The key concept of laser dentistry

What does a dental laser actually do?

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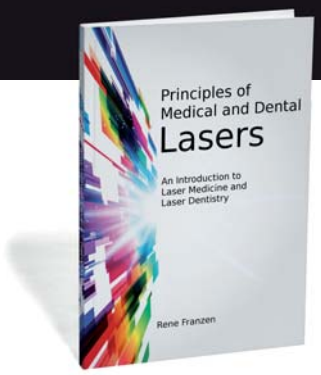


[ORIGINAL BACKGROUND: ©QUINKY]

_In his new book "Principles of Medical and Dental Lasers", Rene Franzen addresses the key issues of laser dentistry in an accessible way, pointing out important facts with regard to laser-tissue interaction relevant for everyday clinical practice. Readers of laser **international magazine of** laser dentistry can now enjoy a free reprint of an original chapter from this piece of basic laser literature.

_Introduction

If I would have to define a medical or dental laser system in just on sentence, this would be it:

A laser is a concentrator of energy.

This is what we want it to do for medical purposes. Its main properties, which are relevant here, are:

A high spectral energy or power density.

Now, since this is the core issue of medical laser therapies, we need to look at this in detail. Let's start with energy and power. These are different parameters, the first one measured in Joules, the other in Watts. The Joules measure the amount of something, and this something can actually be interpreted as the medication you use on your patient. In pharmacology, we measure the amount of medication in milligrams. Often they are given orally, and the effect is a systemic one. With lasers, our medication is the amount of energy, of Joules, which will cause an effect. Almost always the laser's medication is working only locally as opposed to systemically, making lasers a highly suitable tool for minimally invasive or selective procedures.

_Energy and time

The power, the Watts, is defined as energy per time. One Watt is 1 Joule in 1 second. If you apply the same 1 Joule in only 0.1 seconds, you have a power of 10 Watt. The amount of medication (Joules) is the same, but the effect will differ. Think of the power as what the dosage is in pharmacology. Example: Take 100 pills of a pain killer. Applying these in a time frame of 100 days may be okay for chronic pain issues, but applying the same amount in 10 minutes might be fatal. Same amount—different effect. The same is true

[PICTURE: ©ROBERT KNESCHKE]

for the laser's Joules. The same amount of energy, 500 mJ in the example, can cause non-thermal removal of hard tissue when given in a fast way, and causes no tissue removal but thermal carbonisation when given too slowly. The relationship between energy and power is the time it takes to deliver this amount of energy into the tissue. And this is the first quality in which a laser concentrates energy. For some medical or dental procedures we want to concentrate a lot of energy within a small timeframe, using a pulsed laser so we can have a high power during the pulse.

Let's look at the other words in that line above. Since energy and power are connected by time, high spectral power density remains. Now, high, is an easy property, isn't it? Often we think about lasers being high power devices, pure focussed light…but that is actually not a property of a laser. To understand this, let us examine one example:

_Compare a light bulb to a laser

Why don't we use a 100 W light bulb instead of a laser? It costs about 1 or 2 Euros or Dollars. How much does a 7 W diode laser cost? How much a larger Erbium or Neodymium laser? 10,000 – 50,000 Euros or Dollars, depending on the manufacturer and what market you are in. And yes, the light bulb really gives you more power than those laser systems. Power alone is nothing. It is one quality of the laser, namely the temporal concentration of energy. But there is more. The line above says power density, not just power. And this is another quality of lasers, the spatial concentration of energy.

