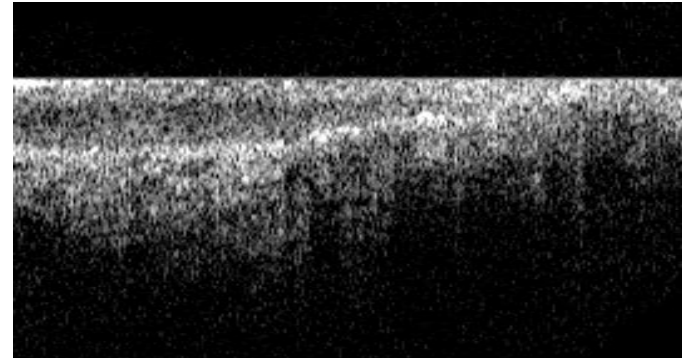
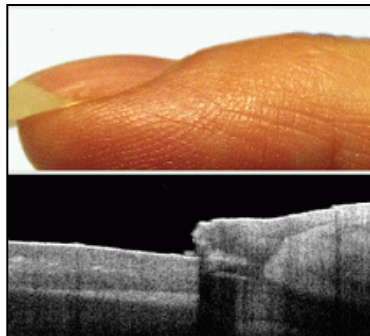


# Optical Coherence Tomography

## 5. Applications

Dr. Gereon Hüttmann / 2009

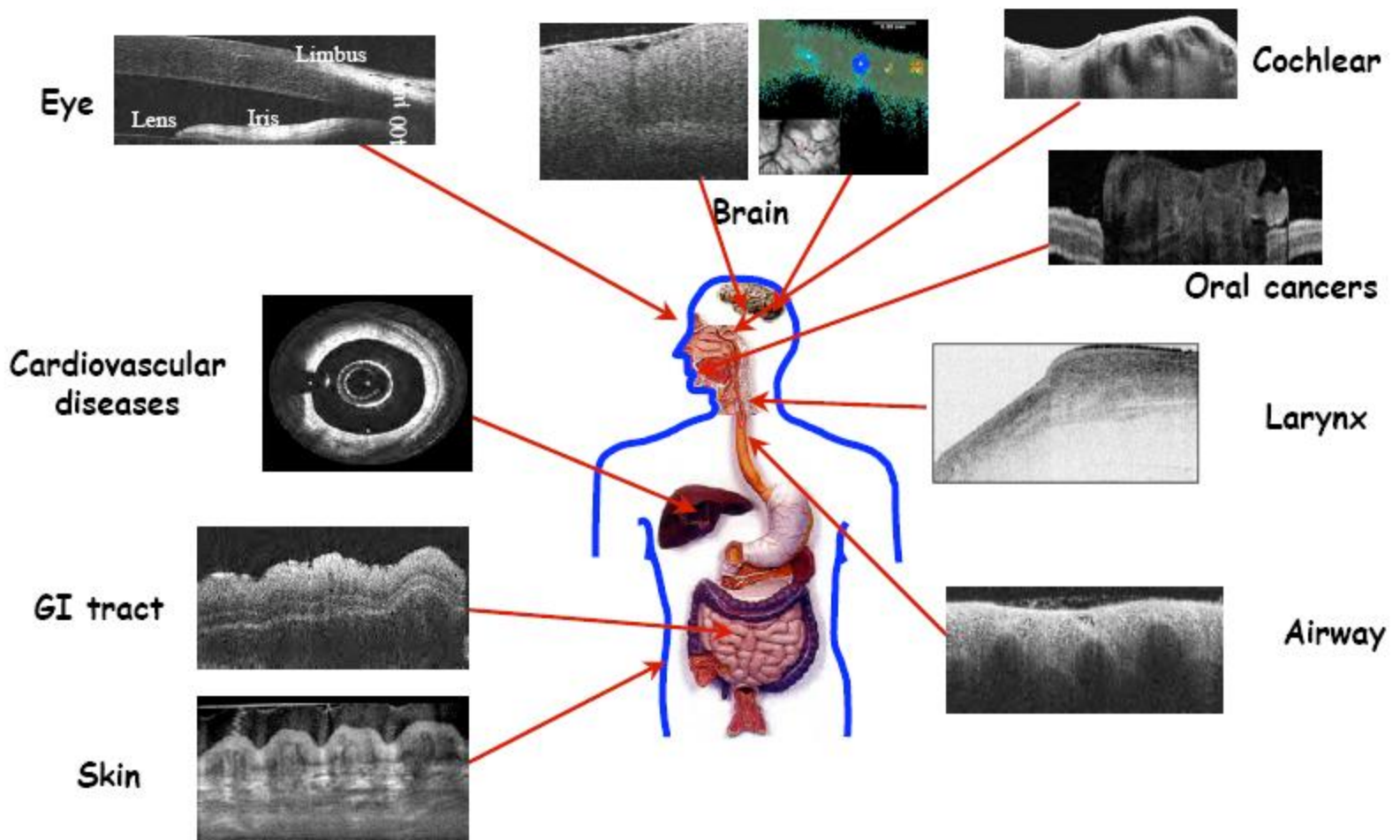


# Applications: OCT in non-invasive diagnostics

- Ophthalmology
  - diagnosing retinal diseases
- Dermatology
  - skin diseases
  - early detection of skin cancers
- Cardio-vascular diseases
  - vulnerable plaque detection
- Endoscopy (fiber-optic devices)
  - gastrology

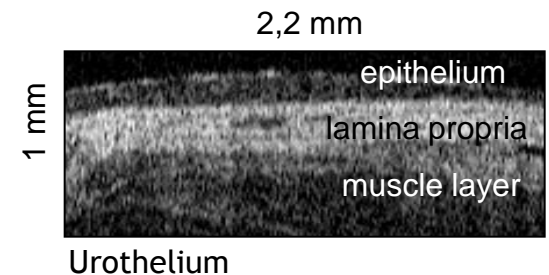
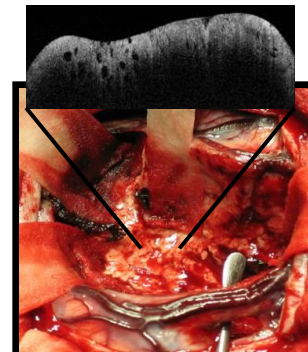
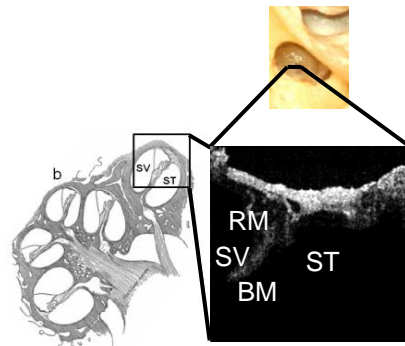
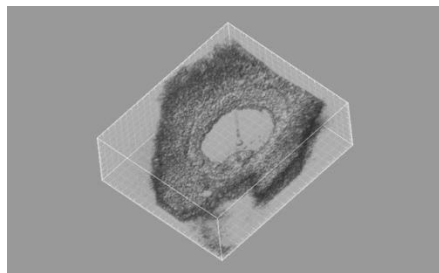
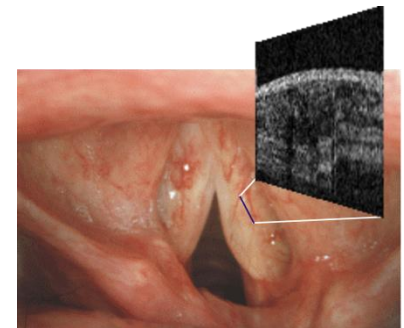
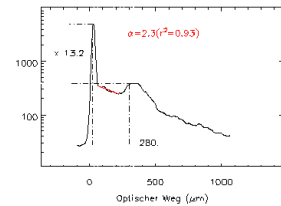
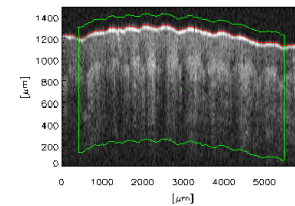
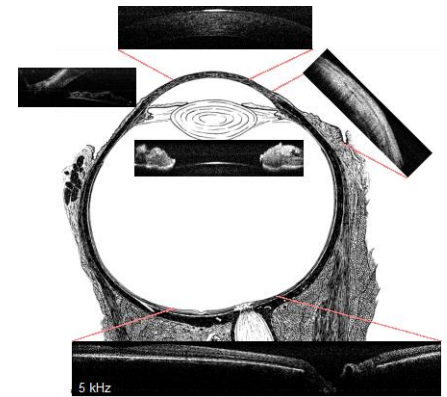
- Functional imaging
  - Doppler OCT
  - Speckle imaging
  - Optical properties
  - Volumetric imaging

- Guided surgery
  - brain surgery
  - knee surgery
  - Spinal cord surgery

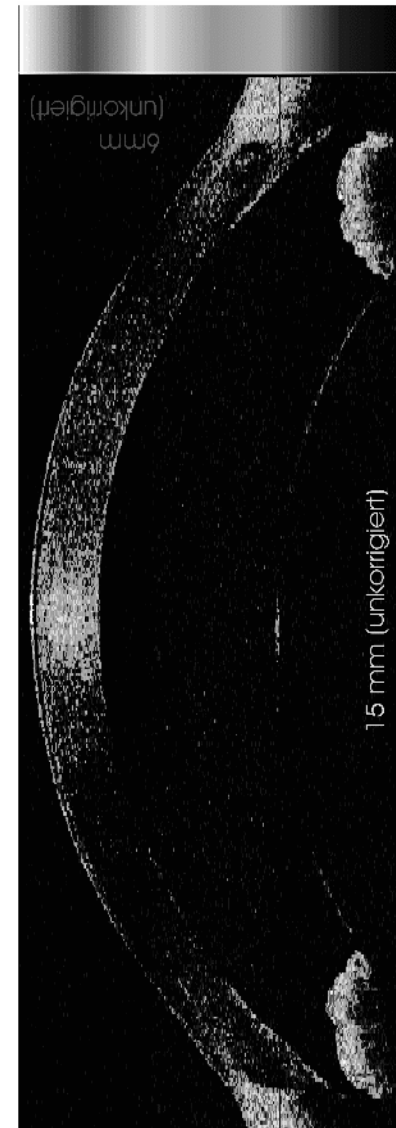
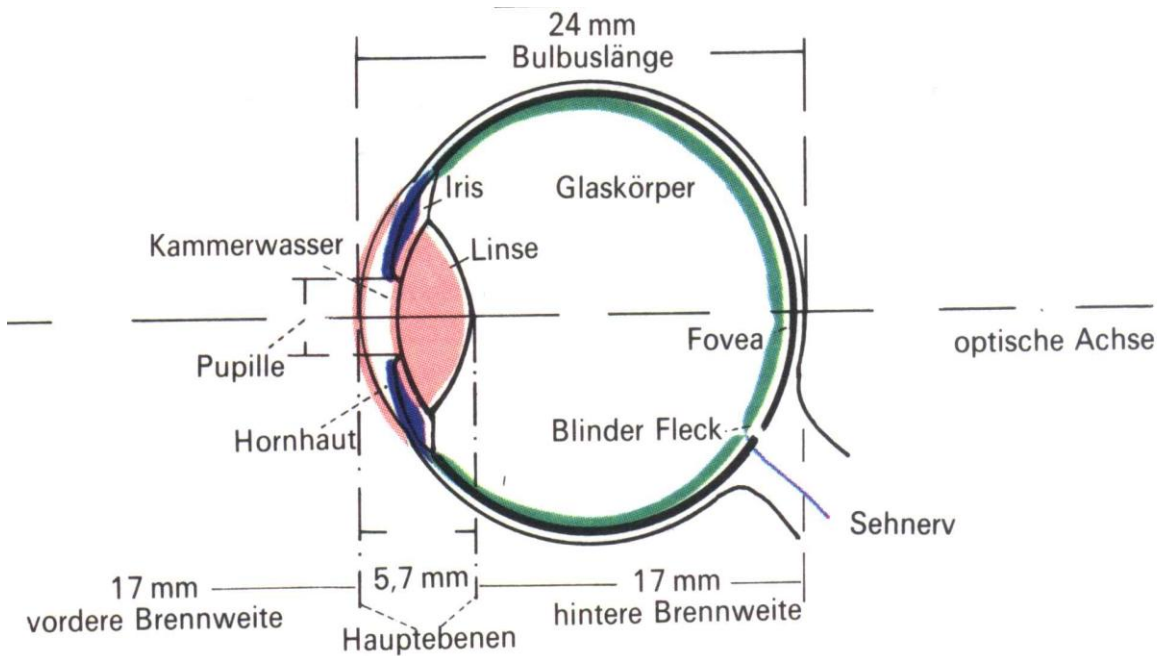


# Clinical Applications of OCT

1. **Imaging of retina and anterior segment of the eye**
2. Skin diagnosis
3. Diagnosis of bladder tumors
4. Diagnosis CIN at the portion uteri
5. Tumor diagnosis at the vocal fold
6. **Intraoperative demarcation of brain tumor borders**
7. Visualization of cochlear structures for correct insert electrodes



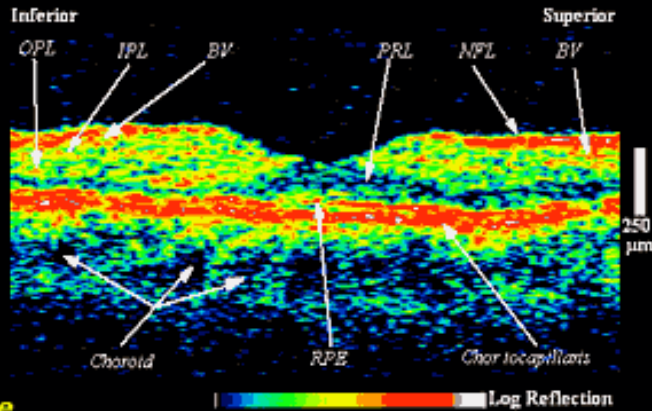
# OCT in Ophthalmology



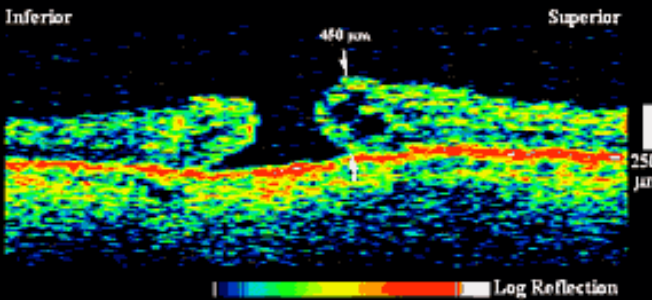
15 mm ·  
6 mm

# Applications in ophthalmology

## Normal retina



## Macular hole



## Impending macular hole

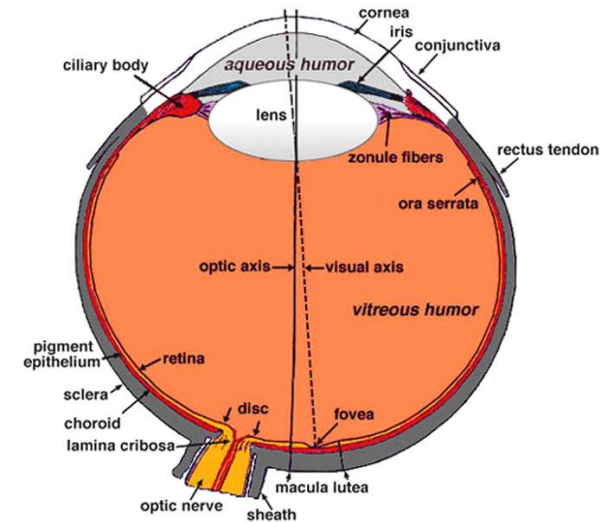
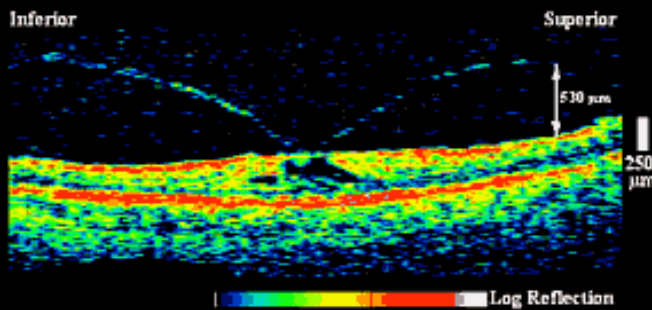


