THE IMPOSSIBLE DOSE – HOW CAN SOMETHING SIMPLE BE SO COMPLEX?

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The dose is the most important parameter in laser phototherapy. At a first glance, the dose seem very simple and obvious – simply give some joules per square centimeter skin.

Looking deeper, the dose becomes extremely complex.

A two dimensional power distribution of the light on the tissue surface leads to a three dimensional energy distribution in the tissue.

This distribution depends on many factors.

What do we mean by joules per point?

What is the size of a point?

If an injury is situated 2 cm under the skin surface, what dose do we get at this depth if 100 joules per square cm is administered to 5 square cm on the skin surface right above the injury?

And what dose do we need?

Some basic facts:

- Generally about dose: What we call dose is more adequately ”energy density”. There are principally two types of energy density – on a surface and in a volume.
- What we usually do, is to enter light energy into a surface and part of this will then be distributed into a volume in the underlying tissue.
- The dose in every point on the surface is measured in J/cm^2 and the dose in every point of the underlying volume is measured in J/cm^3.
- We practically never have an even dose distribution over the treated surface – even if we try.
- The energy density (dose) is the same as the power density multiplied by the exposure time.
- Power density is the same as light intensity.
- A laser probe has an opening (aperture), through which the light passes out. Usually, the intensity is different in different points in the aperture. The aperture can be covered by glass or a lens.
- The out coming light may be divergent, parallel or convergent.

I will start from a letter:

Dear Lars,

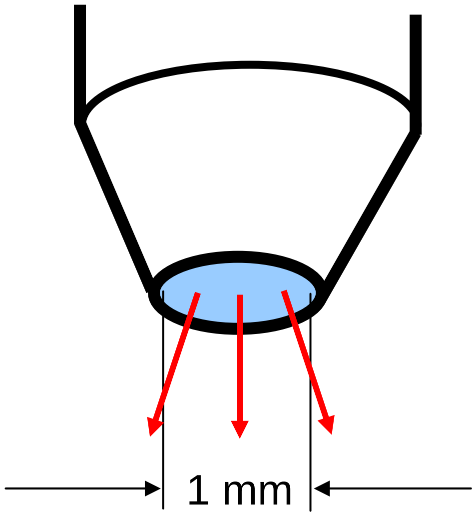
I have found a discrepancy (I think) in the publication by R. Mirkovic on his reported doses. He says that the energy density was 0.9 J/cm^2 but my calculations show that it is 95 J/cm^2. Can you check and tell me if you agree?

These are the parameters:

- 50 mW continuous wave.
- Diameter of the laser beam 1 mm.
- Each point is treated for 15 seconds.
- The laser used is an MID-laser 1500.

I'd be grateful if you could look at this.
Thanks,

Erik



Laser aperture

Dear Erik,

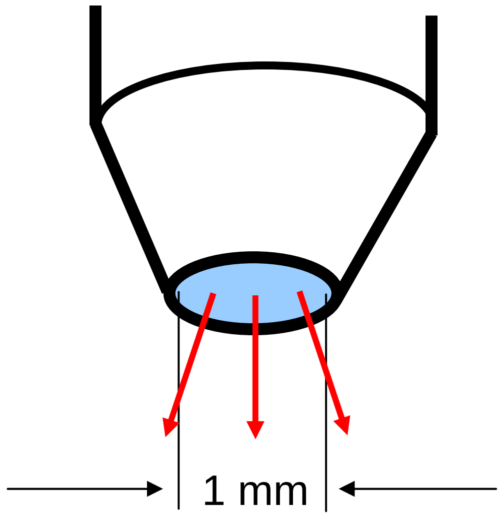
To be able to calculate the **dose** (= energy density) we need two things – the total energy emitted and the area that this energy is distributed over.

Generally 50 mW, flowing during 15 seconds mean that an **energy** of 750 mJ = 0.75 J have been emitted from the laser.

The aperture **area** (1 mm in diameter) equals 0.785 mm^2, which is 0.00785 cm^2.

Assuming that the intensity across the aperture is the same in every point, we will have a dose: 0.750 J / 0.00785 cm^2 = **95.5 J/cm^2**. This dose is then given to the cells <u>situated in the aperture</u> assuming contact between aperture and skin surface.

You got the same result. However, Mirkovic et. al. got another value – how come?

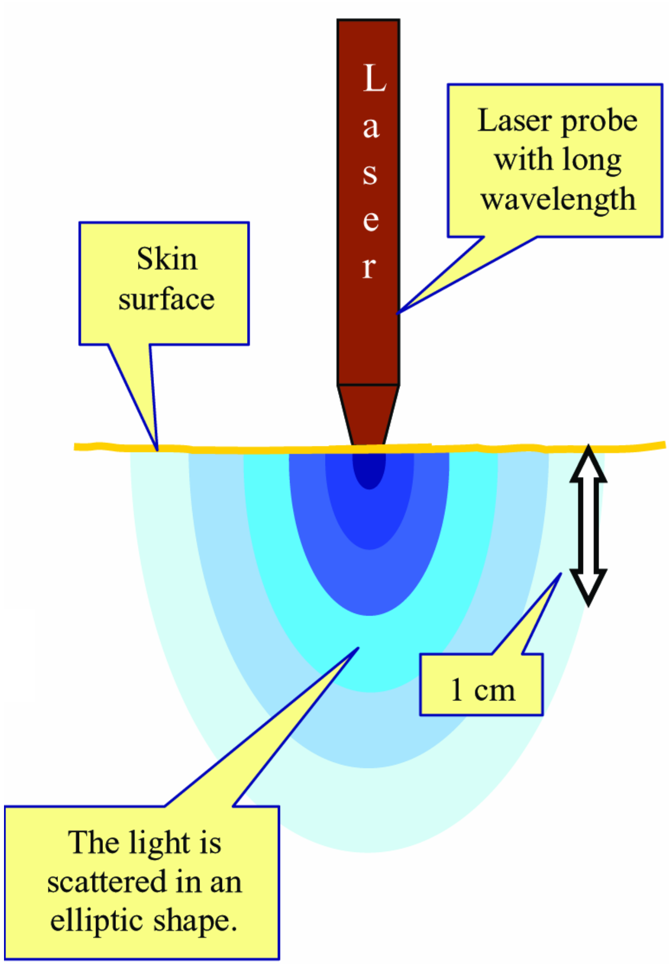


Laser aperture

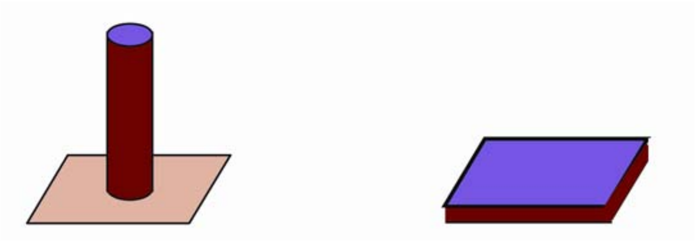
Depending on how we define dose, we can have different opinions on whether this is the dose or not. The cells outside the aperture border gets also laser light due to the scattering in tissue below and around the aperture, however a lower dose.

