Medical Image Processing in a Clinical Environment – A Medical Physicists Perspective

Wolfgang Birkfellner
Center for Medical Physics and Biomedical Engineering, Medical University Vienna
www.meduniwien.ac.at/mip

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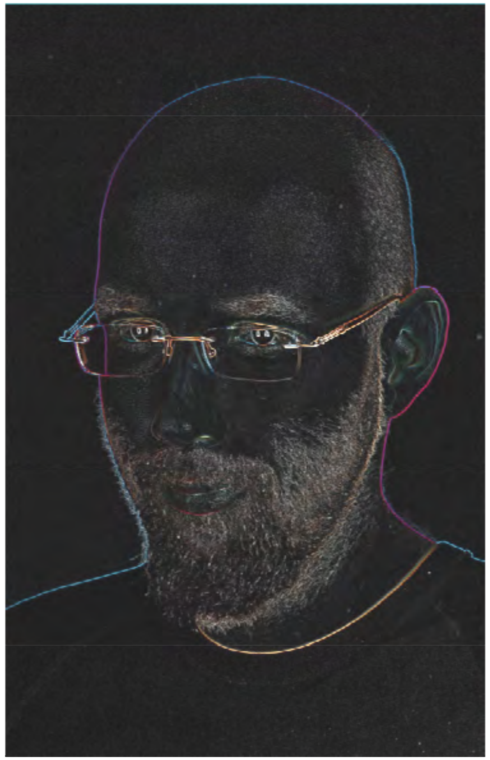
Some musings ...

Given my research background, I can only try to provide some insight on:

- What is the real challenge in developing an image processing solution for the medical field?
- What is being used and asked for in terms of medical image processing in a clinical environment?
- A few examples of research in medical imaging

… since my knowledge of Computational Algebraic Topology is – to tell the truth – a little bit frail ...

Who is the bald guy?

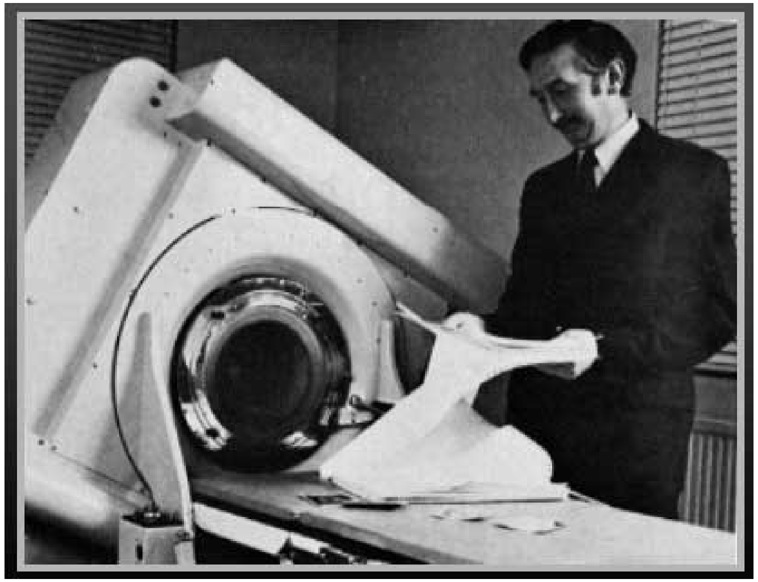


- Born in 1970 in Steyr/Upper Austria.
- Humble high school career in Vienna/Austria and Germany until 1990.
- Student of Physics from 1990-1996, MSc in Theoretical Physics
- PhD-Student (and later on Assistant Professor) at the Center for Medical Physics and Biomedical Engineering at the Medical University Vienna until 2000.

...

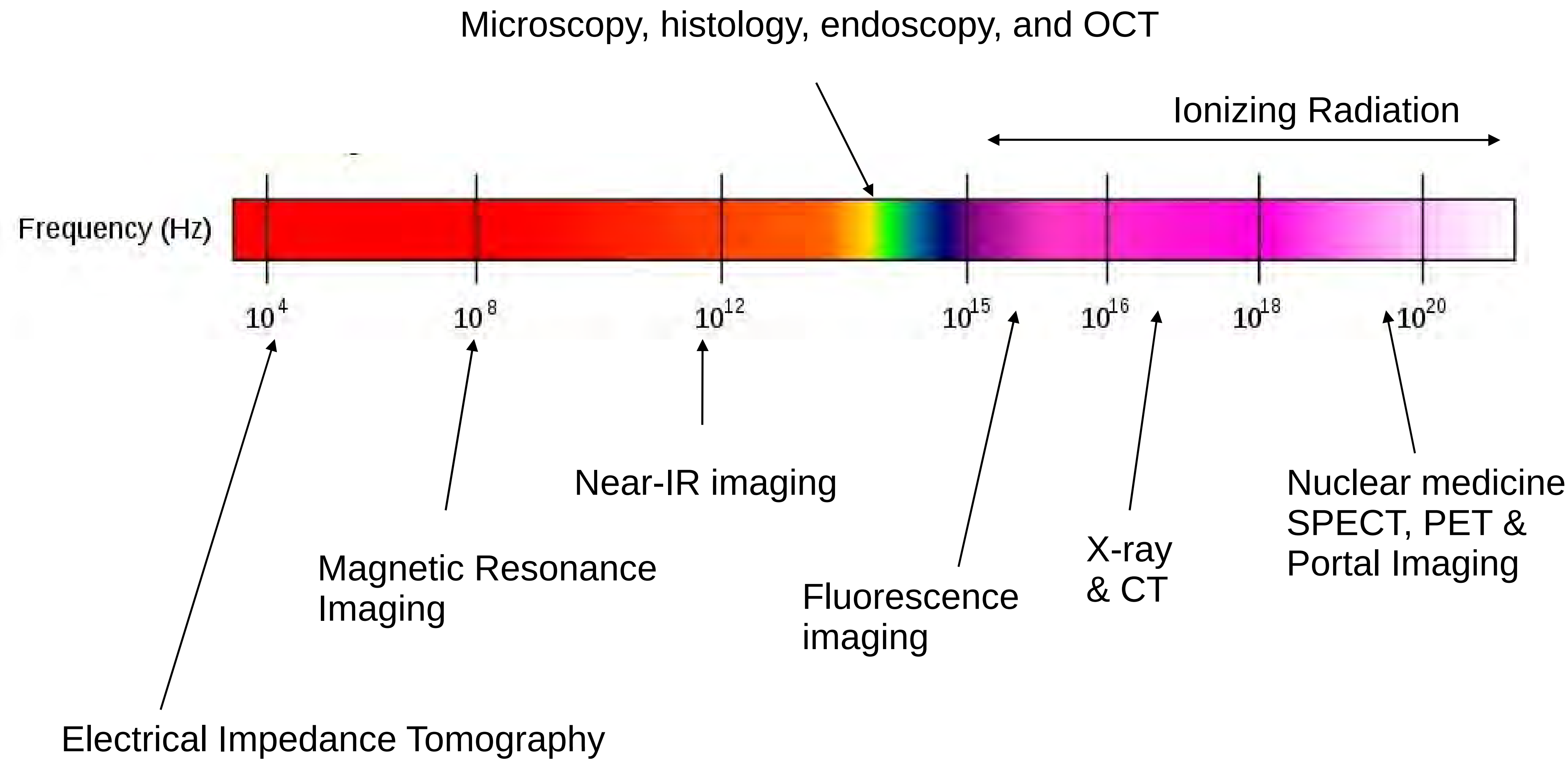
- Senior researcher at the Cantonal Hospital Basle at the Dept. of Trauma Surgery from 2001-2003
- Senior reader in Medical Physics (back at MU Vienna) in 2004, including the nobilitation to the position of Associate Professor of Medical Physics
- 88 papers and reviewed proceedings articles, cited approx. 1050 times in the literature, total grant money acquired as PI or co-applicant: ~ 1.5 M€
- www.meduniwien.ac.at/mip

What is Medical Physics?



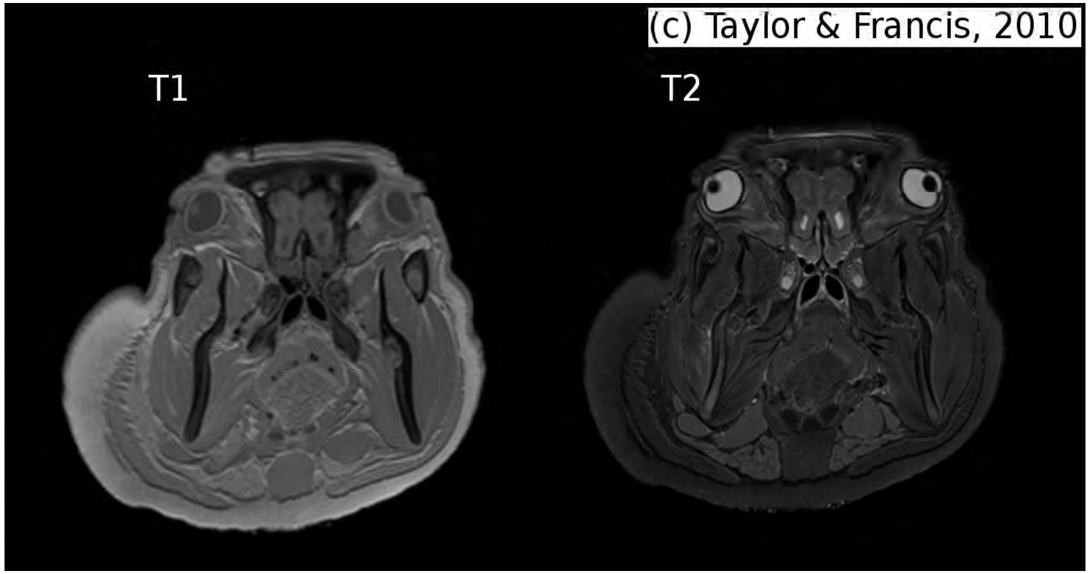
- *Medical Physics* is an applied branch of physics mainly dealing with the *diagnostic* and *thera-peutic* use of *electromagnetic radiation*.
- Medical Physicists usually work in hospitals, research institutions, and in the medical device manufacturing industry.
- While physics is closely linked to the development of medical imaging devices, the treatment of patients in radiotherapy is the field where most medical physicists can be found ...

… and what is special about medical imaging?

