Lasers in Spinal Discectomy

Miles A. Finn, Ph.D.
Goals

• Understand the mechanisms of laser ablation
• Understand the scientific basis for the choice of the Ho:YAG
• Review the long-term clinical results of laser discectomy
Lasers in Spinal Discectomy

- Laser types
- Mechanisms
- Long term results
Lasers in Spinal Discectomy

• Laser types
  - The many types of lasers
  - Key parameters that vary from laser to laser

• Mechanisms

• Long-term clinical results
Laser types

• Lasers are used for:
  - Welding
  - Precision cutting
  - Illumination
  - Reading bar codes
  - Picking up single atoms
Laser types

... but we simply need to create heat by using the laser beam to boil the water in the nucleus pulposus.
Laser types

... and complete the boiling so fast that little or no heat flows to nearby tissue ...

Vaporization
What’s important

• Laser parameters
  - Matching tissue optical properties
  - Controlling thermal diffusion
Parameters

• These vary between laser types:
  - Wavelength/ color
  - Power/ energy
  - Timing: short pulses/ long pulses/ steady
<table>
<thead>
<tr>
<th>Name</th>
<th>Wavelength (microns)</th>
<th>Pulsed/ CW</th>
<th>Fiber?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nd:YAG</td>
<td>1.06</td>
<td>CW*</td>
<td>Yes</td>
</tr>
<tr>
<td>KTP</td>
<td>0.532</td>
<td>CW*</td>
<td>Yes</td>
</tr>
<tr>
<td>CO₂</td>
<td>10.6</td>
<td>Either</td>
<td>No</td>
</tr>
<tr>
<td>Ho:YAG</td>
<td>2.1</td>
<td>Pulsed</td>
<td>Yes</td>
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</tbody>
</table>

CW – “continuous wave” (steady, not pulsed)
Absorption graph

Absorption peak at 2.1 microns
Absorption graph

 Cutting depth (mm)

 Nd Ho

 Laser

 pigmented
 unpigmented
Absorption of Radiation by Water

- Microwave ovens cook food by heating water
- The microwave is tuned to a water absorption peak
- The Ho:YAG works the same way, except that the “cooking” happens so fast that the tissue is vaporized.
Mechanisms

• Absorption creates heat
• The speed with which the target is heated is important
## Comparison

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<td>CW</td>
<td>Yes</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>10.6</td>
<td>Either</td>
<td>No</td>
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<tr>
<td>Ho:YAG</td>
<td>2.1</td>
<td>Pulsed</td>
<td>Yes</td>
</tr>
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Nd:YAG heating

- 4 mm average absorption depth
- CW laser
- Dry environment
Nd:YAG heating

“One to 5 sec pauses between pulses are used to allow for heat dissipation. Sometimes puffs of vapor can be seen to exit the needle, and a characteristic odor of burning protein can be appreciated.” (http://pldd.com/journal.html)
Ho:YAG heating

- Localized to 0.5 mm
- Actively cooled
- Pulsed
Mechanism - pulsed lasers

- Time-lapse photo
- Aqueous environment
- Millimeter scale
- Laser fiber on left
- Target on right (at 3.5 mm)
At $t = 0+$ microseconds, the first part of the 350 microsecond laser pulse leaves the fiber, heats up the water at the fiber tip, and creates a tiny bubble
At $t = 50$ microseconds, the next part of the 350 microsecond laser pulse leaves the fiber, passes through the bubble created by earlier parts of the pulse, heats up the water at the right-hand side of the bubble, and enlarges it.
At $t = 100$ microseconds, the bubble has reached the target, and the target is being vaporized.
At $t = 200$ microseconds, the vaporization zone is advancing through the target.
At \( t = 300 \) microseconds, the vaporization zone is advancing through the target.
At $t = 400$ microseconds, the laser pulse is finished, and the bubble is shrinking.
At $t = 500$ microseconds, the bubble is shrinking more.
Going, going . . .
At $t = 700$ microseconds, the bubble is almost gone.
Approximately 100,000 microseconds pass before the next laser pulse arrives, and the process is repeated.
CW vs. Pulsed Lasers

CW lasers
While energy is entering tissue, a significant amount of heat flows out, causing thermal damage, before the irradiated tissue arrives at the boiling point.