If, instead, we calculate the average dose in a surrounding circle with the area of 1 cm^2 (= a circle with the diameter 1.13 cm) we have a dose that is **0.750 J/cm^2**.

Due to scattering, the light will reach also the edges of said circle, but much weakened. You could say that the dose distribution will approximately look like a circular-symmetric Gaussian distribution.



As the aperture is rather small, we can instead say that the dose is 0.75 J per **point**. Particularly, this will be true if the treated points are at a relatively large distance from each other, e.g. more than a centimeter.



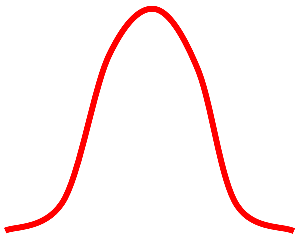
Due to the lack of a consensus in the dose nomenclature we are very often talking different languages.
Lars

Dear Lars,
I have to say that I don't believe that you can talk about an "average" dose of laser over a square centimeter when you have such a tiny aperture. I feel that one has to assume that there is a Gaussian distribution over the aperture which means that the energy density is 95 J/cm^2 under the area of the aperture, where the laser light hits the tissue.

The question is now: Will we have the same biological effect if we treat 0.1 cm^2 with 10 J/cm^2 as if we treat 1 cm^2 with 1 J/cm^2 evenly distributed? In both cases we have administered the same amount of energy to the tissue!

That is the really important "dose"!! What happens in the surrounding tissue is dissipating in an exponential way, and to average it out does not tell you what is happening with regard to energy density in the target tissue, which may be less than a square centimeter in area. I feel strongly about this because to say that a dose of 0.9 J/cm² is being used is completely misleading. Don't you think so?
Thanks for the reply!   Erik.

Erik,
Of course you can talk about average over a cm² - what about 5 mm in diameter, or 4? You can choose any surface, of course. Whatever surface you choose, <u>you will never achieve an even light distribution over that surface</u>. You are anyway averaging in many other ways. E.g. you mention "there is a Gaussian distribution over the aperture". Well, already if that would be so, you give a much higher dose to the cells in the middle of the aperture than those closer to the edge!



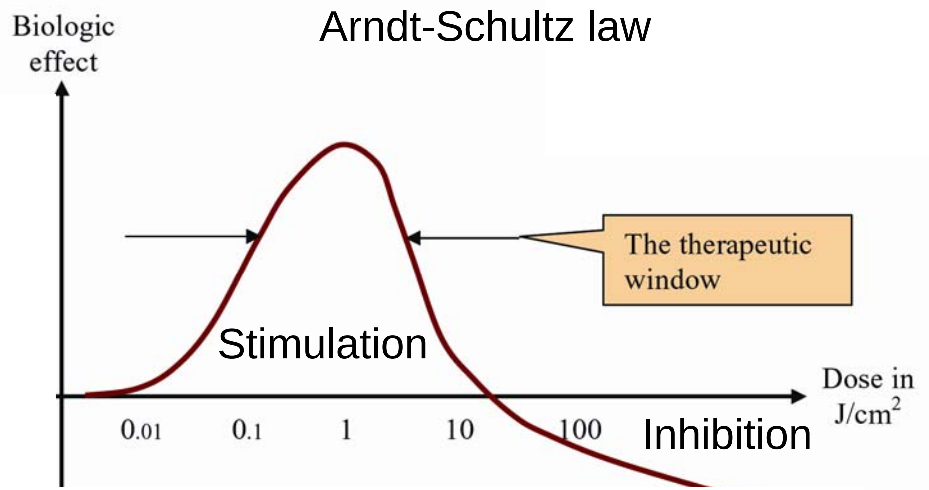
Gaussian curve

Which ever you choose, two things are sure:

1. You feed the same number of joules into the person which will not only have an effect on the cells right in front of the very probe aperture - it will have effect also on the nearby situated cells, reached by the scattered light and those cells are a thousand times more!

2. Also, you will always get systemic effects (e.g. from treating blood cells).

In the top layer of the skin, you have cells that gets very high power density (with possible inhibition as result) while cells situated beside the aperture and lower down (that may be stimulated). In the case of a more even illumination the cells will be more evenly influenced.



Further, these things matters mostly on the surface – a bit down the differences are much less, and usually the problem you want to treat is situated at some depth.

However, in the surface (and of course in an in vitro experiment) it can be a big difference in result between the two ways of illumination, so it is worth thinking of.

What really matters is that you describe the physical situation as accurate as possible so that it will be possible to repeat the experiment.

Lars

Yes, of course you are right! It doesn't matter as long as the parameters are reported! Thanks for taking your time.

Erik

Laser light can be focused to a spot with a diameter less than 0.01 mm (like in a CD-player).

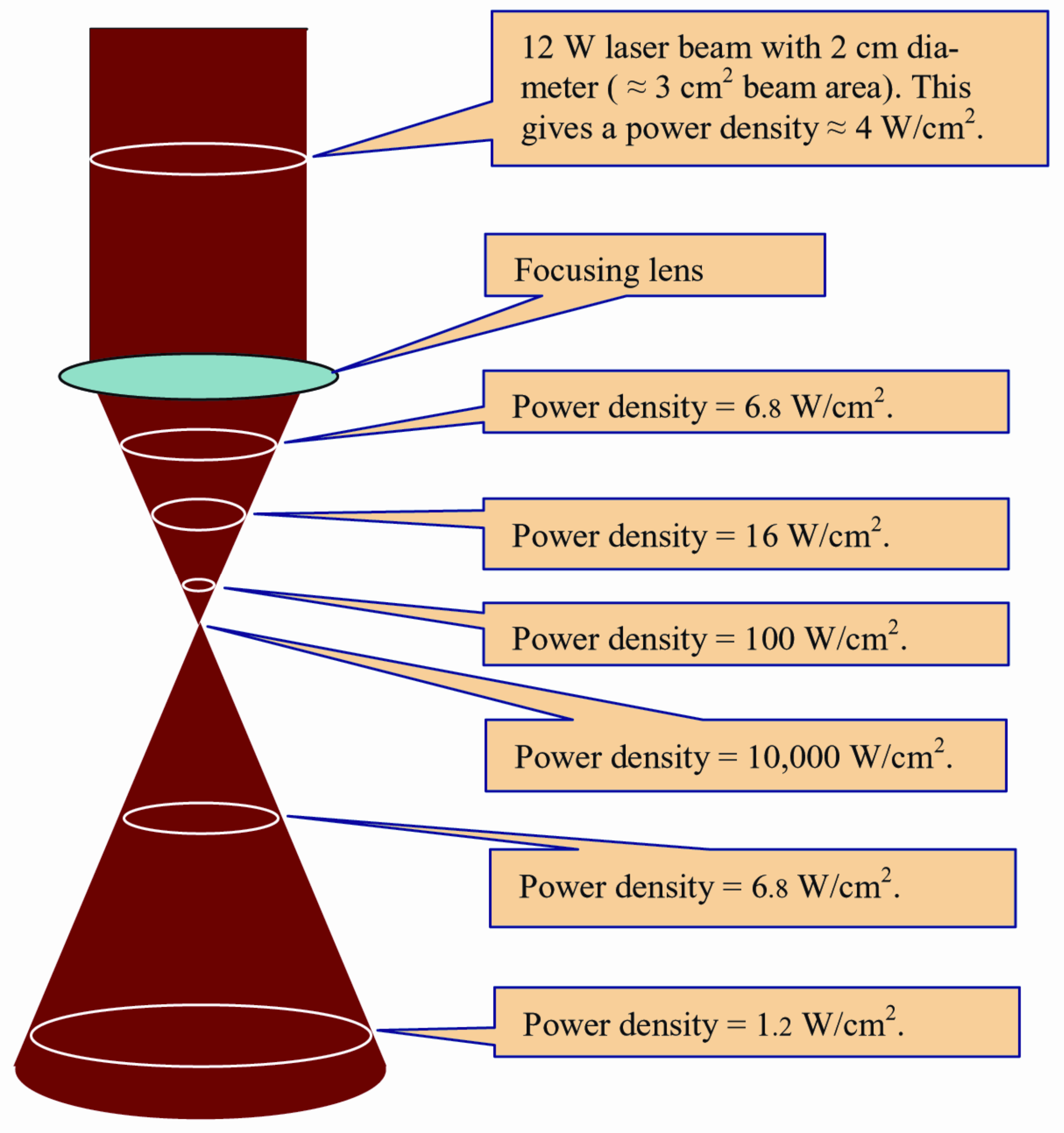
1 mW laser focused to a point of 0.01 × 0.01 mm (let us make it squared instead of round to get more even values). The are is then 0.0001 mm^2 = = 0.000001 cm^2 = 10^{-6} cm^2. 1 mW light, evenly distributed over that area gives a power density of 1000 W/cm^2 [0.001 mW divided by 0.000001 cm^2]