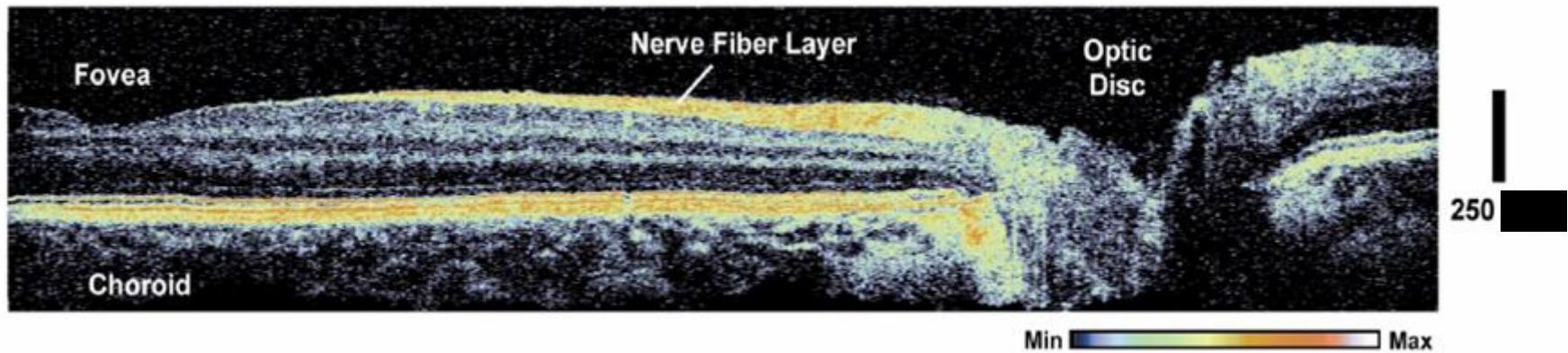
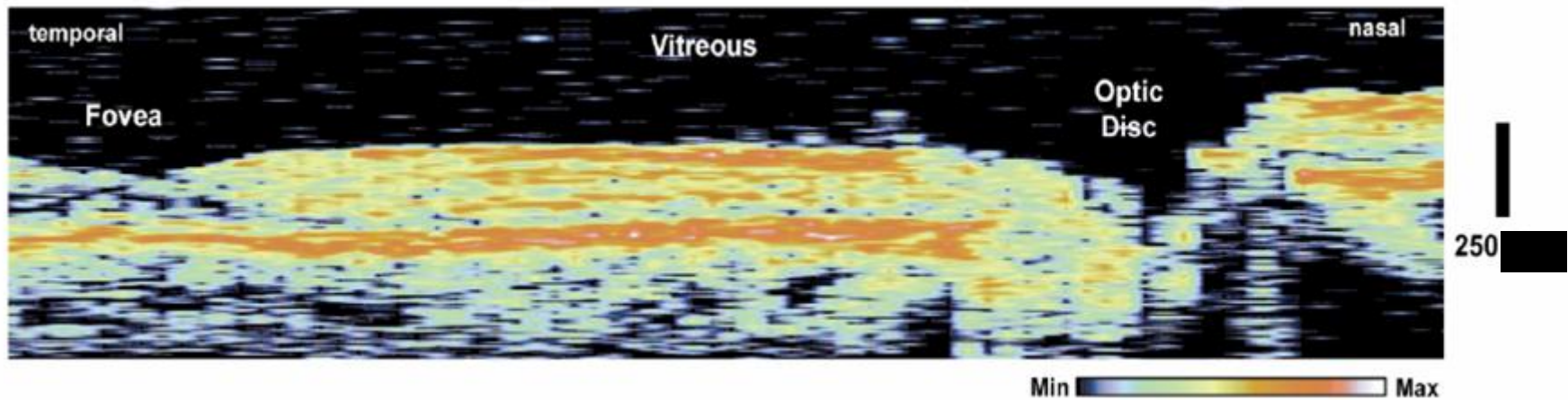
Fig. 2. Sagittal horizontal section of the adult human eye.

Normal patient

Patient with impaired vision (20/80):  
The cause is a macular hole

Patient's other eye (vision  
20/25):  
Impending macular hole, which  
can be treated

# Ultra-high-resolution-OCT versus commercial OCT



W. Drexler *et al.*, "Ultra-high-resolution ophthalmic optical coherence tomography", *Nature Medicine* **7**, 502-507 (2001)

# Optische Kohärenz-Tomografie (OCT)

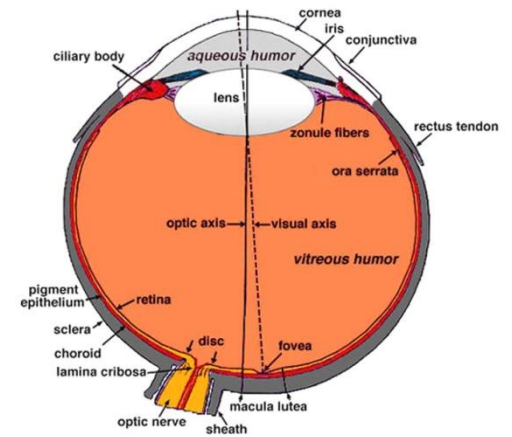
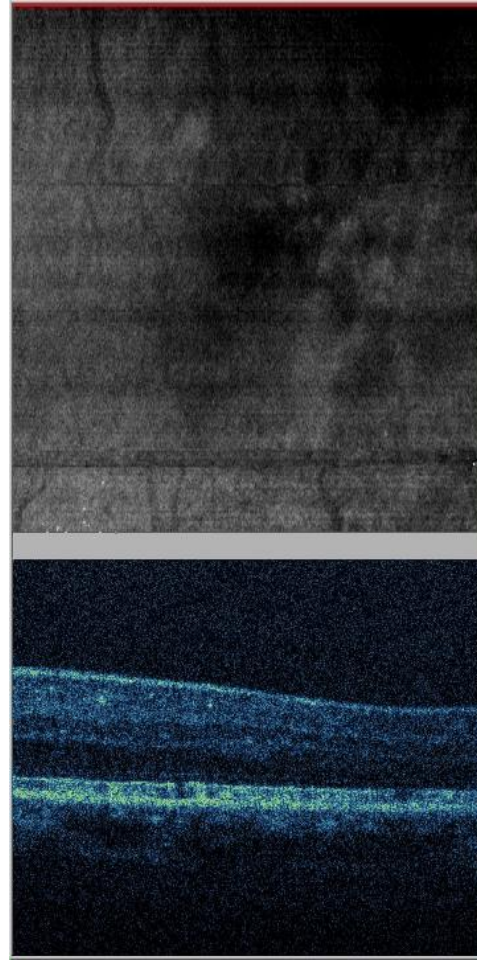
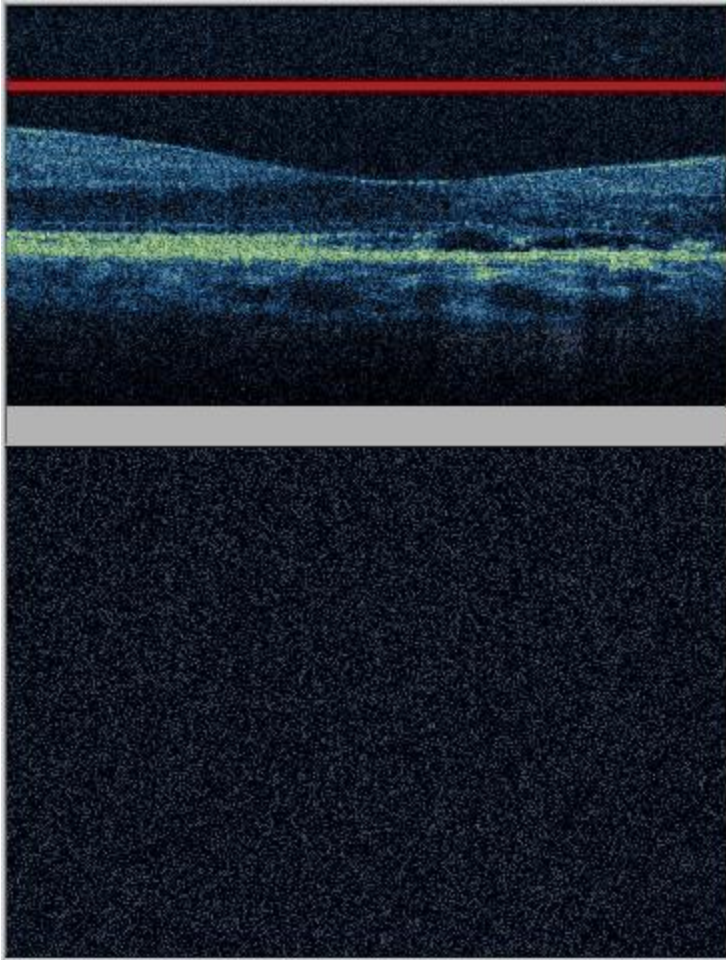
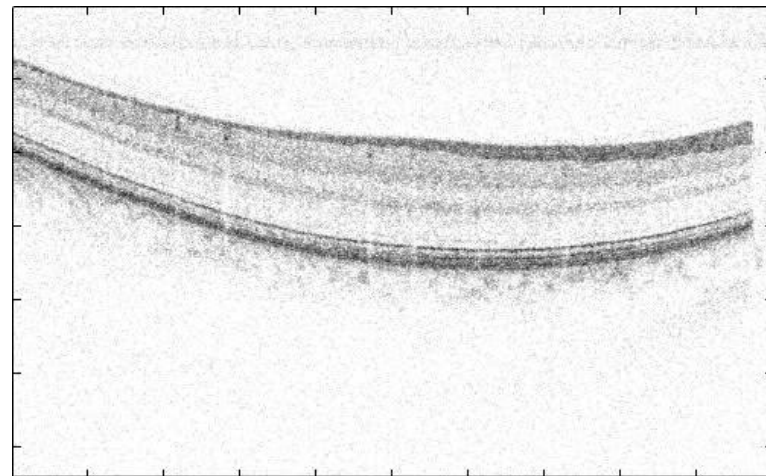
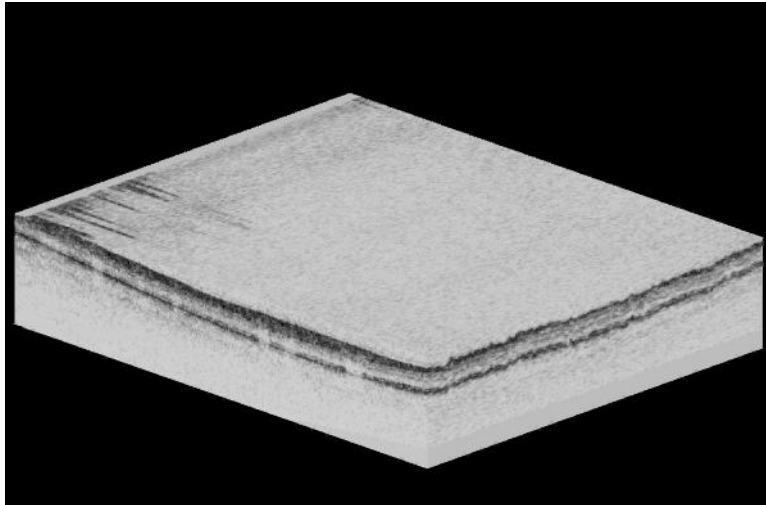


Fig. 2. Sagittal horizontal section of the adult human eye.

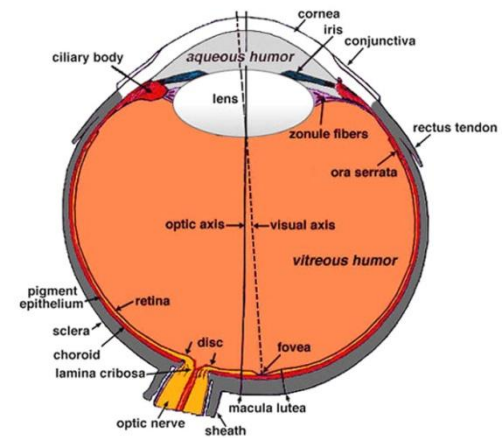
3D-Darstellung der Retina eines Patienten mit 10 µm Auflösung



# Optische Kohärenz-Tomografie (OCT): Beispiel 1



3D-Darstellung der Retina mit 10  $\mu\text{m}$

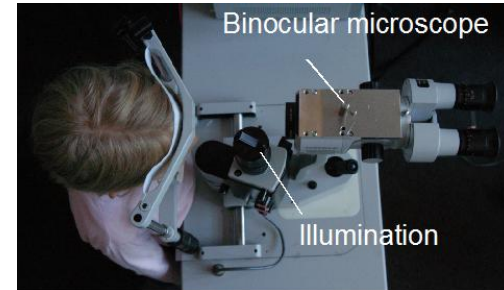


OCT  
Apparatur

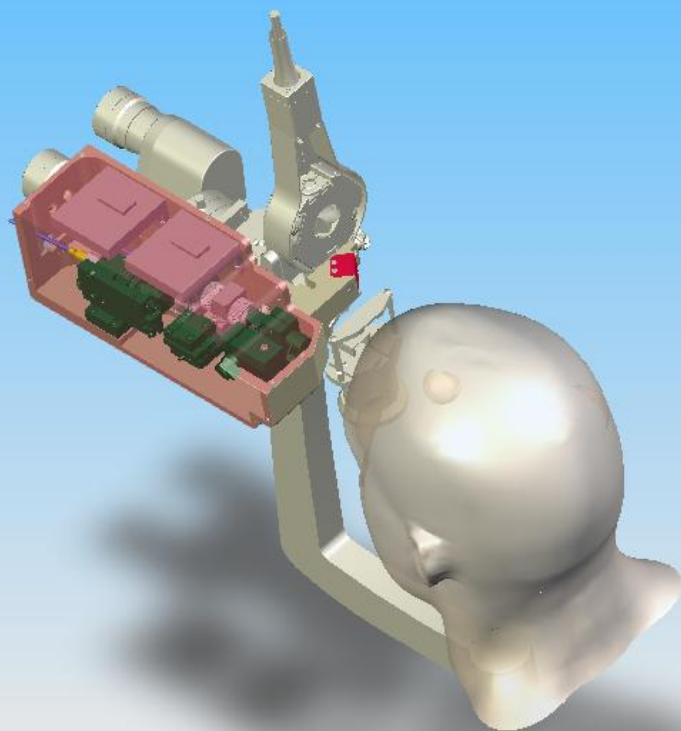


# Slit-Lamp Adapted SD-OCT for Retina Diagnosis

- The slit lamp is one of the most versatile and most common used instrument
- It combines a binocular 5 to 40x microscope is combined with an independently adjustable slit illumination.
- The anterior part of the eye (cornea, sclera, and lens) is imaged directly,
- With an ophthalmological lens (e.g. Volk lens or contact glass) the retina can be imaged.
- Combination with OCT was successful only for the anterior part of the eye. Retinal imaging was too complicated with slow-scanning TD-OCT systems, because focal plane and path length have to be adjusted independently by the ophthalmologist.

