

**WINTER COLLEGE ON
SPECTROSCOPY AND APPLICATIONS**

(8 - 26 February 1999)

"Medical Applications of Spectroscopy"

1. The Institute of Laser Medicine
Short Presentation of Selected Topics

presented by:

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These are preliminary lecture notes, intended only for distribution to participants.

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"Medical Applications of Spectroscopy""

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Outline:

1. The Institute of Laser Medicine

Short presentation of selected topics

2. Laser induced Interstitial Brain Tumor Therapy with Optical On Line Control

Monte Carlo Simulations and first medical applications

3. Isotope Selective Breath Analysis

Nondispersive methods with medical applications

Institut für Lasermedizin Universität Düsseldorf, Germany

www.ilm.uni-duesseldorf.de

founded in 1991 as an interdisciplinary institute in
the medical faculty

„theoretical“ institute without patients,
devoted to basic research

cooperation of physicians, biologists, chemists and
physicists

in Germany the only **pure** university institute

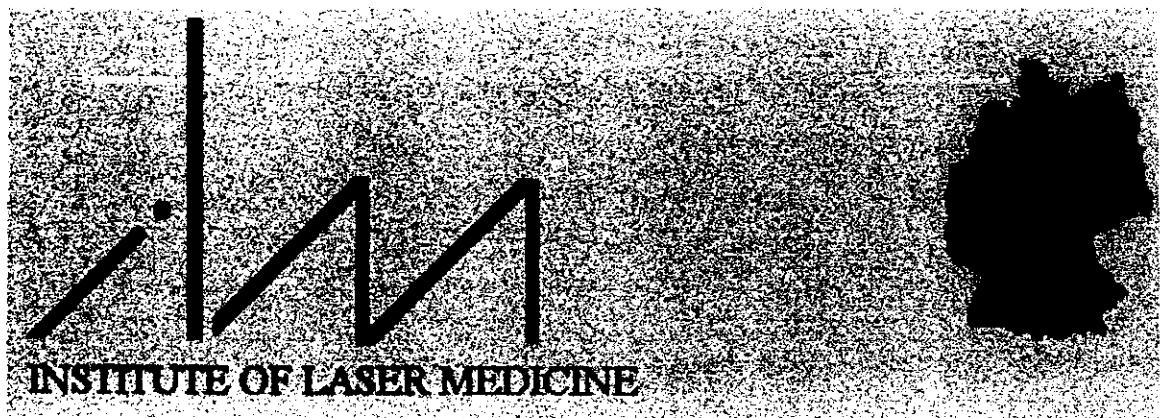
subject „Laser medicine for physicists“

presently 40 coworker
(14 university positions, rest from funding
agencies)

main topic of interest:

analytical and diagnostical use of lasers in bio- and
environmental medicine

close cooperation with many clinical institutes



Prof. Dr. R. Bayer:

- Laser Diffractometry
- Laser diffraction as a diagnostic tool
- Laser ablation and reflection spectroscopy of tissues

Prof. Dr. P. Hering:

- Liquid light guides
- Laser isotope separation of ^{13}C and ^{12}C
- Ablation of biological tissues with a Q-switched CO₂ laser
- Isotope selective breath analysis
- Trace Gas Cavity ring-down (leak out) spectroscopy in the UV and IR
- Laser-Tissue Interaction, Monte Carlo Simulation
- Optical Properties of Tissues and Turbid Media
- Laser Therapy Treatment Planning
- Laser Applicator Design
- Holographic Facial 3D Reconstruction
- Transmyocardial Laser Revascularisation (TMLR)
- Laser safety, Laser pointer

Prof. Dr. J. Moser:

- Photodynamic Laser Therapy (PDT) of tumor cells
- Molecular pharmacology of adrenergic receptors

Methods in Laser Medicine

Treatment	Physical Effect
cutting with laser scalpel	heating, evaporation
coagulation for tissue disintegration	ditto
welding of tissue and vessel	ditto
removal of tissue	photoablation
disintegration of hard tissue	photodisruption
irradiation of tissue	photochemical effect

laser analysis	spectroscopy, microscopy
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biostimulation	effect unknown
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Medical application of lasers

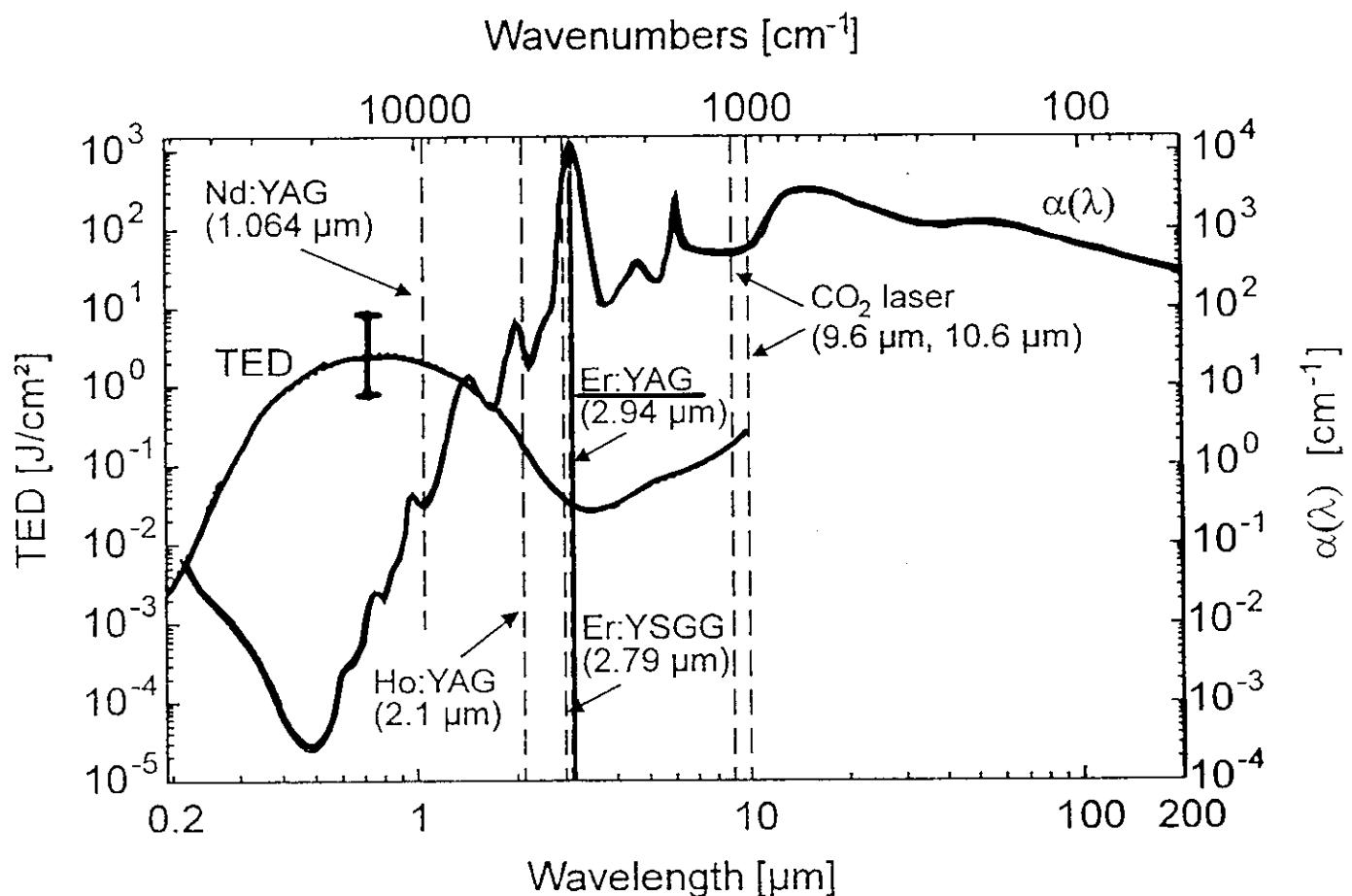
laser therapy more effective?
less painful?
less complications?

simpler, faster for operating surgeon?

higher price justified?

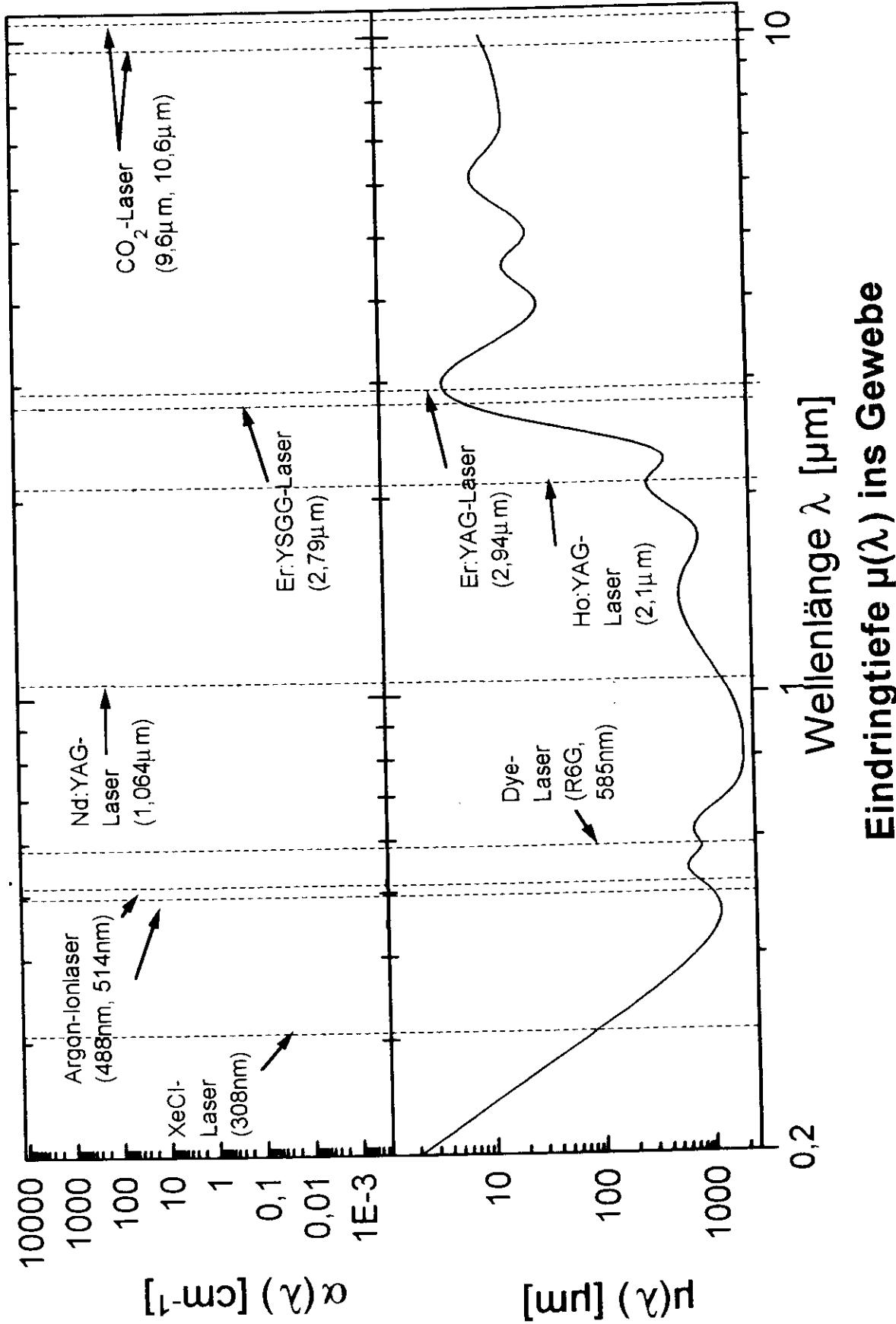
luxury medicine?