If that laser is on for 1 second, the dose value in that small area is 1000 J/cm^2 and the total energy given is 0.001 joule.

In the focus of a **1 mW** laser,
switched on for **1 second**,
we get a dose of **1000 J/cm^2**

Typical example of the large differences in power density in different places in a focused laser beam, e.g. from a CO_2-laser.

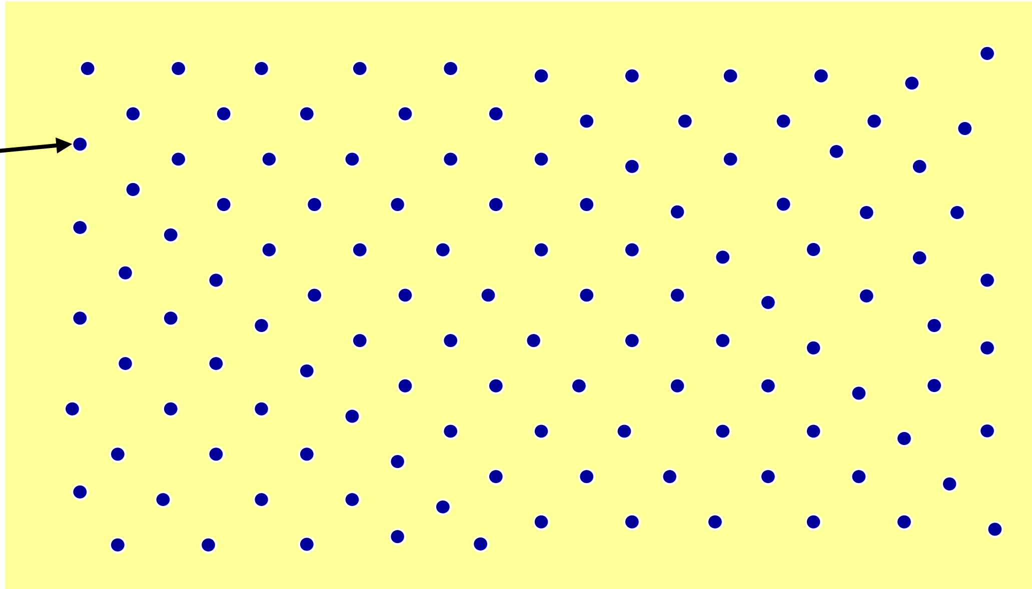
After the lens but before the focus point the light is convergent. After the focus point the light is divergent.



What is the dose.

120 ”points”, each with an area of 2 mm^2 spread out over an area of 10 × 20 cm (200 cm^2) and 10 mW light, 10 sec in each point.

0.1 joule in each point with an area of 0.02 cm^2 gives a dose of 5 J/cm^2



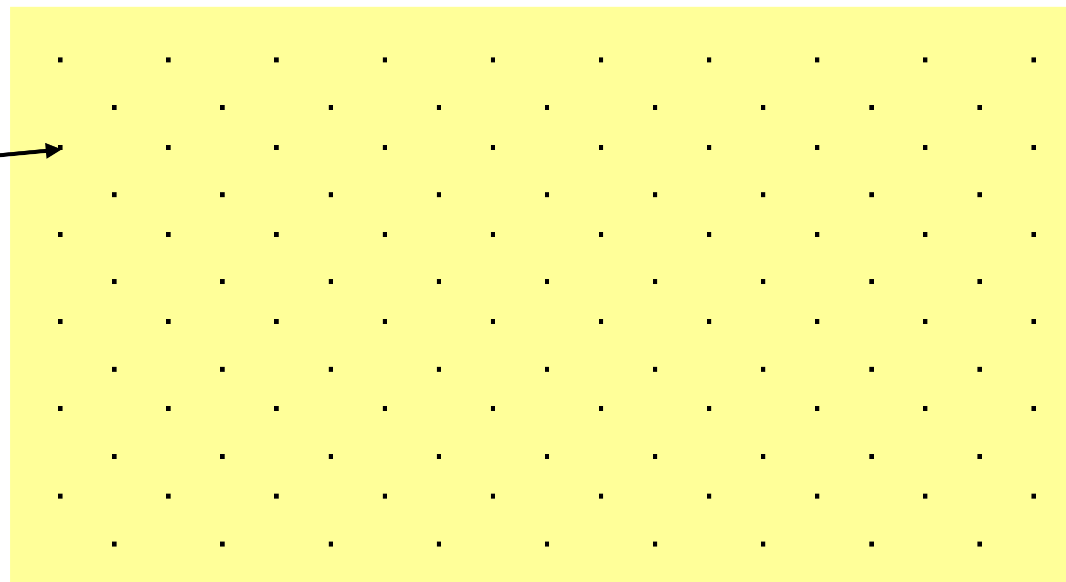
Or: Totally 12 joules over 200 cm^2 = 0.06 J/cm^2.

Which dose is correct?

Let us go one step further:

Let us focus the light to a diameter of 0.5 mm. Now we have 120 ”points”, each with an area of 0.2 mm^2 spread out over an area of 10 × 20 cm (200 cm^2) and 10 mW light, 10 sec in each point.

