De-mystifying the physics jargon behind light-based treatments

The world of lasers and IPL systems is full of physics terms and expressions. Many of these are quite daunting to non-physicists and we tend to forget that not everyone is a nerd!!

So, here's a breakdown of some of those terms….

Wavelength - colour of light

The wavelength of light is simply its colour. So, a 700nm wavelength is a red light, while 532nm is green. Physicists prefer to use wavelengths as they are much more precise than colour. Many wavelengths are invisible to the human eye. Anything above 700nm is usually invisible, but we can feel these wavelengths as heat!

Spectrum - range of colours

We often hear about the 'spectrum' when talking about light. A spectrum is just a collection of wavelengths (colours of light). It can be any range of colours you want. The visible spectrum is the range of wavelengths that humans can see naturally. This is usually in the range 400 to 700 nanometres, or thereabouts – this does vary a little depending on individuals.

The 'near' infra-red spectrum is in the range 700 to around 1500nm. Many lasers used in medical/aesthetic treatments are in the visible and near infra-red ranges. Most IPL systems will generate a spectrum between around 400 and 1200nm.

Energy – 'stuff'

Energy is a strange thing to describe! There are many forms of energy including heat, sound (vibration), light, kinetic (movement), gravitational, potential, electrical….

For physicists, energy is the 'stuff' which makes things change or happen. So, we know that heat energy will raise the temperature of something, while gravity keeps us all grounded! We use light energy to generate heat energy in tissues, to induce a change of some sort.

We measure energy in 'Joules' (or millijoules or megajoules).

Photothermal treatments

A photothermal treatment results from photons (light energy) inducing a thermal (heat) reaction in the target tissues (hair, blood, pigment).

Photomechanical treatments

These are sometimes called ‘photoacoustic’ treatments. In these treatments, the energy is delivered so rapidly that there is no time for the absorbed energy to flow from the targets, during the pulse. This induces a very large temperature increase (over 1000°C in tattoos!!), which then leads to a physical, or mechanical, rupturing of the tattoo ink aggregates.

Fluence - “concentration of energy” = temperature rise in skin

The fluence is simply the ‘concentration of energy’ in a spot. The subsequent temperature rise in the tissues is directly dependent on the fluence.

So, if we fire a certain amount of energy into a large spot, then the concentration is relatively low. This will induce a fairly low temperature rise.

Whereas, if we fired exactly the same amount of energy into a smaller spot, then the concentration is higher and the resultant temperature rise will be higher too.

Consequently, the fluence is very, very important when considering any laser/IPL treatment. It directly affects the outcome and must be chosen very carefully.

The fluence is found by dividing the energy (in Joules) by the spot size area (usually in cm^2) and is measured in ‘Joules per square centimetre’ (J/cm^2).

Absorption

When the light energy interacts with something in the skin (collagen, melanin, blood etc) there is a chance it might be absorbed. This means that the light energy is ‘kept’ by that object – the light photon is converted into heat (usually) which raises the object's temperature.

As a consequence, the total energy of the light is then reduced, since it has lost one of its photons.

This is the whole purpose of laser/IPL treatments. We are trying to 'force' something in the skin to 'absorb' the energy we have thrown at it. Absorption of the light energy is the goal!

To do this efficiently, we need to 'match' the wavelength of the light we're using to the absorption of the target(s).

For example, the haemoglobin in blood is known to absorb yellow light very strongly, but not blue or red light. So, we use yellow light to try to increase the absorption in blood – this is the 'matching' process.

Blood generally reflects most red light – that's why blood appears red! So there is little point trying to heat up blood using red light – it simply will not be absorbed!

Choosing the correct wavelength to match the target's absorption peak is very important in all these treatments. Otherwise, you are wasting your time…

Pulsewidth (pulse duration, pulse length) - "cooking time"

The pulsewidth (or pulse duration or pulse length – they are all the same!) is how long the light energy pulse is ON. It can be thought of as the 'cooking time' in all photothermal treatments.