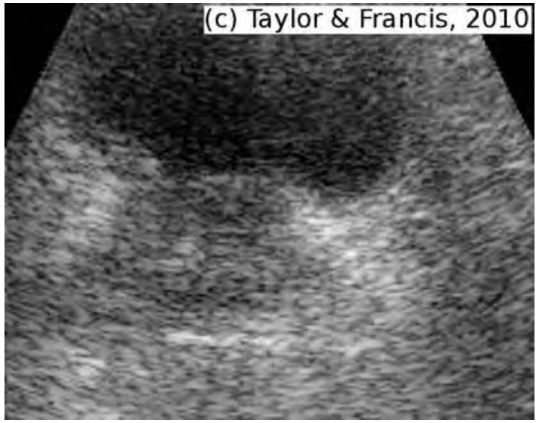


Non-EM based imaging: Ultrasound

… some examples

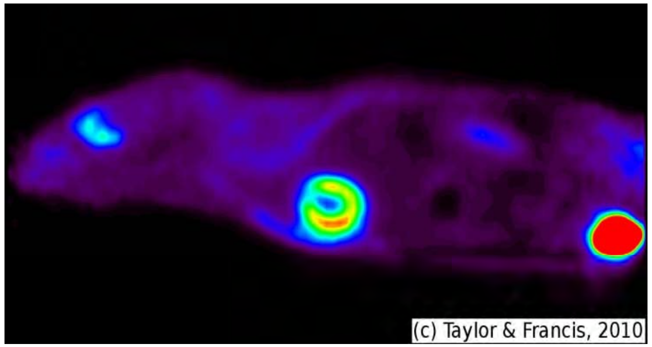


Pig skull, MR-imaging

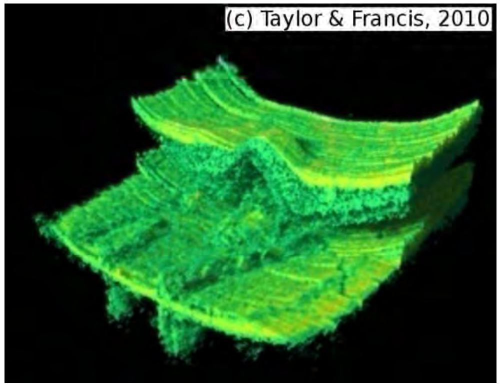


Prostate, B-mode US

X-ray, Angiography



Small animal PET



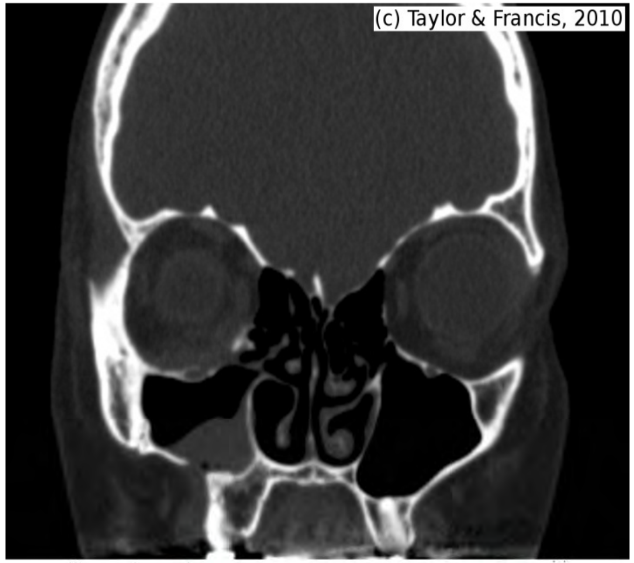
3D-visualization of retinal layers, OCT

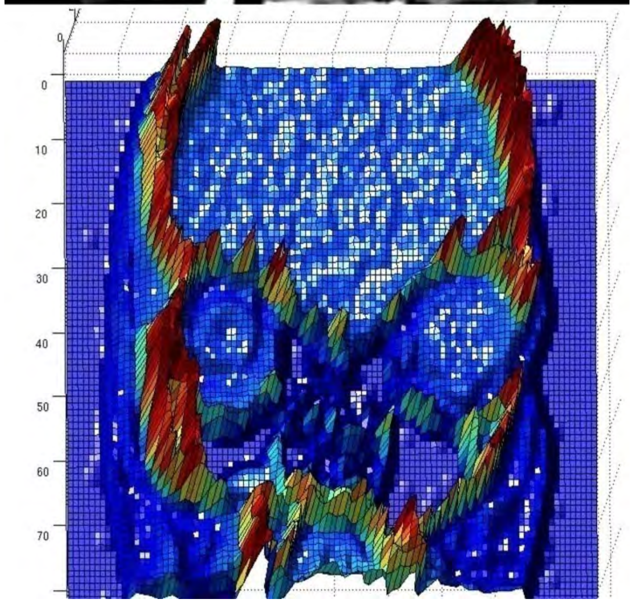
Some special issues ...

- Medical images **do not** reflect *patient anatomy* – they are *physical data* on some special tissue properties …
- Computed tomography ~ Mass number
- Magnetic resonance ~ Density of protons
- Ultrasound ~ mechanical density of tissue
- Nuclear medicine ~ Metabolism of substances marked with radionuclides

… and some consequences ...

- Data are highly dependent on acquisition routines
- Data are usually 12-16 bit
- Data are usually 3D and must not be considered a “stack of slices” - as a matter of fact, most machines nowadays do no longer acquire slices ...





Medical image processing research...

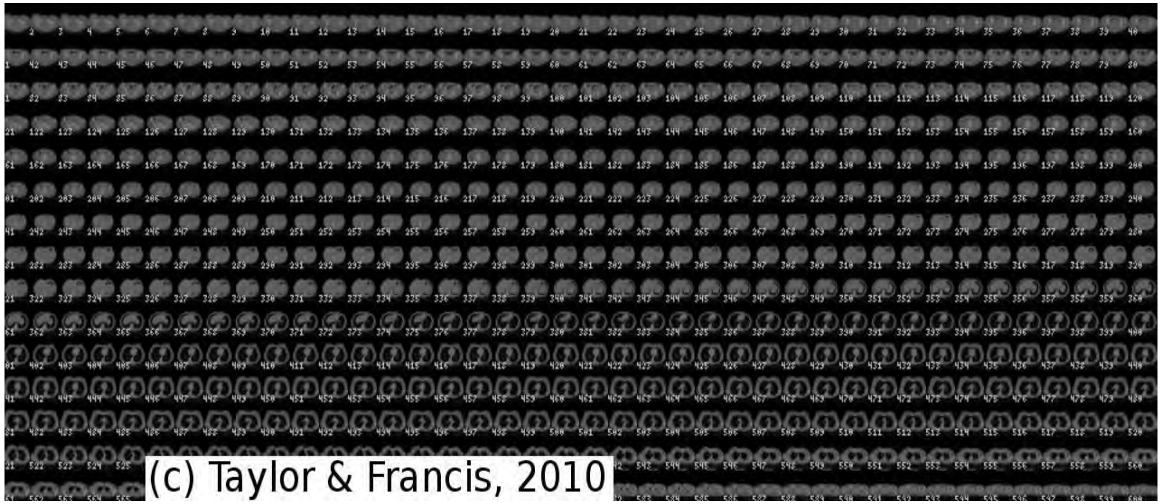
… is driven by clinical problems which have to be identified in **close cooperation** with **technologists** (= the people that know what imaging machines can do) and **physicians** (= the people that have the problem to be solved)

- “I've got a solution – where is your problem” research should be avoided
- Clinical acceptance depends on the **weakest link** in the workflow
- **Validation** on a variety of data is crucial

Understanding a physician's needs

- The purpose of medical research is to optimize the treatment of a patient (surprise).
  - There is **no special interest** in advancing your field of science
  - There is a **crucial need** to prove that there is a **measurable benefit** – one has to do patient studies and statistics in the long run.
  - The usability of your research might be limited by financial concerns, patient numbers, or legal reasons ...

What does that, for instance, mean?



… use real medical image data ...

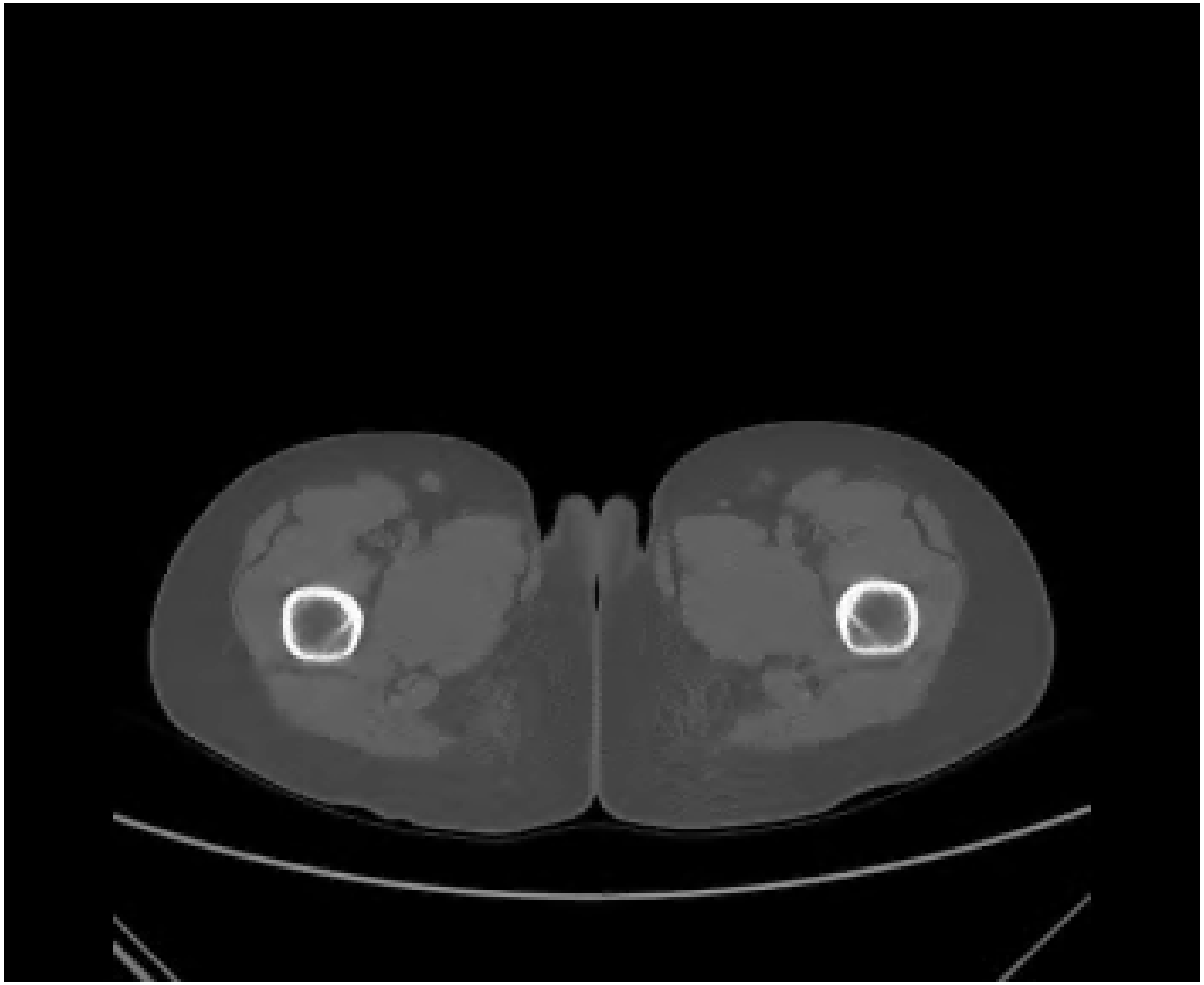
- Know the state of the art
- Avoid algorithms that work on exactly one dataset (e.g. the visible human)
- Avoid validation on phantom images

… instead of standard datsets, e.g. from computer vision ...

An example of clinical consulting – not necessarily research...

- An eleven year old patient, suffering from Ewing's sarcoma located at the left illium, undergoes multislice CT (64 Philips MDCT) and MR (3T Philips Achieva). Resection of the tumor by the orthopaedic tumor team of Vienna General is scheduled for wednesday
- The use of a commercial navigation system (Stryker Navigation System II ©) is planned.