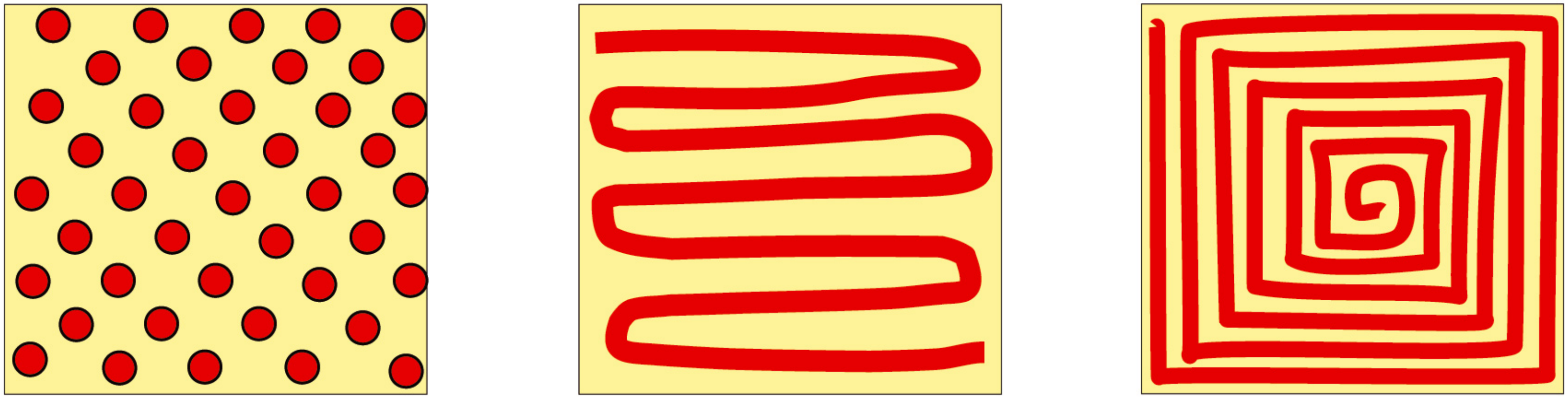
0.1 joule in each point with an area of 0.002 cm^2 gives a dose of 50 J/cm^2



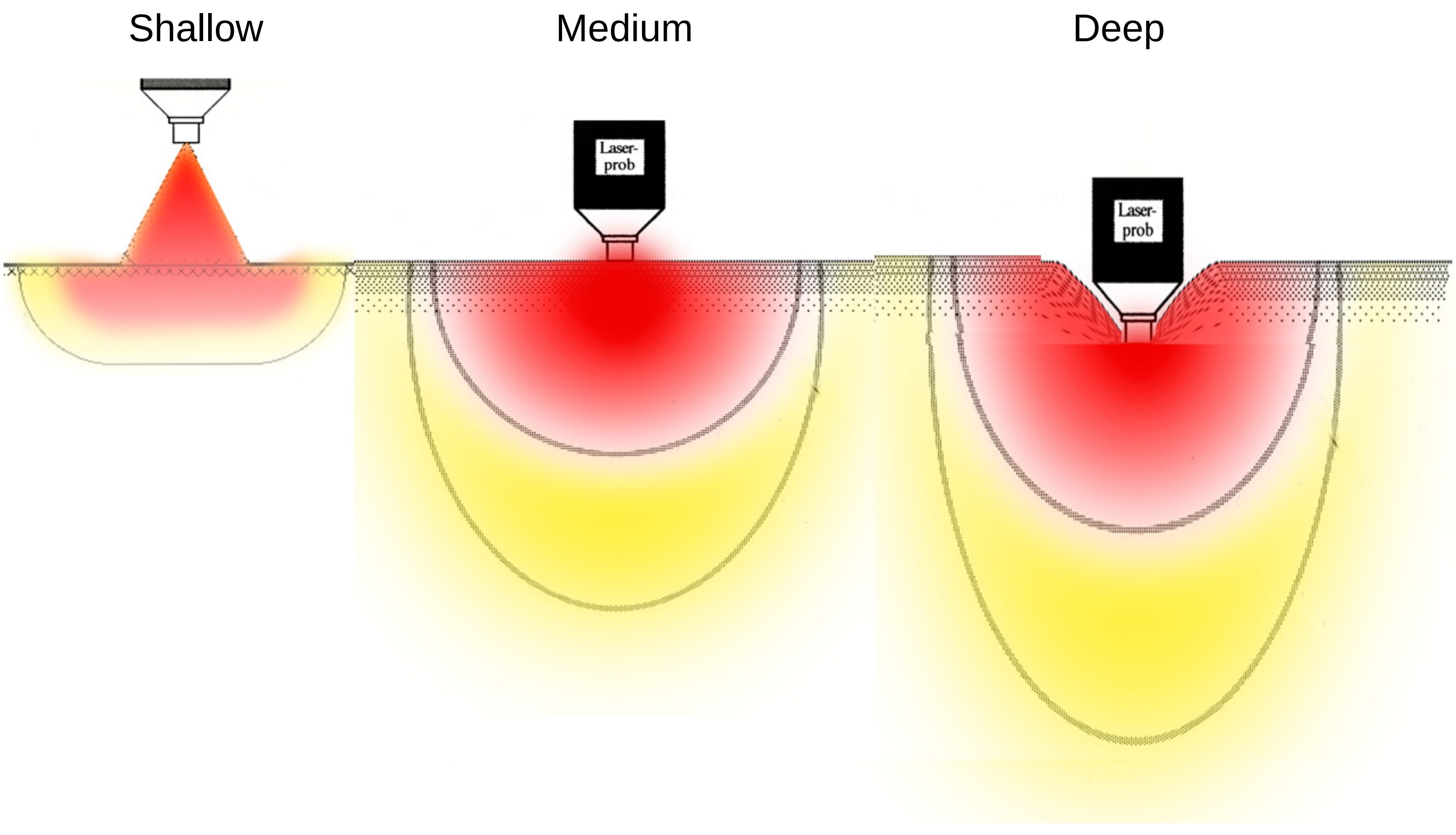
Still: Totally 12 joules over 200 cm^2 = 0.06 J/cm^2.

