LOW POWER LASER: PRESENT AND FUTURE
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INTRODUCTION
Although the application of Laser in Medicine can be dated as far back as early 1960s, it was not until a little over a decade ago that its use had widespread throughout the world as a medical and surgical armamentarium. The achievements reached have become synonymous of advanced applied technology in medicine.

Since its very first appearance in a operating room, the Laser instrumentation was intended to give rise to a light beam that possessed the precise scope to burn tissues by evaporation. In other words it was an instrument capable of giving rise to a very high power Laser light (1).

However, over a decade ago, timidly and with a sort of hesitant initiatic attitude, but with great expectations, a laser instrument set at a very low power, was employed to verify whether in vitro cell cultures could respond to it (7), and later was used on patients to heal superficial skin lesions (8), to relieve pain and overcome deeply situated inflammatory ailments, with a rather good degree of specificity. It was then disclosed, in a simple but realable manner, that tissues could respond to a monocromatic coherent light stimulation with satisfactory results.

These experimental and clinical studies have given rise to a new science called "Photobiology".
Through the years, photobiology studies have increased to such an extent that ad hoc instruments have been constructed and considerable scientific and clinical reports have been published on specialized Medical Journals. Congresses have been yearly organized and Low Power Laser Medical Societies have been founded and are to day very active.

THE LASER BEAM

The Laser beam can either be generated at high power with burning effects or at very low power, without heat effect, but preserving unaltered all its physical properties.

How can this be possible? How can a light beam made to burn and destruct tissues, be transformed into a beneficial tool, deprived of any ill effect on tissue? what is the physical entity and magnitude of Laser light? What does Low Power Laser mean?

An analysis of some facts concerning Laser light shall be conducted here, together with an attempt to find adequate answers to these very important questions, and at the same time to indicate reasonable justifications of the usefulness of Laser light as a therapeutic tool.

Concept of Low Power Laser. The Laser instruments used for therapeutic purposes have been denominated according to the source of the light; He-Ne, I.R., Diod, CO2, Nd-YAG, Argon etc. Many are the denominations used to indicate the characteristics of low power Laser light: "Mid Laser", "Soft Laser" "Low Level Laser" are some of the many suggested. These terms, however, are employed without additional specifications, although some author include potency, wl or frequency. These terms, albeit acceptable in the past, do not seem to be any longer useful, since they do not express the physical entity and magnitude of the Laser light. Indeed, more order should
be made as to the denomination and classification, not for mere matter of semantics, but to identify both the desired tissue responses and the indication of its use.

Therefore, Low Power Laser (LPL) and Low Energy Laser (LEL) seem to better satisfy the needs of a more appropriate classification and identification of Laser-light(2): LPL takes into value the source, while LEL accounts for the energy dissipated in tissues.

**Definition of Laser-Light.** The use of LPL in medicine is strictly related to the interaction between light and tissues. This interaction is based on several factors that characterize the physical properties of the Laser-beam.

Thus, the Laser-light can be defined as a monochromatic, coherent beam that propagates itself by plane waves.

**Physical Properties of Laser-Beam.** The physical properties of a Laser-beam can be identified in three different elements.

The first is the light-dose intensity, which is also known as power-density. The power-density is the expression of the impact of Laser-light on tissue: at high power the light absorption is maximum with burning effects, at low power the light absorption is minimum, so it can dissipate itself in the tissues. The dissipation of Laser-light in tissues gives rise to a precise and well documentable light-tissue interaction.

It can, therefore, be stated that, with a low-power-density-Laser-beam, little energy is delivered on the tissues, with however, the persistence of the tissue-light interaction, but without thermal effects.

