning temperature is not reached at the impact site. During tissue evaporation, the thermostatic effect of boiling water would maintain the temperature at the wound edges close to 100°C[24]. The small size of the beam and the poor heat conduction of soft tissues account for the destruction of a very thin layer of cells when this laser is used as a scalpel[36]. Unlike the stainless steel blade, the laser beam produces a conical incision with a width proportional to the power and inversely proportional to the speed of the incision When the laser power is high and the speed of incision is slow, the conductivity of the heat away from the centre of the crater also increases. This leads to devitalisation of the wound's margins which can be seen macroscopically as a blanching of the area around the crater, and is microscopically demonstrated by the presence of coagulation necrosis and nuclear-cytoplasmic modifications in the cells close to the impact site[37]. For this reason, the CO_2-laser scalpel should be used at the maximum possible power that the surgeon can manage, and for the shortest possible time. This will ensure that minimum secondary damage occurs[3 17]. When an unfocussed beam is used, the spot of light is considerably larger. This allows for the vaporisation of large volumes of tissues or the coagulation of blood vessels larger than 0,5 mm or the occurrence of both of these phenomena at the same time[5 50].

WOUND HEALING, TENSILE STRENGTH AND HAEMOSTASIS IN TISSUES INCISED WITH THE CO_2-LASER

Until 1970, all research related to the healing process of surgical wounds was based on incisions made with steel scalpel blades. With the advent of the CO_2-laser, surgeons needed more