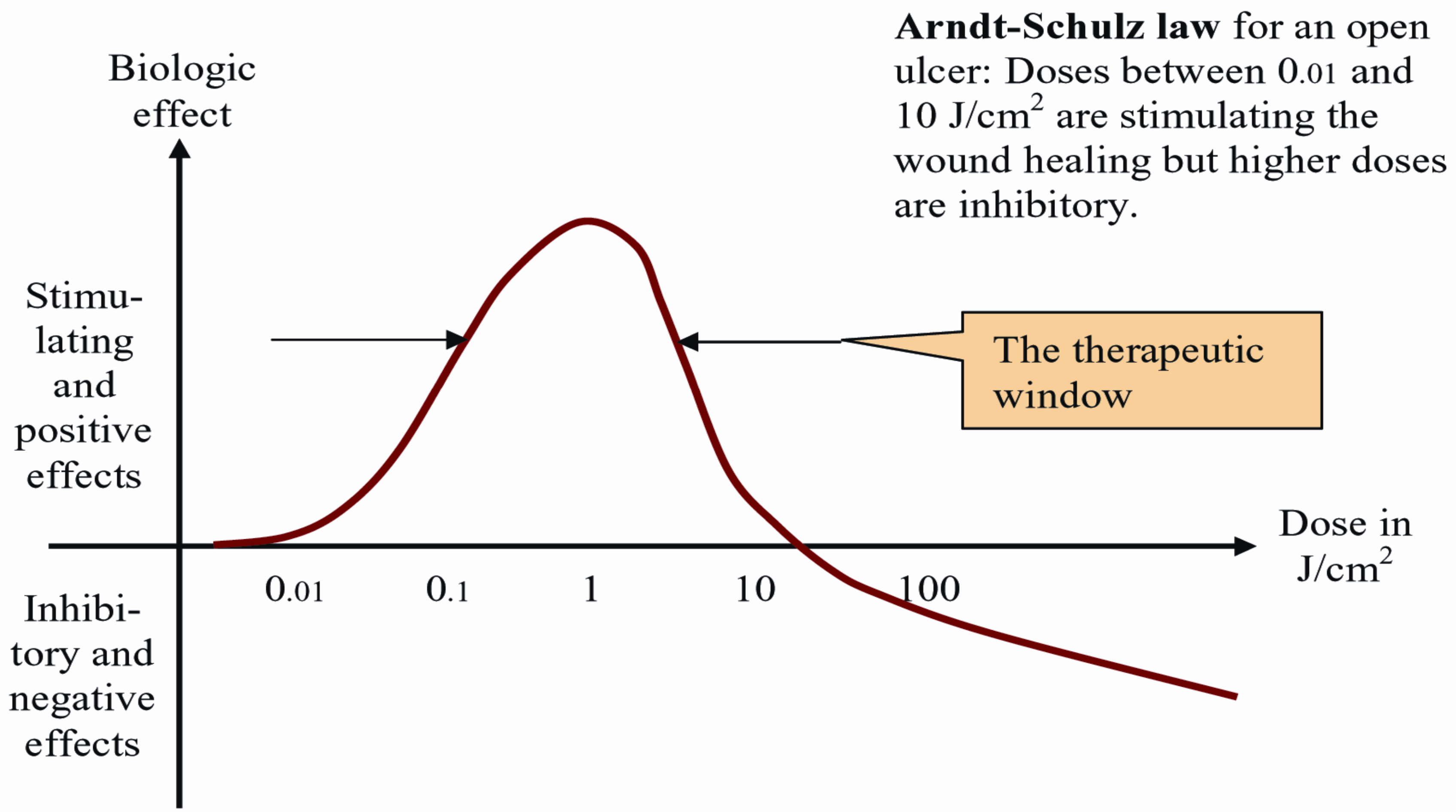
Which dose is correct?

Some examples of distributing the laser light energy when treating over a surface with a light source with small aperture.



Three ways of treating





This is a dose (energy density) response curve and there is a similar one for the power density.

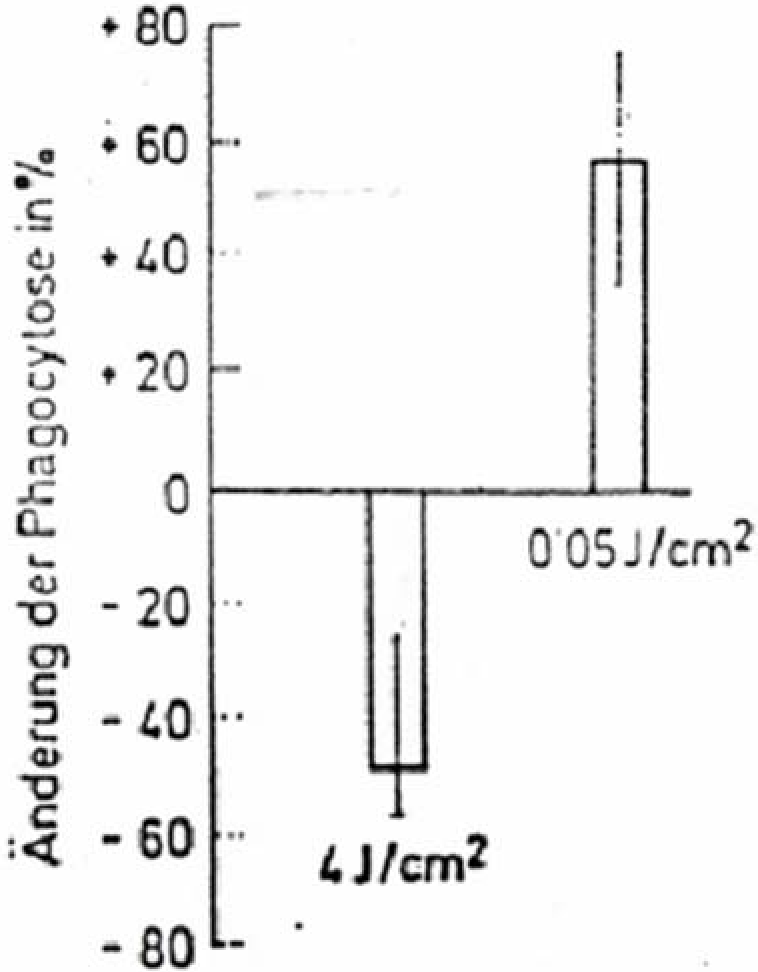


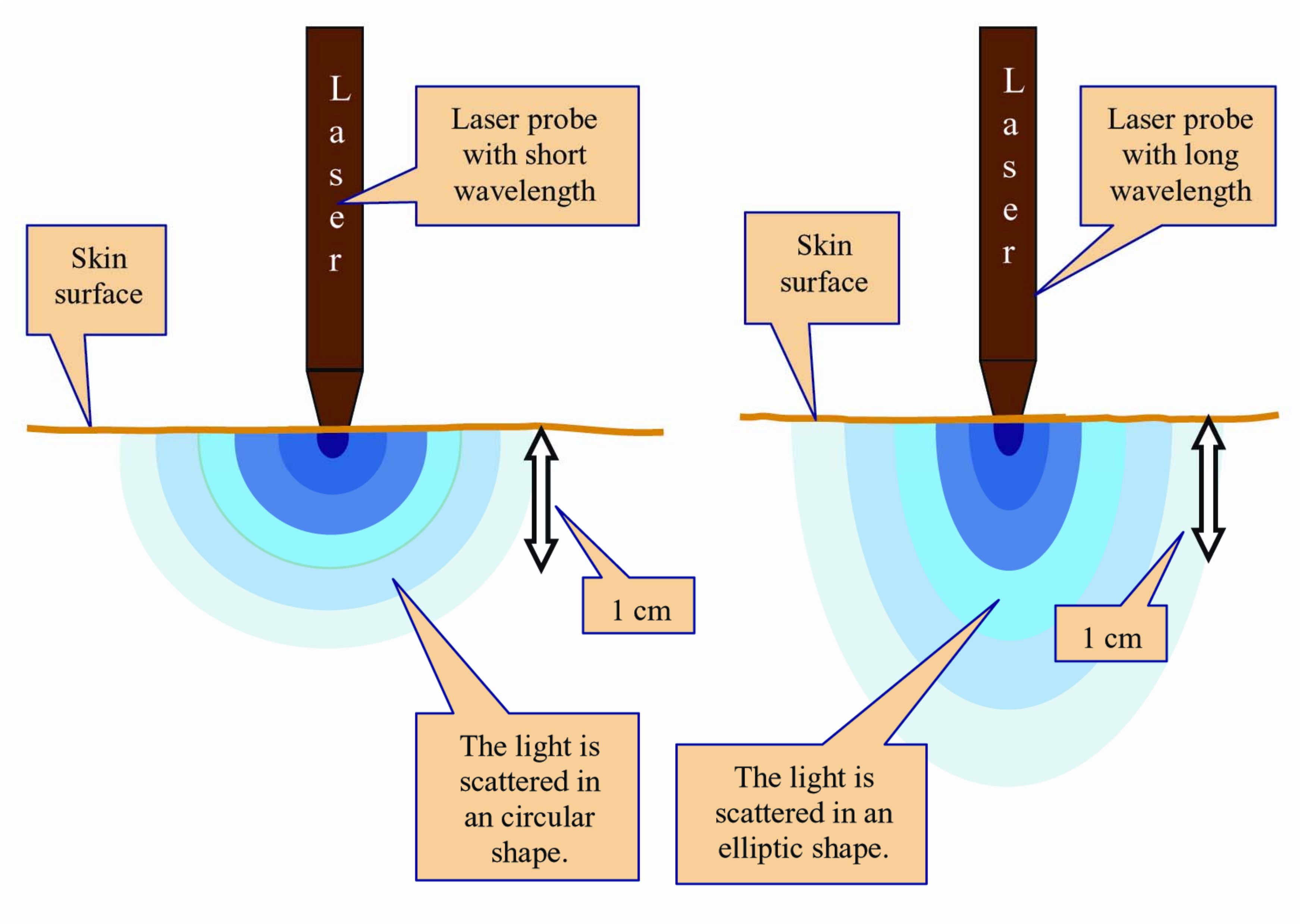
Abb. 1. Änderung der Bakterien-Phagocytose von menschlichen Leukocyten nach Laserbestrahlung