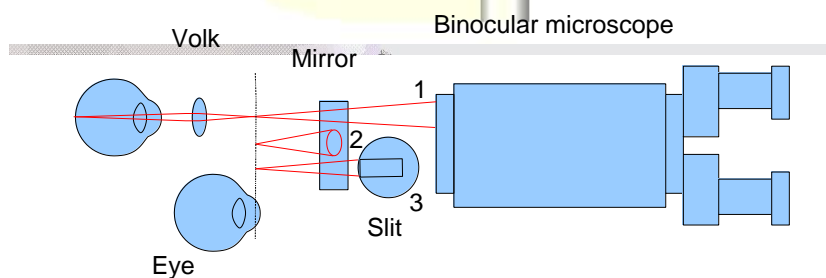


# Design

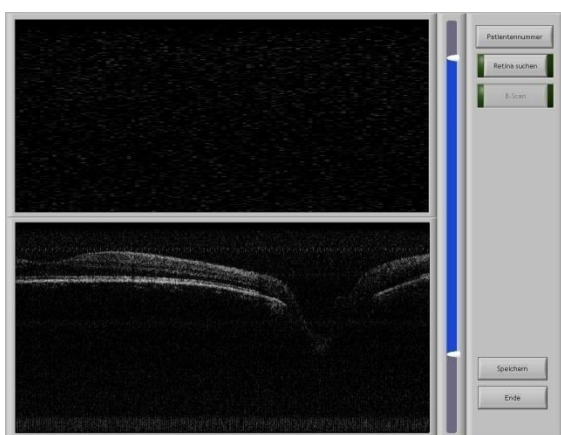
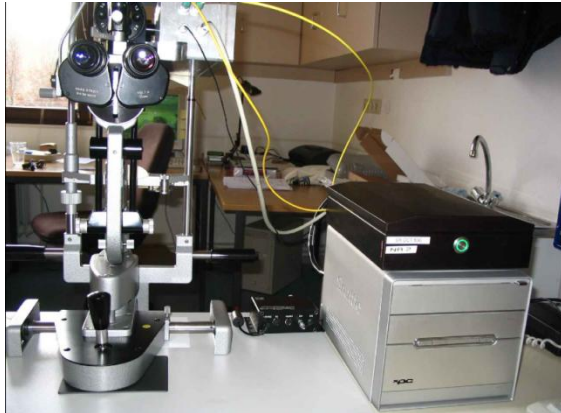


## Specifications:

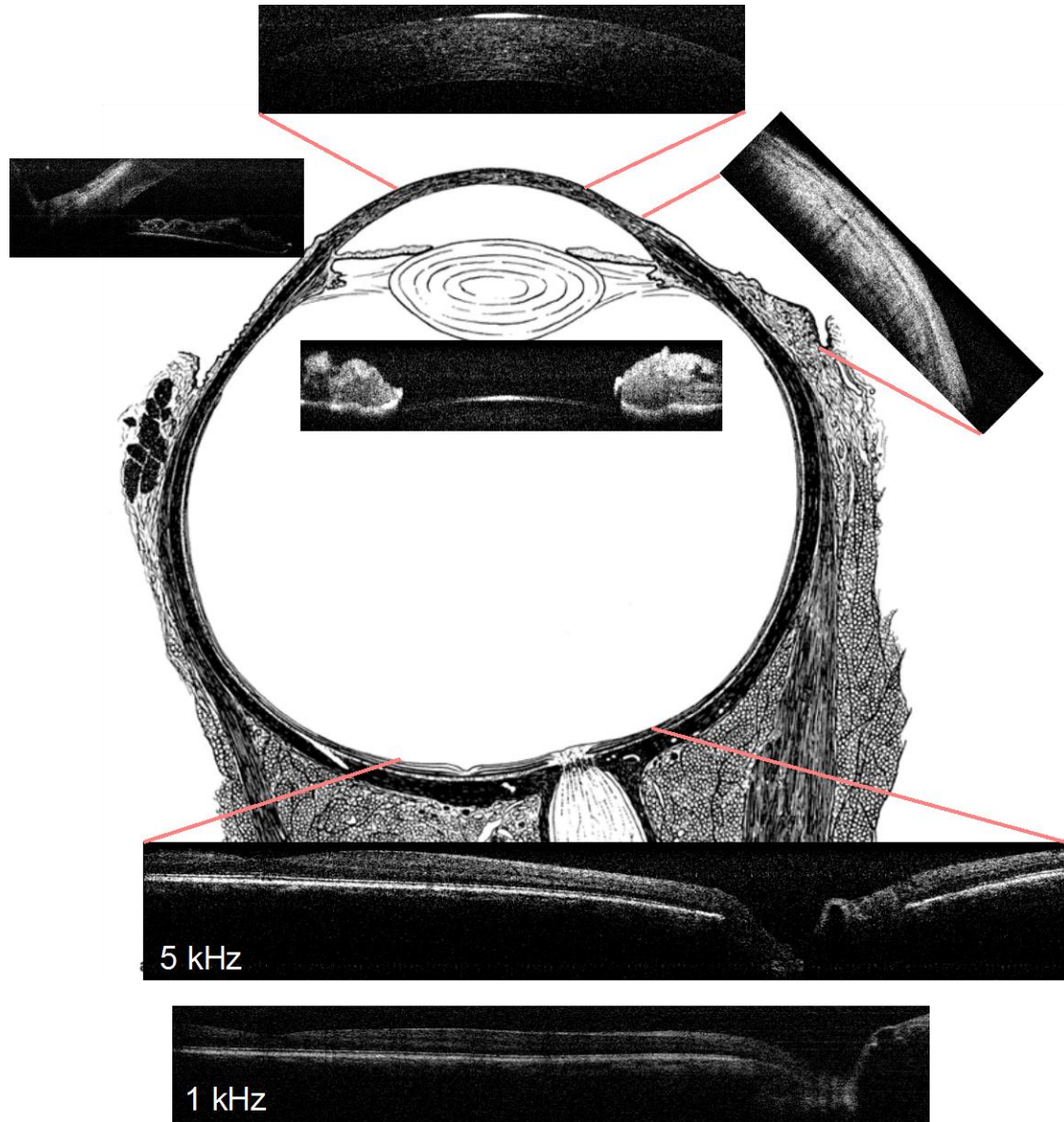
Long. Resolution:	8 $\mu\text{m}$
Z-Range:	3 mm
Lat. Resolution:	10-15 $\mu\text{m}$
Scanfield on retina:	5x5 mm <sup>2</sup> $\pm 8^\circ$
Scan speed:	>4k A-scans/s
Light power:	< 0.7 mW
Wavelength:	840 nm
Sensitivity:	>110 dB
Dynamic range:	>50 dB
Object distance range:	>70 mm
Retina imaging by	>60D Volk lens contact lens correction optics
Anterior chamber	custom made correction optics
Adaption via Iridex slit lamp adapter	
CE certified for documentation	



# Realization



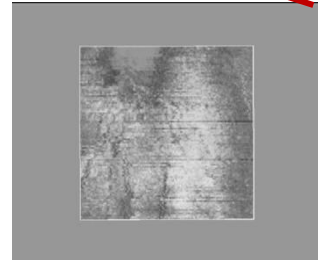
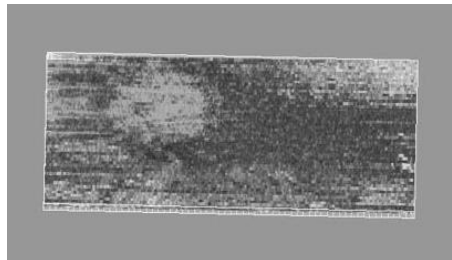
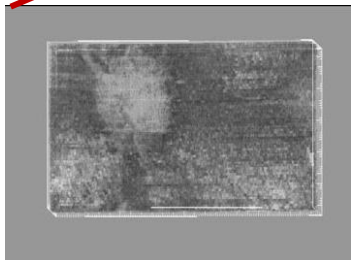
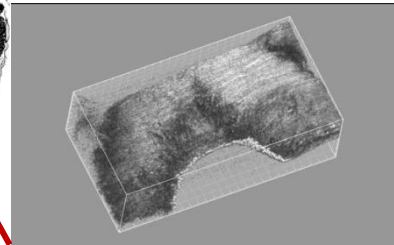
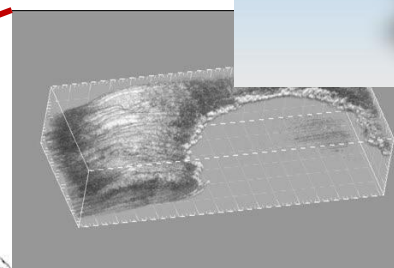
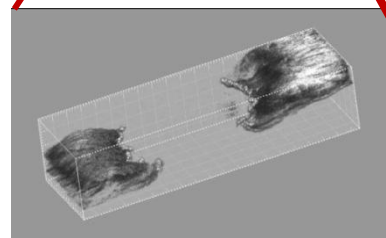
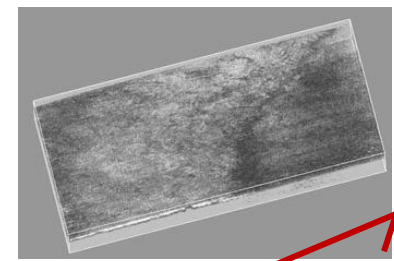
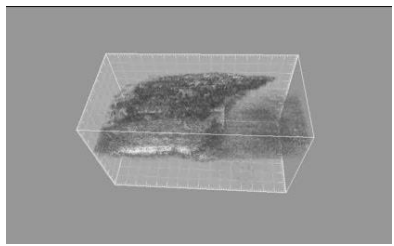
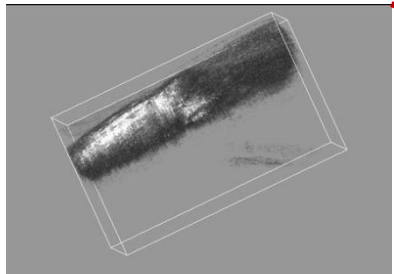
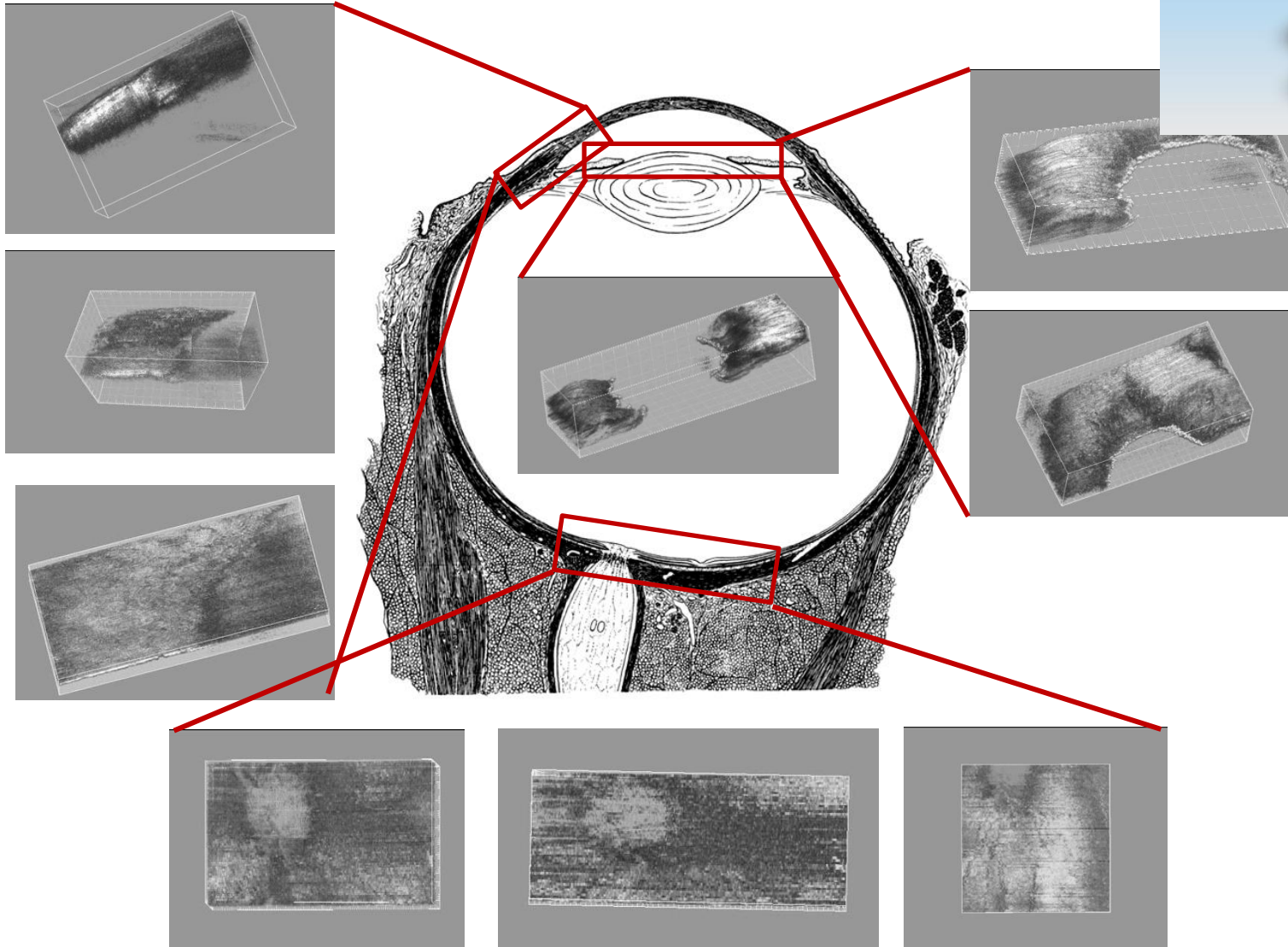
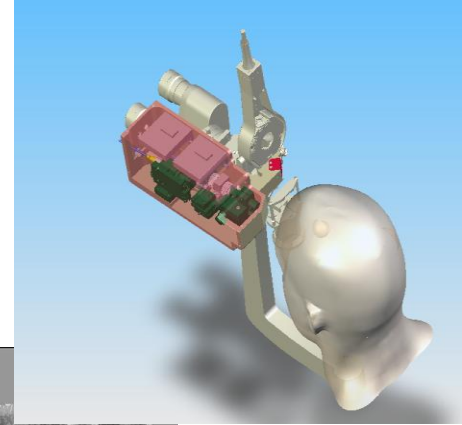
# Measurable sites