Monday, 8.30 am



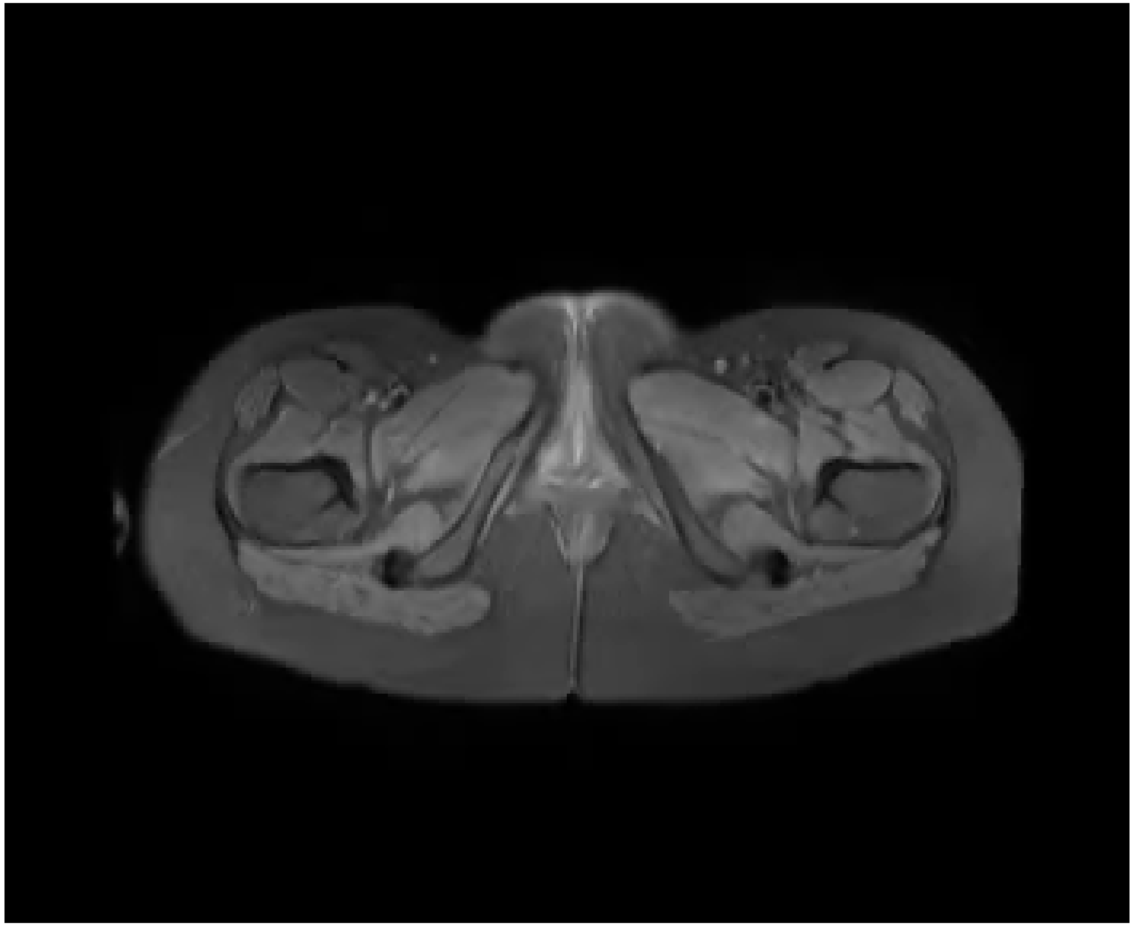
Multislice CT, $1 \times 0.62 \times 0.62\ mm^3$ resolution

CT-Exams – Volume Rendering

Monday – MR exams

HiRes sequence fails due to massive motion artifacts

Monday – MR sequence used



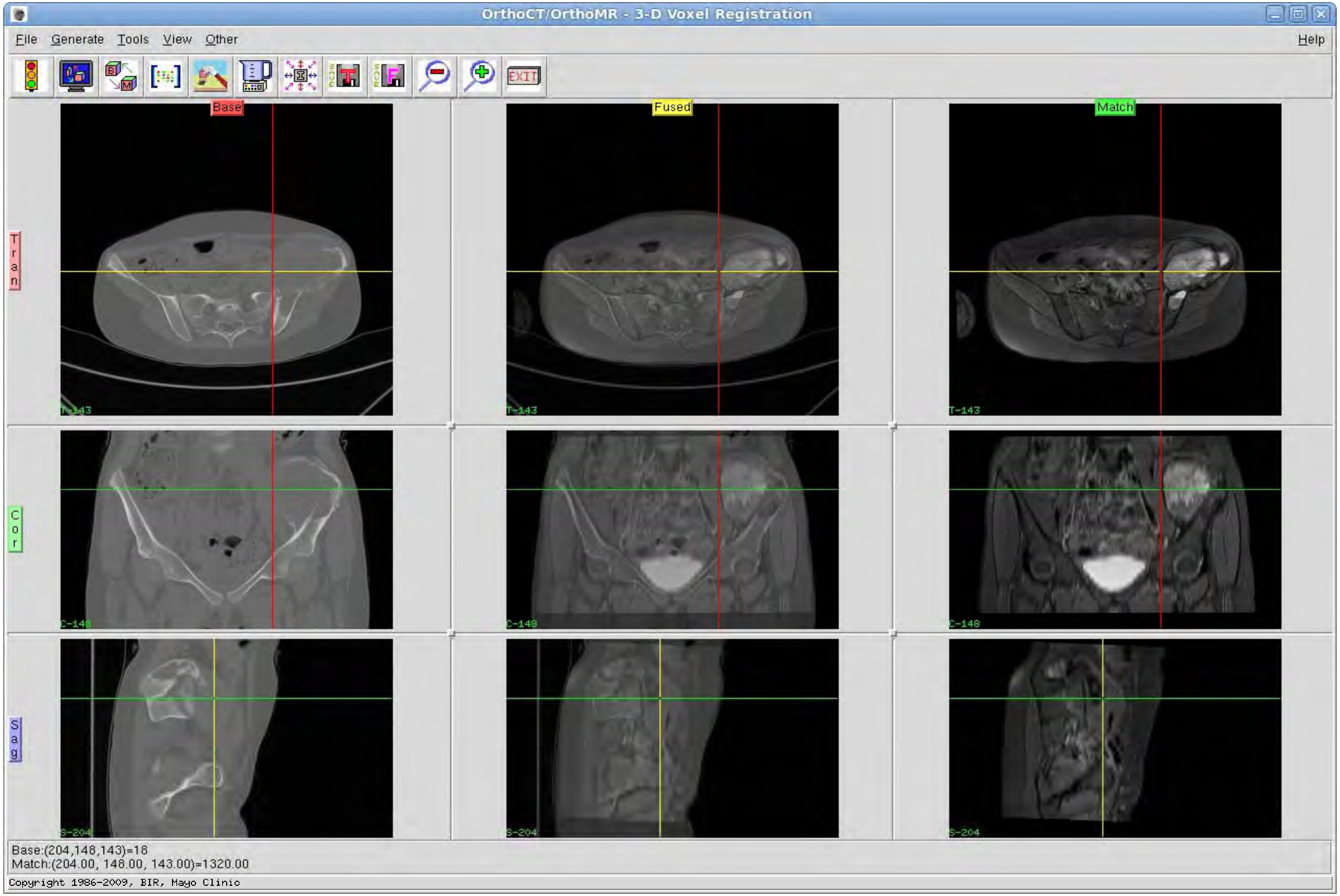
PD-Sequence, 4x1x1 mm³ resolution

Monday - sometime

Monday, even later ...

- Interpolation of the segmented and full MR volume to 1 mm^3 voxel size.
- Padding of MR-volume to match the volume size of CT
- Fusion of the full MR and the full CT using the normalized mutual information algorithm of AnalyzeAVW
- Retrieval of the homogeneous transformation matrix and transformation of the segmented volume

NMI at work



Selection of VOI and appropriate thresholds is inevitable...

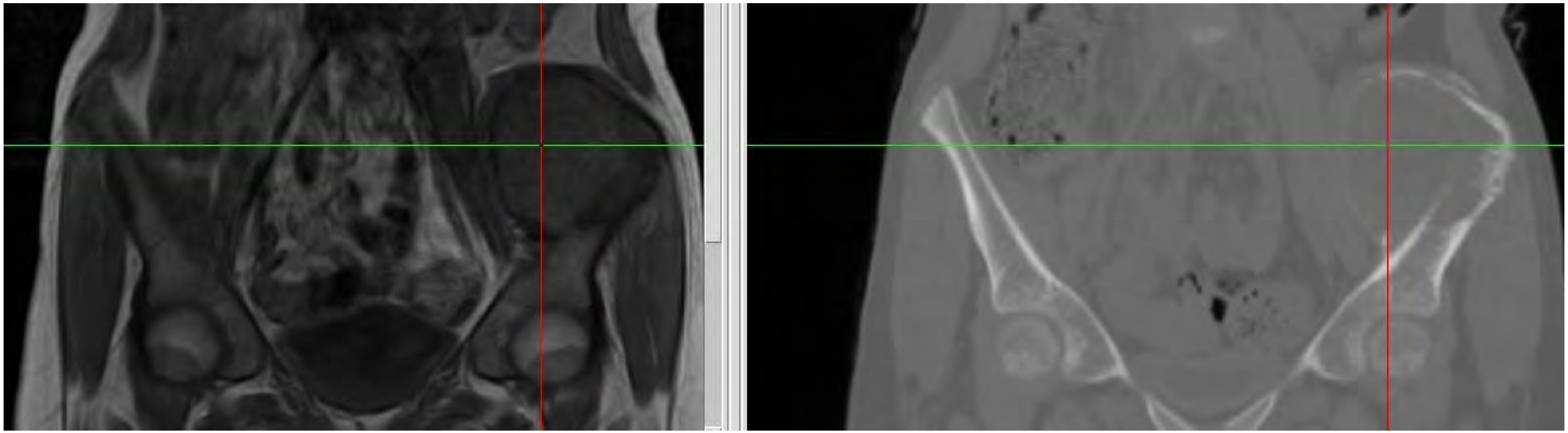
Fusing the segmented tumor margins from MR to the CT

The Stryker software registers an optical position sensor mounted by a Schanz – screw to the patients pelvis to the image data by

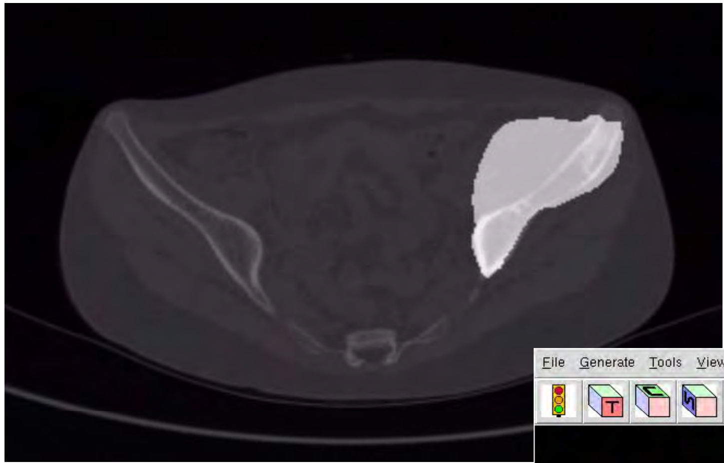
- ➔Point-to-point registration of anatomical landmarks
- ➔Subsequent refinement of the registration by an ICP – algorithm applied to the exposed bone surface as digitized by the tracker and a segmentation of the bone

