Medical Applications of 2µm Laser

Ronald Sroka

ESLA – Workshop 2015
Core Competence: Clinical Biophotonic
Minimally invasive and endoscopic approaches

Light Application Systems
Diagnostic
Light-Tissue Interaction
Feedback & Sensors
Photodynamic Therapy
Thermal Laser Application

from In-vitro to clinical from prototypes to products
Support and consulting for clinical trials and research projects
OUTLINE

• Coagulation
  hyperplastic turbinates
  varicosis vein

• Vaporisation / Cutting
  prostate
  bronchi tumors
  kidney tumors

• Disruption / Fragmentation
  lithotripsy
Coagulation

- Disruption
- Ablation
- Vaporisation
- Koagulation
- Photodynam. Therapie
- Biostimulation

Leistungsdichte $W / \text{cm}^2$

- $10^{16}$
- $10^{12}$
- $10^8$
- $10^4$
- $10^2$
- $10^0$
- $10^{-2}$
- $10^{-6}$

Energiedichte $J / \text{cm}^2$

- Einwirkzeit sec

- >>150°C
- 100°C
- <70°C
- <40°C
Laser- Coagulation
nasal turbinate hyperplasia
Laser- Coagulation
nasal turbinate hyperplasia

Tm:fiber laser
2-4W
365µm-fiber
2-4mm/s

Otorhinolaryngology - Synechia

Precise cutting without any bleeding and small coagulation
Tm:fiber laser, 2-4W, 365µm-fiber

VARICOSIS

- **Varicosis**
  - Longterm widened vessels
  - Irregular bending
  - Lower extremeties

- **Origin**
  - Insufficiency of vein valve
  - Reflux problems
  - Ineffective connective tissue
  - Sometimes genetic preconditions

- **Clinical symptoms**
  - Tension
  - Edema
  - Pain while sitting and standing
  - Pigmentation, skin irritation
  - Phlebitis
  - Ulceration
VARICOSIS

- **Incidence**
  50% population in med-Europe aged 20 - 75
  women / men 4 / 2
  50% needs therapeutic intervention
  2010: n>350,000 treatments in Germany

- **Target vessel**
  Vena saphena magna (VSM)
  Vena saphena parva (VSP)

Thiery L et al. Insightful Phlebology 2009
Leitlinie DGP und DGG 2009
VARICOSIS  Therapy-Options

- **Primary aim of treatment**
  - Reduction of reflux in superficial vein system
  - Destruction / ablation of vessel

- **Therapy**
  - conservativ
  - surgery (CHIVA, EVP,…)
  - stripping (Cryo-Stripping, Partial-Stripping)
  - minimally invasive procedures:
    - Sclerosis (medication, foam, …)
    - Radiofrequency
    - Endovenous Lasertherapy / Laserablation (ELA)
RADIAL LIGHT APPLICATION

radial direction: 65°
divergency angle (FWHM): 25-30°

Sroka R et al. Phlebologie 2013;42:121
### TISSUE OPTICS

<table>
<thead>
<tr>
<th>Wellenlänge [nm]</th>
<th>( \mu_a ) ( \text{H}_2\text{O} ) [1/cm]</th>
<th>( \mu_a ) ( \text{Hb} ) [1/cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>830</td>
<td>0.03</td>
<td>4.15</td>
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<tr>
<td>940</td>
<td>0.27</td>
<td>5.41</td>
</tr>
<tr>
<td>980</td>
<td>0.43</td>
<td>6.95</td>
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<tr>
<td>1320</td>
<td>1.38</td>
<td>n.m.</td>
</tr>
<tr>
<td>1460</td>
<td>28.4</td>
<td>n.m.</td>
</tr>
<tr>
<td>1940</td>
<td>70-80</td>
<td>n.m.</td>
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</tbody>
</table>

![Graph showing absorption spectra of water (\( \text{H}_2\text{O} \)) and hemoglobin (\( \text{Hb} \)).](image)

**WAVELENGTH comparison**

**Experiment:** oxen-foot-model  
**Parameter:** Fibre radial, v=1mm/s, \( P_{\text{start}} = 2\)W increments 1-2W  
**Aim:** same outer macroscopic sensation  
shrinkage, rigidity – palpable „macaroni al dente“

\[ \lambda = 980\text{nm} \]

\[ \lambda = 1470\text{nm} \]

\[ \lambda = 1940\text{nm} \]

\( P=20\)W  
LEED=200J/cm  
carbonized blood

\( P=6\)W  
LEED=60J/cm  
coagulated tissue

\( P=3\)W  
LEED=30J/cm  
coagulated tissue

Sroka R et al. Phlebologie 2013; 42:121
WAVELENGTH  Histology

$\lambda = 980\text{nm} / \text{bare fibre}$  
$\lambda = 1470\text{nm}$  
$\lambda = 1940\text{nm}$