This is an example of stimulatory dose, 0.05 J/cm² and inhibitory dose, 4 J/cm².

This is from one of Mesters early investigations (1970), but conforms very well with later experiments.

It is an in vitro study, but the dose levels are close to what is found when treating open wounds - no overlaying skin that reflects, scatters and absorb light.

Shape of the light profile in illuminated tissue



How long time should I treat?

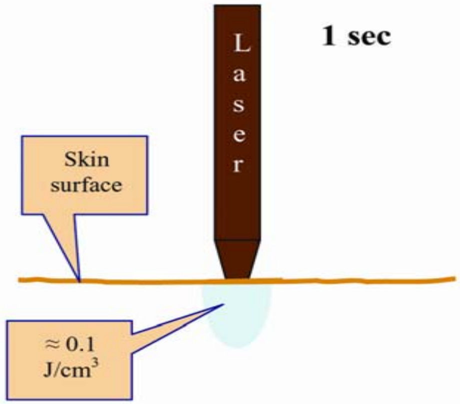
This is one of the most frequent questions that come to us. ”I have a laser, 808 nm wavelength, 450 mW diode laser, how long time shall I treat an Achilles tendon?”

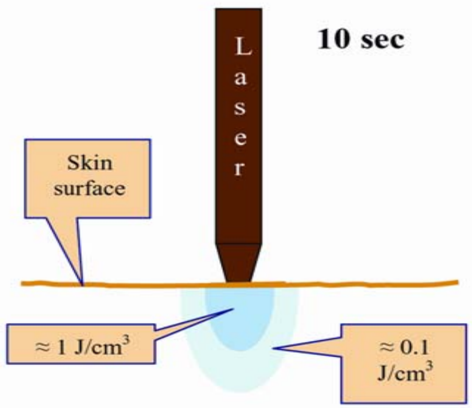
The formula below is recomended by the Swedish Laser-Medical Society.

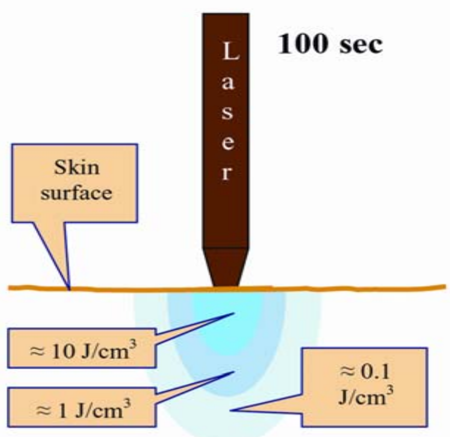
$$t = \frac{D \times A}{P} (1+d) \quad [\,\mathrm{sek}\,]$$

t is treatment time in seconds, **D** is dose in J/cm², **A** is area in cm², **P** is output power from the laser, measured in watt, **d** is the deep factor with value from 1-4 cm, indicating the approximate depth of the problem to treat.

The reason why a linear factor is used instead of an exponential factor is that it accounts for systemic effects. Further an exponental factor would anyway not be more correct, only more complicated for the layman to use and gives easily unrealistic values of the treatment time. We have today a good practical experience in using this formula.

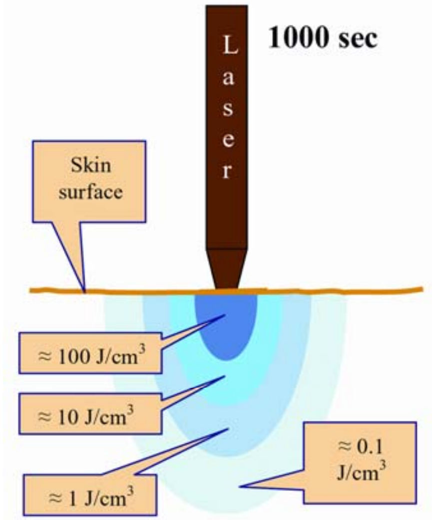


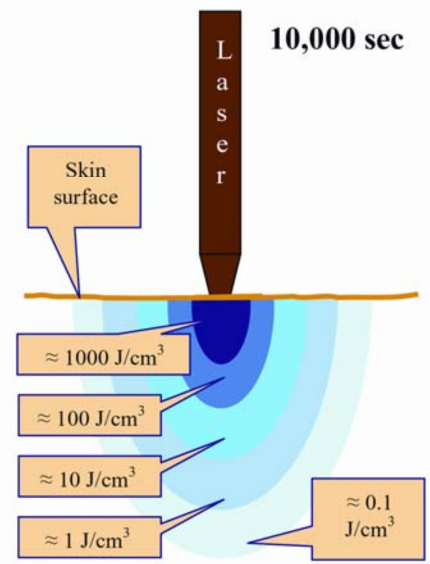




Here we can see the dose distribution in tissue when for different exposure time with the laser power is kept constant and the laser probe is held still in one position.