Consequences

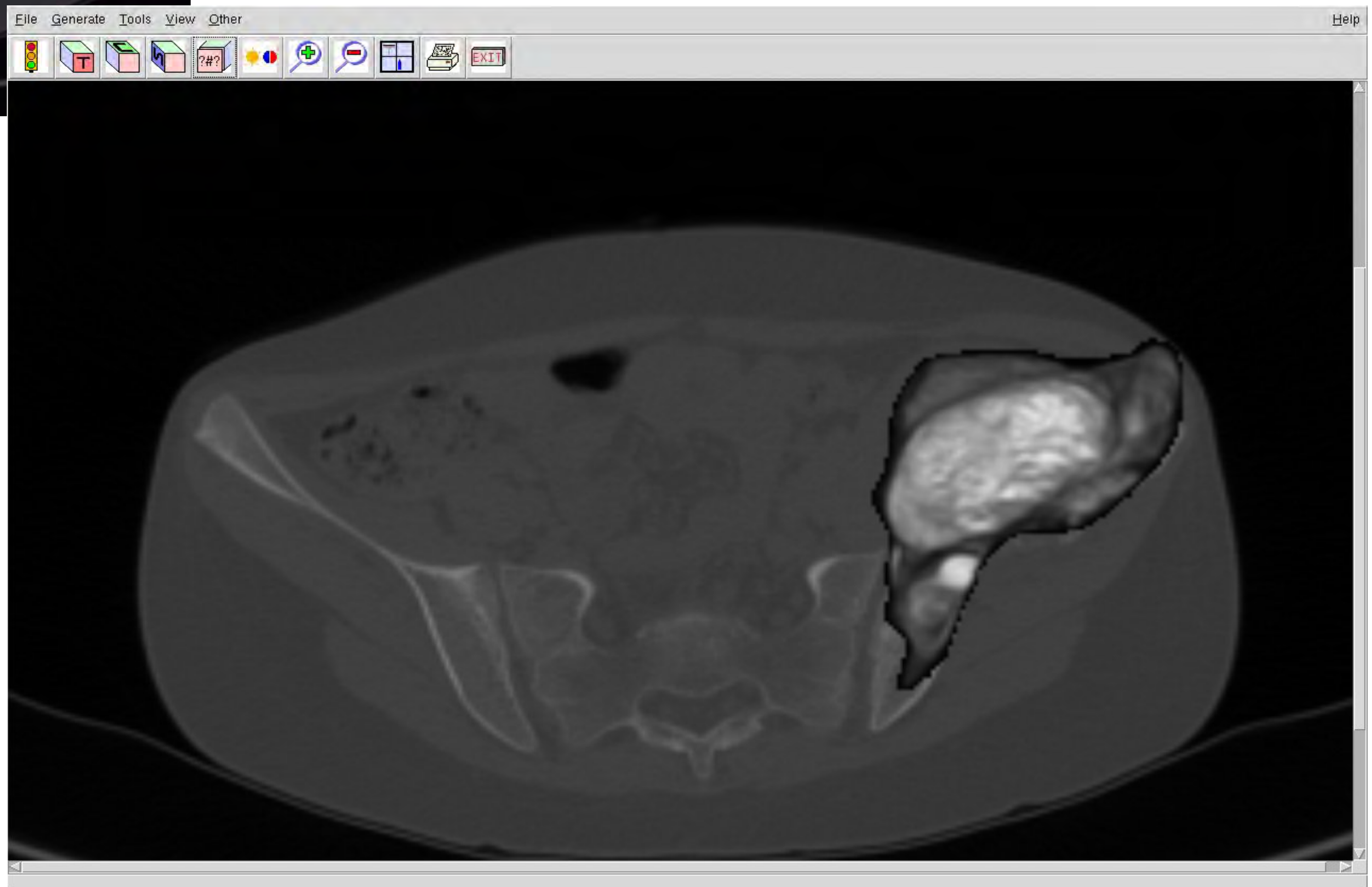
- The basic modality for navigation is CT, but tumor margins cannot be identified
- Therefore, the tumor margins had to be „inserted“ into the CT data.



A Solution – Masking and Adding



Fused image data were exported as Analyze 7.5 .hdr and .img volume

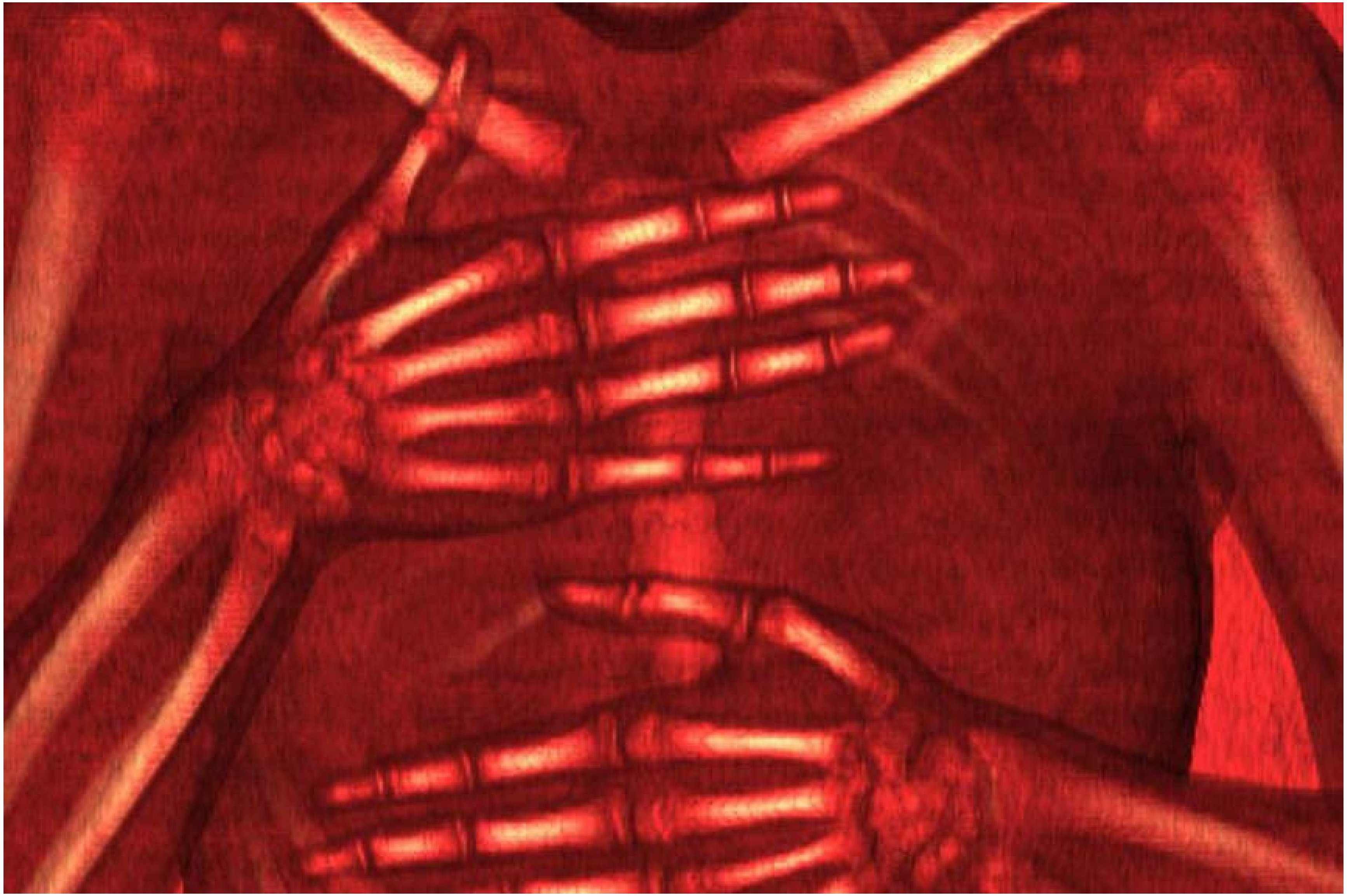


The fused CT/MR volume

Tuesday – PET/CT

- Whole body PET-CT was carried out for metastasis search
- The PET data were also used to verify the segmentation of the tumor