5 kHz

1 kHz

# OCT Slit Lamp



# First Clinical Experience after 5 weeks

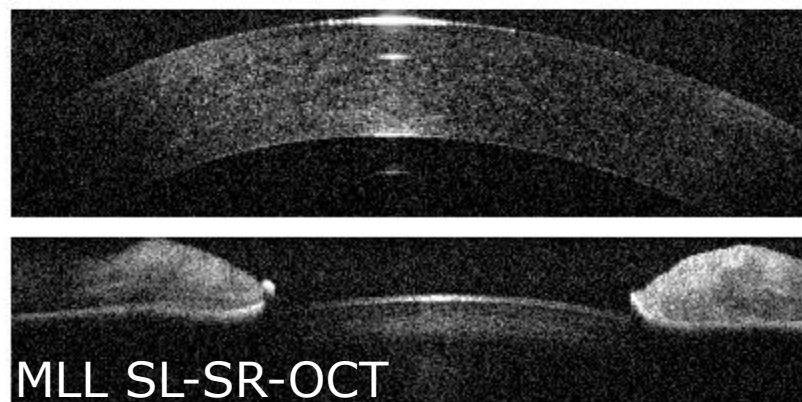
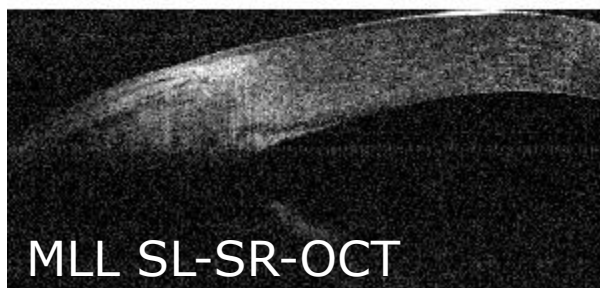
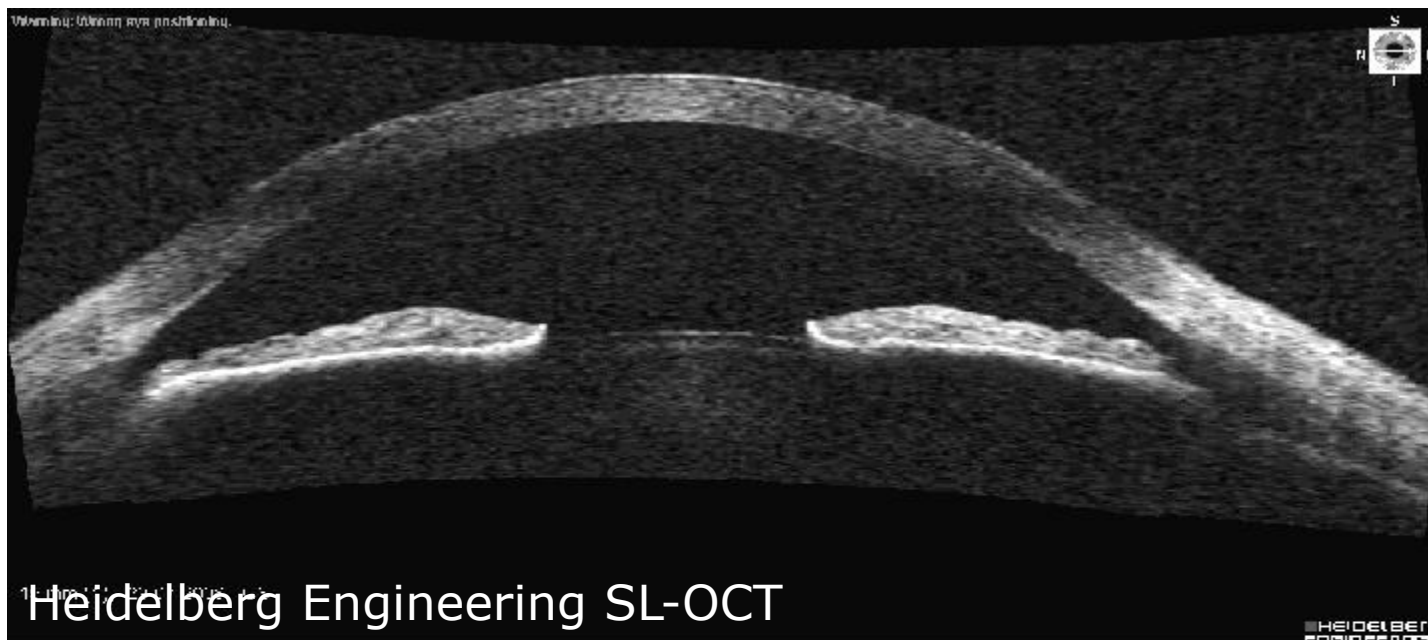
## Design of the Study:

Comparison of OCT images from normal tissues and pathologies with SL-SR-OCT with Heidelberg Engineering SL-OCT (AS) and Zeiss Stratus 3 (PS)

## Number of Patients investigated:

AS:	conjunctiva	10 (11)	
	cornea	10 (12)	
	eye lid	10	
	Ahemd Valve	7	
	filtering bleb	6	
	corneal scar	7	
	anterior chamber angle	10 (12)	
PS:	macular	10 (15)	
	papilla	10 (15)	
	retinal vessel	10 (11)	
	macular edema	10 (15)	
	papilla during glaucoma	5 (9)	
	central venous occlusion		2 (4)

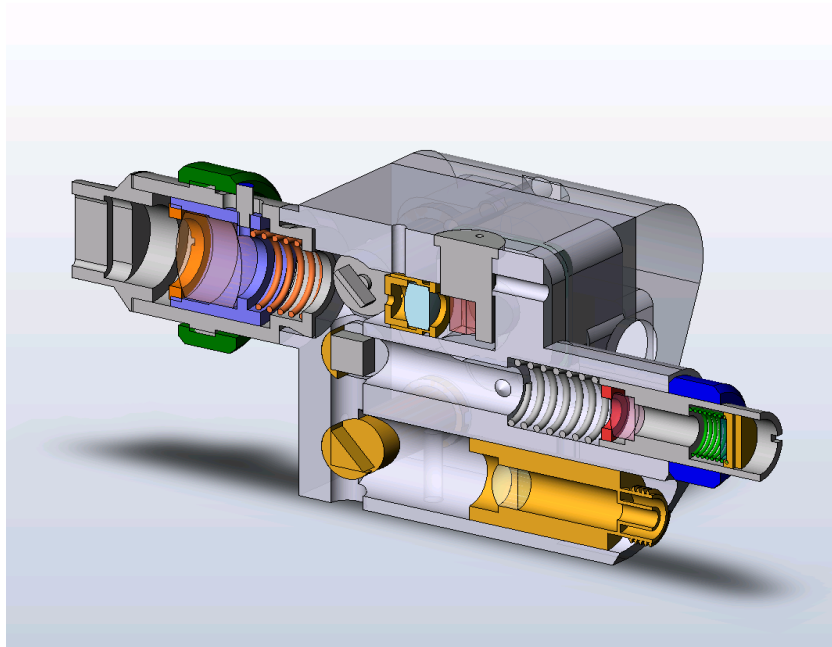
# Anterior Segment



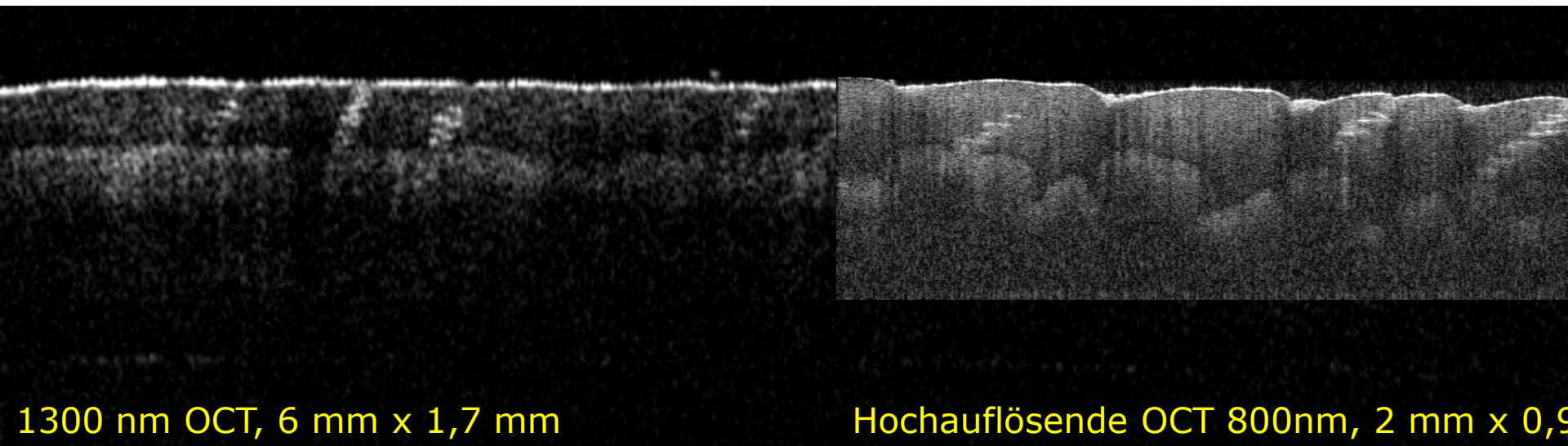
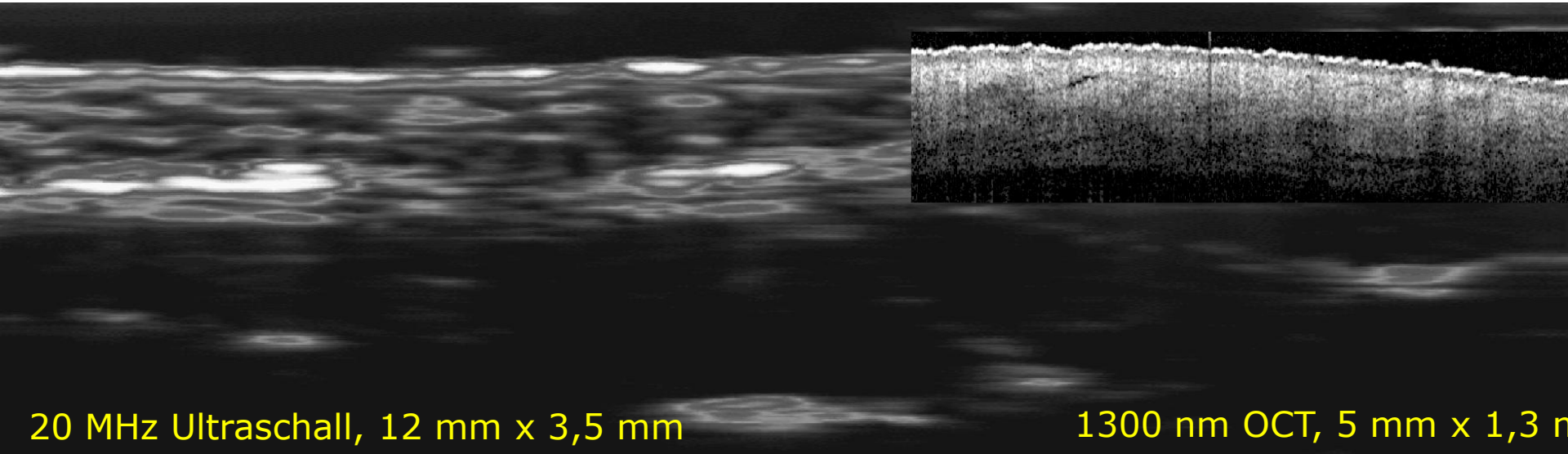


# Applications devices

## OCT Scanner for the Skin



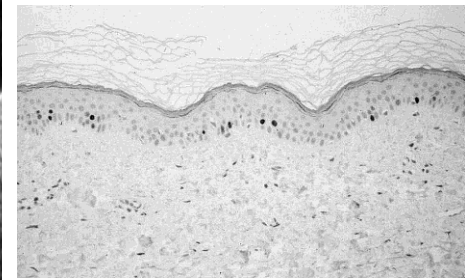
# Skin



# Irritation of the skin

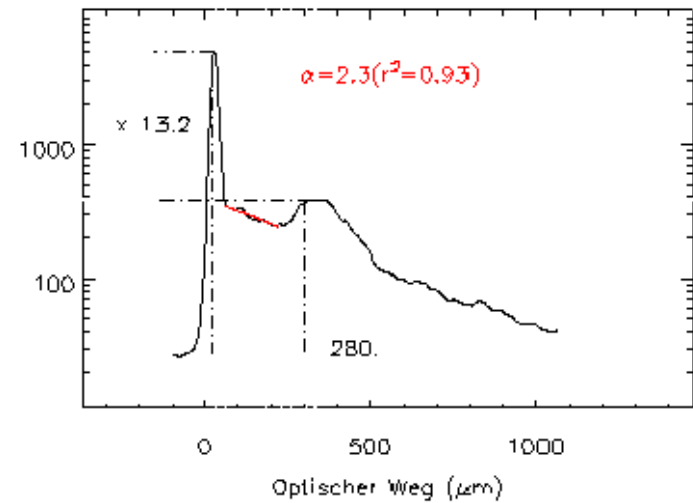
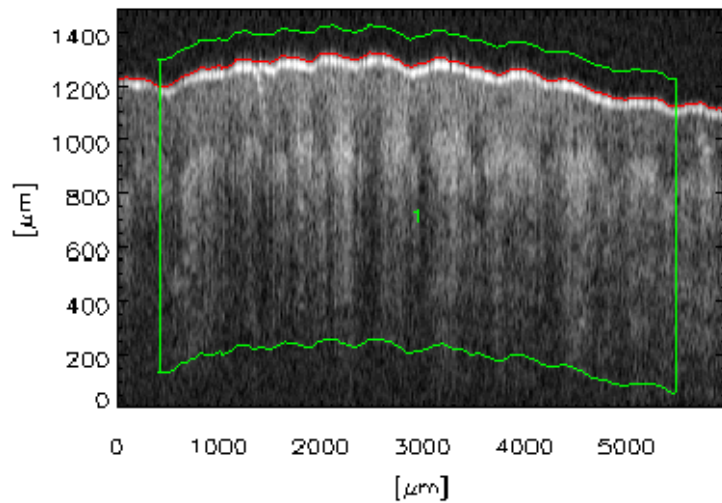
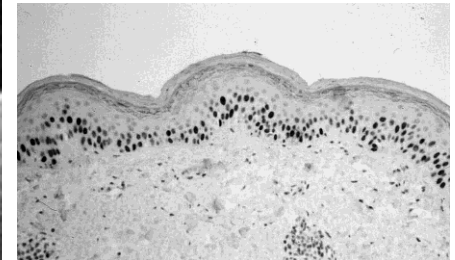
before irritation