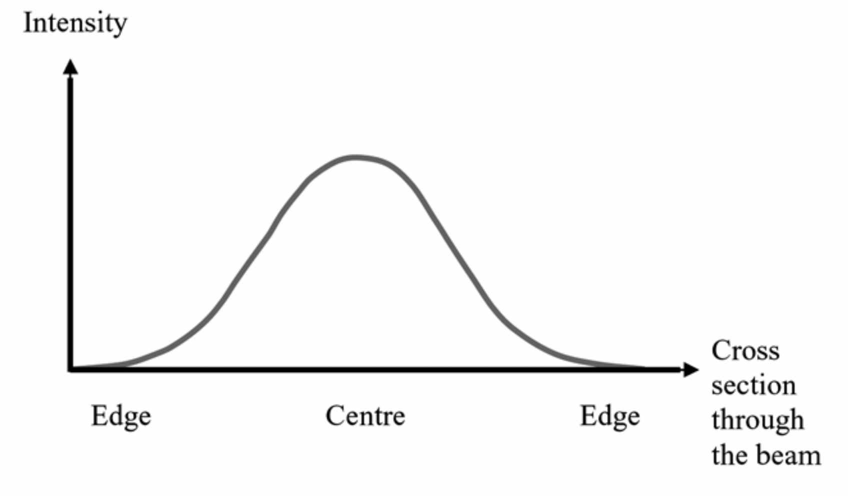
Dark blue color may indicate inhibiting dose.

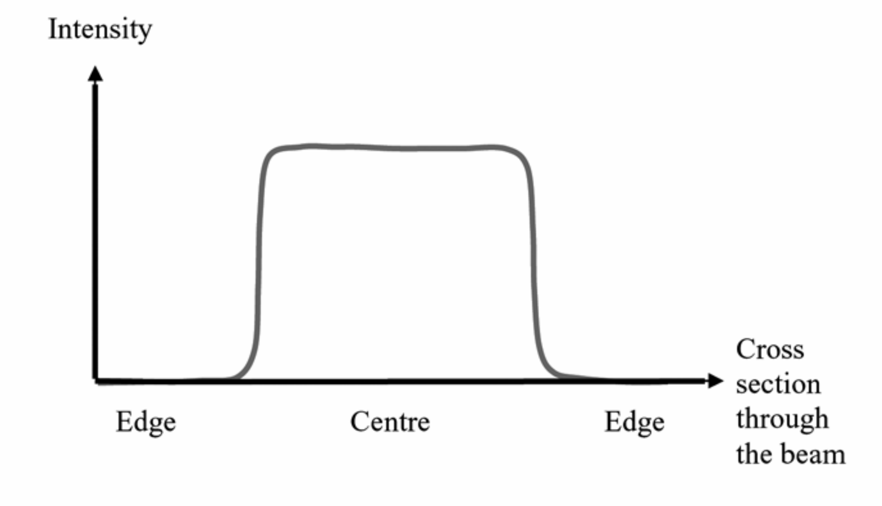




Examples of beam profiles.

Looking close, neither gaussian nor flat profiles are seen in reality, especially when the light source is a diode laser.

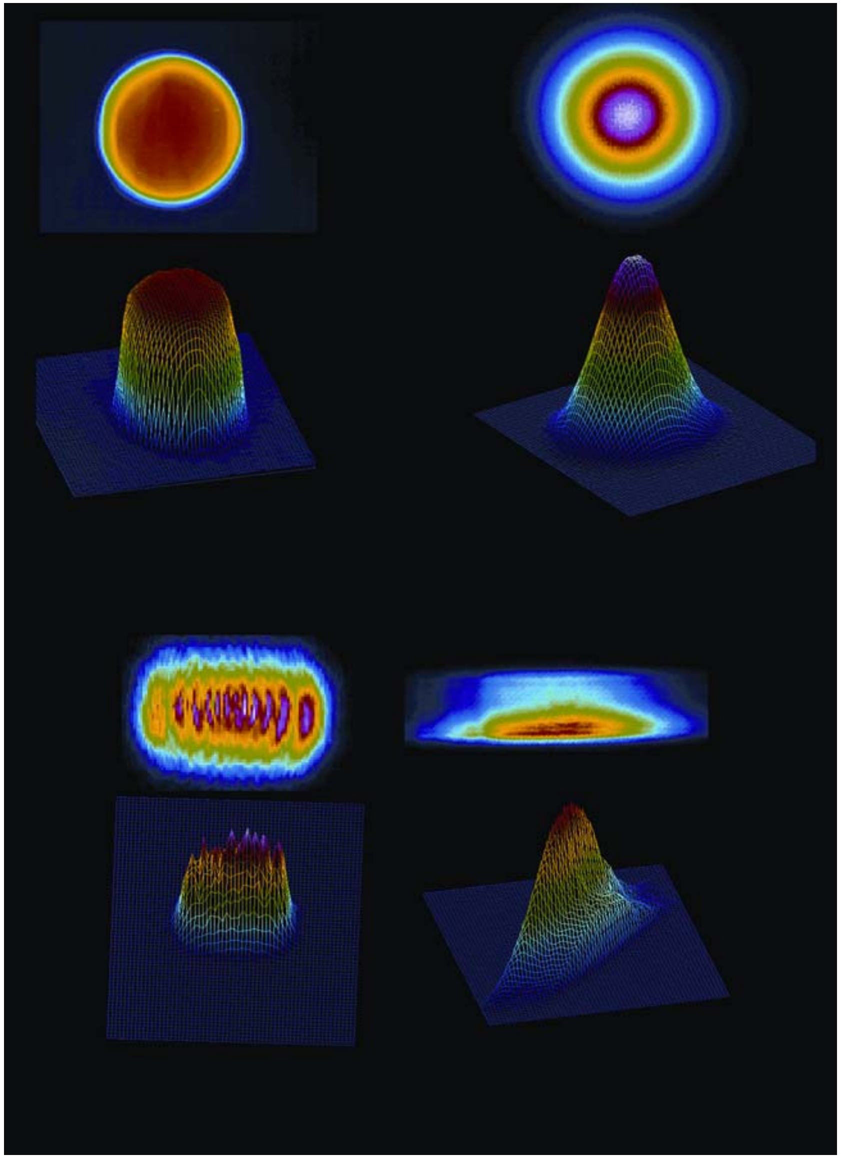




Three dimentional pictures of the beam structure of different laser types.

- Top left: Flat
- Top right: Gaussian
- Bottom: Semiconductor

From: James Caroll,
Thør Laser UK.



Thanks for listening, folks!