**Threshold energy density (TED) for ablation of tissue
and
Absorption coefficient $\alpha(\lambda)$ of water**



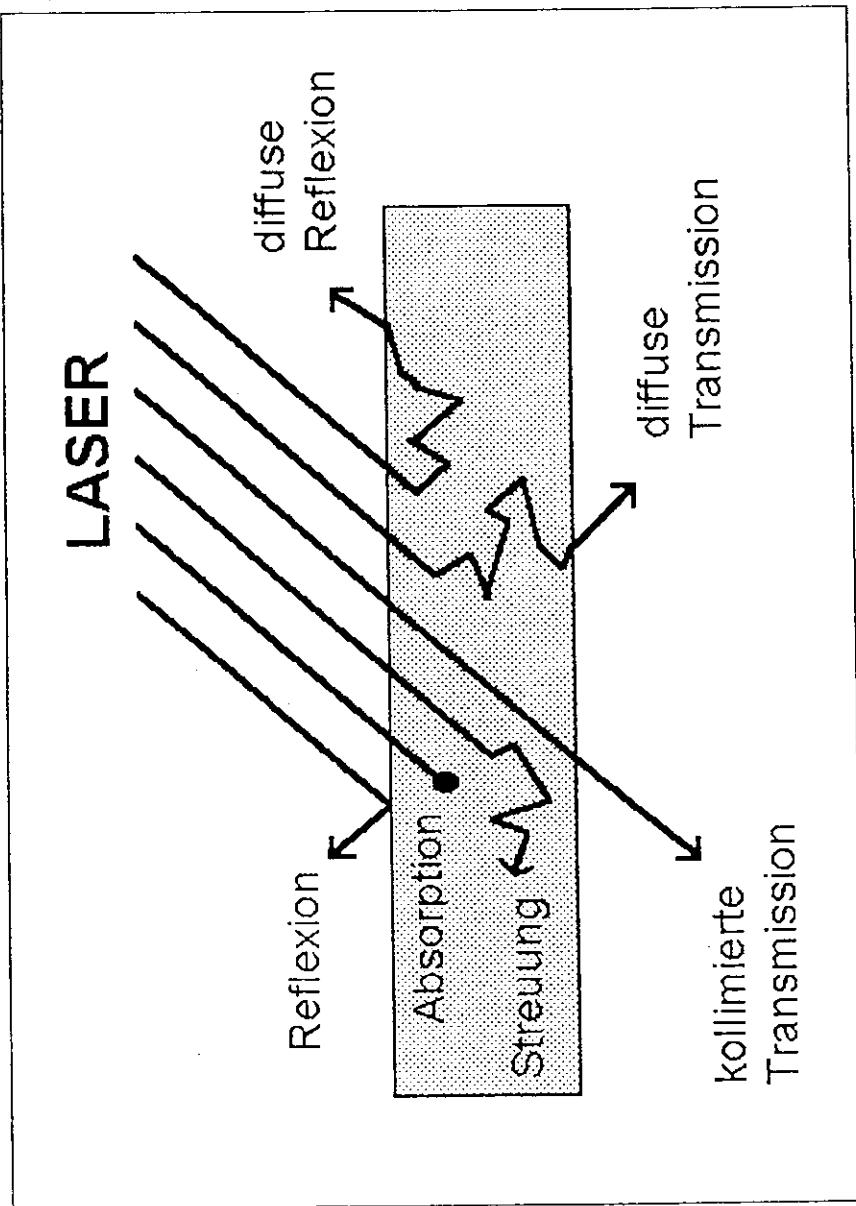
Tissue	Water weight
aorta	79 %
cartilage	75 %
cornea	70 %
skin	70 %
bone	10 - 30 %
dentin	13 %
enamel	2 - 4 %

Absorptionskoeffizient $\alpha(\lambda)$ für Wasser



Wellenlänge λ [μm]
Eindringtiefe $\mu(\lambda)$ ins Gewebe

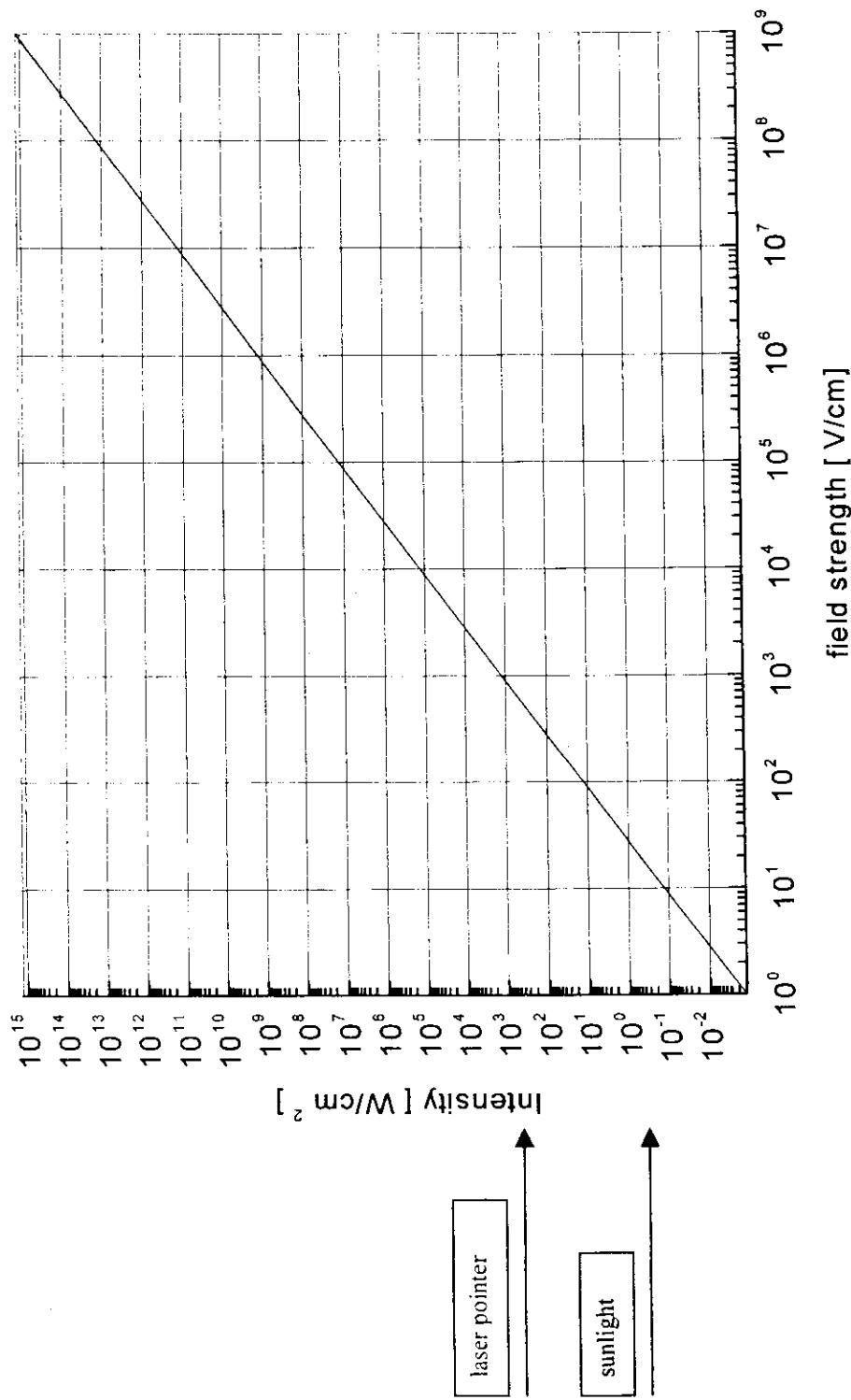
Absorption und Streuung in Gewebe



Laser-Tissue Interaction

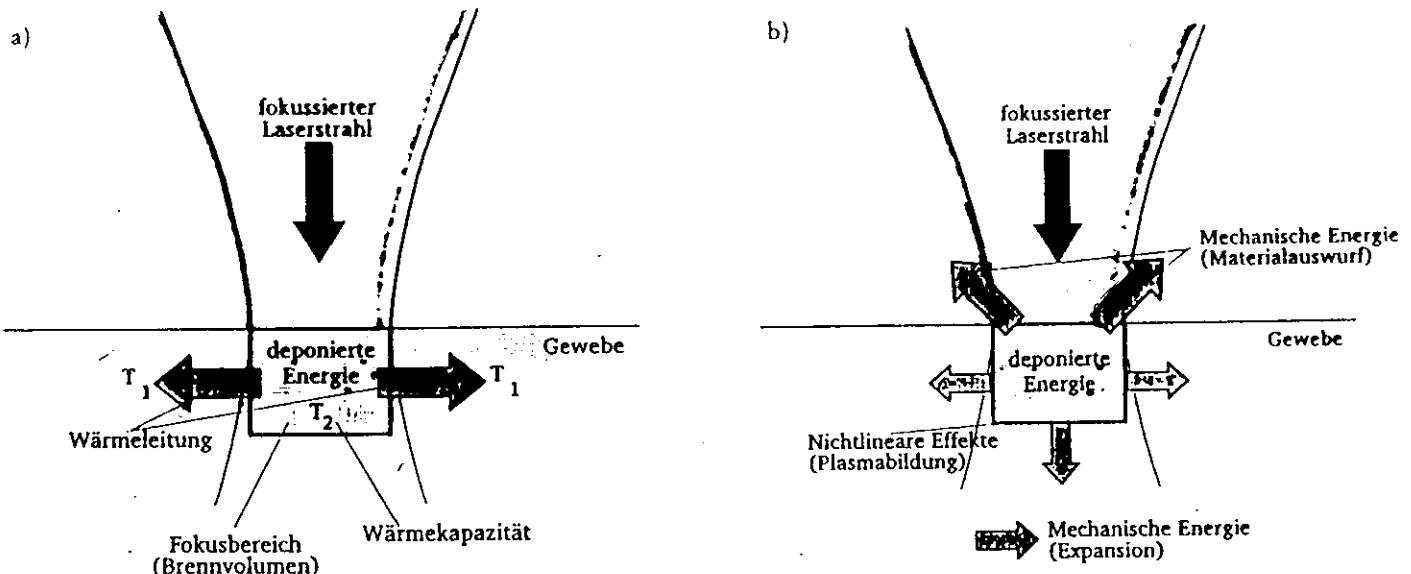
	laser-induced effects	power density	interaction time	physical effect
Linear Processes	photochemical effects	<1 W/cm ²	>1s	Bio stimulation PDT
	photothermal effects	W/cm ² -KW/cm ²	μs - s	coagulation, carbonisation, vaporisation,
Nonlinear Processes	photoablation	MW/cm ²	ns	thermal explosion
	photodisruption	GW/cm ²	ns - ps	optical breakdown, mechanical shock wave

Intensity vs field strength



Photoablation oder Photodisruption

$$T = 10 \text{ K} \sim 1 \text{ m}$$



b. S: Schematische Darstellung des Energiesflusses bei der Wechselwirkung von Laserlicht mit Gewebe. a: Thermische Wechselwirkung: Temperatur im Brennvolumen, T_1 ... Umgebungstemperatur), b: Mechanische Wechselwirkung.