Let us compare a laser to a light bulb. We take a 1 mW laser pointer, red laser light, and the 100 W bulb illuminating a room of roughly 25 square meters (sqm). The power of the light bulb is 100,000 times larger than that of the pointer. For simplicity, let's assume the pointers beam diameter is about 1 square millimeter (sqmm). It does not chance much when pointing it at different objects in a common room. The power density (or intensity) will be 1 mW/sqmm or 1,000,000 mW/sqm which equals 1,000 W/sqm. The light bulb illuminates the complete room, radiating in all directions since its emission is based on spontaneous emission. The floor is lit, but so are the ceiling and the walls. Again for simplicity, let's assume those add up to roughly 100 sqm, which means we talk about 100 W/100 sqm which is just 1 Watt per square meter at the position of the floor. We can use rough approximates here since we just need to see the order of magnitude which is between them: the pointer has an intensity 1,000 times higher than the bulb, even though the bulb is 100,000 times more powerful. This is concentration of power in space—the laser concentrates energy, in time (Watt) and space (energy or power density).

[PICTURE: ©IR STONE]

When we compare this laser pointer with a common dental diode laser of 7–10 Watt we will arrive at a power density of roughly 7–10 million Watts per square meter. If you would just buy power with your laser, the medical/dental laser should not exceed a sales price of 10 ct, but when comparing power density the bulb is at 1 Euro per 1 W/sqm, so the dental laser would be at 7–10 million Euros. Luckily, the real price is between those two extremes.

_Monochromasy

Going back once more, we see there is only one word left: A high spectral energy or power density. The power density is not just high, it is spectrally high. This relates to the position of the emission in the electromagnetic spectrum, the wavelengths being involved in the emission. The light bulb emits white light, which means that all the visible colours are present. But the light bulb is inefficient, less than 10 % of the power are emitted in the visible range; more than 90 % are emitted as infrared radiation. The red laser pointer is emitting its 1,000 W/sqm on just one narrow wavelength which is around 650 nm for a common diode laser based pointer. The light bulb is of course also emitting 650 nm, among other wavelengths. But in a strict comparison, when we use an optical filter to block out all the light of the bulb which is not between 649 and 651 nm, then what remains? Of the 1 W/sqm only 10 % are in the visible range at best, that's a mere 0.1 W/sqm. And this power density is spread across the complete visible area. So, in fact, we are looking at about 0.001–0.005 W/sqm around 650 nm. This is the value which competes against 1,000 W/sqm of laser pointer intensity, about a million times higher. This is what we mean when we say high spectral power density. A laser can concentrate the energy (the medication!) in time, space and on only one wavelength. Just

having one wavelength in the emission is what is called monochromasy.

_The key concept for selective treatments

This is the key element of minimally invasive laser treatments since it enables the doctor to put the medication exactly where it is needed to invoke a certain effect. Monochromasy directly leads to selectivity, in the sense that the optical properties of tissues can be used in conjunction with choosing a suitable laser wavelength, so that certain tissues or components inside a tissue can absorb significantly higher amounts of energy than others. This key concept opens up a tremendous amount of selective laser treatments.

_Selectivity

Using a medical laser system selectively in fact means to not only concentrate energy into a small volume of tissue in a certain time frame, but it also means to concentrate energy on certain components in the tissue.

Let us start with an easy, every-day example. Assume you are on vacation somewhere, staying at a nice hotel or resort with a lovely swimming pool. The pool is surrounded by tiles, white and black ones. The sky is blue and the sun is shining intensely. You walk around the pool just after breakfast. What happens?

Walking on the white tiles, you will feel they are cool, maybe even still cold from the night. The black tiles will feel hot when stepped upon (most pools will therefore not even have black tiles!). This is because the relationship