The second physical element characterizing the Laser beam is the wavelength (wl). Different Laser sources are available producing light at different wl, that go from visible to invisible light spectrum (Fig.1). Many speculate that light at different wl will have a different diffusion capa-
city in tissues. In other words, the dissipation of light in tissues is directly proportional to its \( \lambda \): the longer is the \( \lambda \) the easier and deeper is its penetration and dissipation, independently of the histological structural and biochemical conditions of tissues. Nd-YAG laser having a \( \lambda \) of 1.060 nm penetrates deeply, while Argon with a \( \lambda \) of 488 nm penetrates less (9). However, it is added that very short and very long \( \lambda \) do not penetrate tissues as easy, if at all. The light produced by a carbon dioxide Laser of 10.600 nm is indicated as a good example: over 50% of its energy is quickly absorbed within the first mm of tissue thickness and after 3–4 mm none is available for further tissue penetration (6). Thus, lights with \( \lambda \) readily absorbed do not penetrate into tissues, while lights with \( \lambda \) not absorbed penetrate deeper into tissues. This represents the differentiated physical characteristics of Lasers, from which derives the concept of differentiated action and indications.

A third physical element that should be brought about, but that sometime is scarcely taken into appropriate consideration, is the coherency.

Coherency is the physical element common to all Laser-lights, independently of their power source, power density, amount and modality of energy-tissue dissipation and the \( \lambda \).

Is energy the quantum entity of Laser therapy? Is the \( \lambda \) the primary element inducing tissue response? Do tissues directly respond to coherency?

Many authors have indicated that \( \lambda \) is the physical entity characterizing both the immediate absorption and the deep tissue penetration of a given Laser-beam (6). In fact, the \( \lambda \) seems to have a specific action with the various biological substrates. But, reasonable doubts do persist about the validity of the experimental data used in favour of \( \lambda \) as essential for laser-tissue interplay. Therefore, in the face of these doubts, it remains
"coherency" to be taken into consideration as possible physical "transport" element allowing the Laser-beam to reach deep tissue layers and maintain intact its property of tissue stimulator.

As a definition, coherency is the product of collimation, phase and monochromacity of a light produced by a lasing instrument (Table 1).

**Differenciated Penetrating Capacity.** On the bases of the physical characteristics of Laser-light, does differenciated Laser-tissue penetrating capacity signify a different tissue response and thus, different results and consequently varied indications? Or is coherency sufficient to explain and define the penetrating capacity of any LEL-light into any tissue at any depth, independently of its wL?

Table 1. COHERENCY OF LASER LIGHT

<table>
<thead>
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<th>a) identical</th>
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<tr>
<td>1) photons:</td>
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<tr>
<td>b) monochromatic</td>
</tr>
<tr>
<td>2) specific wave length</td>
</tr>
<tr>
<td>3) parallel rays</td>
</tr>
<tr>
<td>4) beam can be focused to small spot-size preserving its physical properties</td>
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This are points of atmost importance and further research work should be done to clear them out.

It would seem, however, that the physical nature of coherency is never
affected by tissue elements, whereas \( \omega \) changes as it goes through the various layers.

**LASER-TISSUE INTERACTION**

In order to adequately comprehend the modalities and the effects of LEL-tissue interaction, it should be reminded that tissues possess variable and a priori unpredictable properties of light absorption and dissipation. The quantity of blood and/or pigments present in a given layer can significantly influence light dissipation and homogeneous distribution in tissues.

The Laser-tissue interaction produces mainly two different types of tissue response:

1) tissue coagulation or evaporation,
2) tissue repair or tissue healing

The first tissue reaction corresponds to its destruction. It is irreversible, permanent and beyond repair. The second, instead, is reversible and corresponds to healing, to repair, to restitution ad integrum of tissue morphology and function. This is the exquisite essence of the therapeutic indication of LEL. Both reactions may be visible, the first coincide with the encounter of highly absorbable laser energy and the tissues, while the second is at first microscopic, affecting cells and molecules, but becomes visible only when healing takes place, pain disappears and function is restored. This latter Laser-tissue rapport is called "photobiostimulation".

We shall take into consideration here only the photostimulation.