Wärmefluss

groß

klein

Laserpuls

kurz

lang

SOME IMPORTANT LASER ABLATION MECHANISMS



ablation = explosion like material removal

DIRECT PHOTOABLATION

with UV (e.g. excimer) laser
 $(10\text{-}100 \text{ ns}, 10^7\text{-}10^{10} \text{ W/cm}^2)$

excitation to repulsive electronic

state

↓

molecular dissociation

↓

ejection of fragments

**very clean ablation crater,
thermal damage is very small**



THERMOMECHANICAL ABLATION

IR lasers: CO_2 , Er:YAG, Ho:YAG, ...
 $(100 \text{ ns - CW}, 10^5\text{-}10^8 \text{ W/cm}^2)$

excitation of molecular vibrations

↓

fast relaxation to heat

↓

explosion-like evaporation of tissue
water

↓

**very effective soft tissue incision,
"rest" heat seals blood capillaries**



PLASMA-INDUCED ABLATION

e.g. with Nd:YLF laser
 $(1 \text{ ps - } 1 \text{ ns}, > 10^{11} \text{ W/cm}^2)$

optical breakdown in laser focus

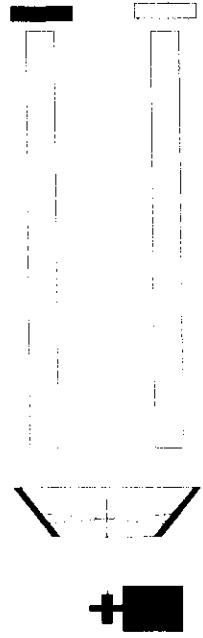
↓

ablation effect is confined to focal
volume, or spatially extended due to
cavitation, shock wave, jet
formation (PHOTODISRUPTION)

**clean and well defined material
removal is possible
(also under surface)**



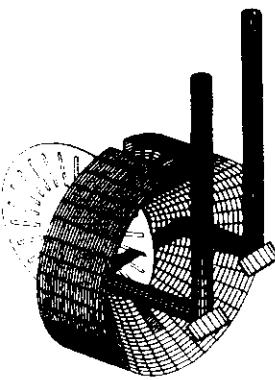
Q-switched CO₂ Laser



Q-switch

CO₂ laser

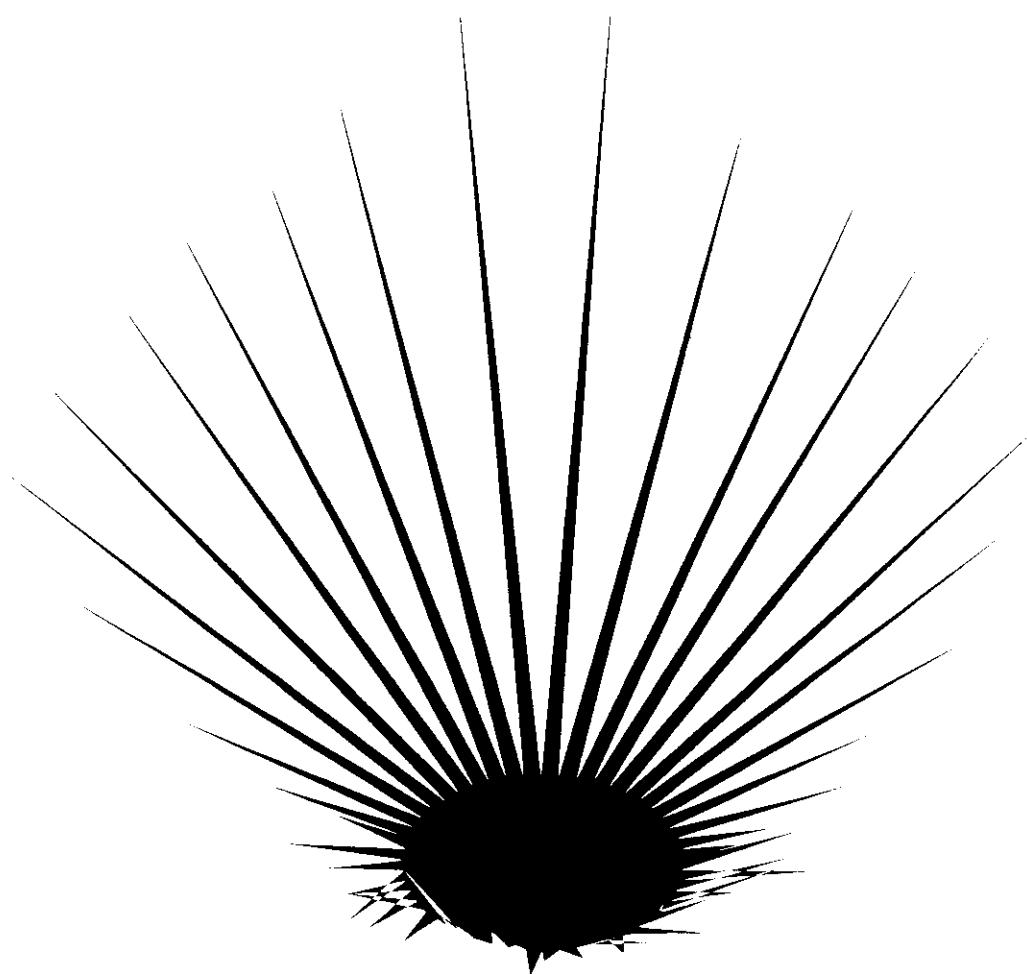
$$\rho_{\text{gas}} = 14 \cdot 25 \text{ mbar}$$
$$\tau_{\text{pulse}} = \boxed{} \cdot 400 \text{ ns}$$
$$f = 150 - \boxed{} \text{ Hz}$$
$$E = 15 \cdot 80 \text{ mJ (9.6 } \mu\text{m)}$$
$$M^2 = 1.1 (\boxed{})$$



Alternative → TEA CO₂ laser
(Transversely Excited Atmospheric-pressure)

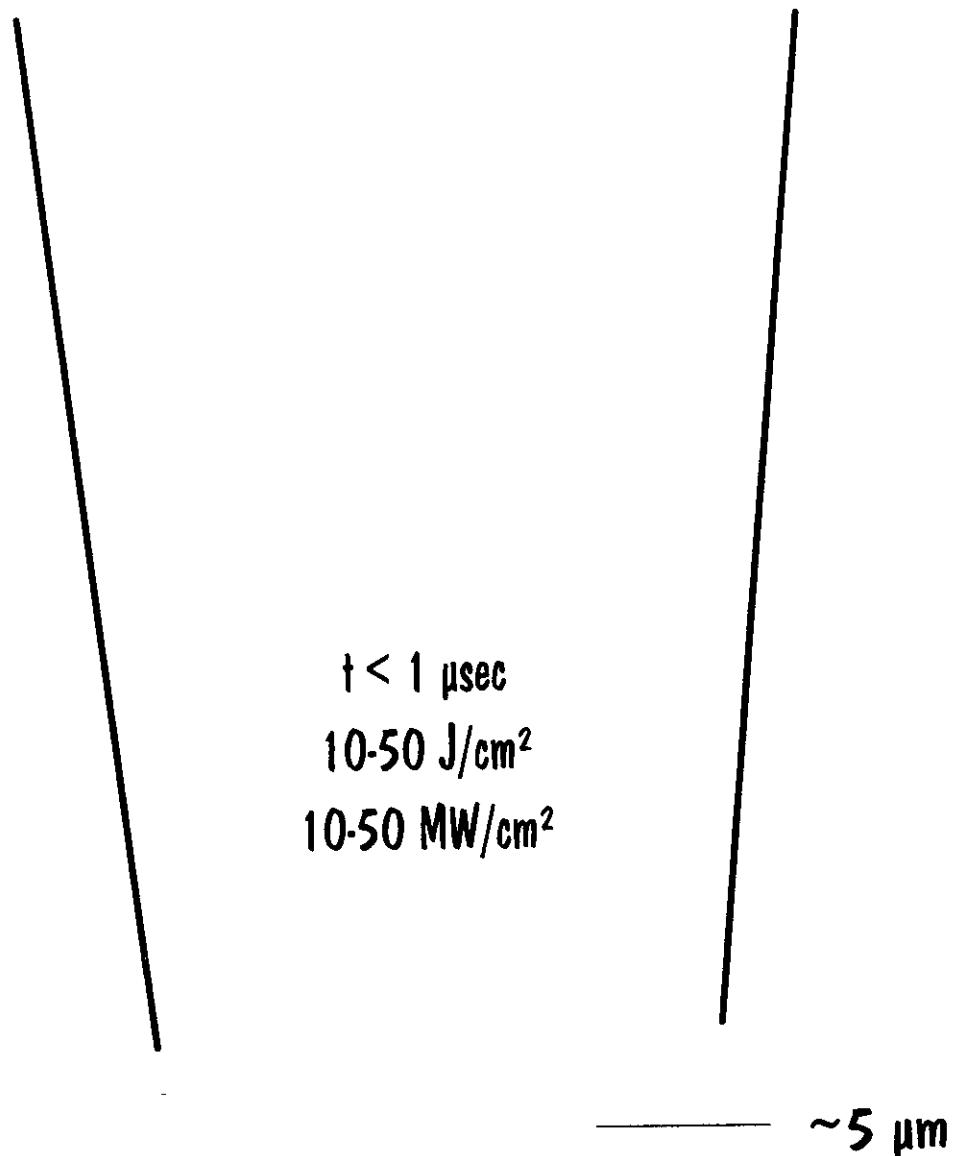
- ⌚ $f < 100 \text{ Hz}$,
- ⌚ bad beam quality,
- ⌚ small reliability and short lifetime,
- ⌚ strong electrical interference.