4 mm x 1.8 mm



4 days after irritation

4 mm x 1.8 mm



# Neurosurgical resection of brain tumors

problems in intraoperative detection of residual tumor

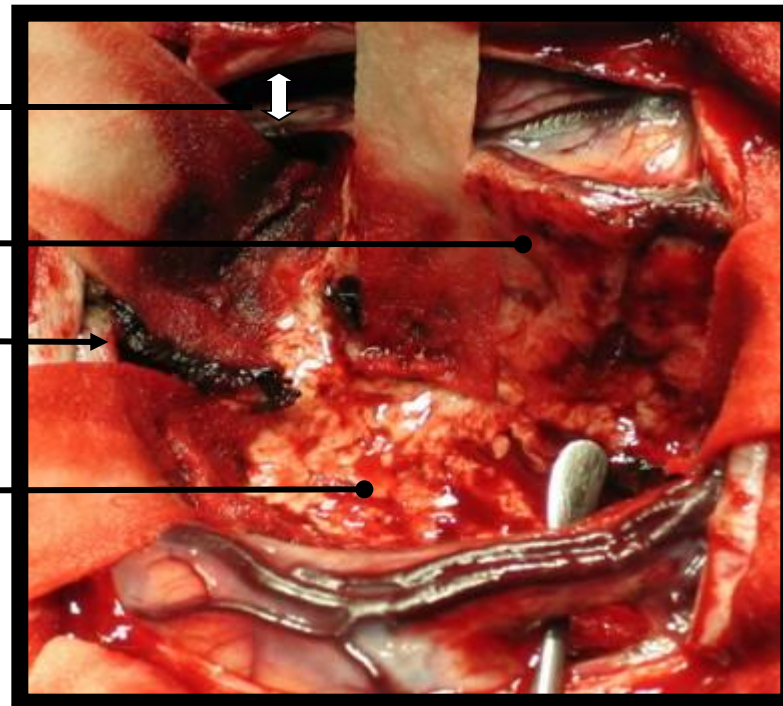


volume shifts during resection  
“brain shift“

hyperaemia of the resection cavity

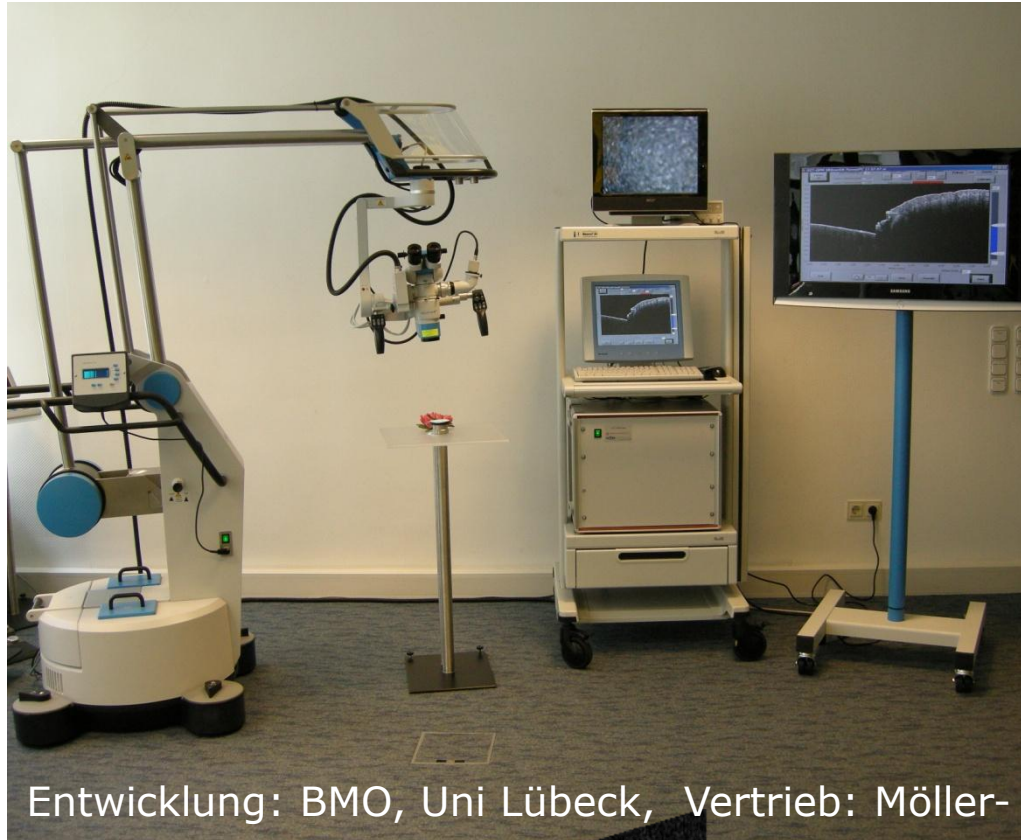
haemostatic materials

blood and  
tissue contusion



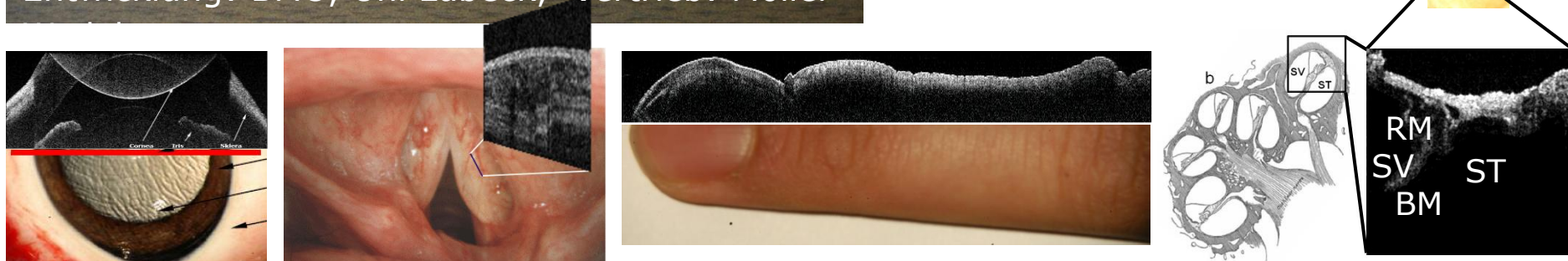
low inherent optical contrast of  
Tumor tissue – invaded brain –  
adjacent normal brain

# Intraoperative OCT mit einem Operations Microskop



Die Mikrochirurgie benutzt bisher ein 3 –30 fach vergrößerndes Operationsmikroskop zur Darstellung der Gewebeoberfläche.

OCT erweitert den Blick des Chirurgen um die 3. Dimension durch Darstellung von Strukturen unter der Gewebeoberfläche.

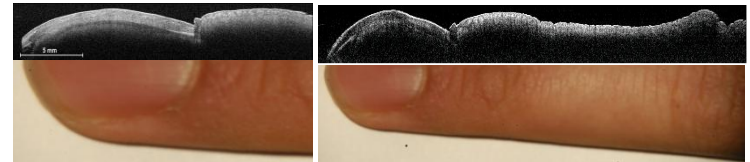


# The OCT Operating Microscope

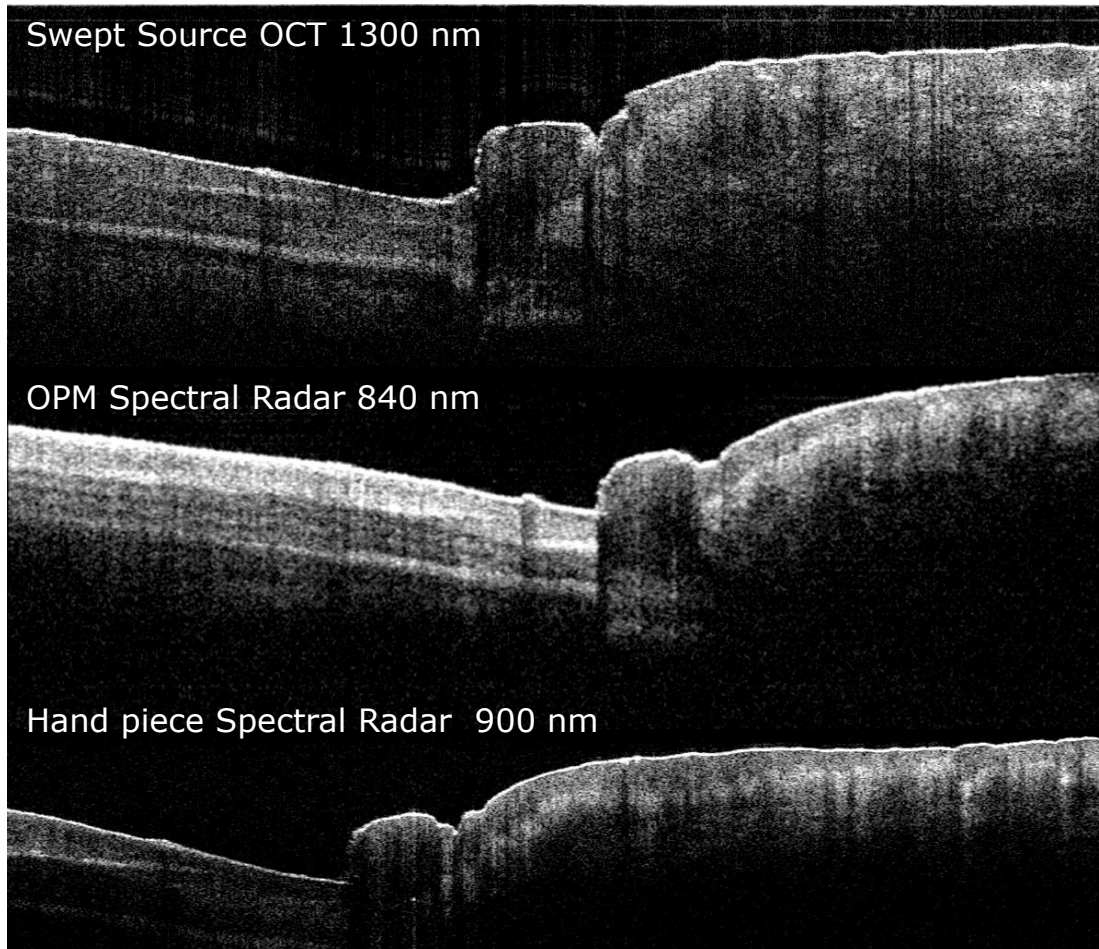


Surgical microscope:  
Möller-Wedel Hi R 1000

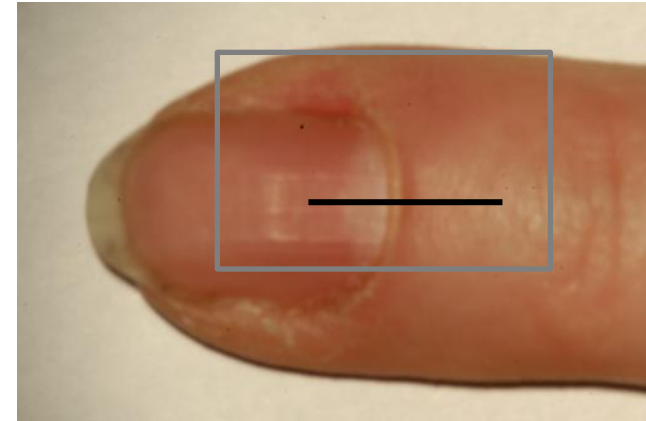
OCT-Device:  
selfbuild Spectral Radar  
central wavelength 840 nm  
axial resolution (air) 11  $\mu\text{m}$   
lateral resolution 25  $\mu\text{m}$   
A-scan rate 1,220/sec  
(30,000/sec)



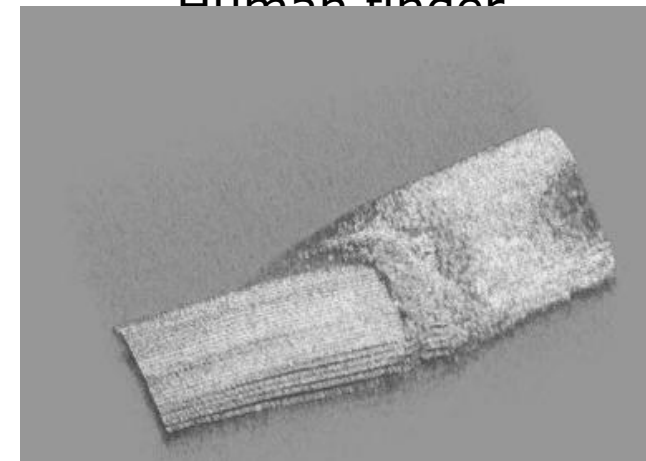
# Comparison of Wavelengths



B-Scan, 1 kHz



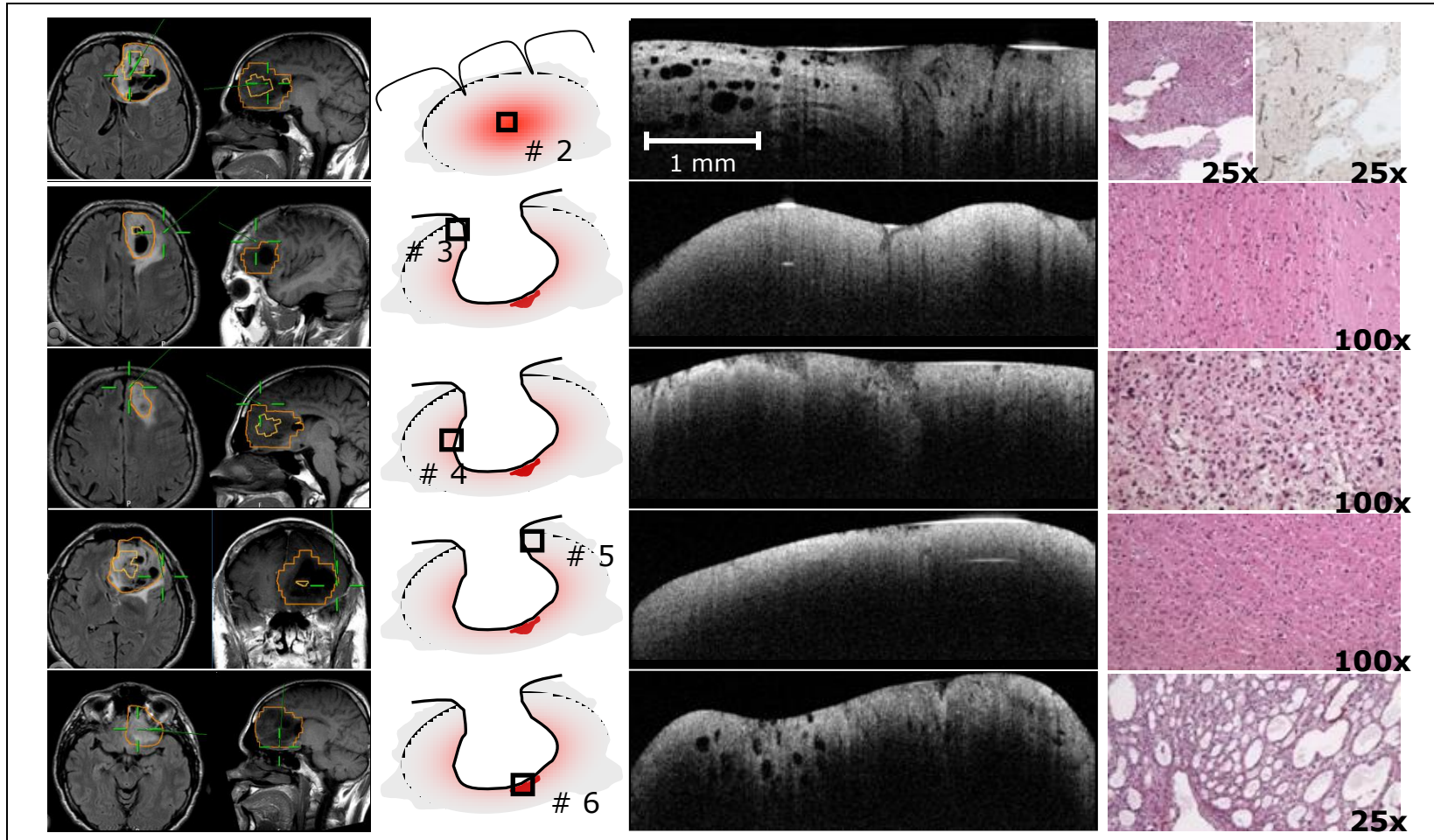
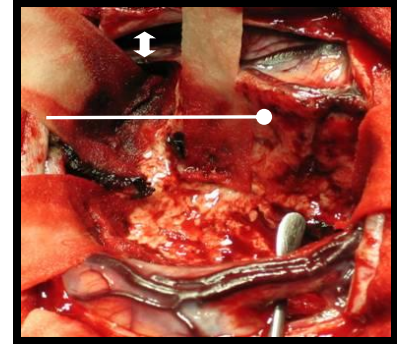
Human finger