- $P=15\text{W}$  
  LEED=150J/cm  
  carbonization/perforation

- $P=6\text{W}$  
  LEED=60J/cm  
  intima / media / adventitia

- $P=3\text{W}$  
  LEED=30J/cm  
  intima / media

- circular thermal destruction
- vacuolization / delamination
SINGLE CENTER PROSPECTIVE CLINICAL STUDY

Study: 1940nm – fibre Laser (Vela XL, StarMedTec, Percha, Germany)

Start: Juli 2013

Patients: 176

Protocol: 1940nm, 3-9W, 1mm/s

Intra-OP: LEED 35-90J/cm
no complication
radial fibre faultless after OP

Follow-Up: 3d, 4m, 6m
DUS & Questionnaire
<table>
<thead>
<tr>
<th>Protocol</th>
<th>prior 2006</th>
<th>2009</th>
<th>2013</th>
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</thead>
<tbody>
<tr>
<td>wavelength</td>
<td>800-1320</td>
<td>1470</td>
<td>1940</td>
</tr>
<tr>
<td>pull-velocity</td>
<td>div.</td>
<td>1</td>
<td>1</td>
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<tr>
<td>fibre</td>
<td>bare fiber</td>
<td>radial</td>
<td>radial</td>
</tr>
<tr>
<td>carbonisation energy</td>
<td>50</td>
<td>600</td>
<td>1000</td>
</tr>
<tr>
<td>power</td>
<td>15-30</td>
<td>8-12</td>
<td>3-9</td>
</tr>
<tr>
<td>irradiance</td>
<td>&lt;10000</td>
<td>&lt;400</td>
<td>&lt;150</td>
</tr>
<tr>
<td>EFE</td>
<td>40-100</td>
<td>25-50</td>
<td>&lt;15</td>
</tr>
<tr>
<td>LEED</td>
<td>40-80</td>
<td>60-100</td>
<td>40-80</td>
</tr>
<tr>
<td>tissue effect</td>
<td>carbonized</td>
<td>cylindrical homo. coag.</td>
<td></td>
</tr>
<tr>
<td>occlusion rate</td>
<td>&gt;90</td>
<td>&gt;95</td>
<td>-100%</td>
</tr>
<tr>
<td>side effects</td>
<td>diverse</td>
<td>pain</td>
<td>minor</td>
</tr>
</tbody>
</table>

Pannier F et al. Phlebology 2009; 24: 26
Pannier F et al. Vasa 2010;39:249
Pannier F et al. Phlebology 2011: 26: 35
Maurins U et al. Int Angiol 2009; 29: 32
Vaporisation - Ablation

Leistungsdichte $W / cm^2$

$10^{16}$

$10^{12}$

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$10^{-2}$

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Energiedichte $J/cm^2$

Einwirkzeit sec

$10^6$

$10^3$

$10^0$

$10^{-3}$

$10^{-6}$

$10^{-9}$

$10^{-12}$

Disruption

Ablation

Vaporisation

Koagulation

Photodynam. Therapie

Biostimulation

$<40^\circ C$

$<70^\circ C$

$100^\circ C$

$>>150^\circ C$
Trans-Urethral Urological Inspection

aus: Körperwelten (v. Hagen)
Prostate Enucleation

HoLEP: the gold standard for the surgical management of BPH in the 21st Century

For many years TURP gold standard to surgically alleviate obstructive voiding dysfunction (BPH).

TURP has been challenged repeatedly over the last decade by consistent data demonstrating the superiority of Holmium enucleation of the prostate (HoLEP).

Review summarizes and compares HoLEP vs traditional therapies

ENDOBRONCHIAL THERAPY WITH 1940 NM

stent removal, no fire, no popcorn, no perforation, more precise

Clinical problem
surgical removal of tumors and malformations

Up to now
surgery open or laparascopic
warm ischemia vessel-clamping
OP-duration max 20min
cold ischemia takes about 15min to $T<20^\circ\text{C}$
OP-duration complete 45min
bloodloss ca. 500ml
LAPARASCOPIC PARTIAL TUMOR RESECTION

diode laser 1320nm, 55-70W, fibre 600µm, 1-3mm/s

Khoder WY, Sroka R et al Journal of Endourology Part B. Videourology. 2011
Cave: large vessel destruction

LAPAROSCOPIC PARTIAL TUMOR RESECTION
AFTER LASER APPLICATION

tumor bed after tumor excision and coagulation

reconstruction of the parenchymal surface covered with cellulose mesh using 0–0 Vicryl sutures

Khoder WY, Sroka R et al. Lasers Med Sci. 2011 (Epub)
LAPARASCOPIC PARTIAL TUMOR RESECTION

HISTOLOGY

Specimen of two patients (HE mag. 200)

tubular structures and stroma are partially destroyed
tubular epithelium shows marked hypereosinophilia