mm



Ablation of bone with a short CO₂ laser pulse

Institut für Lasermedizin

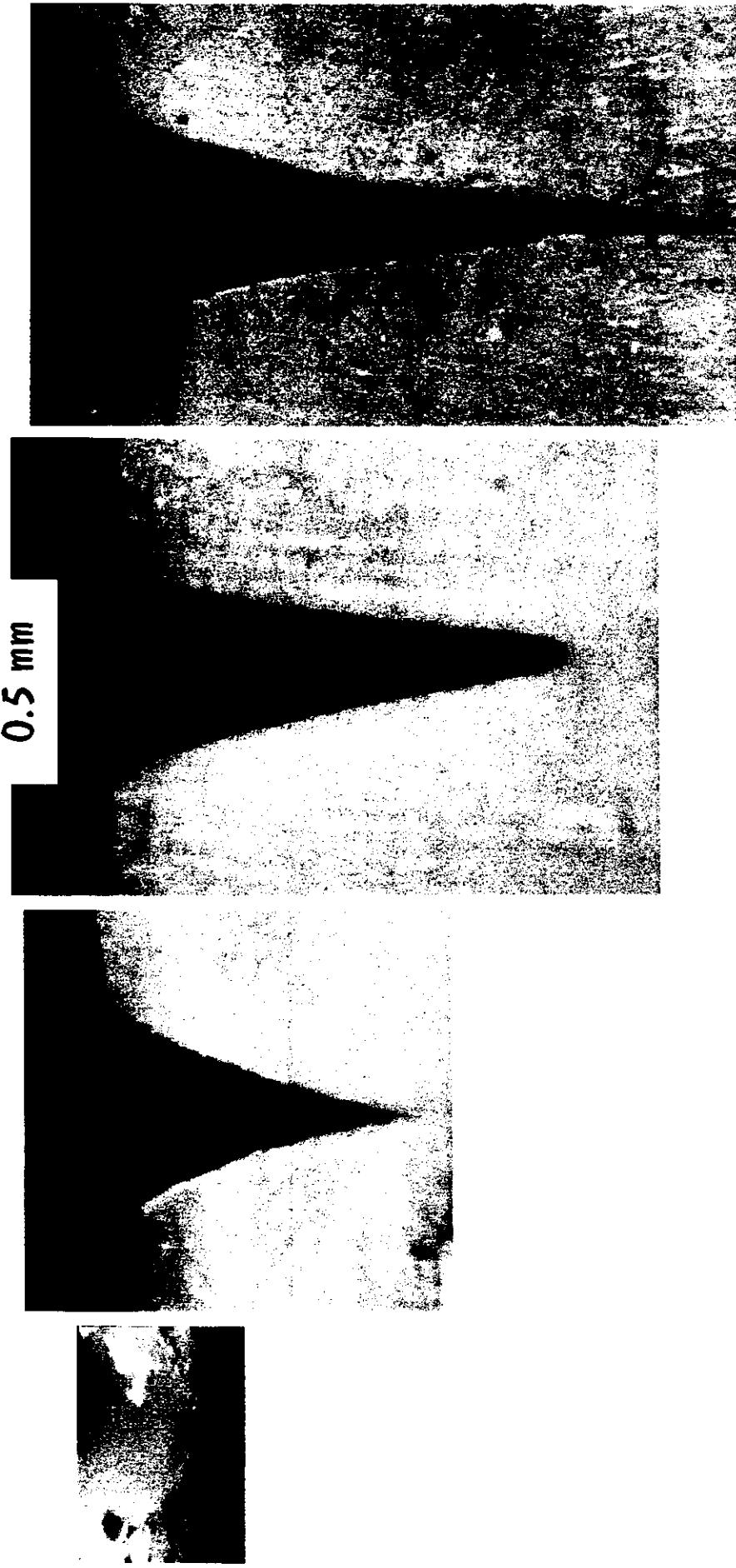


$\tau_{\text{temp}} = 25 \mu\text{sec}$

Cut profile alteration with increasing depth.

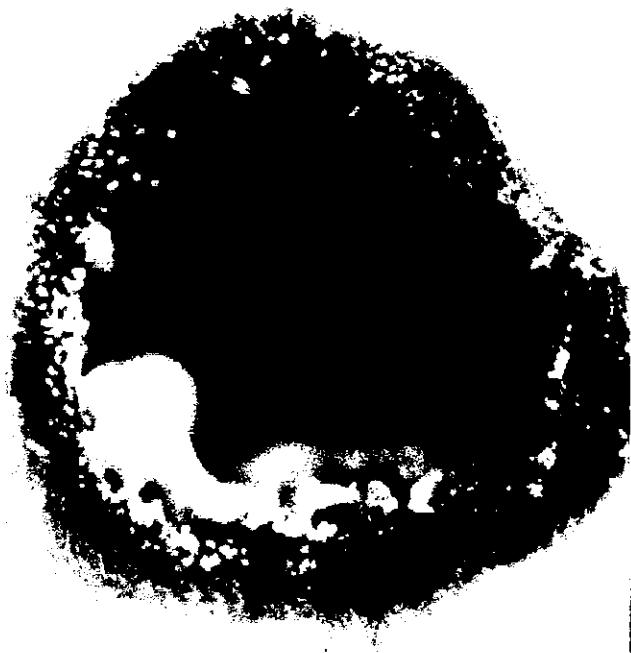
Wet ablation of porcine femur compacta with Q-switch CO₂ laser.

$N_{eq} = 200$
few pulses → →



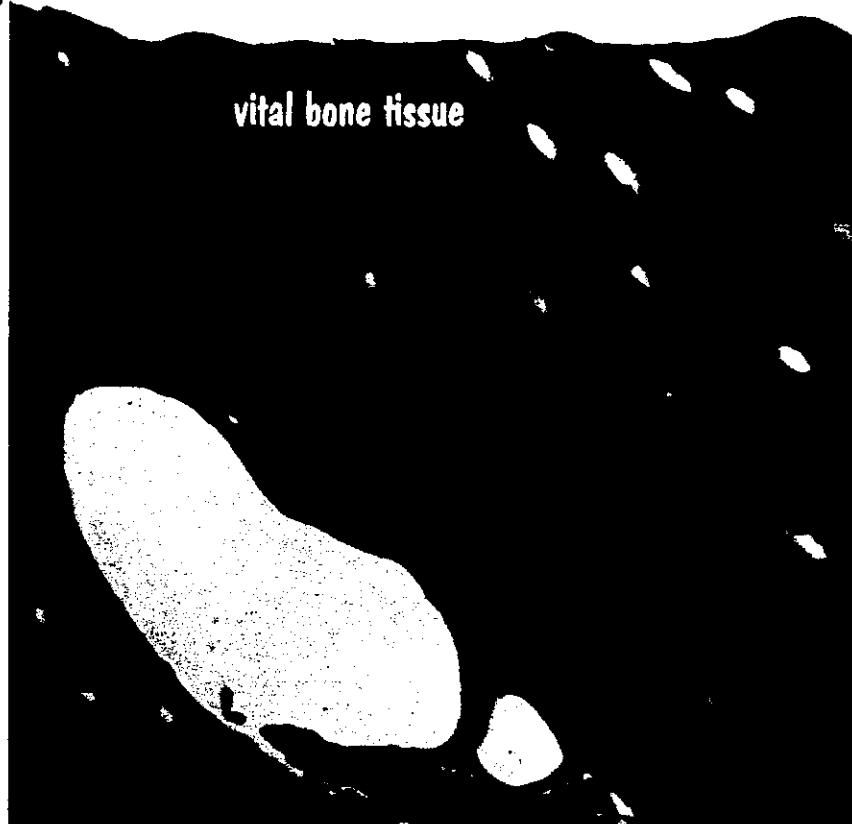
SOME QUALITATIVE RESULTS WITH SUB- μ SEC CO₂ LASER PULSES :

- only first few laser pulses produce "clean" ablation. When the crater depth reaches several hundred μm , the efficiency of the ablation drops quickly and visible thermal damage appears even at the low repetition rate $f \approx 20$ Hz. Prolonged irradiation and/or higher repetition rates lead to pronounced melting structure and charring ↑
- An auxiliary gas jet (N₂, CO₂, Ar, He), if applied for several tens of seconds, promotes drying of the bone tissue and only aggravates the damage.
- (?) Every laser pulse reduces the water content in the vicinity of the ablated volume. After some time it drops to such an extent that water no longer participates in the ablation process. Subsequent laser pulses will melt and burn the solid bone components.



HISTOLOGIC RESULTS

Laser cut edge →



carbonization
= 1-3 µm

COMPACTA (PELVIS HUMANus):

in vitro, standard preparation after irradiation (Formaldehyde, decalcification, staining)

MECHANICALLY Q-SWITCHED CO₂ LASER:

$$\lambda = 9.57 \mu\text{m}, \tau_{0.5} = 250 \text{ ns},$$

$$E = 17 \text{ mJ/pulse}, f = 5 \text{ kHz}, \langle P \rangle = 85 \text{ W},$$

$$\text{focus size} = 440 \mu\text{m}, \Phi = 11.4 \text{ J/cm}^2,$$

$$\text{geometrical pulse overlap by scanning} = 0.5$$

WATER SPRAY:

$$1.5 \text{ ml/min}$$

Kraniofaciale Chirurgie

12 Kraniofaziale Chirurgie

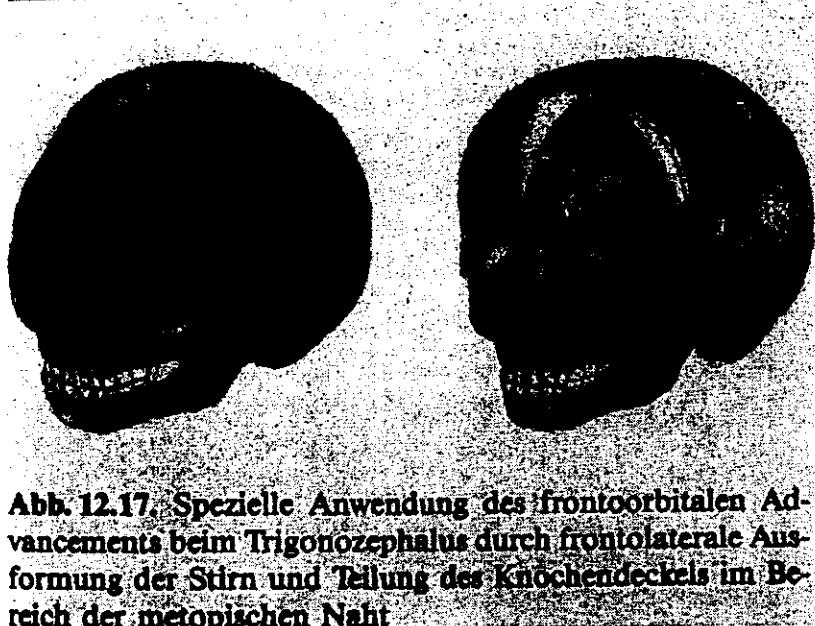


Abb. 12.17: Spezielle Anwendung des frontoorbitalen Advancement beim Trigonocephalus durch frontolaterale Ausformung der Stirn und Teilung des Knochenbeckens im Bereich der metopischen Naht