power is energy divided by time

can also be expressed as

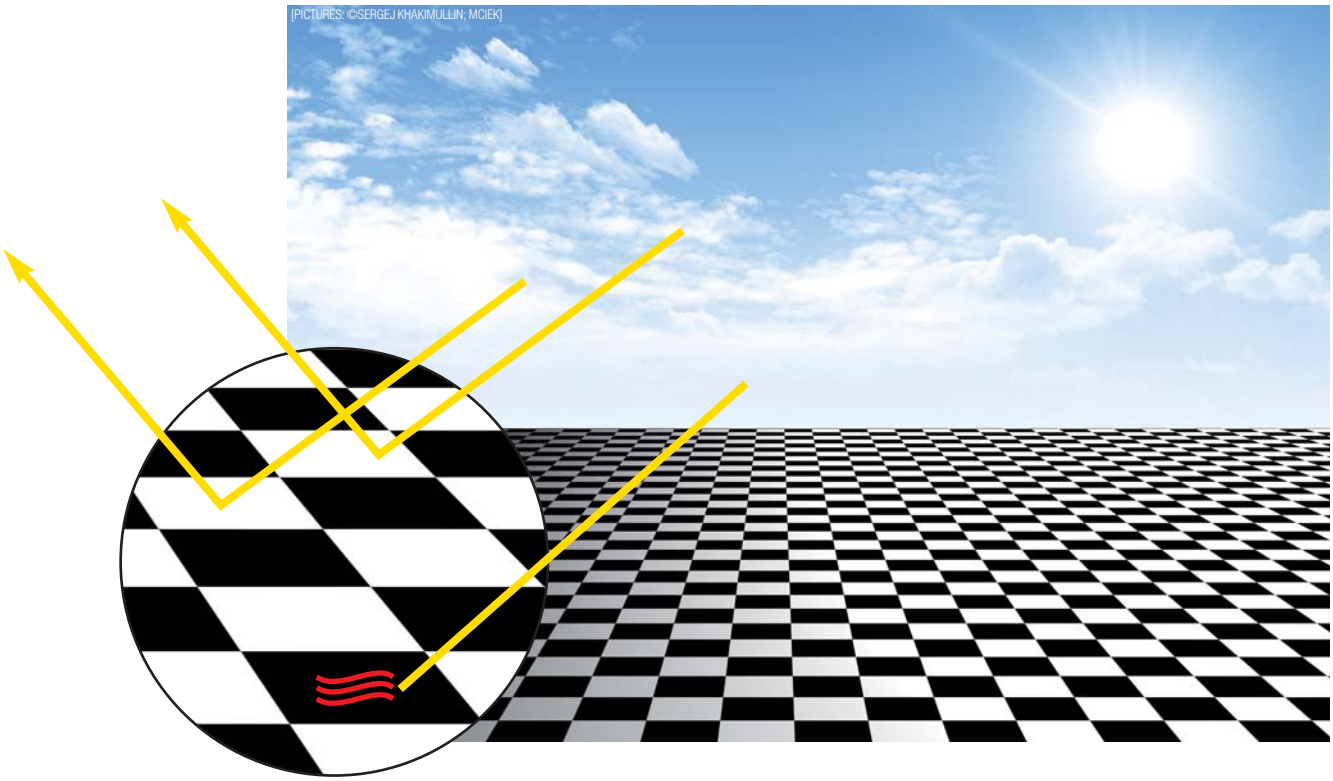
energy is power multiplied time.

Or in this case: absorbed energy (heat) in the tiles is power (sunshine) multiplied time (hours after sunrise). In this simplified example, the absorbed power in the white tiles will be low, because most sunlight will be scattered and reflected. Indeed, this is why they appear white in the first place: most of the sunlight is "bounced off" the tiles and reaches your eyes—the tile is bright. The fact that the tile is bright white is a direct consequence of this "bounced off" light being collimated by your eyes, focussed onto your retinas, where an image is projected. This is what we define as seeing.

The black tiles absorb most of the sunlight. Only a small fraction of the light is being scattered and reflected, only a small amount of light reaches your eyes—the tile appears dark or black. Black is actually no colour in itself but the absence of light. The absorbed energy will be converted mostly into heat and you will find the tile hot under the soles of your feet.

This is selective absorption of energy. A different response by different components, even if in close spatial proximity, and under the same irradiation.