This parameter is as important as the fluence! If you put an egg into a pot of boiling water (which is at 100°C), and then remove it after 10 seconds, is it properly cooked? Of course not!

Why? Well, it's just because the egg was cooked for a long enough time. This is obvious!

Yet, it is exactly the same with photothermal treatments in tissues. If the tissues are not kept at the required temperature for a long enough period of time, then they will not cook!!

As an example, collagen needs a certain amount of time to coagulate' depending on its temperature. If you heat collagen to 60°C, then it needs to maintain that temperature for at least 1.1 seconds to properly coagulate. If, however, you raise its temperature to 80°C, then it only needs 1.4 milliseconds to fully coagulate – that's nearly 1/1000 of the time at 60°C for only a 20°C rise!!

So, what this means in treatments is that you MUST match the fluence (temperature rise) with the pulsewidth (cooking time) to ensure you obtain the right result. If you don't cook the tissues for long enough (the pulsewidth is too short!) then it might survive the cooking process and regenerate.

In most cases (for photothermal treatments) we measure the pulsewidth in milliseconds. For laser tattoo treatments we typically use either nanoseconds or picoseconds to ensure that most of the energy is concentrated into the tattoo ink particles.

Repetition rate – the 'Hertz'

This is simple. The repetition rate (rep rate) is just how quickly the shots or pulses are coming out of the laser/IPL. So, if one shot is fired each second, then we say the rep rate is 1 Hertz. Likewise, if 5 shots are fired per second, then it's 5 Hertz (or 5 Hz).

Now, how important is this?

Well, 'not very', is the answer!!! The rep rate doesn't really have much bearing on most treatment outcomes. It's more to do with how quickly you might cover an area of the skin. A faster rep rate will cover a larger area more quickly – obviously!

But, the rep rate has very little effect, if any, on the actual treatment outcomes. It's a personal choice depending on the individual treatment area.

Spot size – more important than you might think

The spot size determines the area of the beam on the skin surface. Very simple.

But, in actual fact, the spot size is much more important than that! Coupled with the energy delivered, it determines the fluence, or 'concentration', onto the skin; and this determines the resultant temperature rise in the skin.

That's pretty straight-forward, but the spot size has a "hidden" property which is very important.

When light enters the skin, it ‘bounces’ around all over the place as it interacts with atoms and molecules. This is called ‘scattering’. This causes the beam to spread out as it progresses into the skin.

So, as the light energy penetrates deeper into the skin, the spot size are increases. Consequently, the fluence drops! And this is purely due to the scattering effects – nothing to do with absorption of the light by anything in the skin (that’s a different issue – see above).

It has been observed, in experiments and computer simulations, that larger spot sizes deliver more fluence to deeper regions of the skin, than small spot sizes. This is due to the effects and ‘intensity’ of the scattering in the upper skin layers. Smaller spots cause more ‘intense’ scattering of the light, which reduces the fluence more rapidly. Larger spots are not so intensely scattered, and so the drop in fluence is not so great.

This means, in terms of laser/IPL treatments, that larger spot sizes are always better when treating deep targets in the skin.

Coagulation or denaturation

This is not a ‘physics’ term, as such, but is constantly used by medical people when describing tissues interacting with heat. Unfortunately, many of them don’t use it correctly, adopting a fairly meaningless, vague notion instead!!

Cells and tissue don’t like too much heat. It can cause their protein structures to fall apart – quite literally. Tissues like collagen are composed of a triple helix of amino acids (a bit like DNA or RNA).

When they are heated to around 45°C, these protein helices begin to vibrate significantly. As the temperature increases, the vibrations increase too. At somewhere between around 48 to 58°C heat shock proteins fight against the thermally-induced vibrations.

Up to 58°C the HSPs can maintain the protein structures reasonably well. But, when the temperature exceeds 58°C for a certain time, the HSPs lose the war, and the proteins begin to unravel. This is when the cells/tissues begin to die!