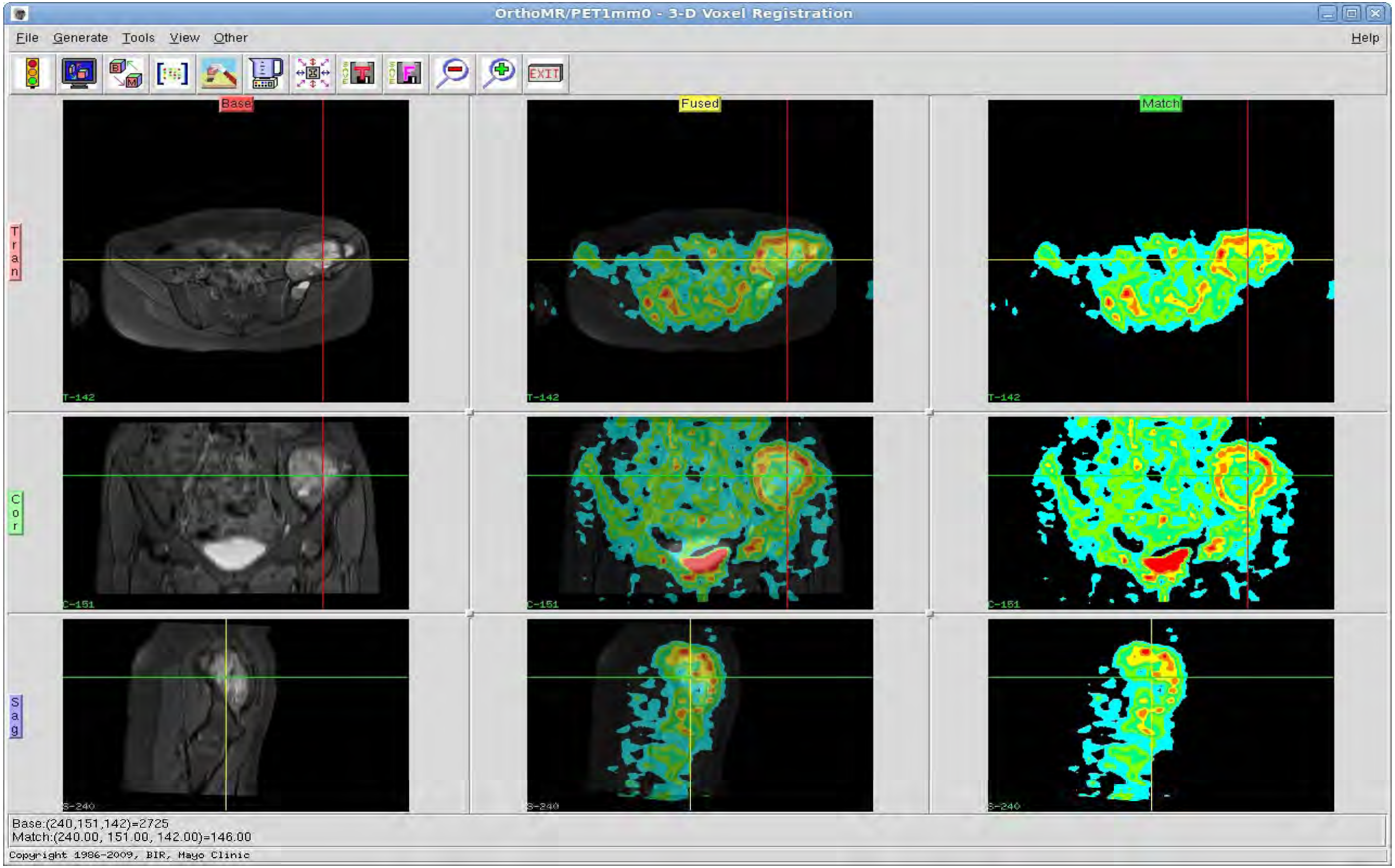
Strange details



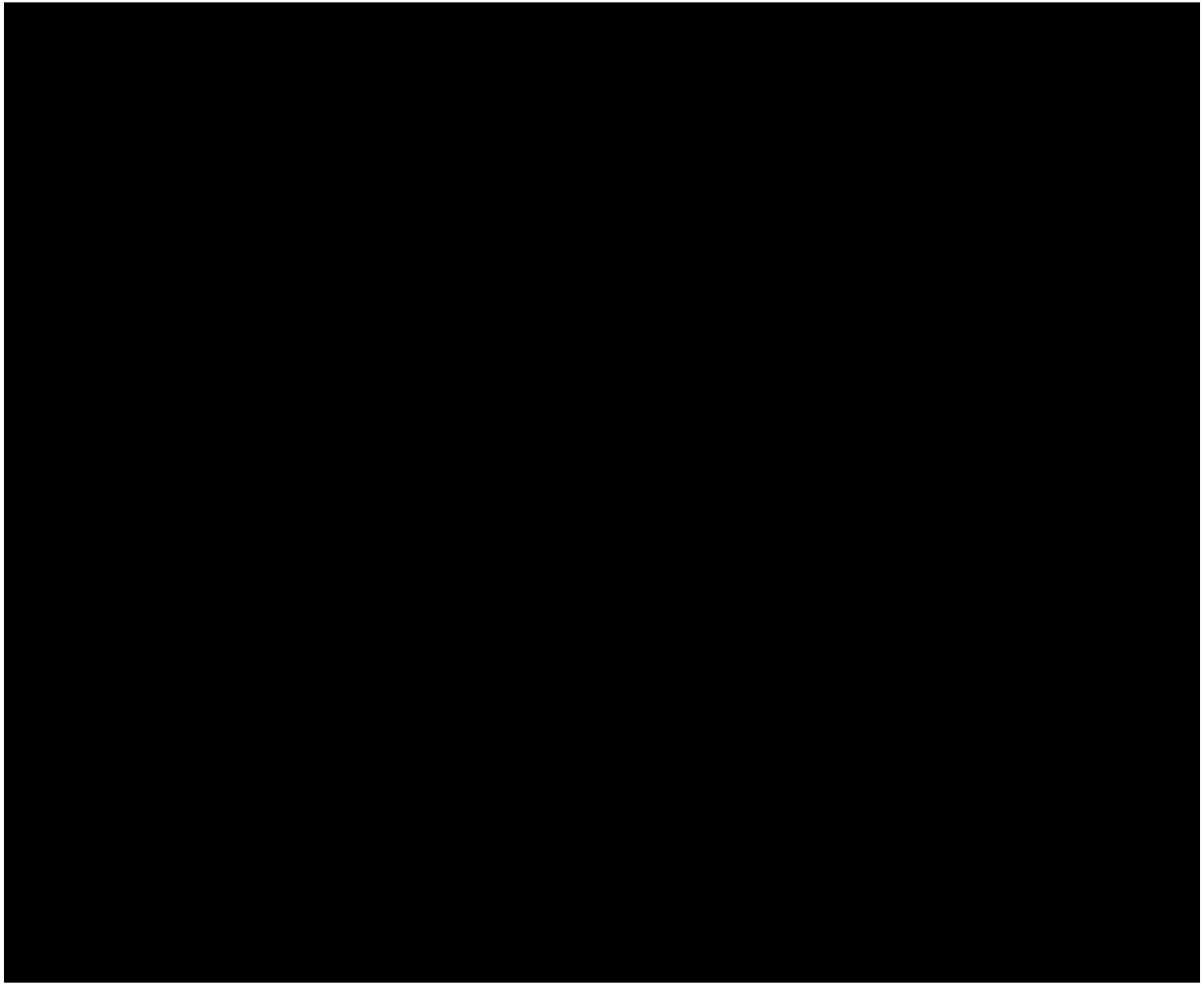
Tuesday – Fusion of PET and MR

- MR segmentation has to be verified together with the orthopaedic surgeon
- For this purpose, the PET data were to be used as well
- Intensity based registration of PET and MR in the abdominal region usually fails due to the poor information content … but CT – MR usually does not ...

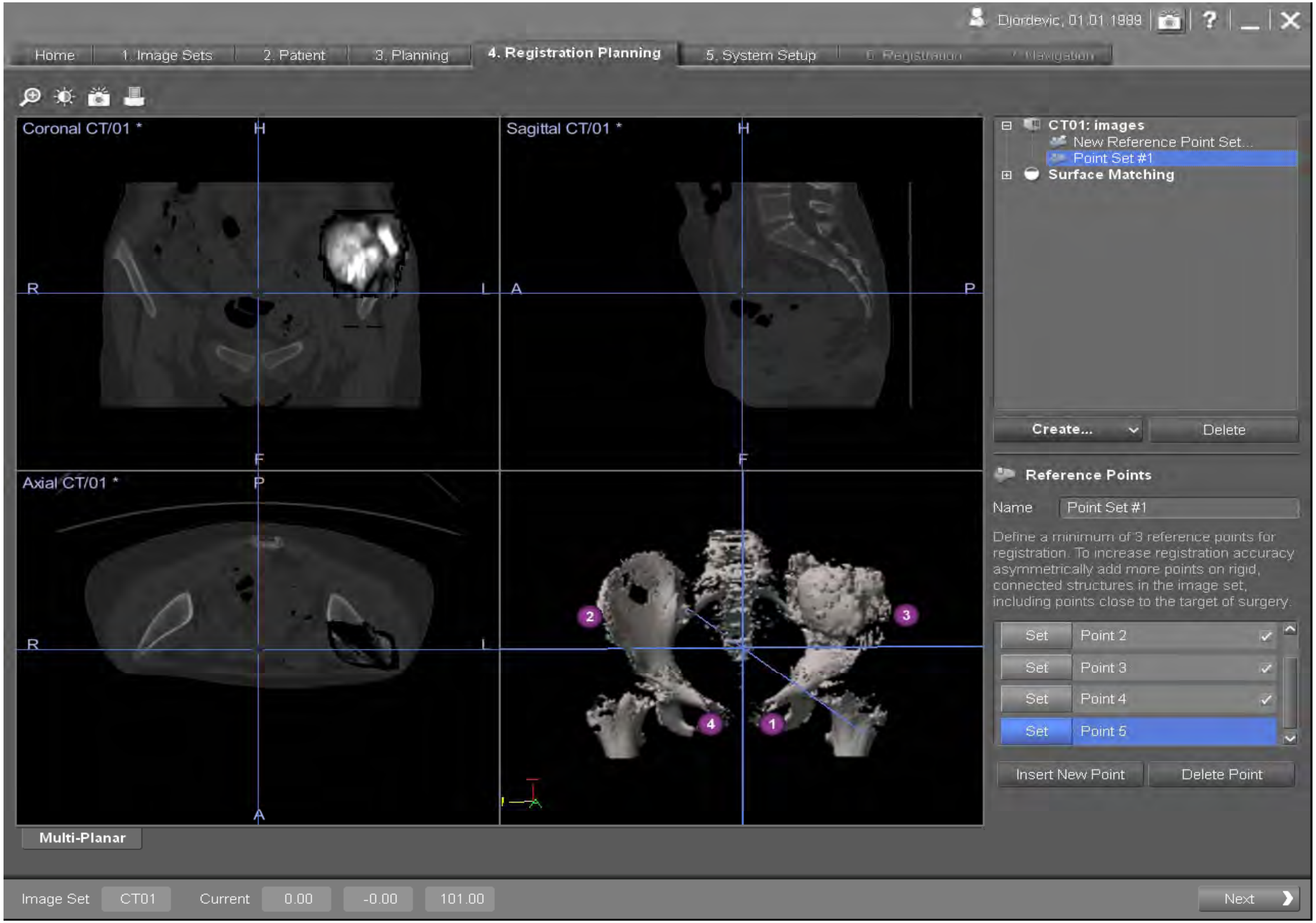
Registering the CT part of PET/CT with the full MR scan