Khoder WY, Sroka R et al. Lasers Med Sci. 2011 (Epub)
<table>
<thead>
<tr>
<th></th>
<th>open surgery n=5</th>
<th>laparascoplic n=8</th>
<th>conv.</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP-time</td>
<td>60-90min</td>
<td>110-175</td>
<td>equal</td>
</tr>
<tr>
<td>Laser time</td>
<td>ca.10min</td>
<td>ca.15min</td>
<td>equal</td>
</tr>
<tr>
<td>Blood loss</td>
<td>20-400ml</td>
<td>50-600ml</td>
<td>equal</td>
</tr>
<tr>
<td>Coag rim</td>
<td>1-2mm</td>
<td>1-2mm</td>
<td>equal</td>
</tr>
<tr>
<td>Ischemia</td>
<td>1/5 partial</td>
<td>2/8 (19, 24min)</td>
<td>better</td>
</tr>
<tr>
<td>Complication</td>
<td>none</td>
<td>none</td>
<td>equal</td>
</tr>
</tbody>
</table>

Khoder WY, Sroka R et al. Lasers Med Sci. 2011 (Epub)
Tissue samples macroscopy:
(superficial view and sagittal cuts)

Note the color changes, the carbonized surface with underlying whitish coagulation

Parameter:
- fiber 600µm
- 1mm/s
- contact mode

Khoder WY et al. Journal of Biomedical Optics 17(6), 068005 (2012)
LAPARASCOPIC PARTIAL TUMOR RESECTION

Challenge

Table 3  Subjective correlation of the appearance of tissue surface colors to laser output and different wavelengths used for laser-induced cutting experiments by means of continuous wave, fiber velocity of 1 mm/s and contact mode.

<table>
<thead>
<tr>
<th>Wavelength (mm)</th>
<th>Contact-mode v=1 mm/s</th>
<th>Correlation of appeared tissue surface color to laser power</th>
</tr>
</thead>
<tbody>
<tr>
<td>940</td>
<td></td>
<td>Whitish-coagulation 10 to 20 W</td>
</tr>
<tr>
<td>1064</td>
<td></td>
<td>10 W</td>
</tr>
<tr>
<td>1318</td>
<td></td>
<td>10 to 20 W</td>
</tr>
<tr>
<td>1470</td>
<td></td>
<td>20 W</td>
</tr>
<tr>
<td>1940</td>
<td></td>
<td>40 W</td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td>5 W</td>
</tr>
</tbody>
</table>

Kidney optical attenuation coefficient in comparison to water absorption coefficient in the spectral region of 900 to 2150 nm.

Khoder WY et al Journal of Biomedical Optics 17(6), 068005 (2012)
Disruption - Fragmentation

![Graph showing the relationship between energy density and interaction time for different processes such as Disruption, Ablation, Vaporisation, Coagulation, Photodynamic Therapy, and Biostimulation. The graph indicates temperature ranges with color coding: >150°C, 100°C, <70°C, and <40°C.]
Lithotripsy Clinically

aus: Körperwelten (v. Hagen)
Lithotripsy

2-10µs-laser pulse

250-1000µs-laser pulse
Scope

MD subjective statement

LongPulse show better effects than ShortPulse

Aim

Objective experiments to show differences in effects related to the pulse duration
Fibre burn back is a stochastic process \( n(LP) \gg n(SP) \) to destroy fibre.

Schematic diagram of the forces involved in the equation of motion of the pendulum experiment:

\[ F \quad \text{Stokes friction} \]
\[ F_{\text{back}} \quad \text{restore force} \]
\[ m \quad \text{mass of the pendulum} \]
\[ r \quad \text{radius of the lead ball} \]
\[ s \quad \text{deflection} \]
\[ L \quad \text{length of pendulum} \]
\[ \Theta \quad \text{deflection angle} \]
\[ \eta_{\text{H}_2\text{O}} \quad \text{viscosity of water} \]

Experimental set-up, measurements and evaluation were previously described

Repulsion result

**max. pendulum deviation**
- high energy per pulse
- short pulse duration
- large fibre core diameter

**repulsion decreases**
- reduced energy per pulse
- smaller fibre core diameter
- longer pulse duration

Hand-held and motivated fragmentation showed no sign. differences LP vs SP but for 2J-5Hz.

Conclusion

Fragmentation experiments showed no sign. difference

Single Pulse trends may reflect clinical observation

Recommendation

LongPulse reduced side effects
additional manoeuvres could be reduced
effect on soft tissue may be reduced
smaller fragments could be beneficial

ShortPulse fixed urolith
repulsion effects are minimized
fast fragmentation looks promising
Summary

• variety of medical application
  coagulation – sealing
  vaporisation – cutting
  disruption – fragmentation

• Challenge
  optimization of treatment parameter
  wavelength
  pulse duration
  fiber

• Acceptance in Medical Community
THANK YOU FOR ATTENTION

Special Thanks

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- Phlebology
- Urology
- Pulmology

**Financial & Equipment:**
- National Grants
- International Grants
- Companies

**Students:**
- Internship
- Bachelor
- Master
- PhD & MD