Overview of Commercially Available Femtosecond Lasers in Refractive Surgery

The author receives research funds from Ziemer Ophthalmic Systems Group
Commercially Available Femtosecond Lasers in Refractive Surgery

- FS laser INTRALASE®
- FEMTO LDV® Ziemer
- FEMTEC ® 20/10 Perfect Vision
- VisuMax ® Zeiss
Laser Tissue Interaction

Intensity [W/cm²] vs. Interaction time [s]

- Photo-disruption
- Photo-ablation
- Vaporisation
- Coagulation
- Photo chemistry

Intensity levels:
- 10 J/cm²
- 100 J/cm²
- 1 J/cm²
- 0.1 J/cm²

Absorption types:
- Linear absorption
- Non-linear absorption

Laser Zentrum Hannover e.V.
Photodisruption, Optical Breakdown

- focussed fs laser beam
- nonlinear absorption
- plasma
- shock wave
- cavitation bubble
- gas bubble
Laser induced Cavitation and Bubble Formation in Water

Laser Pulse

\[ E_{\text{puls}} \sim 4 \mu \text{J} \]
\[ \tau_{\text{puls}} \sim 160 \text{fs} \]
Preconditions of Photodisruption for precise Corneal Surgery

- **Threshold** for disruption scales with pulse **intensity**
  many, many photons on the same place, at the same time

- **Unwanted** side effects (bubbles, collateral damage) scales with pulse **energy**
  photon energy is converted into heat, kinetics, chemistry

![Diagram showing intensity, pulse energy, beam diameter, and pulse width relationships to threshold for disruption.](image)
Factors that minimize Energy Threshold for Photodisruption

- Pulse Duration
Threshold for Optical Breakdown as a function of Pulse Duration

Intensity [$10^{11}$ W/cm$^2$]

Fluence [J/cm$^2$]

Puls Duration [ps]

- own measurements
- num. simulation (Noack et al.)
Factors that minimize Energy Threshold for Photodisruption

- Pulse Duration
- Numerical Aperture
The larger the \textit{NA},
  \Rightarrow \text{ the smaller the focal spot volume,}
  \Rightarrow \text{ the smaller the energy threshold}
Two ways to increase NA

- increasing lens diameter

\[ NA = \frac{w_1}{f_1} = \frac{w_2}{f_2} \]

INTRALASE® FS laser
Two ways to increase NA

- increasing lens diameter
- decreasing focal length

\[ NA = \frac{w_1}{f_1} = \frac{w_2}{f_2} \]
Two ways to increase NA

1. Increasing lens diameter
   \[ NA = \frac{w_1}{f_1} = \frac{w_2}{f_2} \]

2. Decreasing focal length
Two Different Concepts in Photodisruption Process

"High" Pulse Energy (µJ)  (nJ)
"Low" Pulse Frequency (kHz) (MHz) "High" Pulse Frequency
Two Different Concepts in Photodisruption Process

"High" Pulse Energy (μJ)
"Low" Pulse Frequency (kHz)

(nJ) "Low" Pulse Energy (MHz) "High" Pulse Frequency
Two Different Concepts in Photodisruption Process

- Spot Size
- Spot Separation

Cutting process driven by mechanical forces (expanding bubbles)

Cutting process limited by focal spot size (many pulses needed)
Two Different Concepts in Photodisruption Process

Pulse Energy: 2 µJ
Pulse Width: 930 fs

Pulse Energy: 30 nJ
Pulse Width: 250 fs
Two Different Concepts in Photodisruption Process

Pulse Energy: 2 µJ
Pulse Width: 930 fs

Pulse Energy: > 30 nJ
Pulse Width: 250 fs
Surface Quality

Mikro Keratome  Intralase  DaVinci

VisuMax  Femtec
Surface Quality

Analysis of Surface Roughness

Surface roughness of the stromal bed was measured with a confocal microscope on ten eyes, each in several selected positions. In the table, the mean (±SD) of all measurements for each device is listed (left columns). In the rightmost column, the mean of the smoothest individual area found for each eye is provided.