Pulsed lasers
The laser energy brings the irradiated tissue to the boiling point before significant heat flows to nearby tissue.
Sherk et al.

Is this statement supported experimentally?

YES . . .
Sherk et al.

- 4 laser types
- Nd:YAG, Argon (KTP), CO2, Ho:YAG
- Dosimetry: 1200 Joules
- Dry
- Measured
  - Histology
  - Temperature
  - Mass loss
# Temperature Rise (°C)

<table>
<thead>
<tr>
<th>Laser</th>
<th>Intradiscal</th>
<th>PLL</th>
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<tbody>
<tr>
<td>Nd:YAG</td>
<td>40</td>
<td>7</td>
</tr>
<tr>
<td>KTP/Argon</td>
<td>14</td>
<td>2</td>
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<tr>
<td>CO2</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>Ho:YAG</td>
<td>10</td>
<td>1</td>
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# Histology

<table>
<thead>
<tr>
<th>Laser</th>
<th>Necrosis</th>
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<tbody>
<tr>
<td>Nd:YAG</td>
<td>Large</td>
</tr>
<tr>
<td>KTP</td>
<td>Moderate</td>
</tr>
<tr>
<td>CO2</td>
<td>Moderate</td>
</tr>
<tr>
<td>Ho:YAG</td>
<td>Minimal</td>
</tr>
</tbody>
</table>
## Mass Removal

<table>
<thead>
<tr>
<th>Laser</th>
<th>cc removed</th>
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</thead>
<tbody>
<tr>
<td>Nd:YAG</td>
<td>.7</td>
</tr>
<tr>
<td>KTP</td>
<td>.9</td>
</tr>
<tr>
<td>CO2</td>
<td>.9</td>
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<tr>
<td>Ho:YAG</td>
<td>2.4</td>
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</tbody>
</table>
An Analogy

- Compare lasers to woodworking tools.
- How much heat is generated?
- How big each each cut?
Woodworking

- Sandpaper
Woodworking

- Chisel
<table>
<thead>
<tr>
<th>Name</th>
<th>Cutting Depth</th>
<th>Pulsed/ CW</th>
<th>Woodworking analogy</th>
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</thead>
<tbody>
<tr>
<td>Nd:YAG</td>
<td>4.0 mm</td>
<td>CW</td>
<td>Coarse sandpaper</td>
</tr>
<tr>
<td>KTP</td>
<td>1 cm+</td>
<td>CW</td>
<td>Very coarse sandpaper</td>
</tr>
<tr>
<td>CO2</td>
<td>.05 mm</td>
<td>Either</td>
<td>Very fine sandpaper or chisel</td>
</tr>
<tr>
<td>Ho:YAG</td>
<td>0.5 mm</td>
<td>Pulsed</td>
<td>Fine chisel</td>
</tr>
</tbody>
</table>
Lab measurements

- “Compressibility”
- Ho:YAG
- Cadaver discs
Long-term follow-up Laser Discectomy

• Casper
• Bosacco
• Nerubay
• Choy
• Malberg - in press
<table>
<thead>
<tr>
<th>Success (%)</th>
<th>Laser</th>
<th>Author</th>
<th>Follow-up</th>
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<tbody>
<tr>
<td>87</td>
<td>Ho:YAG</td>
<td>Casper</td>
<td>2 yr</td>
</tr>
<tr>
<td>82</td>
<td>Ho:YAG</td>
<td>Malberg</td>
<td>4.3 yr</td>
</tr>
<tr>
<td>76</td>
<td>KTP</td>
<td>Bosacco</td>
<td>2.7 yr</td>
</tr>
<tr>
<td>75</td>
<td>Nd:YAG</td>
<td>Choy</td>
<td>0-4.8 yr</td>
</tr>
<tr>
<td>74</td>
<td>CO2</td>
<td>Nerubay</td>
<td>2.6 yr</td>
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</tbody>
</table>
References

Copies of the articles cited are available from Clarus Customer Service (763-525-8403). Title pages of many of the cited articles are available by an automated fax service. Dial 763-525-8496 and request document 10.
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