As we have anticipated above, the effects of LEL on tissues takes place through a rather complex phenomenon called "energy-dissipation".

The pathways of energy dissipation are based on the Einstein-Stark law on
the equivalence in photochemistry: in a photochemical reaction, every absorbed photon promotes important changes in molecules, atoms or free radicals, causing a state of excitation.

While dissipating into tissues:
1) the energy may be transformed into heat, producing tissue coagulation or evaporation.
2) the wavelength may change due to the dye-effect of tissues and blood.
3) light promotes photo-dinamic effects.

It is reported that Laser-tissue interaction is related to its wavelength (6,9). However, the wavelength not only is different according to the instrument and the medium used, but can also be modified while being dissipated, due to the tissue-dye-effect. Therefore, the capacity of tissue penetration of the different chromatic lights with their wavelength, should be revised and new definitions found, reviewing also the limitations of therapeutic indications of Laser lights.

**MODALITIES OF PHOTOBIOSTIMULATION**

When a low-energy coherent light meets and is dissipated in tissues, a very interesting and peculiar tissue-energy symbiosis is established. This symbiosis becomes synthesis when the energy is transformed into a biostimulus and restitutio ad integrum of the ill tissue is the final product.

**Definition:** The term "Photobiostimulation" indicates a stimulus induced by a Laser-light, capable of evoking a physiological response. This physiological response is produced when a photon meets a molecule. This photon-molecule encounter is also called "photobioactivation"(9), indicating with
the term "activation" the state of excitation of the stimulated molecule. The modalities of action that contribute to photobiostimulation are numerous and can be identified in well defined elements, none of which seem to be the primary cause of tissue stimulation. They have as primary target the cell membrane enzymes through complex phases of action, namely stimulation, adaptation, regulation and rehabilitation (Fig. 2).

The photostimulation can be evoked by:
1) Power-density (at the source)
2) Energy delivery and wavelength (impact)
3) Coherency and penetration in tissues (tissue-dye-effect)
4) Tissue response:
   a) Stimulation: cell membrane enzymes
   b) Adaptation: Microcirculation system
      1) Capillary proliferation
   c) Regulation: 2) cell replication
      3) Tissue repair
   d) Rehabilitation: Restitutio ad integrum of teguments and function

Albeit all Laser instruments possess diversity of qualitative power source, wavelength and a precise index of tissue absorption and dissipation, they have in common a single element: the coherency. Perhaps coherency acts as the primary stimulus giving rise to the cascade of biological events within the tissue. Thus, if this were true it could be stated that any Laser-light could be used as tissue activator, so long as its power can be reduced to prevent adverse effects.

A particular study should be conducted with the precise finality to verify and classify the importance of coherency that together with the
tissue-dye effect, could give us important informations as to how deep into tissues a given Laser-beam penetrates. This, perhaps, would also help to identify the factors inducing tissue healing and the quantification of tissue response to LEL.

TISSUE RESPONSE TO LASER

On the bases of what has been analysed above, it remains to take into consideration the fundamentals of the patho-physiological mechanisms that promote, maintain and regulate optimal spontaneous tissue healing.

The physiology of tissue repair is essentially based upon local conditions of blood supply and the minute-by-minute wound nutrition. In other wards: oxygen supply (capillaries), elimination of carbon dioxide and neutralization of hydrogen ions (cell membrane) (4).

It is stated that the tissue repair begins at the moment of injury. That is to say that the moment in which a wound is created corresponds to a vascular and nutritional response. The metabolic needs of an injured tissue should correspond exactly to an optimum state of blood supply.

However, the environment produced by the cause that has created a tissue injury is always unpredictable, but is largely made by: dead space, necrosis, fall of oxygen tension, increased pCO2, accumulation of hydrogen ions, acidosis, hypoxia. In this hypoxic, acidotic, hypercarbic environment, in the presence of often bacteria and tissue necrosis, both fibroblasts and capillaries, together with macrophages and neutrophiles should develop. However, such extreme gradients present in an open wound, do not always permit a correct, immediate and efficient tissue healing. At times some factors fail to be activated and the wound repair is defective, or repair does not take place at all.