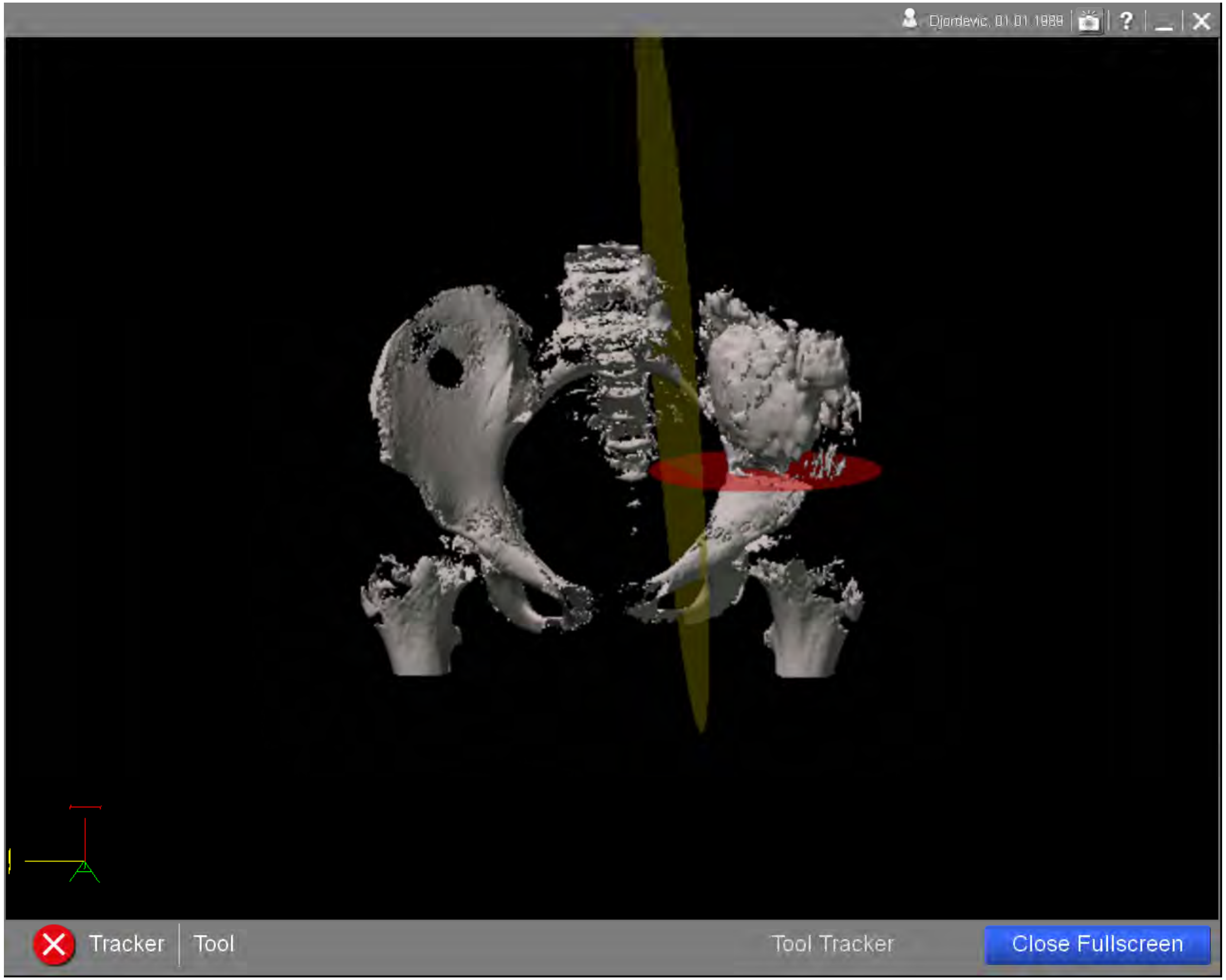
MR-PET fusion



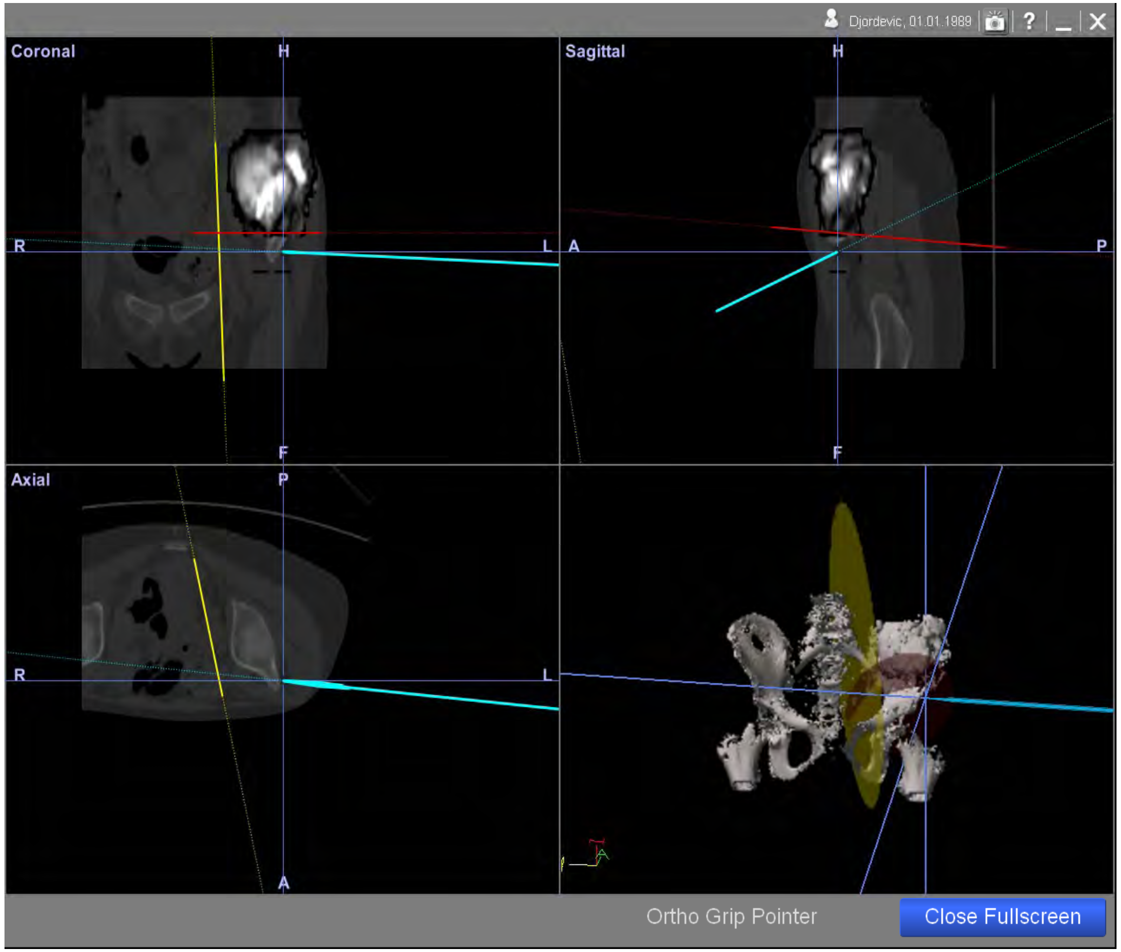
Tuesday, later on … transfer to the Stryker system