C-Scan, 30 kHz

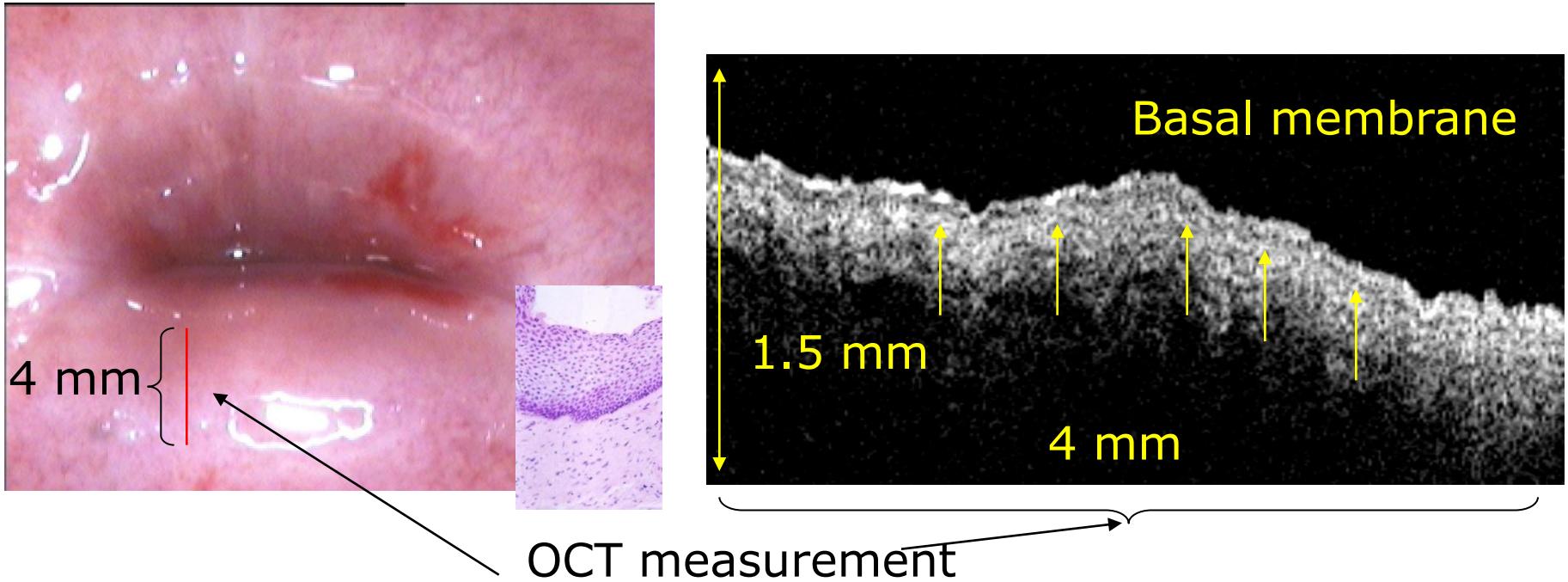
# Ex-vivo experiments

OCT can visualize brain tumor tissue



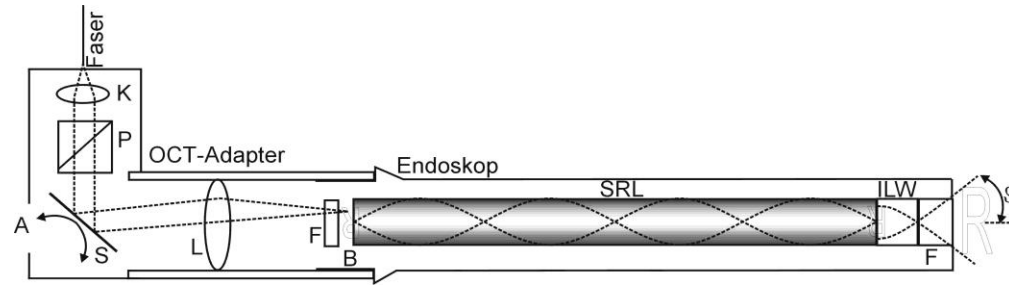


# OCT-Colposcopy

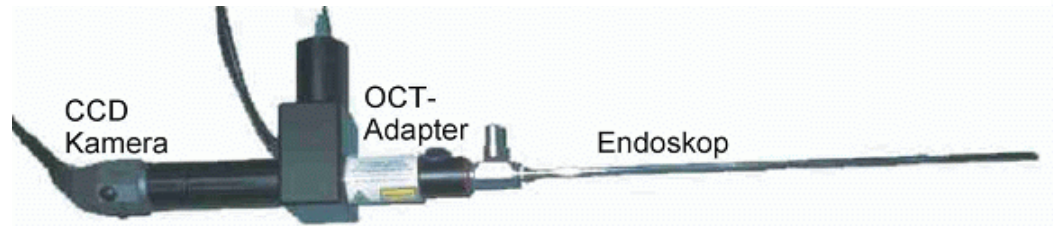


Colposcopy:	Squamous epithelium
OCT image:	Squamous epithelium, Tissue layer and basal membrane are visible.

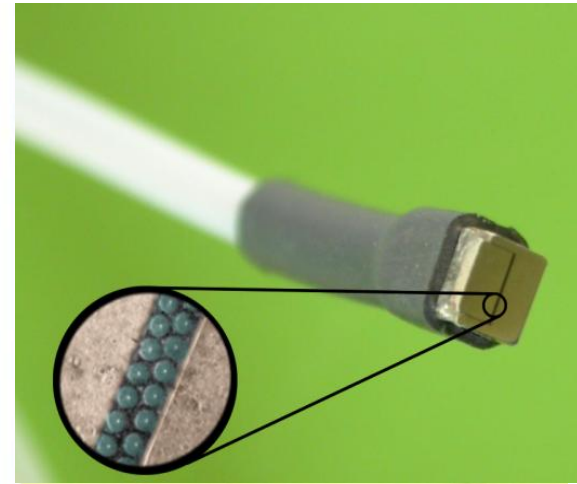
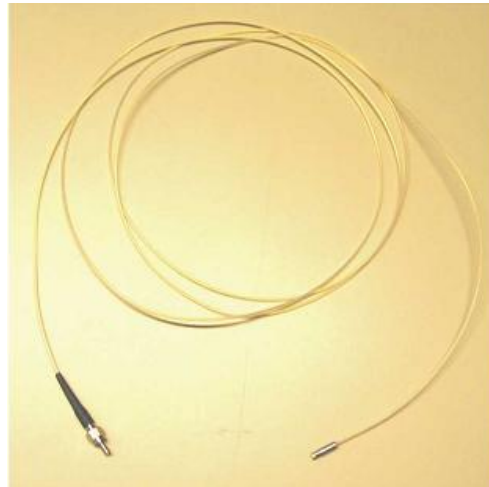
# OCT-Endoscopy



rigid



flexible



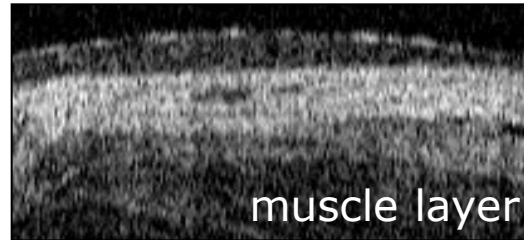
Wolf GmbH, MLL GmbH

# OCT of bladder tumours



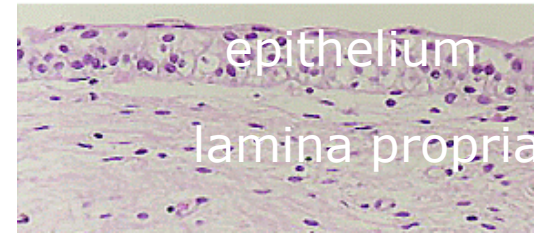
1 mm

2,2 mm



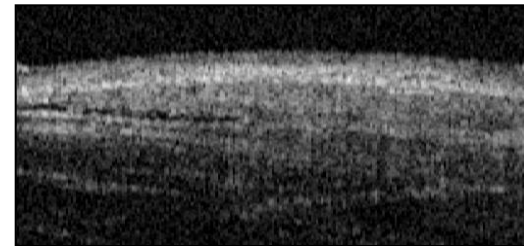
muscle layer

Normal urothelium

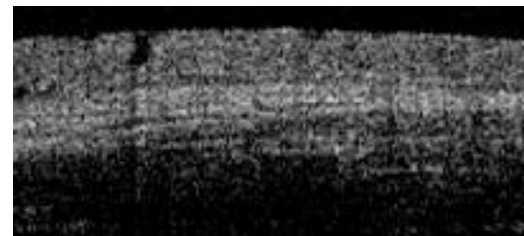
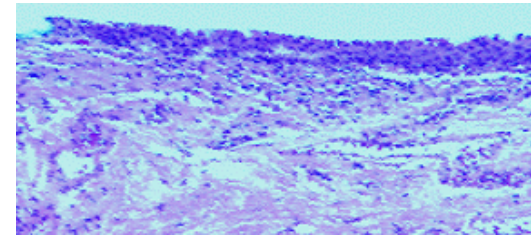


epithelium

lamina propria



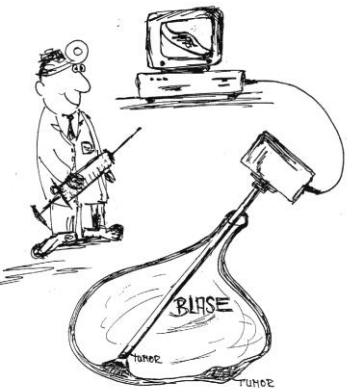
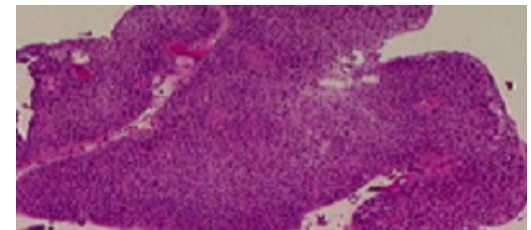
Cystitis



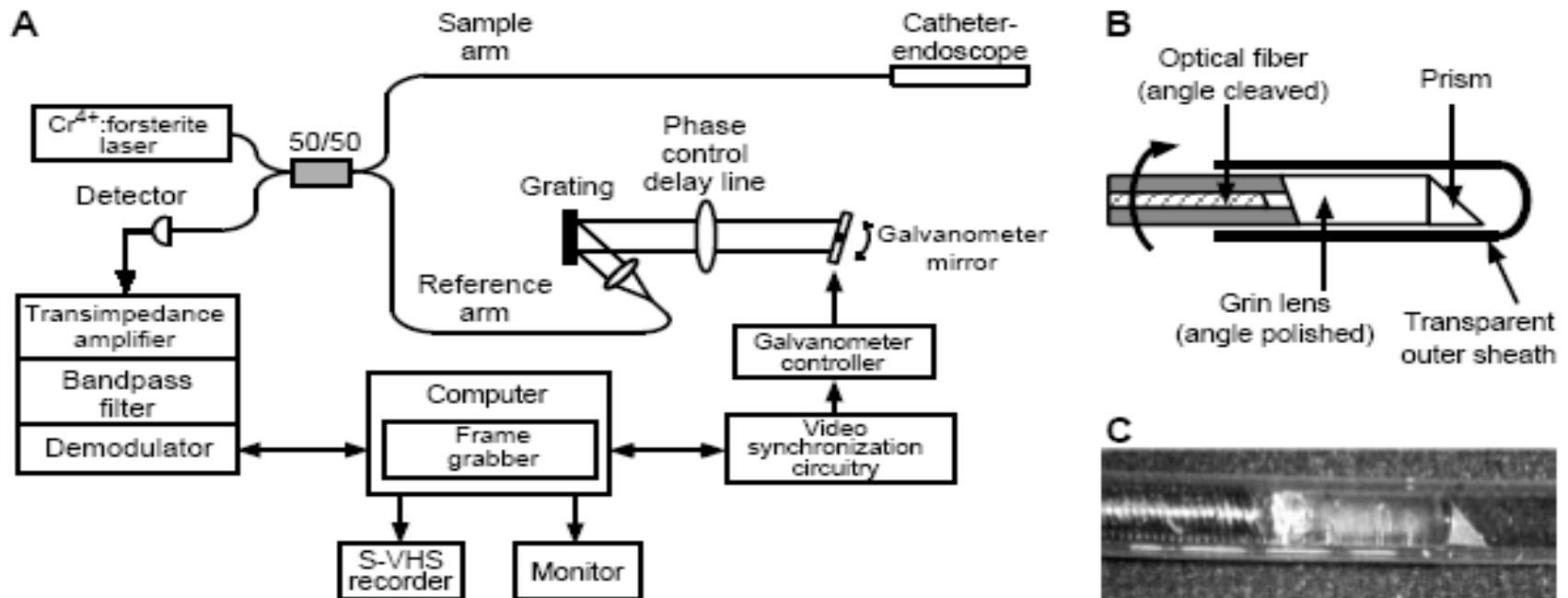
Metaplasia



Papillary tumor

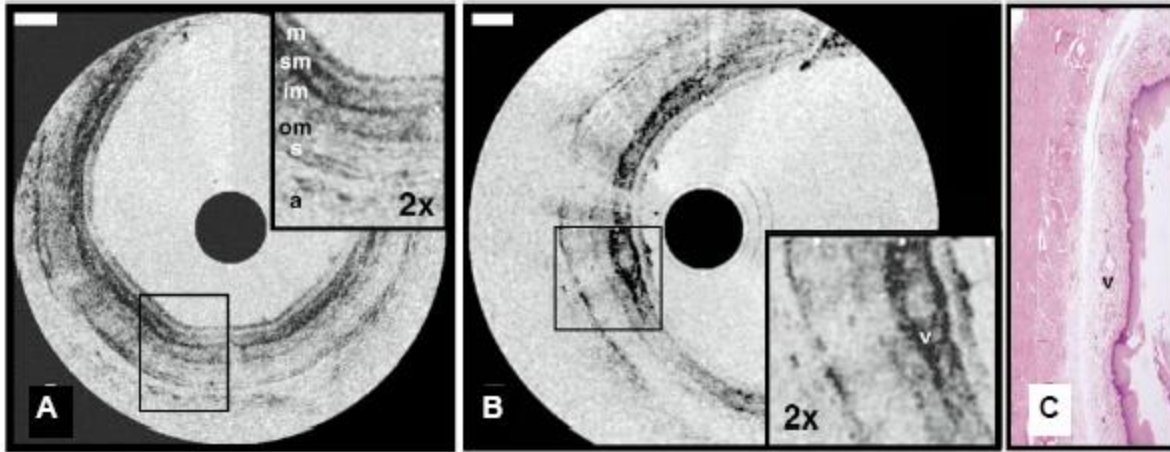


# OCT Endoscope



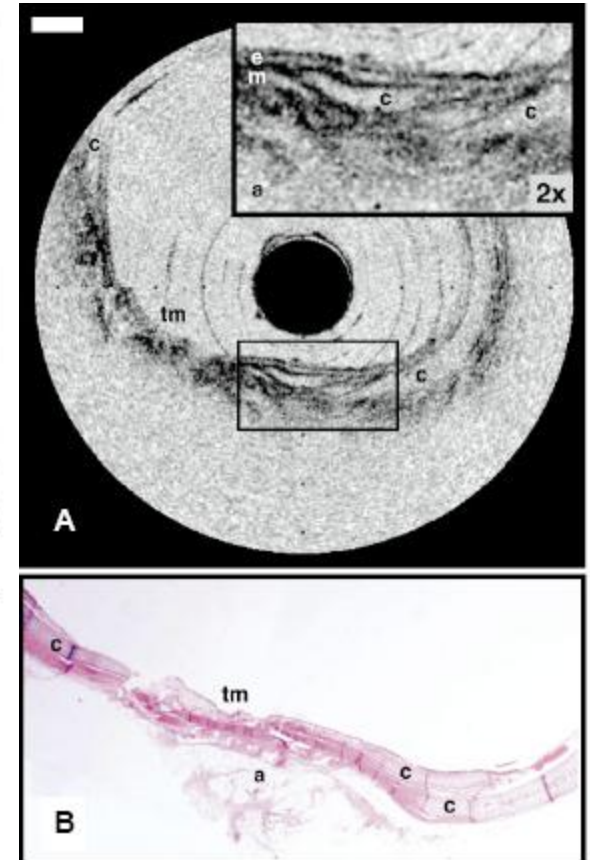
**Fig. 1.** (A) Schematic of the high-speed endoscopic OCT system. (B) Schematic of the distal optics of the second-generation OCT catheter-endoscope. The angle cleaving the optical fiber and the angle polishing the GRIN lens minimized internal reflections. (C) Photograph of the OCT catheter-endoscope distal optics.