<table>
<thead>
<tr>
<th>Surface Roughness</th>
<th>all surface areas</th>
<th>smoothest surface area per eye</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nidek MK2000</td>
<td>2.6 ± 1.5 μm</td>
<td>1.1 ± 1.1 μm</td>
</tr>
<tr>
<td>Intralase FS15</td>
<td>3.1 ± 0.7 μm</td>
<td>2.1 ± 0.6 μm</td>
</tr>
<tr>
<td>Intralase FS30</td>
<td>2.8 ± 0.8 μm</td>
<td>1.9 ± 0.4 μm</td>
</tr>
<tr>
<td>DA VINCI</td>
<td>3.0 ± 0.3 μm</td>
<td>2.0 ± 0.4 μm</td>
</tr>
</tbody>
</table>

Comparison of various Femtosecond Lasers and Conventional Microkeratomes for Corneal Lamellar Cuts


Poster presented at the 19th Congress of German Ophthalmic Surgeons (DOC), Nuremberg, Germany, May 25-28, 2006
Special Features during Operation

Intralase, Femtec, VisuMax:

Cutting process is visible during operation

DaVinci:

Operates like a mechanical Knife, no direct view on cutting process (AMADEUS technology)
Special Features during Operation

Femtec, VisuMax:

Spherical contact interface to cornea
• Minimal applanation & IOP increase

VisuMax:

Corneal fixation of the contact glass
• assures a better fixation than scleral fixation
FS Lenticule Extraction (FLEX)
• "All fs-LASIK" (10 eyes)
Special Features during Operation

DaVinci:

Fits under all Excimer Lasers
- no movement of the patient necessary
## Comparison (tech. features)

<table>
<thead>
<tr>
<th>Concept</th>
<th>Amplifier</th>
<th>Amplifier</th>
<th>Amplifier (?)</th>
<th>Oscillator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>≈1040 nm</td>
<td>≈1040 nm</td>
<td>≈1040 nm</td>
<td>≈1040 nm</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>&gt;500 fs</td>
<td>&gt;500 fs</td>
<td>≈400 fs (?)</td>
<td>≈250 fs</td>
</tr>
<tr>
<td>Spot Size</td>
<td>&gt;1 µm</td>
<td>&gt;1 µm</td>
<td>≈1 µm (?)</td>
<td>&lt;1 µm</td>
</tr>
<tr>
<td>Rep Rate</td>
<td>60 kHz</td>
<td>some 10 kHz</td>
<td>some 100 kHz</td>
<td>some MHz</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>≈1 µJ</td>
<td>&gt;1 µJ</td>
<td>&lt;1 µJ</td>
<td>some nJ</td>
</tr>
</tbody>
</table>
Comparison (handling)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>INTRALASE® CORP</th>
<th>FEMTEC®</th>
<th>ZEISS</th>
<th>Ziemer FEMTO LDV™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation speed (@ 9,5 mm):</td>
<td>&lt; 30 sec</td>
<td>1 min (?)</td>
<td>&lt; 40 sec (?)</td>
<td>&lt; 40 sec</td>
</tr>
<tr>
<td>Surface quality:</td>
<td>comparable to microtome</td>
<td>comparable to microtome</td>
<td>comparable to microtome</td>
<td>comparable to microtome</td>
</tr>
<tr>
<td>Cutting geom. / flexibility:</td>
<td>very high</td>
<td>high</td>
<td>very high (?)</td>
<td>limited</td>
</tr>
<tr>
<td>Size, mobility:</td>
<td>bulky, fixed</td>
<td>bulky, fixed</td>
<td>very bulky, fixed</td>
<td>very small, mobile</td>
</tr>
<tr>
<td>Requirements to environm.:</td>
<td>const. temp/ humidity</td>
<td>const. temp/ humidity</td>
<td>(?)</td>
<td>industr laser head</td>
</tr>
<tr>
<td>Clinical exp.:</td>
<td>1 Mio eyes</td>
<td>(?)</td>
<td>≈ 20 eyes</td>
<td>&gt; 400 eyes</td>
</tr>
</tbody>
</table>