This may be described as the onset of coagulation or denaturation. But, the chemistry of this process is very well understood, and it is easy to show that the rate of coagulation is very low at such temperatures.

But there is a very important issue here – as the temperature increases above 58°C, the rate of coagulation increases exponentially!!

As described above in the 'Pulsewidth' section, the amount of time required for a certain volume of tissue to fully coagulate (or denature) depends on the temperature. At 60°C, collagen takes around 1.1 seconds, whereas it only needs 1.4 milliseconds at 80°C.

Read my blog post on this.

Power

Power is good! We can't do anything without power. But what is it?

Power is simply how quickly or slowly energy is delivered. That's it! It's just a rate of delivery. Or, in other words, the number of Joules (energy) per second. We call this 'Watts' after the famous Scottish engineer, James Watt, who essentially, kick-started the industrial revolution with his genius!

So, if you have a certain amount of laser/IPL energy, let's say 1 Joule, and you fire it at the skin over a long period of time, say 5 minutes, what will be the effect?

The answer is obvious – you would not feel a thing!! That's because the energy is being absorbed so slowly that it dissipates everywhere with no real temperature effect on the tissues.

But, if you delivered the same energy at the skin in 1 microsecond (1 millionth of a second), then you would probably feel something. The reason is just because the energy doesn't have as much time to flow away from the absorption sites, so it mostly stays in one small(ish) area or volume. As a consequence, the temperature rise may be significant.

If the same energy (1 Joule) is delivered to the skin in even less time (say 1 picosecond – that is 1 millionth millionth of a second) then there is virtually no time at all for the absorbed energy to flow away during the pulse. So, the energy is mostly concentrated in a small area, therefore inducing a larger temperature rise.

While the energy is critical in causing temperature rises, the power is also critical! As with everything in life, timing is all…

Laser – Light Amplification by the Stimulated Emission of Radiation

All light is radiation. Radiation is good stuff – we can't survive without it. A lot of people seem to confuse radiation with 'radioactivity'. Radioactivity is nasty – we don't really want to be exposed to much of that!!

Laser light is unique to humans. Laser light does not exist in the universe (unless some aliens have developed it too!). Laser light is simply the energy is a single wavelength (not quite 'single' – that would be impossible, but it's close!)

But, laser light energy is merely a means to generate heat energy in the skin. That's all!

IPL – Intense Pulse Light

IPL is just a bright flash of light across a range of wavelengths - typically 400 to 1200nm, or thereabouts, from the blue end of the visible spectrum to the near infra-red bit. This range of wavelengths can contain a significant amount of light energy.

However, not all of it might be useful so we use filters to block those wavelengths we don't need. So, to damage blood vessels, we use the yellow light energy because it is strongly absorbed by haemoglobin.

For hair, we're targeting the melanin, which absorbs all visible light. However, the real targets – the stem cells – are found nearer the bottom of the hair follicles, so we use red light to ensure that enough light energy gets deep enough to reach those cells.

Calibration

Calibration seems to cause consternation and problems in the medical/aesthetic community! With many devices, the fluence that is delivered to the skin is NOT what it claims on the screen.

In fact, the numbers on the screen are quite meaningless.

The only way to actually know is to calibrate the device. This requires an external energy meter and taking a bunch of measurements. This will tell us precisely what is really coming out of the device.

In reality, **ALL systems should be calibrated regularly** since their outputs can change over time and usage.

Calibration is important because it allows you to be consistent with your treatment records.

I hope this helps to demystify some of the expression we use in lasers and IPLs. If there are any others you'd like us to tackle, just email me.

Mike.

Blog – MikeMurphyBlog.com
Web site – dermalasetraining.com – if you're looking for some training on lasers and IPLs
You Tube channel - click here – this has a bunch of animations and videos which describes some of the above

You can also find our eBook at https://thelaserguysblog.wordpress.com/our-book/

P.S. I wrote a wee article on this stuff for the Journal of Aesthetic Nursing.