# Endoscopic OCT Images



**Fig. 2.** OCT imaging of the rabbit esophagus in vivo (22). **(A)** This image allows visualization of the esophageal layers of the rabbit including the mucosa (m), the submucosa (sm), the inner muscular layer (im), the outer muscular layer (om), the serosa (s), and the adipose and vascular supportive tissues (a). **(B)** A blood vessel (v) is apparent within the submucosa of the esophagus. **(C)** Corresponding histology for (B) (H&E stain). Bars, 500  $\mu\text{m}$ .

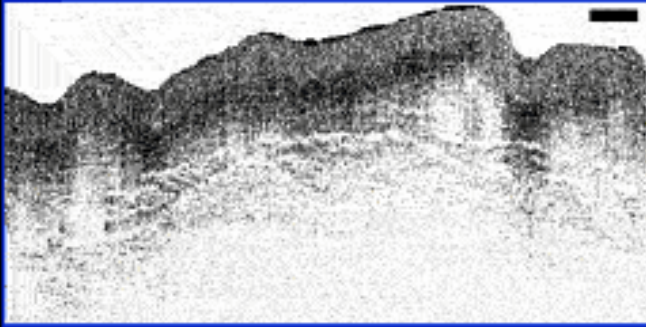
Tearney GJ, Brezinski ME, Bouma BE, et al. [In vivo endoscopic optical biopsy with optical coherence tomography](#) SCIENCE 276 (5321): 2037-2039 JUN 27 1997



**Fig. 3.** OCT imaging of a rabbit trachea in vivo (22). **(A)** This image allows visualization of distinct architectural layers, including the epithelium (e), the mucosal stroma (m), cartilage (c), and adipose tissue (a). The trachealis muscle (tm) can be easily identified. **(B)** Corresponding histology (H&E stain). Bar, 500  $\mu\text{m}$ .

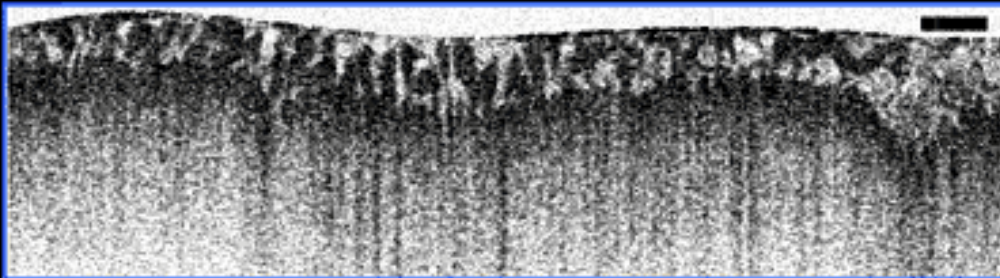
# Applications in cancer detection

*Normal esophagus*



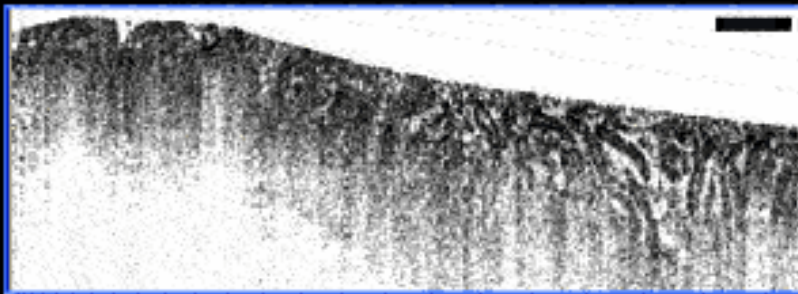
Squamous epithelium

*Normal colon*



Columnar epithelium: crypts

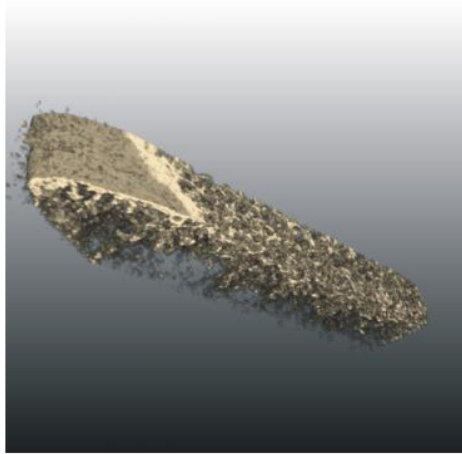
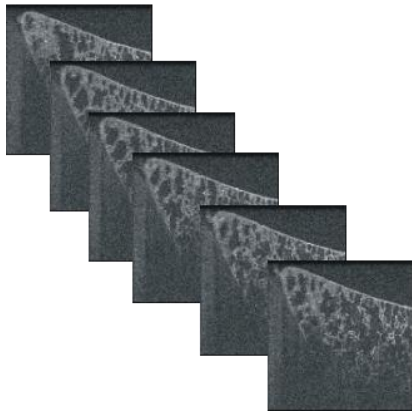
*Carcinoma*



Loss of organization

# Microscope Probe

- 2D, 3D, and Imaging
- Surface Topography
- 2.5x2.5mm Imaging Range
- Axial Resolution of  $8\mu\text{m}$
- x, y, and z Adjustment



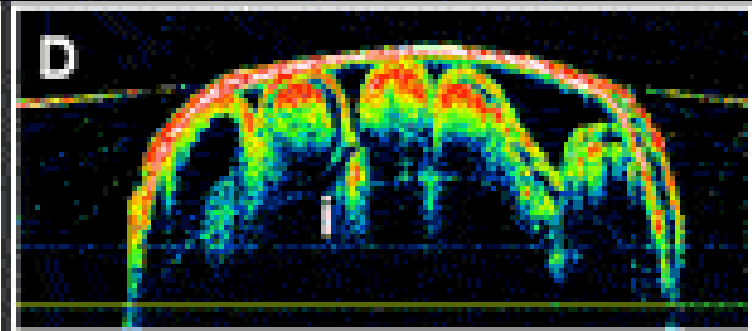
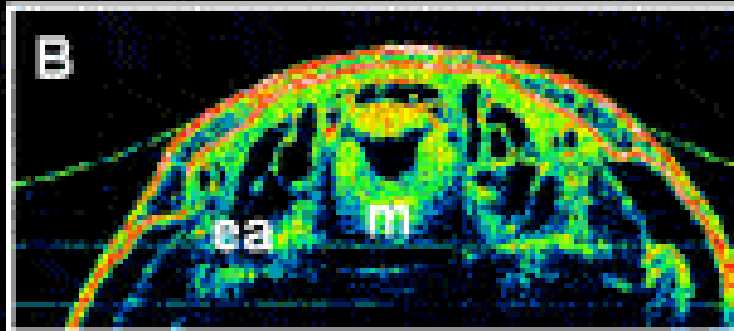
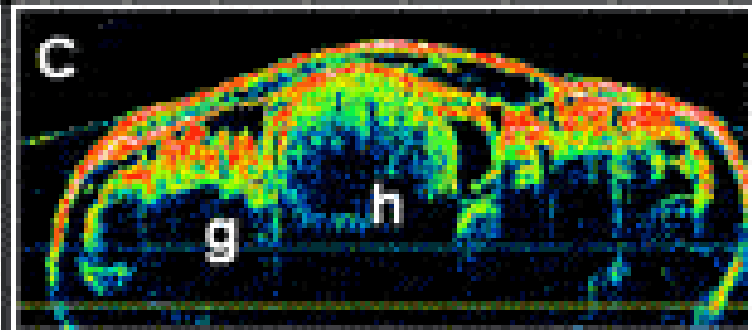
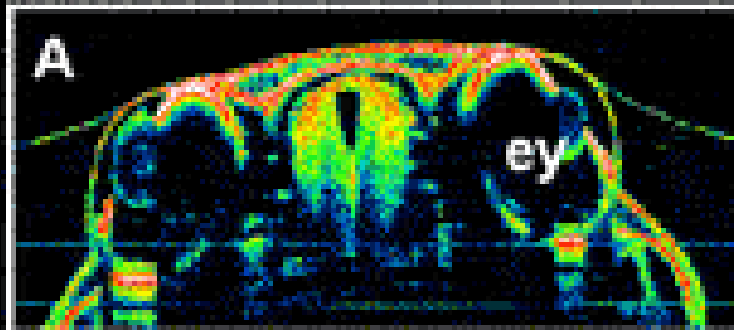
# Applications in developmental biology

## OCT in Developmental and Molecular Biology

### Leopard Frog (*Rana pipiens*) Tadpole

Dorsal

Ventral



Reflectance

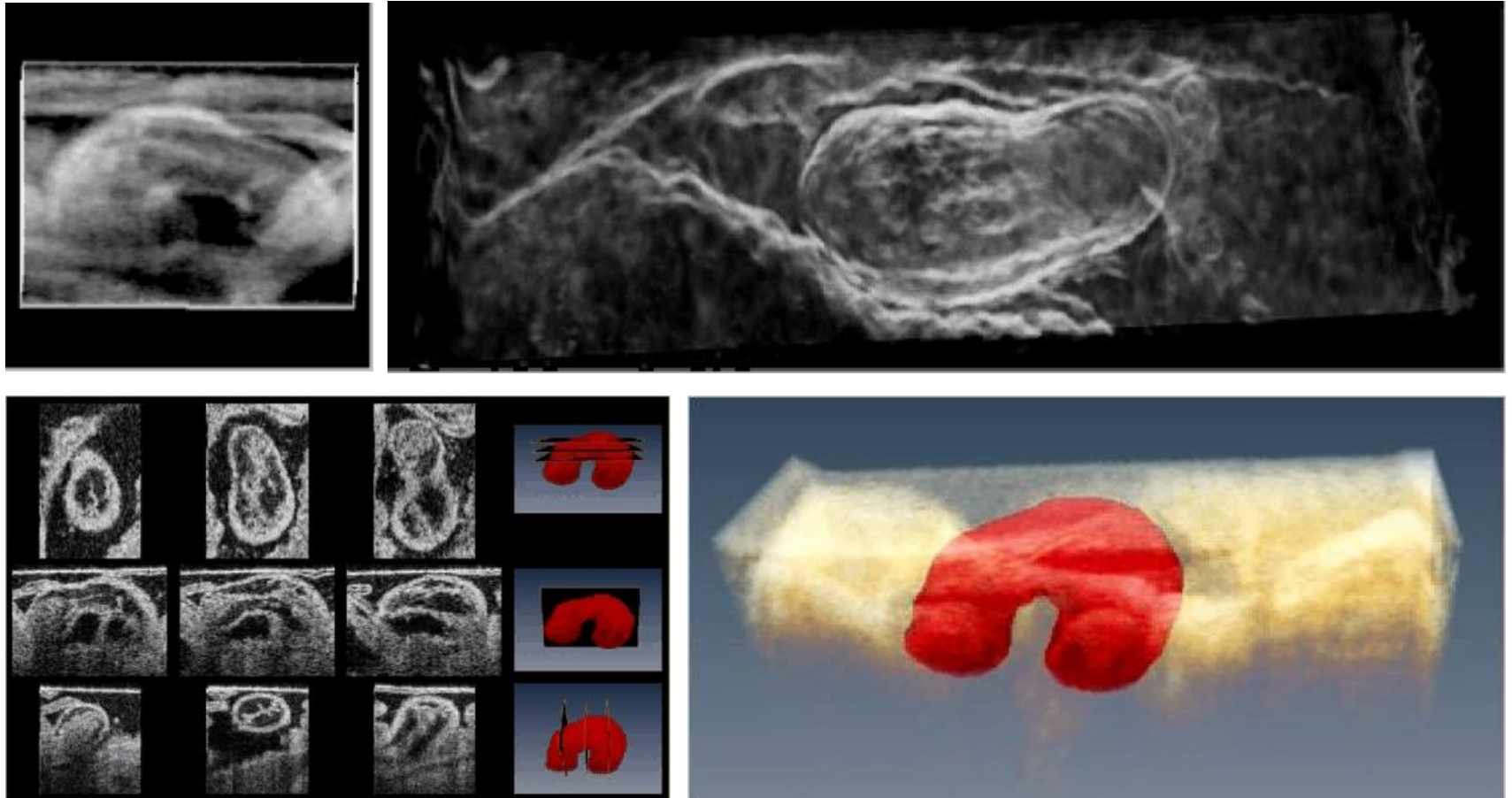


1 mm

Ey=eye; ea=ear; m=dedulla; g=gills; h=heart; i=intestine



# Ultrahigh-speed optical coherence tomography imaging and visualization of the embryonic avian heart using a buffered Fourier Domain Mode Locked laser