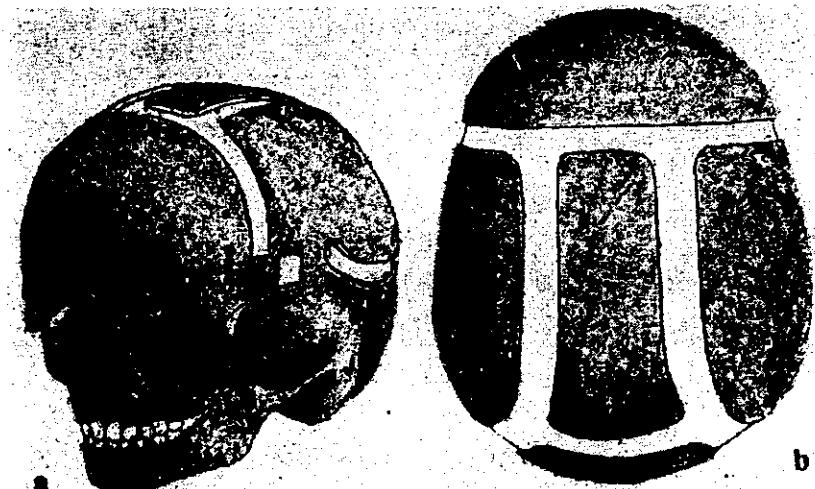
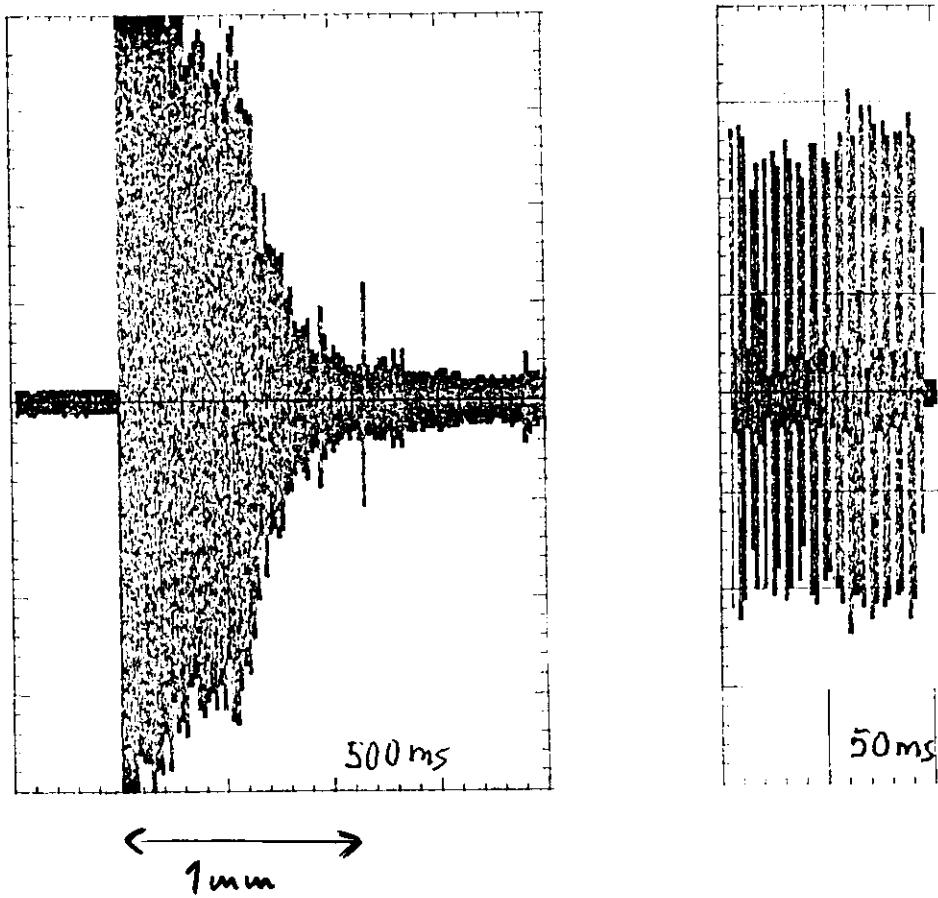


Abb. 12.21
a Frontoorbitales Advancement in Kombination mit linearer
Kranioektomie
b kraniale Aufsicht

OPTOACOUSTICAL SIGNAL DURING BONE ABLATION



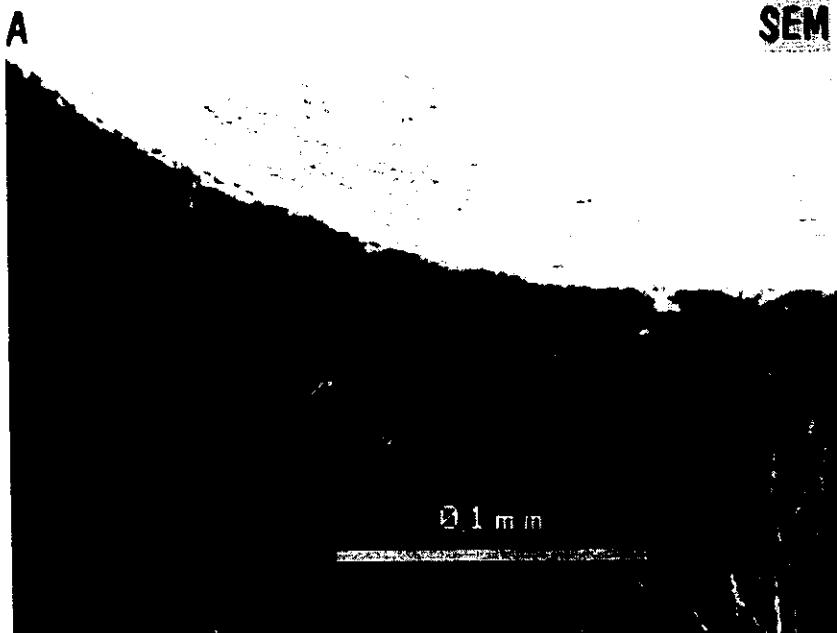
Bone: bovine femur, 1 mm

Laser: 9P(22) line, 325 Hz, $\langle P \rangle = 11.5 \text{ W}$,
 $35 \text{ mJ/pulse}, \tau_{1/2} = 500 \text{ ns}, \Phi = 17 \text{ J/cm}^2$

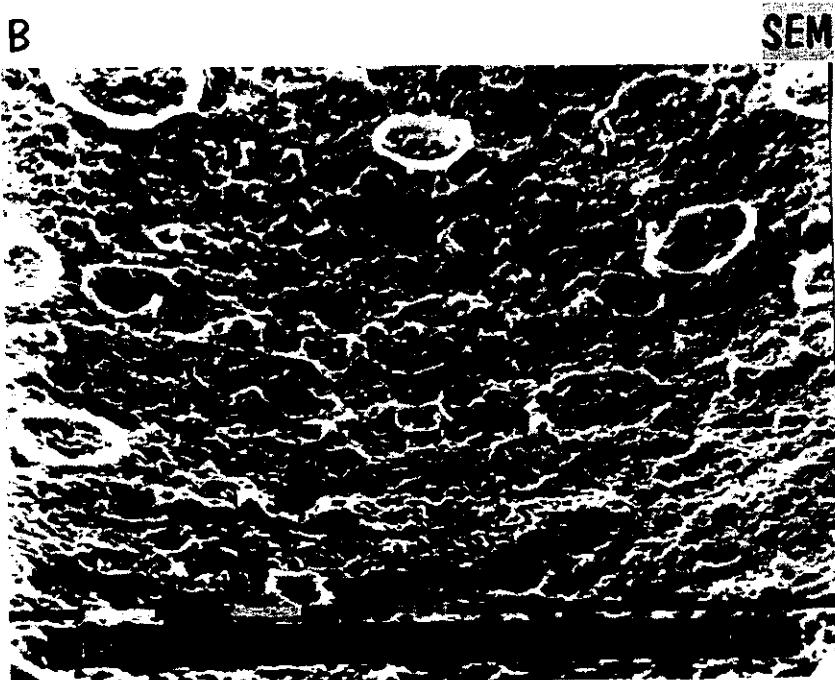
Microphone: at the distance of 20 cm from the bone

TOOTH TISSUE ABLATION WITH SHORT CO_2 LASER PULSES AND WATER SPRAY

wavelength $\lambda = 9.57 \mu\text{m}$,
pulse duration $\tau_{0.5} = 450 \text{ ns}$,
focus diameter $2w_f = 0.5 \text{ mm}$,
energy density $\Phi = 14 \text{ J/cm}^2$,
peak intensity $I \approx 30 \text{ MW/cm}^2$



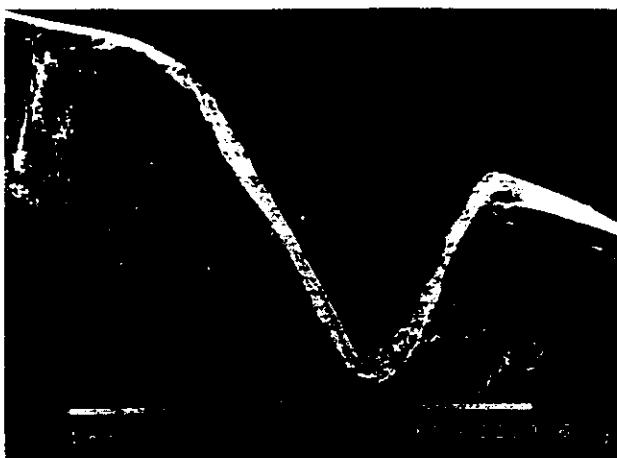
$f = 980 \text{ Hz}$, $P = 27 \text{ W}$,
scanning rate $v = 50 \text{ cm/s}$,
overlap factor $w_f f/v = 0.5$,
water spray = 2 ml/min



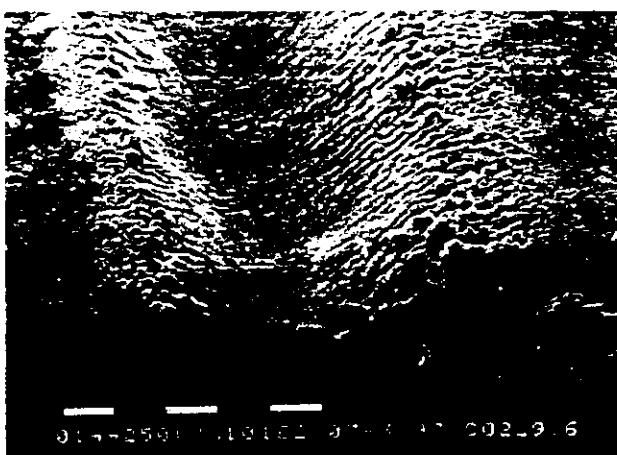
$f = 330 \text{ Hz}$, $P = 9 \text{ W}$,
scanning rate $v = 28 \text{ cm/s}$,
overlap factor $w_f f/v = 0.3$,
water spray = 1 ml/min

Preliminary results of tooth enamel/dentin ablation with Q-switched CO₂ laser and miniature water spray

wavelength = 9.6 μm ,
energy density = 14 J/cm²,
pulse duration = 450 ns,
beam diameter = 0.5 mm,
sample at a rotating (1.5 Hz) plate of 45 mm radius,
water consumption is about of 1 ml/min.