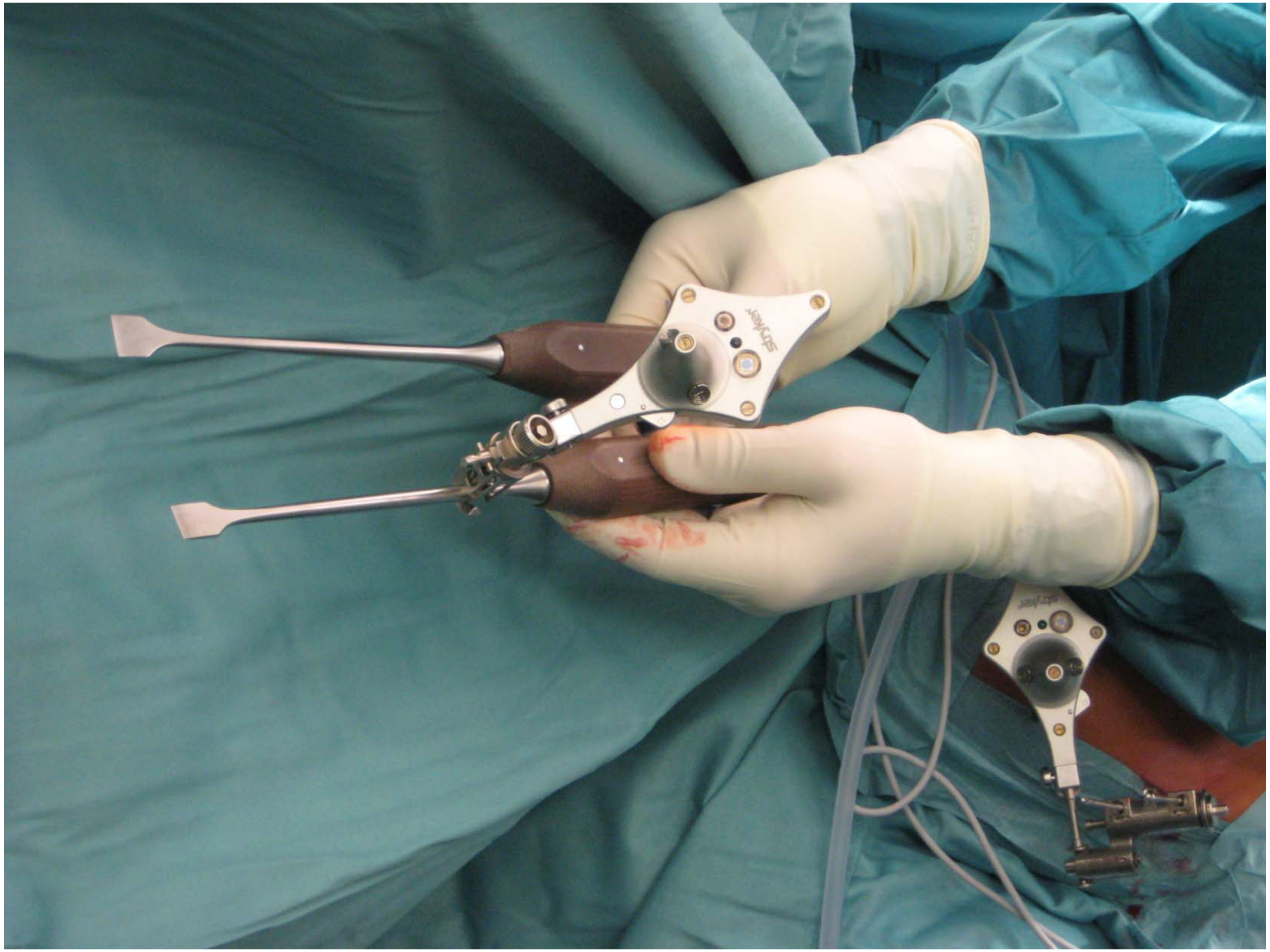
Tuesday – resection planning



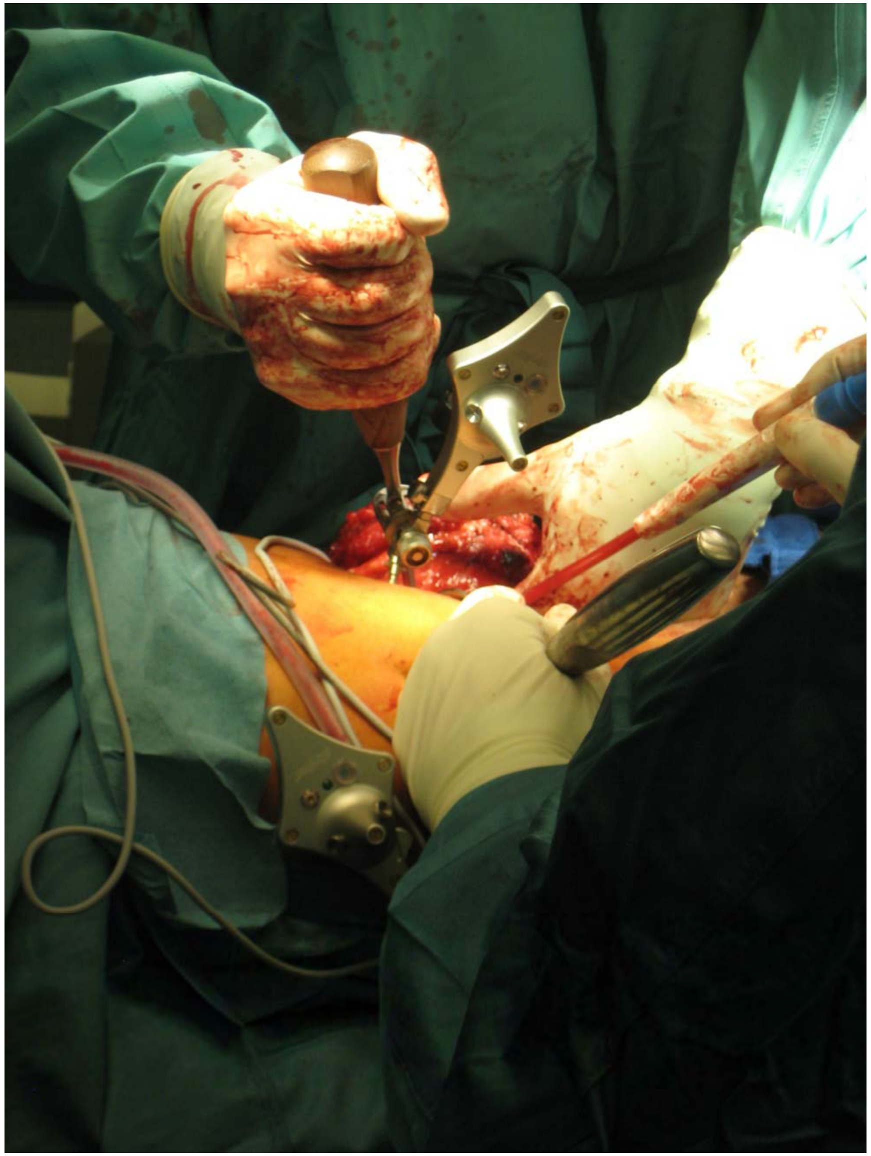
Wednesday-Registration in the OR

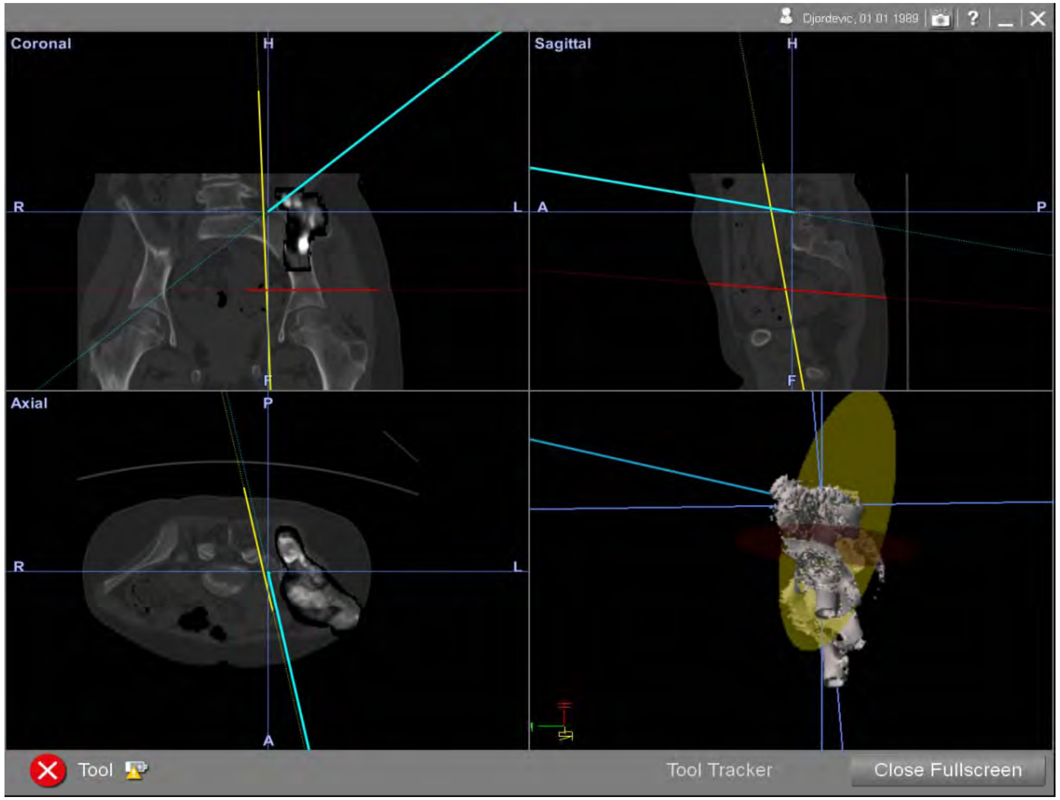


Instrumentation



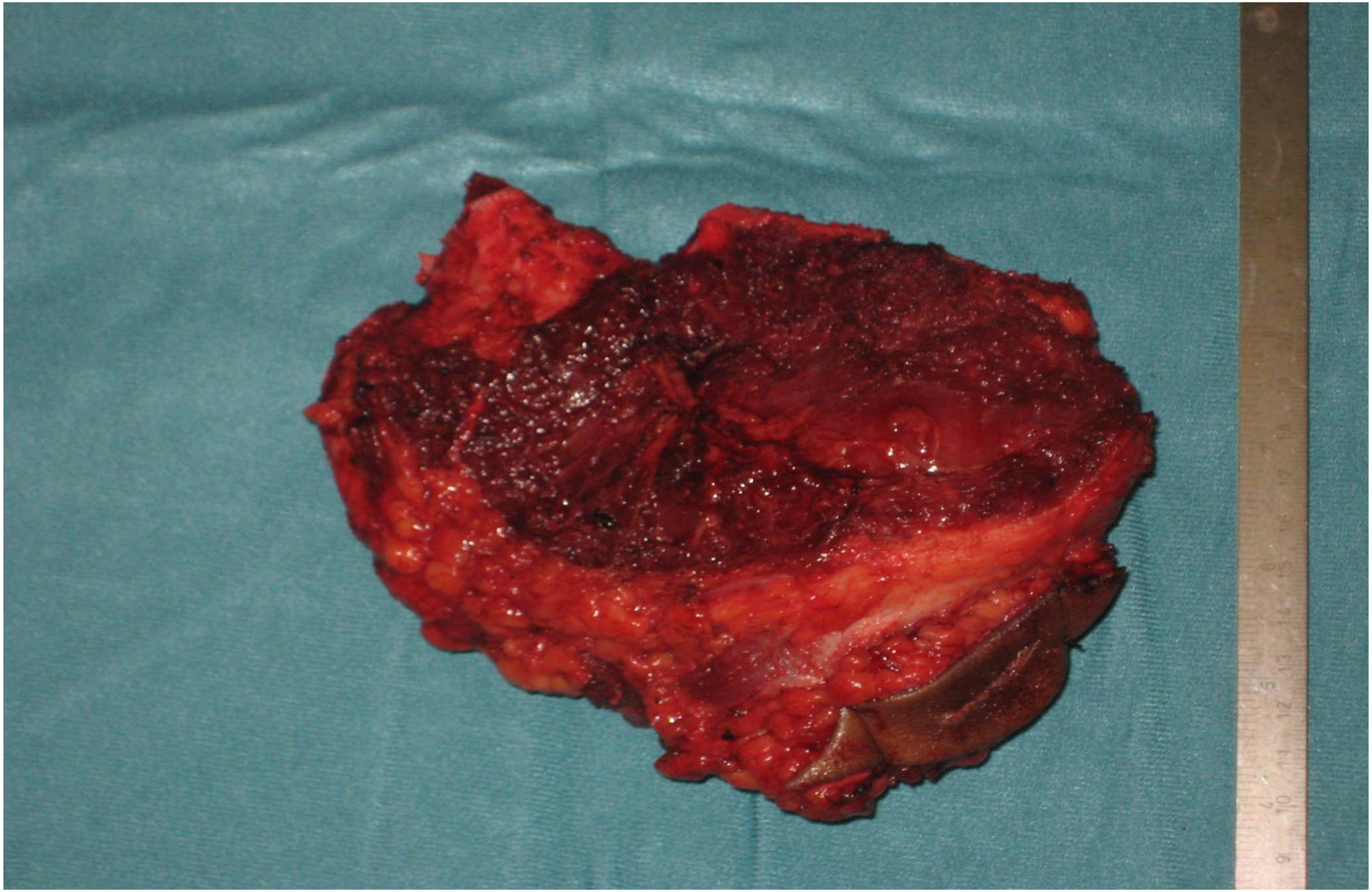
Resection



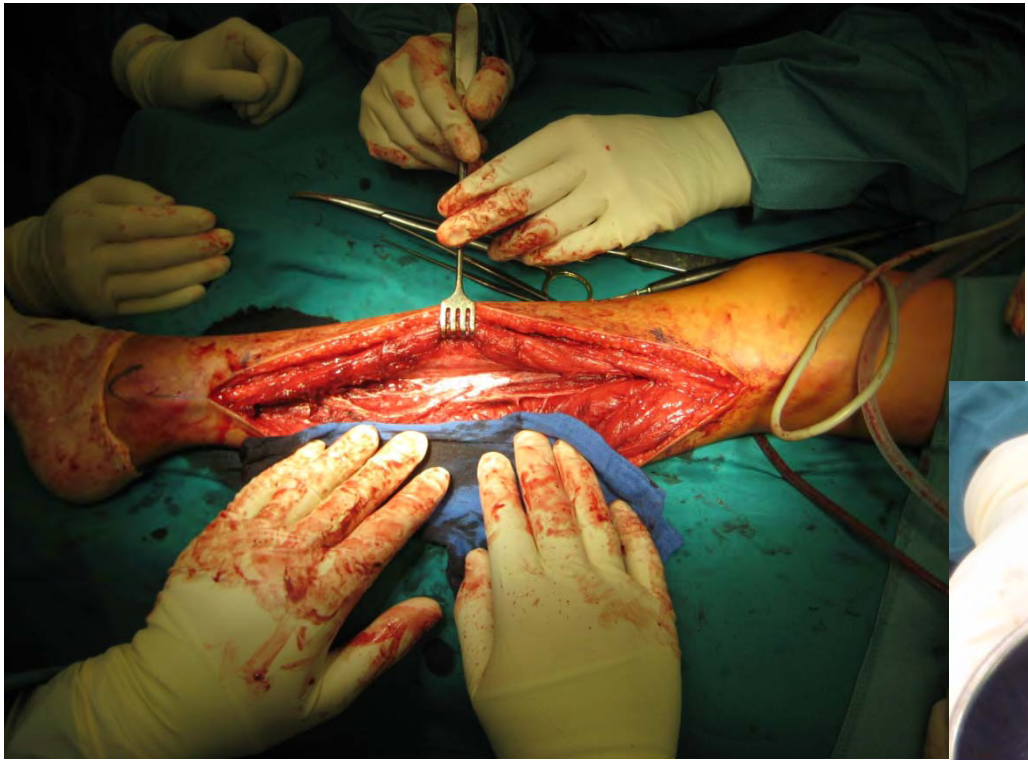

Coronal
H
R
L
F
Sagittal
H
A
P
F
Axial
P
R
L
A
Tool
Tool Tracker
Close Fullscreen

