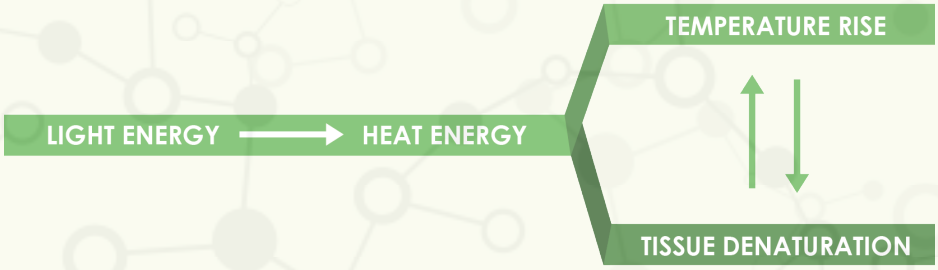
BEING SELECTIVE

Mike Murphy on selective photothermolysis in hair and blood vessels - a new interpretation of thermal relaxation times

Selective photothermolysis was introduced in 1981 by two American scientists, Anderson and Parrish, Boston following their study with a pulsed dye laser on blood vessels, particularly port wine stains. They theorised that by carefully selecting the most appropriate wavelength a clinician could selectively deliver laser energy into target blood vessels in such vessels. The light is absorbed by the target's chromophores – in this case oxyhaemoglobin and deoxyhaemoglobin within the blood cells. The blood then heats up preferentially and induces damage to the vessel wall thereby destroying the target vessel. An important part of their theory was that the duration of the light pulse had to be less than the 'thermal relaxation time' (TRT) of the blood vessel to minimise damage to surrounding tissues. The TRT essentially determines the cooling time of the targets and is dependent on the target's physical size. As a consequence of this theory many laser systems were devised which adhered to these principle parameters – the optimum wavelength, energy and pulse duration. However, my colleague and I have recently discovered that this interpretation is incorrect. While the choice of wavelength is essentially determined by the absorption characteristics of the target chromophore the pulse duration of the light energy should not be tied to the TRT of the target, as originally proposed.

The Science

When light energy is absorbed by tissue there are at least two processes occurring:
1. light energy is converted into heat energy which raises the tissue temperature;
2. the proteins within the tissue break down once the temperature exceeds a threshold.



Mike Murphy

Mike Murphy is a physicist/bioengineer who has been involved in medical laser research since 1986 and in the commercial sector since 1989. His original research group developed the scar-free removal of tattoos by Q-switched ruby laser in Canniesburn Hospital, Glasgow. He now runs training courses on IPL systems and aesthetic lasers and their applications.

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The protein breakdown rate is governed by the Arrhenius Damage Integral which determines the amount of tissue damage for a given time and temperature. Once a threshold temperature has been exceeded the breakdown, or denaturation, process can begin. This process will continue for as long as the threshold temperature is exceeded or maintained. The total amount of tissue damage then dictates the clinical outcome – if sufficient damage occurs then that tissue dies and new tissues will grow in its place. The important point here is that the amount of protein denaturation is entirely dependent on the tissue temperature and the time that those temperatures are maintained. When 63.2% of the proteins have been irreversibly damaged the tissue dies. Hence if a blood vessel or a hair follicle is heated using light, or radio frequency, energy and the correct set of temperature and time is achieved then those targets will be irreversibly destroyed. In many clinical setting this does not occur because either the temperature is not maintained long enough or the temperature achieved is too low. In these situations an insufficient amount of the target tissue is denatured (less than 63.2%) and so the tissue has the capacity to regrow in its original state. This explains why poor results occur so frequently when treating hair or blood vessels (especially those with large diameters which require more damage).

Undercooked – some proteins remain intact

All of the egg white's proteins have been denatured. (Note that the yolks have not been denatured–they have different thermal properties compared with the albumen)

I usually explain this process as follows – everyone knows how to fry an egg (I assume)! We can all see the 'white' of the egg changing from a transparent appearance to a white appearance. What we are observing is the denaturation of the proteins in the egg white. It is clearly obvious!

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Likewise, we all know that if the cooking temperature is too low then the egg will take forever to cook. Similarly, if we have a high temperature but take the frying pan off the heat too early then some of the egg white will still be transparent – in other words, not all of the proteins will have denatured. As with tissue we need to achieve the correct set of temperatures and times to achieve the best results. So, when targeting skin tissues keep in mind the fried egg analogy – you must 'cook' the tissue at a sufficiently high temperature (energy) for a sufficiently long period of time (pulse duration) to ensure complete destruction of the target proteins. In fact, it turns out that the most important parameter in determining the final outcome is the power density (energy per unit area per unit time, measured in watts/cm2). The fact is that the TRT does not matter in the denaturation process - it is merely an indicator of how quickly the target cools – it has nothing to do with the protein denaturation process. You can see a more scientific description of this process in my new report[1] in 'Lasers in Medical Science'.

Conclusion

To achieve good clinical results with lasers or IPL systems it is important to understand the physical processes which are occurring in the tissues. The heating process is relatively simple to grasp and is quite obvious to most patients. However, the physical destruction of the tissue proteins is a more subtle process which is not so immediately obvious. I think this is why the TRT idea stuck around for so long. However, we should now realise that we must always consider the correct parameters when targeting tissues – energy, spot size, wavelength and pulse duration. By selecting the correct combination of these parameters, based on an understanding of the processes, we should always be able to achieve a good clinical outcome.

1 - 'Thermal relaxation times: an outdated concept in photothermal treatments', Murphy M.J., Torstensson P.A., Lasers in Medical Science, October 2013.