Basic principles of laser tattoo removal

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Removal of Tattoos with Lasers
Removal of Tattoos with Lasers – so far

No destruction of the whole tissue…

Selective Photothermolysis

- appropriate wavelength that is selectively absorbed in pigments
- sufficient energy to heat up the pigment
- appropriate pulse duration to heat the pigment only
Removal of Tattoos with Lasers – so far

ultrashort pulse duration 10 ns
extremely high intensity $10^9$ W/cm²

ruby laser (694 nm)

~ 800 °C
Removal of Tattoos with Lasers – so far

Ruby laser

before laser therapy

5 min after laser therapy

4 weeks after laser therapy
Preliminary and Short Report

Radiation from a Q-Switched Ruby Laser

Effect of Repeated Impacts of Power Output of 10 Megawatts on a Tattoo of Man*

not in the white skin. As yet, the mechanism of this change in the skin reactions of the tattoo to Q-switched ruby lasers is not known, but the differences were probably not due entirely to thermal factors.

Q-switching produces laser impacts of high peak power outputs with the duration of the impact in the order of nanoseconds. There is considerable interest in the type of tissue change produced by approximately 0.9 cm², while the focused beam area was approximately 0.01 cm². Impacts were made directly on the dark tattoo and on the edge of the tattoo. Control impacts were made on ad...
Removal of Tattoos with Lasers, 1965 - so far

But is that the correct explanation?

Selective Photothermolysis

- appropriate wavelength that is selectively absorbed in pigments
- sufficient energy to heat up the pigment
- appropriate pulse duration to heat the pigment only
One doubt - Appropriate wavelength

![Graph showing absorption spectra at different wavelengths for various pigments.]

- P.Y. 14: Wavelengths 400, 600, 800, 1000 nm
- P.Y. 74: Wavelengths 400, 600, 800, 1000 nm
- P.Y. 83: Wavelengths 400, 600, 800, 1000 nm
- P.Y. 106: Wavelengths 400, 600, 800, 1000 nm
- P.O. 13: Wavelengths 400, 600, 800, 1000 nm
- P.R. 5, P.R. 9, P.R. 22, P.R. 112, P.R. 170, P.R. 122
- P.V. 23, P.G. 7
- P.B. 15a, P.B. 15b

Wavelengths highlighted: 532 nm, 694 nm, 755 nm, 1064 nm
Removal of Tattoos with Lasers
Old + new ideas

Endogenous target, Tissue coagulation or vaporisation

• Normal light absorption in endogenous targets like water, hemoglobin, melanin
• Biological, water-containing material
• Normal light intensities
  ➢ e.g. blood vessel coagulation with pulsed dye laser
  ➢ $6 \text{ J/cm}^2$ (1 ms pulse duration) $6 \cdot 10^3 \text{ W/cm}^2$
• Destruction of tissue: removal by usual endogenous mechanisms
Exogenous target, Pigment Particle destruction

- Normal (?) light absorption in exogenous target: pigment particle
- Solid state material with complex chemical and physical properties
- High light intensities
  - Tattoo removal with Q-switched laser
  - $3 - 5 \text{ J/cm}^2$ (0.5 - 20 ns pulse duration) $\sim 10^9 - 10^{10} \text{ W/cm}^2$
- Destruction of exogenous solid state material:
  - unclear removal via lymphatic or blood vessel system
  - re-agglomeration of fragmented particles possible
  - and others
Removal of Tattoos with Lasers – old + new ideas

Normal absorption?

What might happen at high intensities?
Linear and non-linear optics

Light is an electrical field (E) or a particle (photon)

**Linear optics:**
- small intensities, therefore photons do not interact with each other
- Interaction with material $\sim E$
  - 1 – Photon absorption

**Nonlinear optics:**
- high intensities (laser), photons can interact with each other
- Interaction with material $\sim E$ or $E^2$ or $E^3$ or $E^4$ or ...
- Yielding various effects
  - Frequency doubling, tripling
  - Frequency mixing
  - 2-Photon absorption
  - Plasma generation (optical breakdown)
  - etc
Linear and non-linear optics

Light is an electrical field (E) or a particle (photon)

Linear optics:
• small intensities and photons do not interact with each other
• Interaction with material $\sim E$
  ➢ 1 – Photon absorption

Nonlinear optics:
• high intensities (laser) and photons can interact with each other
• Interaction with material $\sim E$ or $E^2$ or $E^3$ or $E^4$ or …
• Yielding various effects
  ➢ Frequency doubling, tripling
  ➢ Frequency mixing
  ➢ 2-Photon absorption
  ➢ Plasma generation (optical breakdown)
  ➢ etc
Possible non-linear effects: 2 – Photon absorption

For instance:
2 Photons with 1064 nm are absorbed like 1 Photon with 532 nm
Possible non-linear effects: 2 – Photon absorption

- energy of 1 photon (754 nm)
- energy of 2 photons (377 nm)

Absorption vs. Wavelength [nm]

- P.Y. 14
- P.Y. 74
- P.Y. 83
- P.Y. 106
- P.O. 13
Possible non-linear effects: optical break down

A clinical and histologic prospective controlled comparative study of the picosecond titanium:sapphire (795 nm) laser versus the Q-switched alexandrite (752 nm) laser for removing tattoo pigment

Robert M. Herd, MD, Maria Beatrice Alora, MD, Bruce Smoller, MD, Kenneth A. Arndt, MD, and Jeffrey S. Dover, MD, FRCPC

Boston, Massachusetts, and Little Rock, Arkansas


black india ink
Possible non-linear effects: optical breakdown

well-known effect in ophthalmology: cornea surgery with focused laser beams

optical breakdown* in water (plasma and bubble formation) $\sim 10^{11}$ W/cm²

<table>
<thead>
<tr>
<th>wavelength (nm)</th>
<th>pulse duration (ns)</th>
<th>threshold intensity for breakdown ($10^{11}$ W/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>532</td>
<td>60</td>
<td>$2.8 \cdot 10^{11}$</td>
</tr>
<tr>
<td>750</td>
<td>76</td>
<td>$0.2 \cdot 10^{11}$</td>
</tr>
<tr>
<td>1064</td>
<td>6</td>
<td>$0.5 \cdot 10^{11}$</td>
</tr>
<tr>
<td>1064</td>
<td>60</td>
<td>$3.7 \cdot 10^{11}$</td>
</tr>
</tbody>
</table>


$\sim 0.3 \cdot 10^{11}$ W/cm²

Removal of Tattoos with Lasers

2 – Photon absorption?
Bubble formation via optical breakdown?

histology, 5 min after laser treatment
Conclusion

- Many mechanisms involved in laser tattoo removal
- Many mechanisms are still unclear
- We need more research
- Optimization of laser treatment requires more detailed understanding of the underlying mechanisms