[PICTURES: ©SERGEJ KHAKIMULLIN; MCIEK]



However, there is an important lesson to learn. You revisit the pool at 5 p.m. in the afternoon. The sun has been shining all day. The black tiles are hot. But now the white ones are also hot! The white tiles have heated up at a slower rate, since the absorbed power is lower. But over enough time, an impressive amount of energy can still be collected. At this time, we don't feel a thermal difference between the different tiles. The selectivity is lost.

_You can lose selectivity if you irradiate too long

The example with the pool tiles can be expanded to a dental example: A laser-supported endodontic treatment follows the same concept of selectivity.

One of the main problems of problematic endodontic cases are bacteria migrating into lateral tubes. Research has shown that the bacteria such as *Streptococcus mutans* can migrate 1,100 µm into the tubules[1], while rinsing agents are only effective to about 100 µm.[2] Secondary canals, an isthmus or apical delta will also make conventional cleaning in these cases near to impossible.

But luckily we have a selective situation. More than 95% of bacterial species in the canal system are pigmented. The remaining fraction is highly sensitive to the residual heat after irradiation. The dentin itself is not pigmented. The bacteria are acting as our black tiles and the dentin acts as white tiles.

We can now choose a laser whose wavelength is highly absorbed in pigments/melanin and is highly scattered and transmitted in dentin.

The question regarding the dose, the amount of medication, the amount of energy need is equivalent to the question "At what time to I need to go to the pool to find the white tiles cold and the black tiles hot". Then we find an answer, something like "At 10:23 a.m.".

In laser medicine, this answer may not be so easy to find. Actually, it involves tremendous efforts in research. For the laser-supported endodontic treatment, already in the 1990's, Prof Dr Norbert Gutknecht tested several irradiation protocols at RWTH Aachen University, measuring bacterial reduction in different depths of dentin. The ideal technique, today known as the Aachen protocol, which we also teach in-depth in courses on our campus, involves specific settings for the laser system, wavelength, average power, temporal modulation (pulsing), fiber diameter and kind, as well as the movement of the fiber inside the open root canal.

If we perform such a treatment, we will have excellent results, because we concentrate energy: in time (pulse duration, repetition rate, movement), in space (movement, different absorption of components—wavelength, fiber diameter), and spectrally (absorption response of dentin and pigments). Don't get lost in too many laser parameters, they all go back to one of these three qualities of concentration. If ever you get confused by a parameter, ask yourself, is this influencing the energy concentration in time, in space, or a certain component?

In our example of an infected root canal, the energy will be concentrated in the bacteria. They will locally overheat and die off due to the absorbed energy, without heating the surrounding dentin up to significant temperatures. We aim to put the medication (energy) selectively into the microorganisms.

And just as in pharmacology, you can overdose and underdose your treatment. If you are too careful, setting only the lowest possible power on your laser, and move out of the canal very quickly, no harm can be done to the dentin and underlying bone structures. But also no harm is done to the bacteria: under dose. This is the same as if you visit the pool just after sunrise. Everything is still cold.

On the other hand, if someone says, "I paid for 10 W, so I will use it, no matter what", and then moves slowly inside the canal, the bacteria will be killed off—along with charring the dentin and destroying significant sections of the bone structure. The same as going to the pool at 5 p.m.: Everything is hot. Selectivity is lost.

At this point I would like to stress that therefore it is very important to learn and study (and understand!) the treatment protocols in medicine. Some things are fundamentally different than with a scalpel.

Continue reading in the book or ebook and learn more about the successful use of laser energy in dental treatments._

Editorial note: The book Principles of Medical and Dental Lasers *by Rene Franzen can be obtained in German, English and Greek, printed or as e-book via www.lulu.com/spotlight/renefranzen and www.amazon.de/Principles-Medical-And-Dental-Lasers/dp/1470905922/ref=cm_cr_pr_product_top as well as via iTunes and iBookstore. A complete list of references is available from the publisher.*

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