Response of microcirculation system. In the complex patho-physiological
situation, when tissues have lost their spontaneous healing capacities, the chance of acting on tissues favouring the return of the ideal healing conditions, stimulating the wound to find the lost elements that should be present spontaneously, we would indeed meet the finality of tissue healing with anatomic and function restitutio ad integrum.

Although the mechanisms involved in tissue healing and the principles of Laser-light effects on tissues remain valid and appropriate, it is rather evident that the most important element in the Laser-tissue interplay, is the quantity of disseminated energy in the unit of time and the quality of the mechanisms promoting and maintaining energy-tissue-dissemination.

The fundamental tissue element that responds to Laser-light stimulation seems to be the "microcirculation system". The microcirculation system is not the capillary, as many suggest, but is represented by the functional unification of the capillary and the cell. Generally, whatever metabolic alteration may take place in tissues, this is always characterized by a profound functional modification of the cell. The functional relationship between the cell and its capillary is compromised due to cell membrane enzym alterations. The blood supply is deficient and the pH, hydrogen ions accumulation and electrolyte modifications are all consequences coinciding with the alteration of the cell-capillary homeostasis. This combination of microvessel and cell is the emblematic functional expression of microcirculation. Therefore, acting upon the microcirculation with a laser-light in the intent to ripristinate function, is the finality of LEL application in these cases.

Can we get the same results. What has been said about the physical characteristics of Laser-light and the effects of laser-energy upon tissues, a question derives and should be answered: is coherency the basic
physical property acting directly upon tissues? If the wl of a given light can change while going through the various tissues components and blood, although the ray produced is at a very low power, can we get the same results using various Laser instruments with different light sources?

Up to recently CO2 Laser was thought not to be the appropriate light to irradiate tissues for therapeutic purposes, since its energy is rapidly absorbed by the first 1 mm of tissue thickness. However, this does not seem to be correct. Infact, CO2 Laser at very low power can be an efficient deep tissue stimulator (3). Infact, a lesion produced on a femoral condilus of a pig's model, repairs very effectively if irradiated with a CO2 Laser-light at 0.5-1 W of source-power, for 5 minutes per time of treatment, if confronted with the control (Fig. 3 & 4).

A LP-CO2-Laser does exert any thermal action on tissues. Therefore its physical nature and properties is modified becoming appropriate for deep tissue dissipation and biostimulation.

Is coherency sufficient to explain these modifications of LP-CO2-Laser? Is tissue-dye-effect the element that allows CO2 laser-light to reach deep tissue layers?

No doubt that the answers to these questions would contribute to verify and re-classify LEL effects on tissues. These phenomena would lead to re-define the whole concept of Laser effects on tissues. Perhaps, this would be also of great help to improve our understanding as to the therapeutic indications of Lasers, and further clarify the concept of wl modification due to tissue-dye-effect.

The Instruments. The Power Source. The Results. Up to now the Laser instruments available, or most of them, have been contructed of rather large dimensions in order to obtain a beam of good quality at the source and an effec-
tive control of its impact on tissues and to guarantee a continuous adequa-
te power supply for the energy needed to stimulate ill tissues. This has
cased the construction of instruments with different power sources at very
high costs, limiting significantly their use in medical practice.

However, indipendetly from these, the analysis of the results in relation
to the type of Laser employed, appears rather interesting.

We have used several Laser instruments as follows:
1) He-Ne, wl 632.8 nm, of 25mW
2) Diod system, 830 nm, 15 mW
3) Diod poised I.R., 20 mW
4) CO2, 10.600 nm, 0.5-1 W

In all instruments the beam could be defocalized and scanned over the
irradiated area. They were used randomly, and followed a very simple proto-
col: daily irradiation until healing was obtained; 5 minutes of irradiation
per day; total number of days in relation to the healing of the skin
lesion, quality of healing.