# Ultra-high resolution OCT

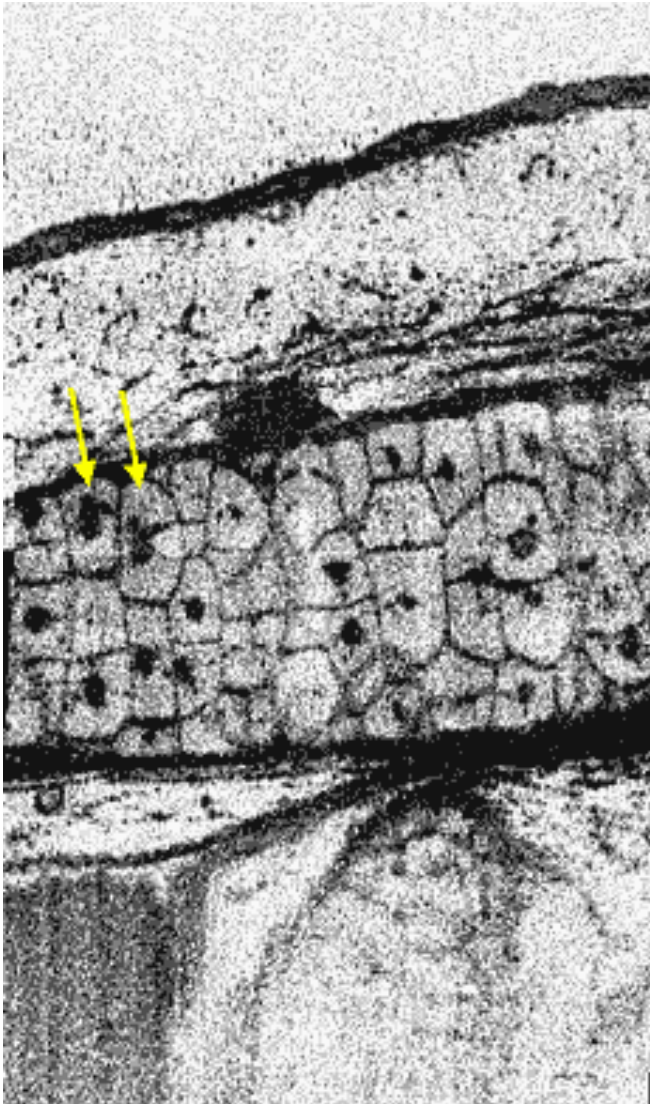
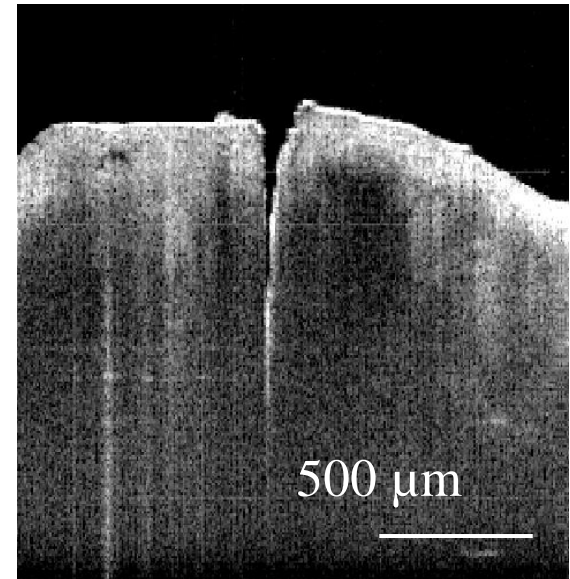
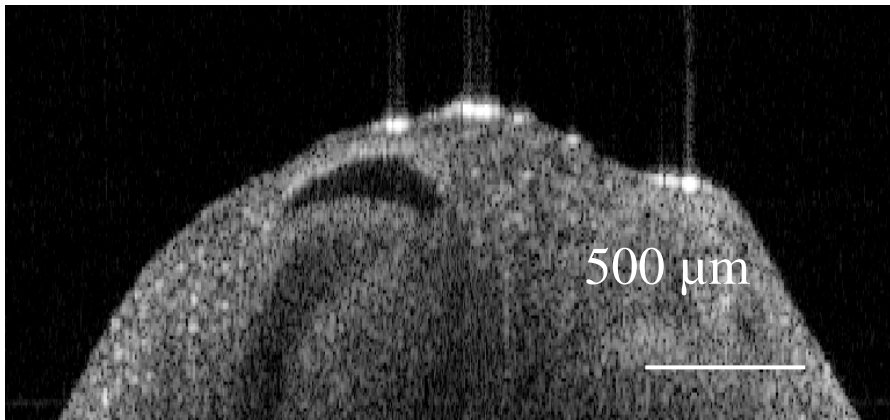
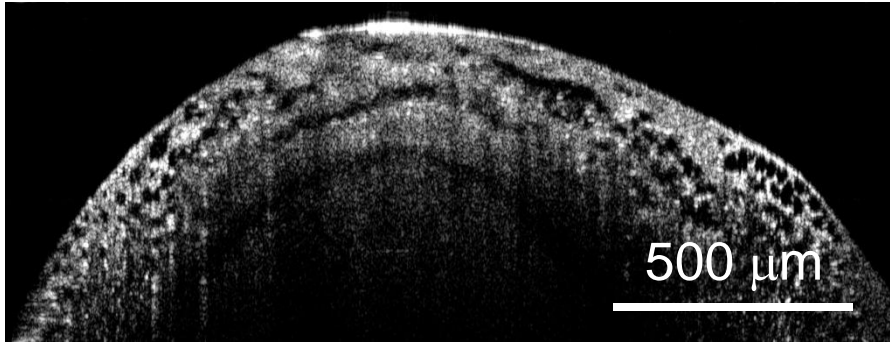


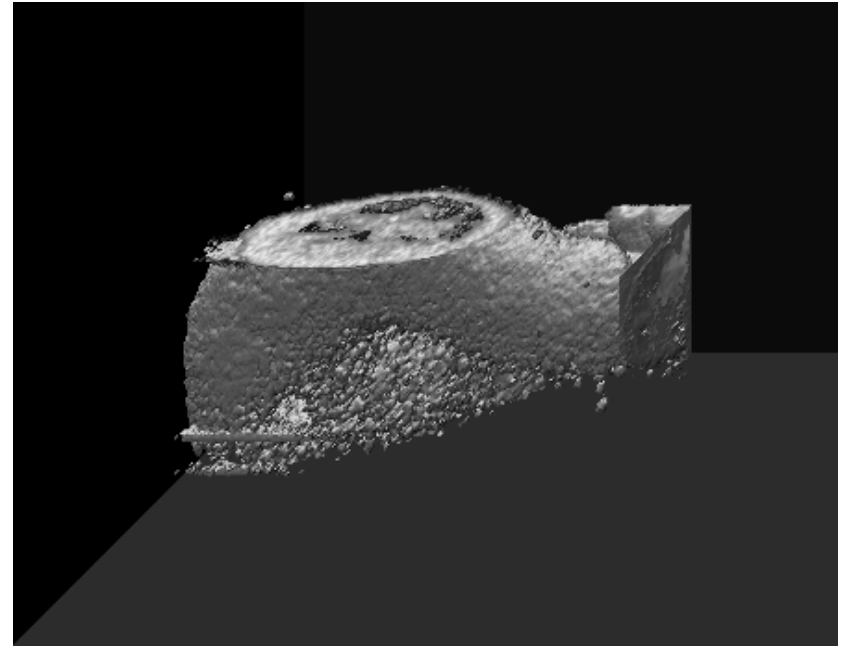
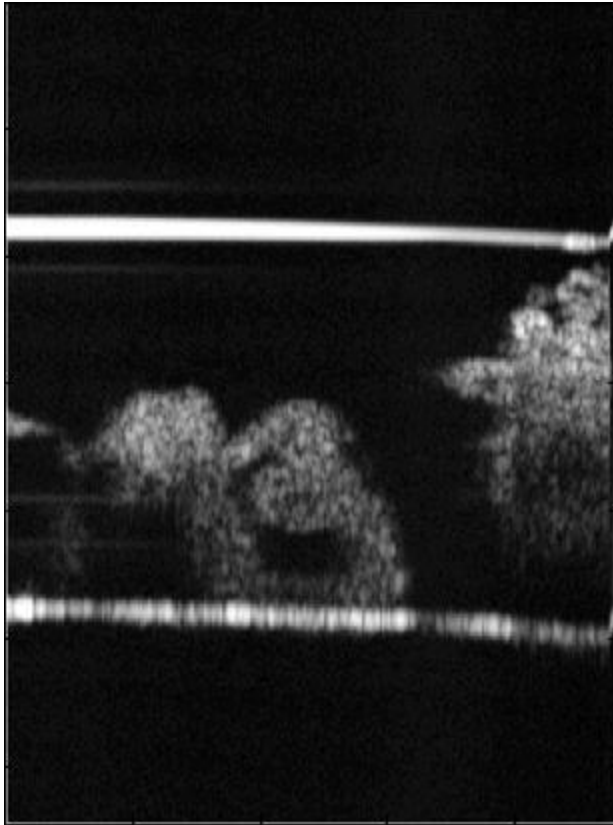
Image through the skin of a living frog tadpole  
Resolution: 3  $\mu\text{m}$

# Some OCT Images



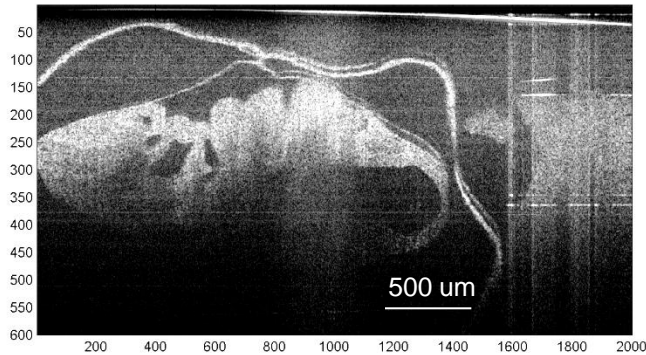
Pig nerve imaged by swept source at Caltech biophotonics group

# 3D OCT Scan Movie of Chicken Embryo Heart

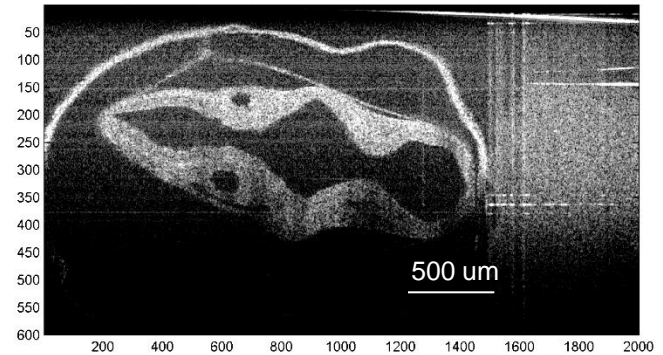


# Some OCT Images

Z=7.42 mm

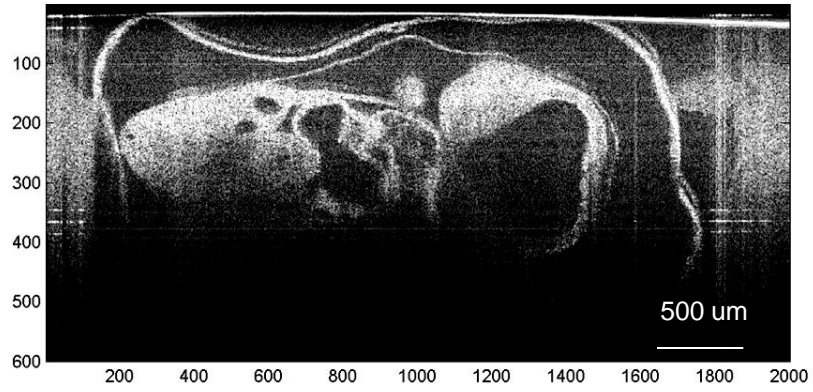


Z=8.17 mm

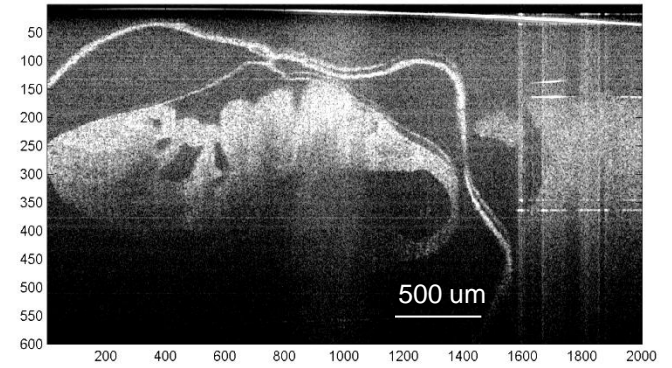


10.8 days old mouse embryo imaged by swept source  
OCT at Caltech Biophotonics group

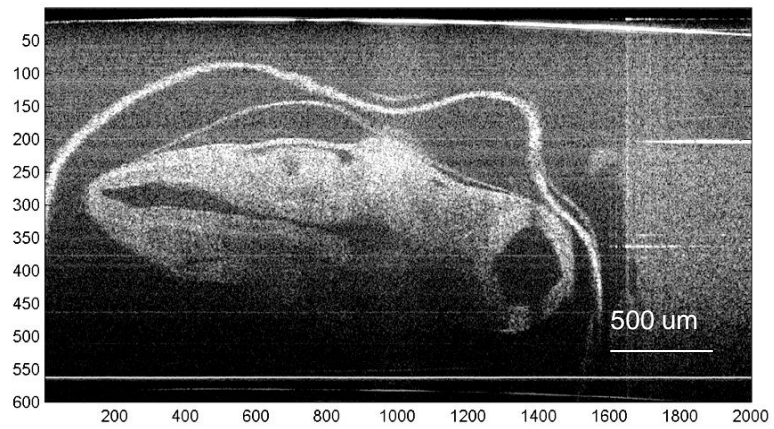
Z=7.17 mm



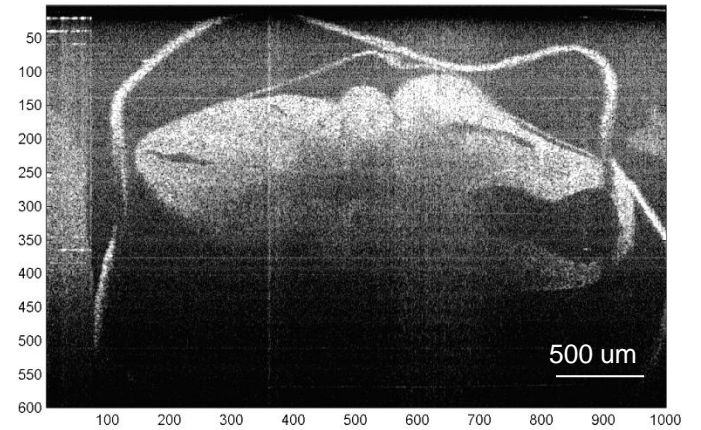
Z=7.42 mm



Z=7.92 mm

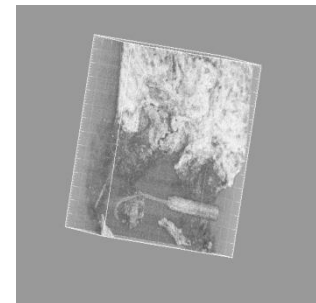
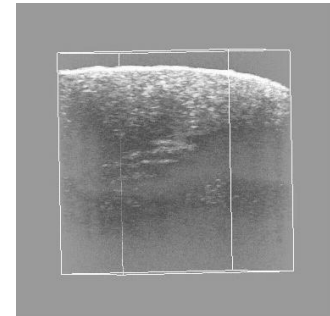


Z=7.67 mm



# Why fast OCT?

- Real-time imaging
- 3-D imaging (C-scans)
- Speckle reduction by averaging of B-scans
- Phase-sensitive imaging (Doppler)
- Functional OCT
- Intra-operative OCT
- On-Line therapy controll



# Conclusion

- OCT provides unique imaging possibilities for monitoring cell and tissue growth in few millimeter depth with a resolution of cell groups.
- OCT is the fastest optical technology for 3-D imaging
- OCT can visualize submicrometer displacements
- OCT works in a non-contact mode and can be combined with microscopy or other optical imaging modalities
- **However**, this potential was barely exploited; partly due to former limitations of the OCT technology and partly due to the lack of understanding of the OCT technology by researchers and companies involved in medical imaging and diagnosis.
- Commercially available system and progress in functional OCT imaging (polarization sensitive, Doppler OCT, and contrast agents) will lead to a wide range of new applications.



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