$f_{\text{laser}} = 980 \text{ Hz}$,
average power = 27 W,
equivalent pulse number = 108 =
radius of focus/shift between two pulses,
beam space-overlap factor = 0.6,
ablation depth = 470 μm ,
effective width = 395 μm ,
average ablation depth per pulse = 4.4 μm ,
average specific ablation energy = 60 J/mm³.

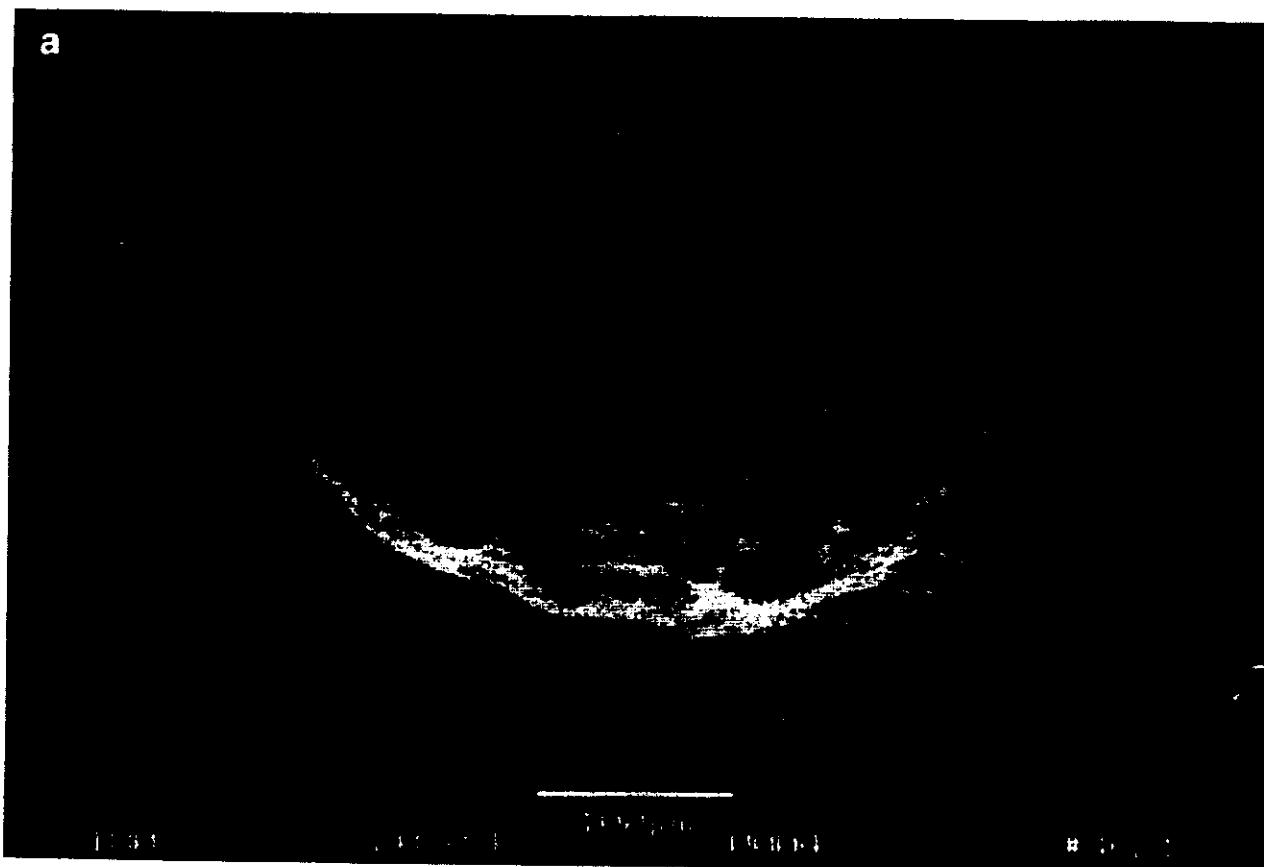


$f_{\text{laser}} = 327 \text{ Hz}$,
average power = 9 W,
equivalent pulse number = 36,
beam space-overlap factor = 0.2,
ablation depth = 145 μm ,
effective width = 340 μm ,
average ablation depth per pulse = 4 μm ,
average specific ablation energy = 76 J/mm³.



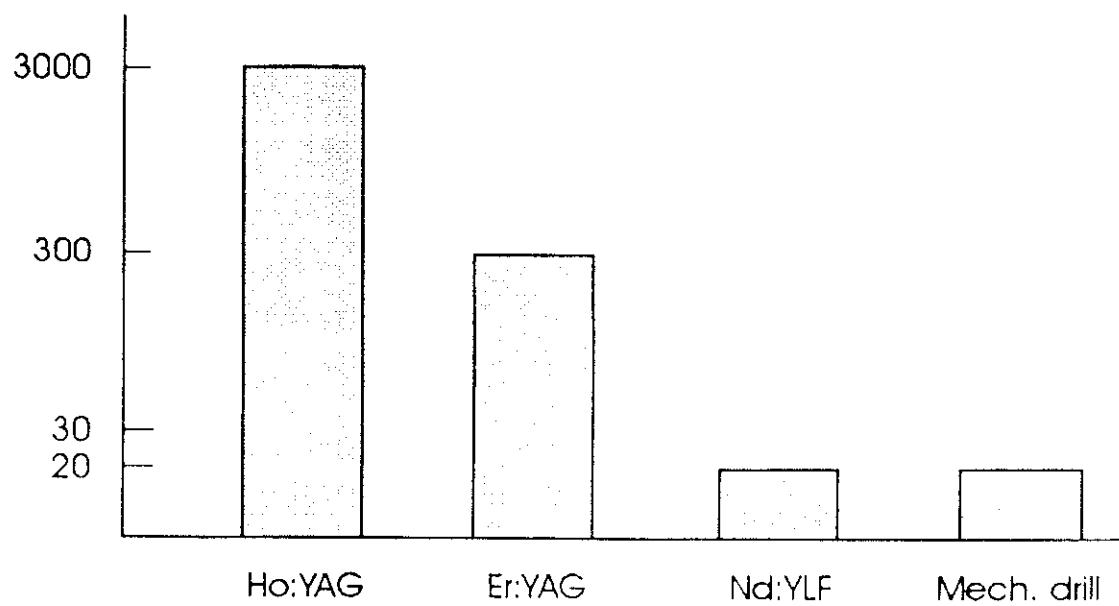
$f_{\text{laser}} = 327 \text{ Hz}$,
average power = 9 W,
equivalent pulse number = 27,
beam space-overlap factor = 0.2,
ablation depth = 90 μm ,
effective width = 330 μm ,
average ablation depth per pulse = 3.3 μm ,
average specific ablation energy = 90 J/mm³.

Other EM pictures corresponds to the same experimental series with $f_{\text{laser}} = 327$ or 980 Hz.



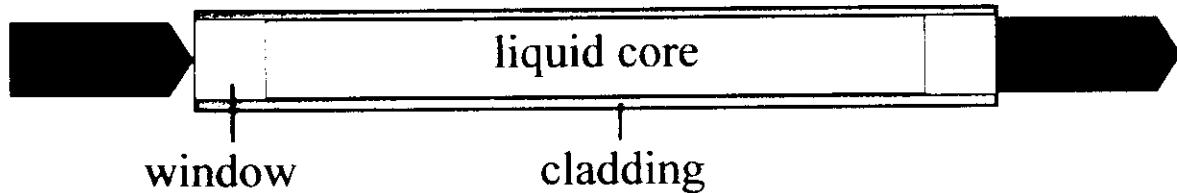
Ho:YAG-Laser (100 Pulse, Rep = 1Hz, $\tau=3,8 \mu\text{s}$,
Pulsenergie: 18 mJ)

Dye penetration (μm)



Principle of LCL

$$n_{\text{core}} > n_{\text{clad}} \quad NA = \sqrt{n_{\text{core}}^2 - n_{\text{clad}}^2} \geq 0.2$$



numerical apertures:

NA = 0.1 - 0.5

transmittance:

400 nm – 3.1 µm

results:

quartz LCL FEP LCL

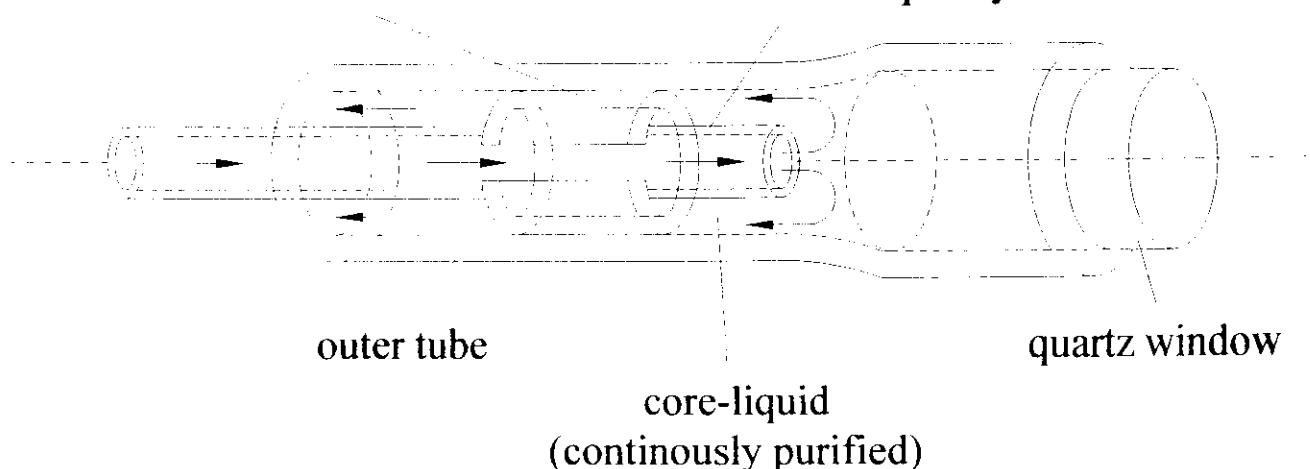
Er:YAG: 91 J/cm² 130 J/cm²

Ho:YAG: 94 J/cm² 200 J/cm²

arrangement of two concentric tubes

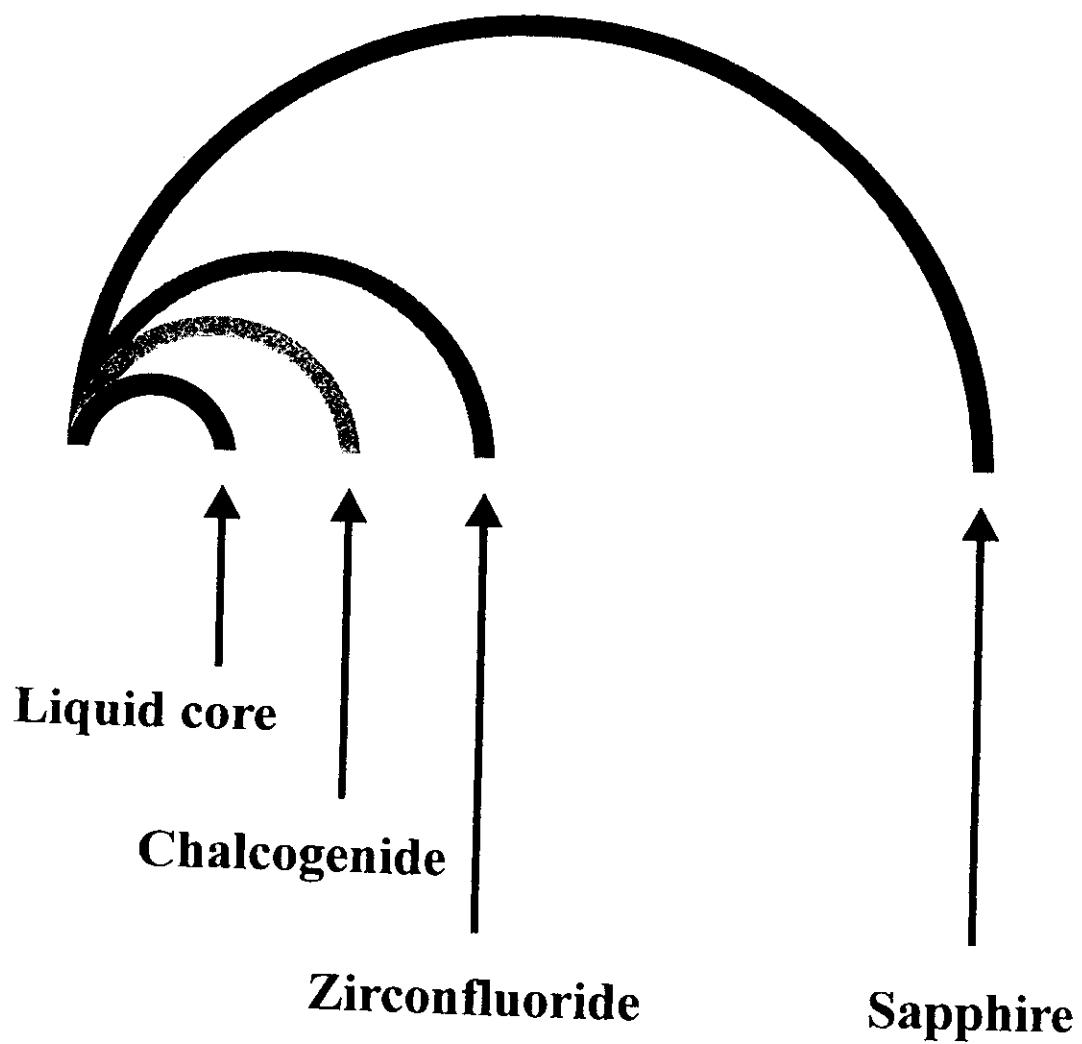
alignment ring

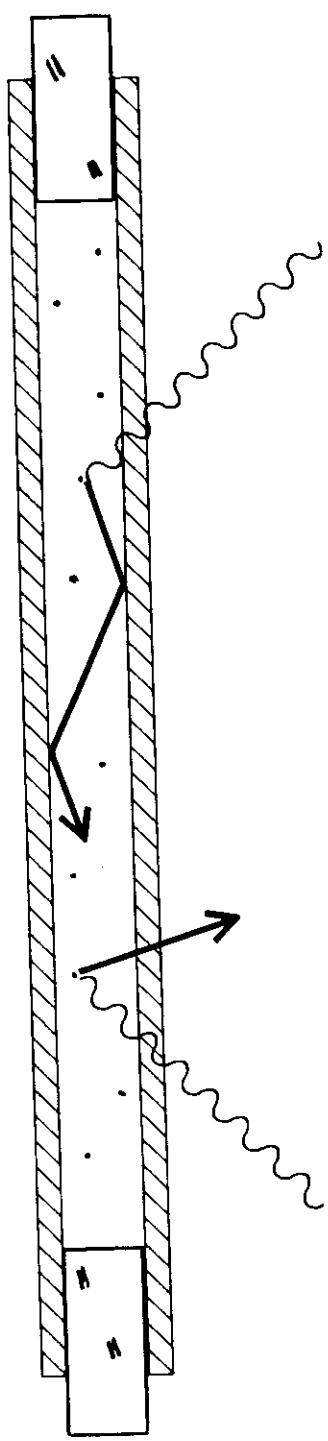
Teflon-FEP tube
or
fused silica capillary

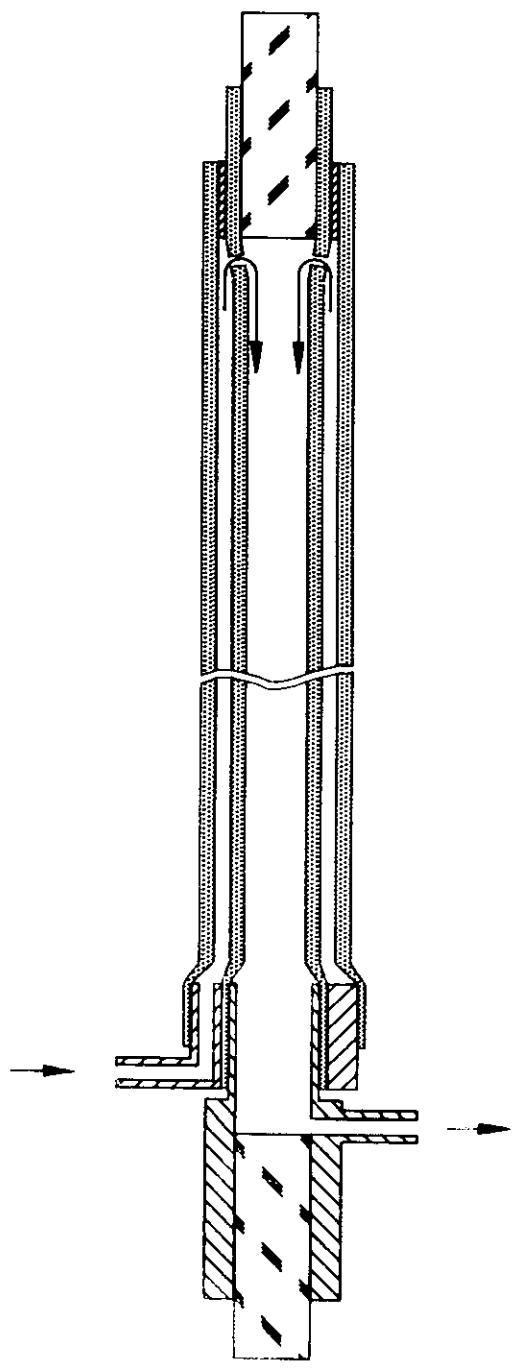


Lightguides for 2.94 μ m

- Minimum Bending Radii -







Klinische Anwendung des flüssigkeitsgefüllten Lichtwellenleiters

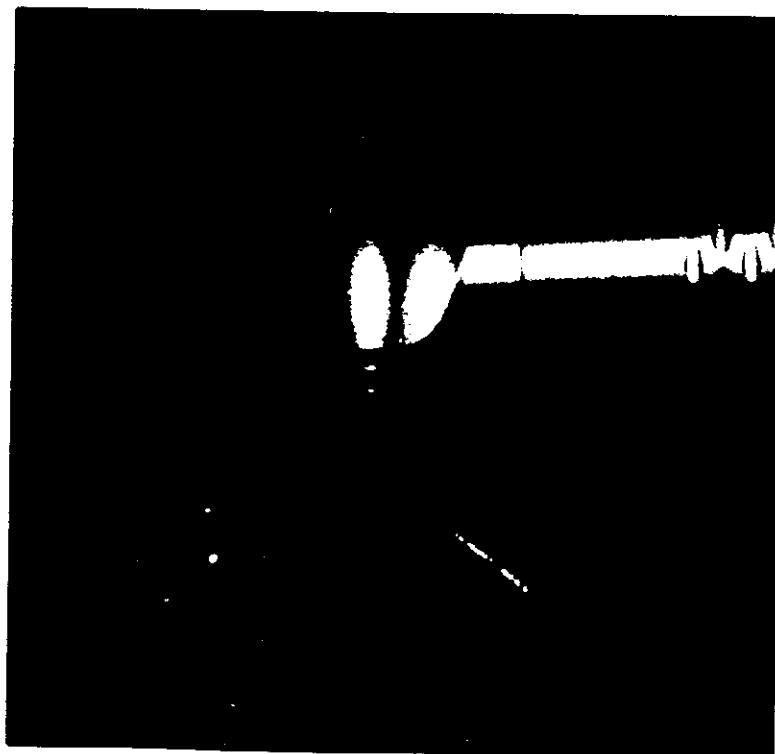
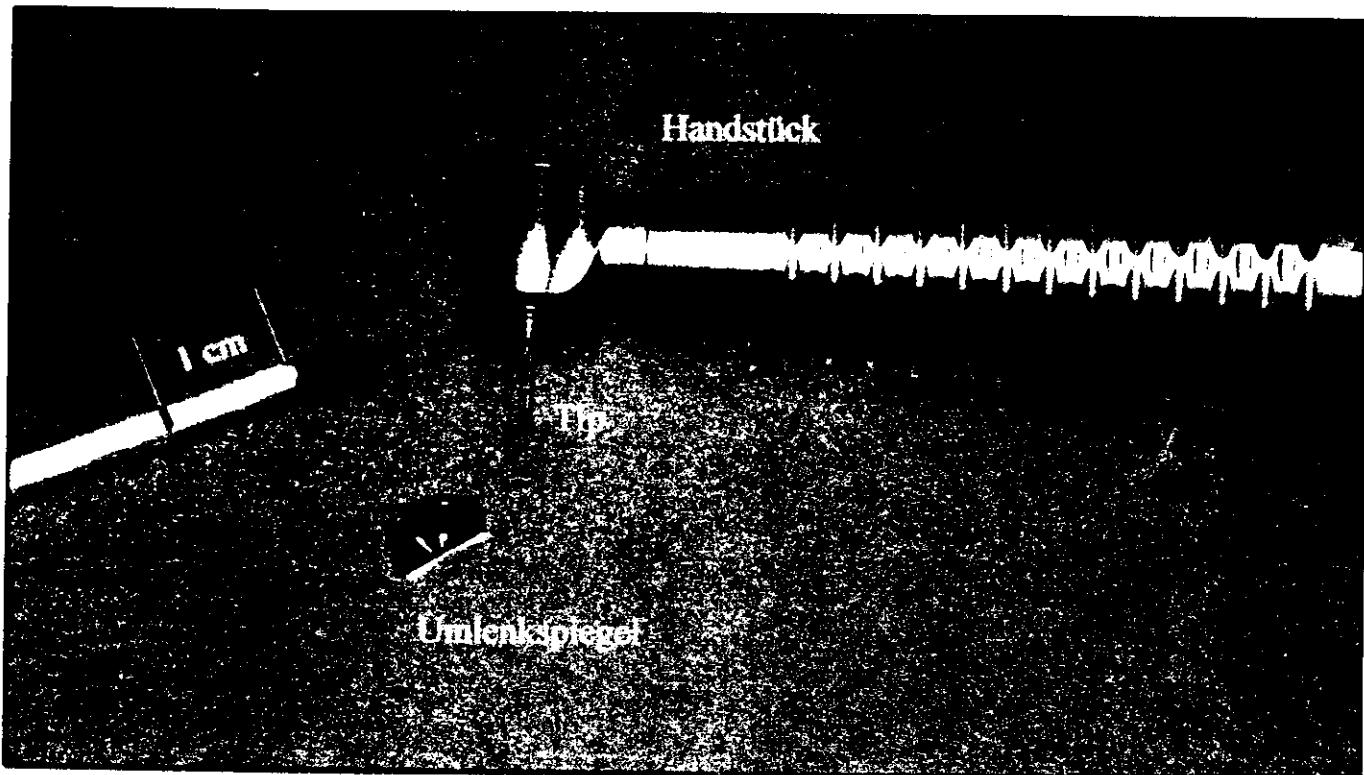