In the last 10 years we have treated a total of 763 patients, 68% of whom
affected by skin lesions of various etiology. The remaining 32% were
variously affected by ailments in which the prevailing simptom was pain. We
shall analyse the effects of Laser light only on the skin lesions.

The total time needed to obtain healing went from 15 days in varicose
ulcers to 165 for ulcers in a patient affected by rheumatoid arthrities, to
275 days for multiple leg ulcers in patients affected by lower limbs
arteriosclerotic disease. These variables were indipendent of the type of
Laser instrument used, but instead strictly related to the underlying
pathology.

Indipendently of the Laser instrument used and the time needed to obtain
healing, all patients were cured and their skin lesions healed. In most cases cosmetic healing, with re-epithelialization of the skin ulcers was the result.

These results bring up again the important question: do all Laser instruments, independently of their power, wl, and erogated energy, produce the same results?

Miniature instruments. In order to find further elements sustaining this concepts, recently we have employed two portable miniature pocket-size laser instruments. One was a 16x6 cm He-Ne Laser 1.0 mW of maximum out-put, of wl 632.8 nm (Fig.5a), the other was a 14x3 cm IR diod Laser of 3.6 mW of wl 670 nm (Fig.5b). The first produces a spot light, the other gives both a spot and a defocalized light. Both instruments were randomly used in a group 15 male semiprofessional basket ball players, 8 of whom exhibited knee joint and 7 tibio-tarsic traumatic lesions. These young men were treated only with this type of instruments, without any other therapeutic support. The Laser appliclations per daily treatment was of 5 minutes and lasted until recovery. The results consisted in suppression of the pain within the third day of treatment, with resumed deambulation, disappearance of aedema or resorbtion of hydrarthrosis day 6. The patients returned to active sport practice after 9 to 18 days of treatment. Any physiotherapy or re-education of the limbs prior to resuming sport activity were not needed.

From these results it seems that the answer to the important question "can we get the same results" with different type of Laser lights, is positive.

Can we get significant results employing very LEL such as 1mW erogated energie and yet still have the same tissue responses indipendently of the lesions treated? Would miniature instruments be the answer to high cost
instruments?
Time and experience will tell. This is the challenge for the future.

*Courtesy of Lasotronic AG, Urdorf, Switzerland
REFERENCES

**TABLE I. ELECTROMAGNETIC SPECTRUM AND PRINCIPAL LASER LINES**

<table>
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<tr>
<th>EFFECT</th>
<th>PHOTON ENERGY</th>
<th>SPECTRA REGIONS</th>
<th>WAVE LENGTH</th>
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<td></td>
<td>10^1</td>
<td>Ultra Violet</td>
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<td></td>
<td>10</td>
<td>Visible</td>
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<td></td>
<td>10^-1</td>
<td>Infra Red</td>
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<td>Molecular Vibration</td>
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**Fig. 1.** Light spectrum and wavelength produced by the different Laser sources.

**Fig. 2.** Schematic representation of the primary target of Laser light. The action upon cell membrane enzymes goes through very complex phases of action.
Fig. 3. Histological representation of the healing capacity of an experimental lesion made on a condilus stimulated by a CO2 LP-laser light. The very active cell replication on the edges of the lesion are evident. (Mallory, original magnification 25x)

Fig. 4. Histological representation of control condilus lesion. In this case the result is represented by a very disorderly connective tissue production occupying the whole cavity. No cell replication is present on the edges of the lesion. (Mallory, original magnification, 25x).
Fig. 5. Miniature instruments used for treatment of sport lesions. a) 16x6 cm He-Ne 1mW, 632.8 nm wl Laser. b) 14x3 cm IR diod, 3.6 mW, 670 nm wl Laser.