Lars Hode

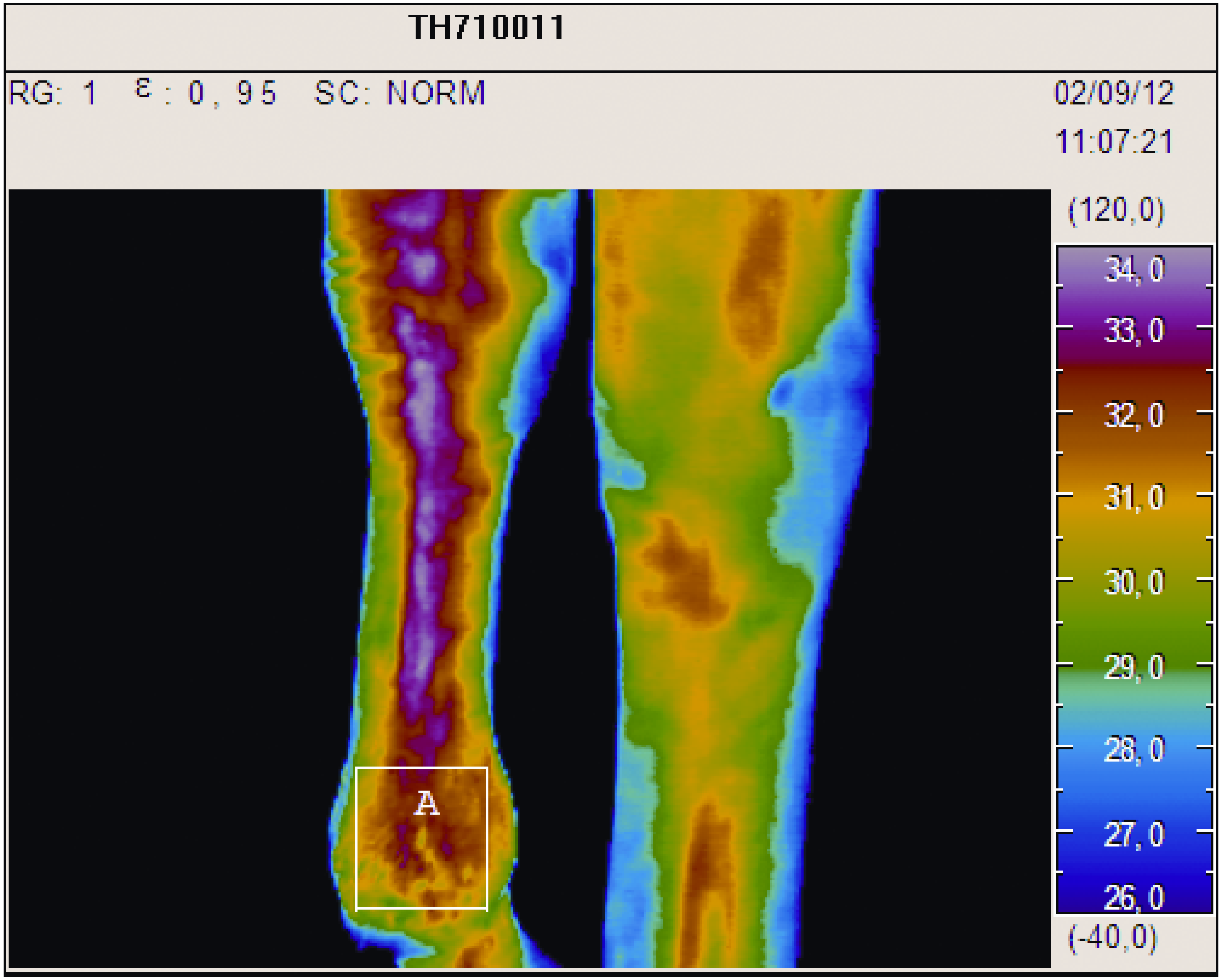
Swedish Laser-Medical Society

First: A glance at the pioneers ...

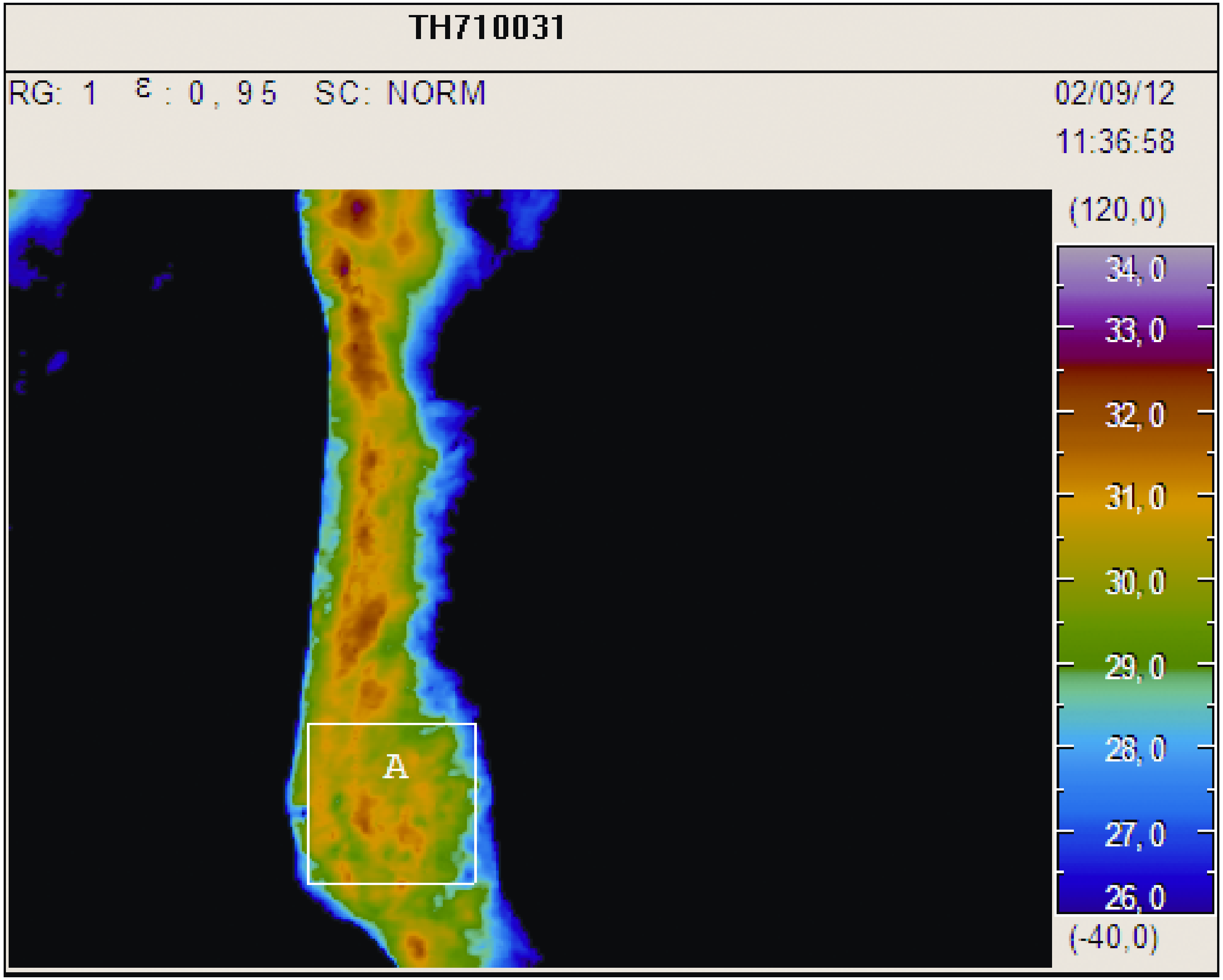
... the Mester family.

Transillluminated hand with 650 nm laser.

Horse that was kicked in point ”A” the day before. The whole area above is hot from the inflamation.



5 minutes after treatment (10 minutes with 60 mW GaAs-laser, 904 nm, 700 Hz) the temperature has gone down with 2.4 °C.



One hour after treatment, temperature has gone up slightly (about 1 °C).