Klinik und Poliklinik für Kiefer- und Gesichtschirurgie
Prof. Sailer
Universitätsspital Zürich

04. April 1998

Entfernung von Leukoplakie am Gaumen und an der
Wangeninnenseite

Laser-handpiece for IR-lasers



transmitted power
of the handpiece: 6 W

(repetition rate of 20 Hz,
pulse energy of 300 mJ)

Holographic Facial 3D-Measurement

Indications in Craniofacial surgery :

- Planning of operation
- Analyses of symmetries
- Documentation of results
- Detection of tumor growth

Requirements :

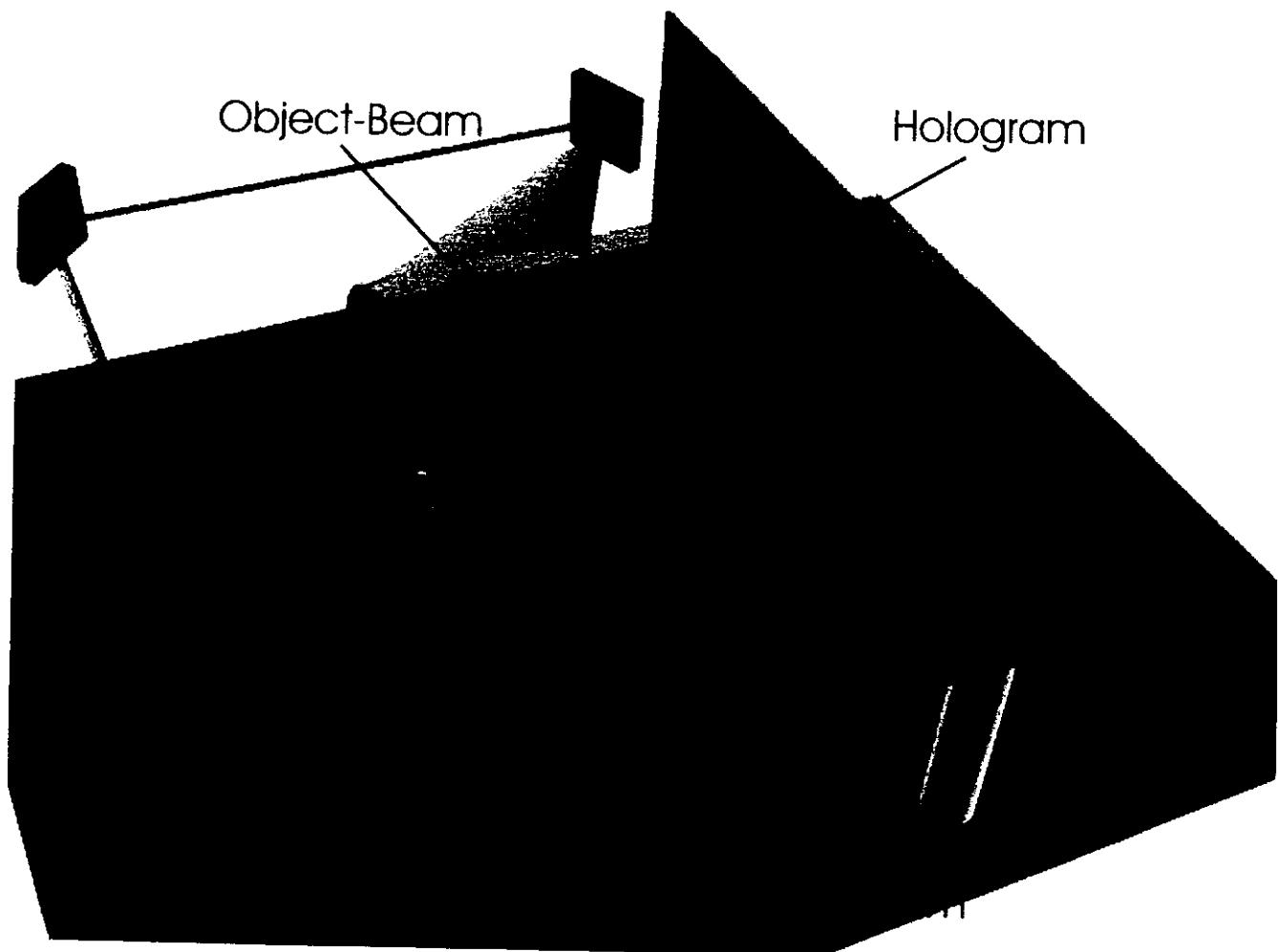
- Spatial resolution 0,1 mm - 1 mm
- Aquisition time < 1/60 s (movement of the patient implies short aquisition time for high accuracy)
- Measurment with open eyes --> laser safety

Idea :

- Taking a pulsed portrait-hologram of the patient
- Time independent analysis of the holographic 3D-information

Holographic Facial 3D-Measurement

Aquisition :

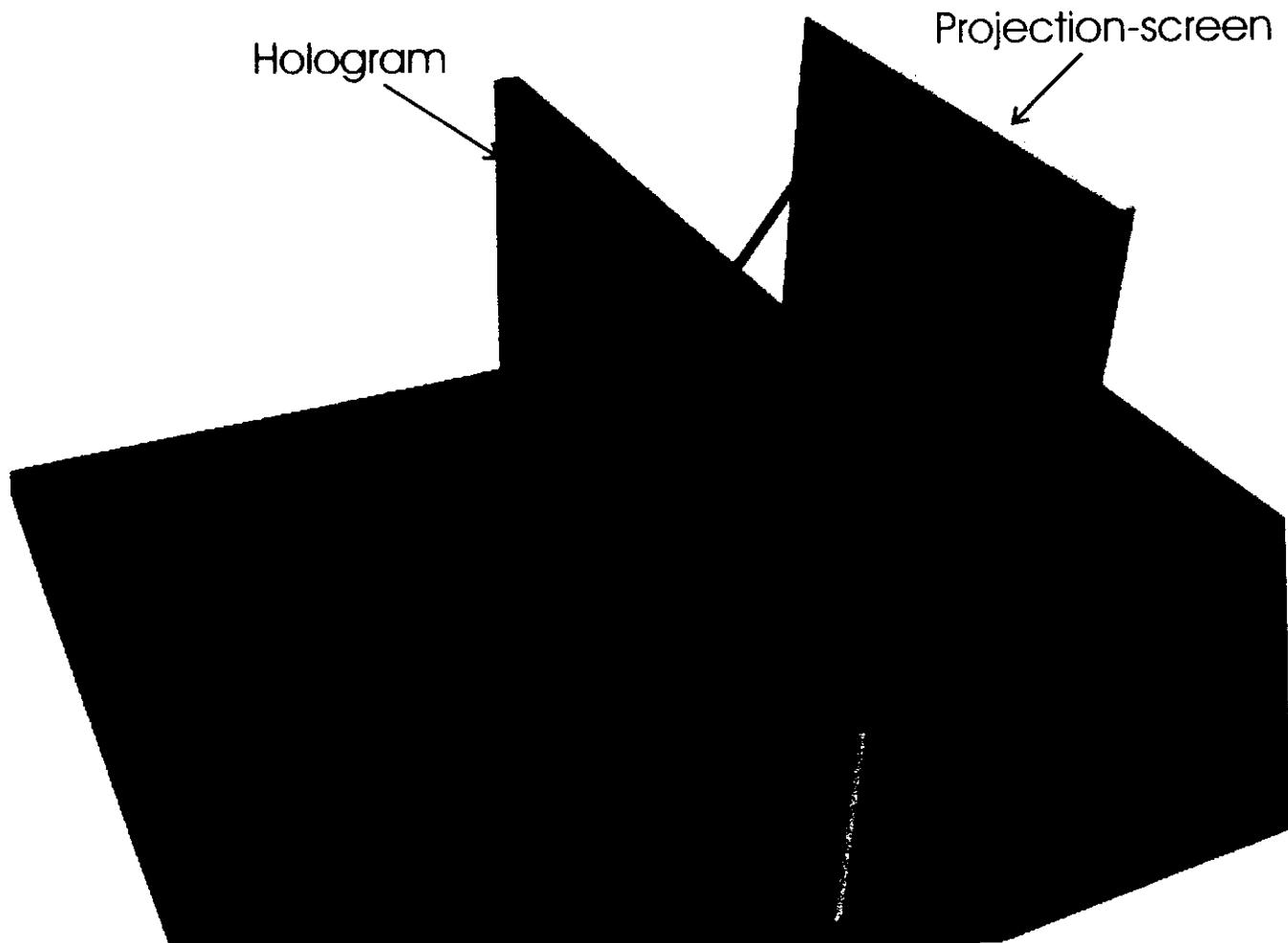


- short Pulses → no stability requirements
- divergent beam and diffusor → laser class I
- off-axis setup → low noise

Laser : pulsed Nd:YLF
526,5 nm (frequency-doubled)
2J puls-energy
20 ns puls-duration
>3m coherence length

Holographic Facial 3D-Measurement

Reconstruction and Analysis :



- Reconstruction of the real image with a frequency-doubled Nd:YAG cw-laser (532 nm).
- The real image is tomographically captured from a porjection screen by a CCD-camera.
- 3D-reconstruction of the projected slices is processed by a computer