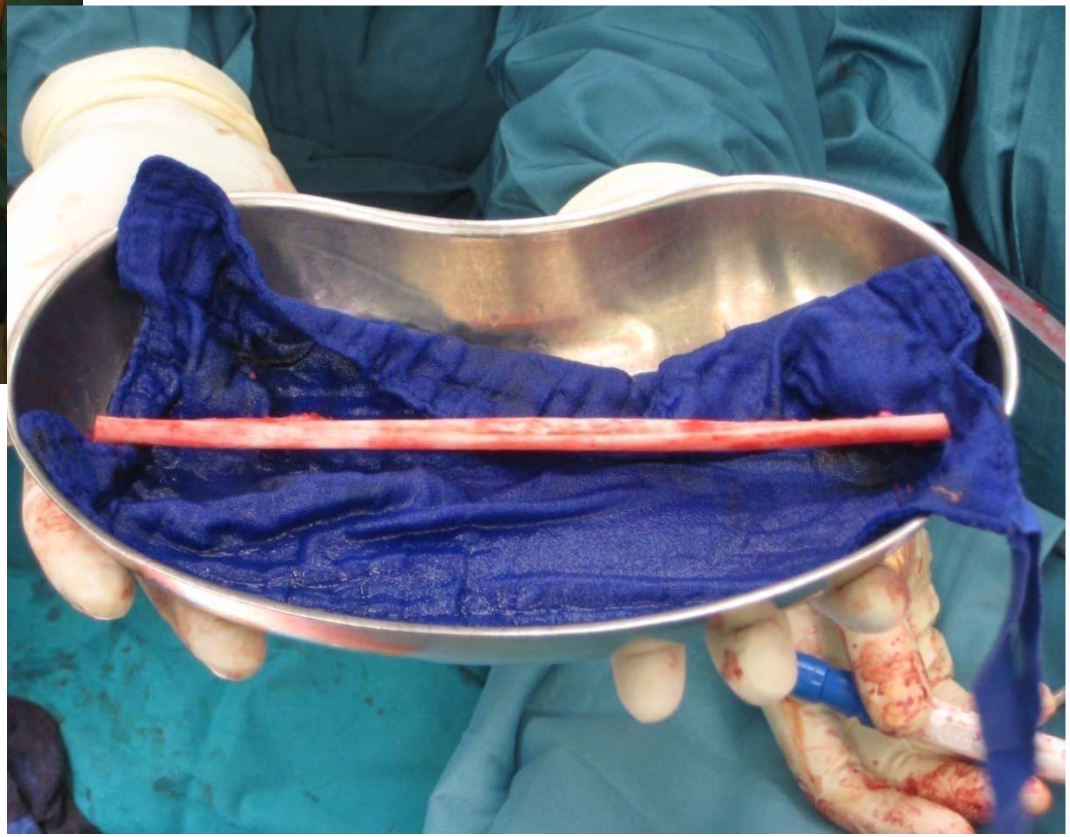
Wednesay, 10.30 am

Wednesday noon

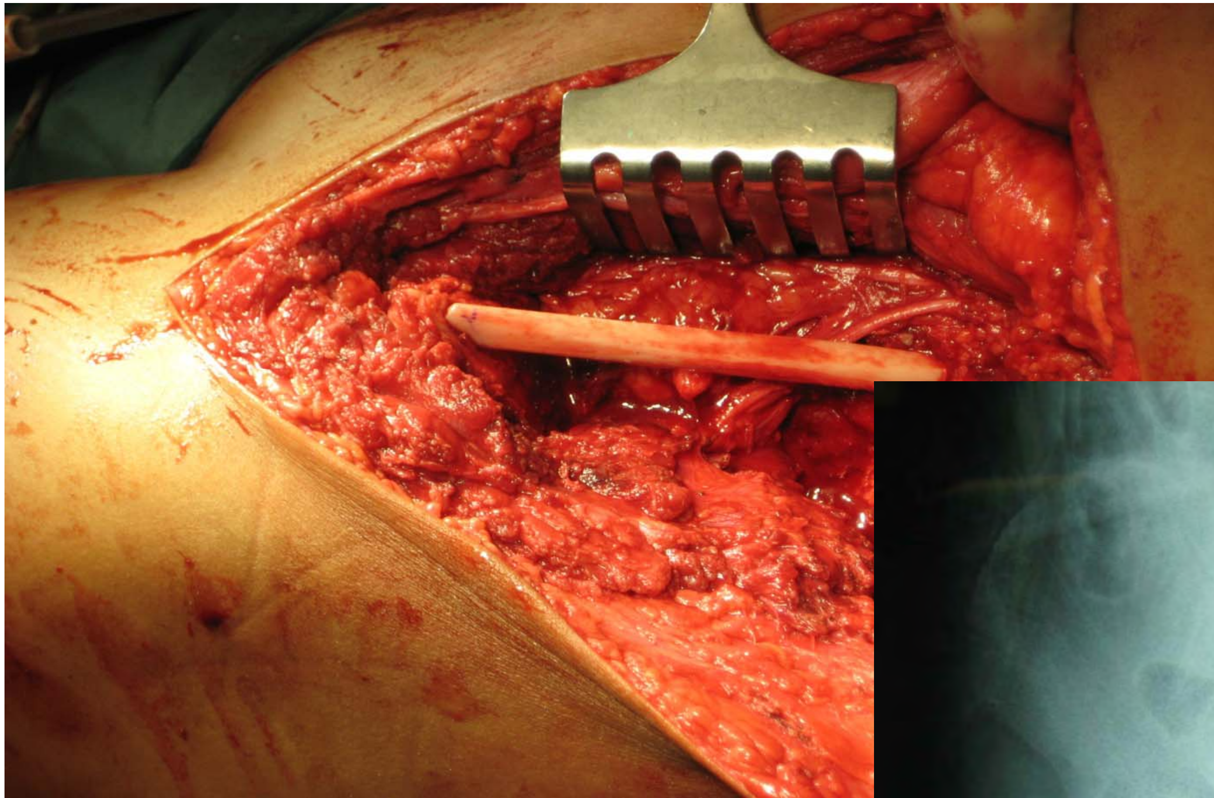


Stabilization I





Stabilization II



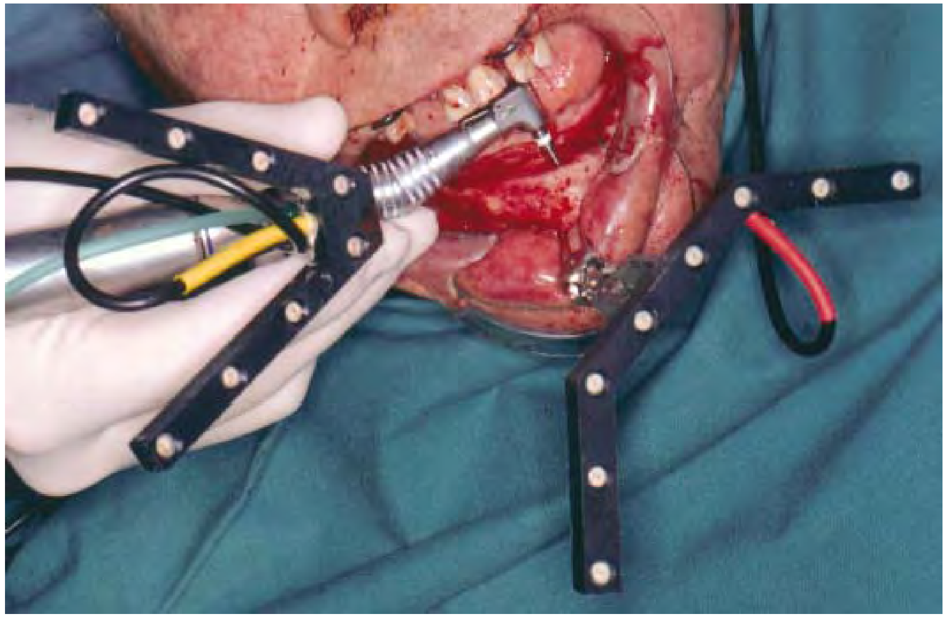
Histology

Histology confirmed a resection in sano

M. Dominkus
P. T. Funovics
C. Laux
W. Birkfellner
M.Figl
S. Domayer
J. Karanikas
G. Dobrozemsky
G. Kasprian
J. Patsch
I. Nöbauer
S. Plischke
...

Some contributors from Orthopaedics, Radiology, Nuclear Medicine and Medical Physics at Vienna General Hospital

Some research examples - Image-Guided CMF-Surgery



W. Birkfellner et al., IEEE Trans Med Imaging. 19(6):616-620, 2000

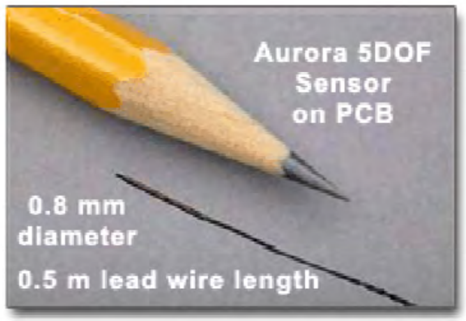
W. Birkfellner et al., Clin Oral Implants Res. 12(1):69-78, 2001

F. Watzinger et al., Plast Reconstr Surg. 107(3):659-667, 2001

A. Wagner et al., Clin Oral Implants Res. 14(3):340-348, 2003

Tracking & Registration- a Link to the Real World

- Registration: Finding a transformation between the coordinate system of a volume image and the real world
- Tracking: Maintaining that registration by measuring motion in 3D by
  - optical tracking
  - electromagnetic probes
  - and image data itself



W. Birkfellner et al., Med Phys 25(11):2242-2248,1998
W. Birkfellner et al., IEEE Trans Med Imaging. 17(5):737-742, 1998
J. Hummel et al., Med Phys 29(10):2205-2212, 2002

Medical Augmented Reality

W. Birkfellner et al., IEEE Trans Med Imaging. 21(8):991-997, 2002

F. Wanschitz et al., Clin Oral Implants Res. 13(6):610-616, 2002

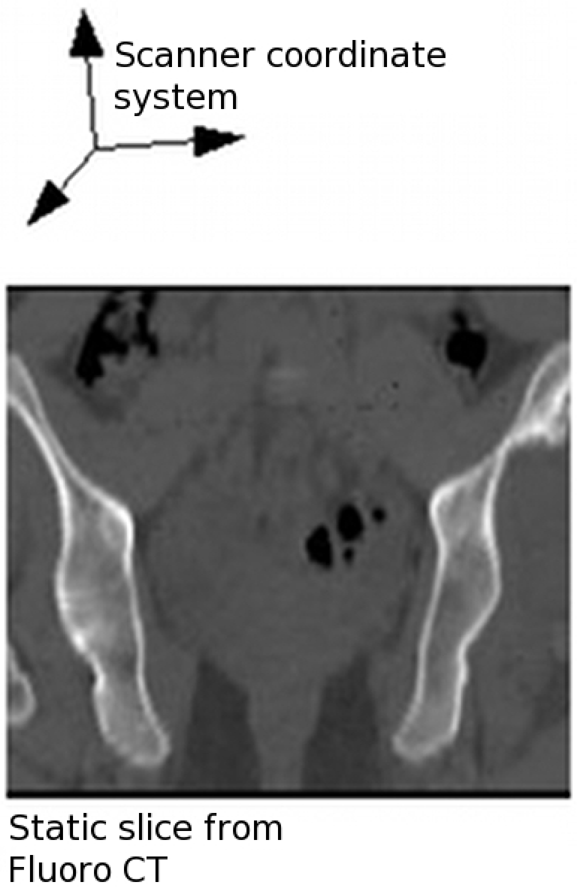
W. Birkfellner et al., Phys Med Biol. 48(3):N49-57, 2003

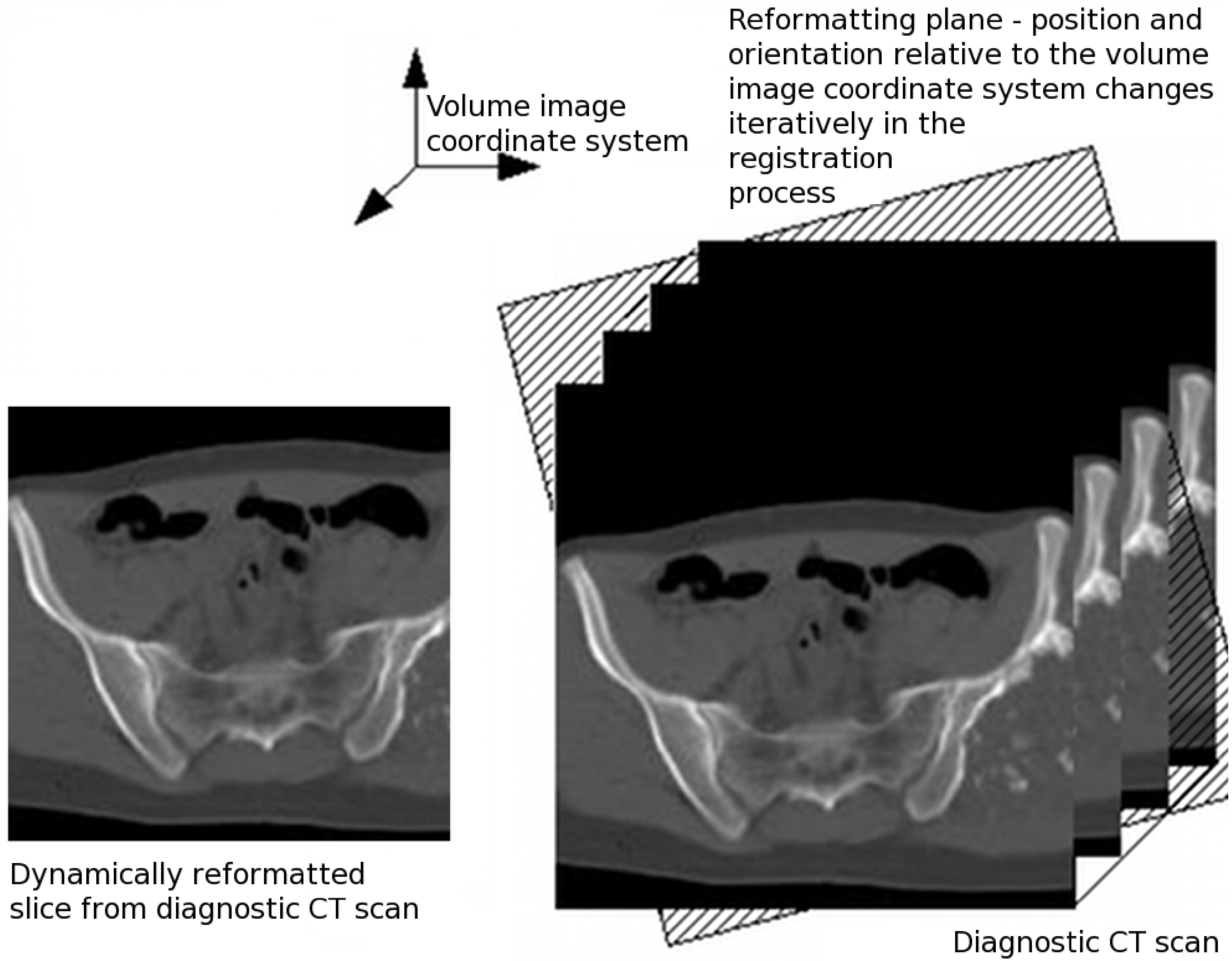
M. Figl et al., IEEE Trans Med Imaging. 24(11):1492-1499, 2005

A new paradigm - Image-based tracking

- Instead of using external sensors, radiological image information itself is to be used to acquire 3D position information
- Radiological modalities may include, for instance, Ultrasound and X-Ray/CT
- The use of ionizing radiation is limited to clinical applications where dose is applied anyhow (Interventional Radiology or Radiation Therapy)
- 2D/3D Registration – the derivation of at least 6 dof of motion from the comparison of 2D and 3D data – is a technology to achieve image-based tracking

Slice-to-volume registration





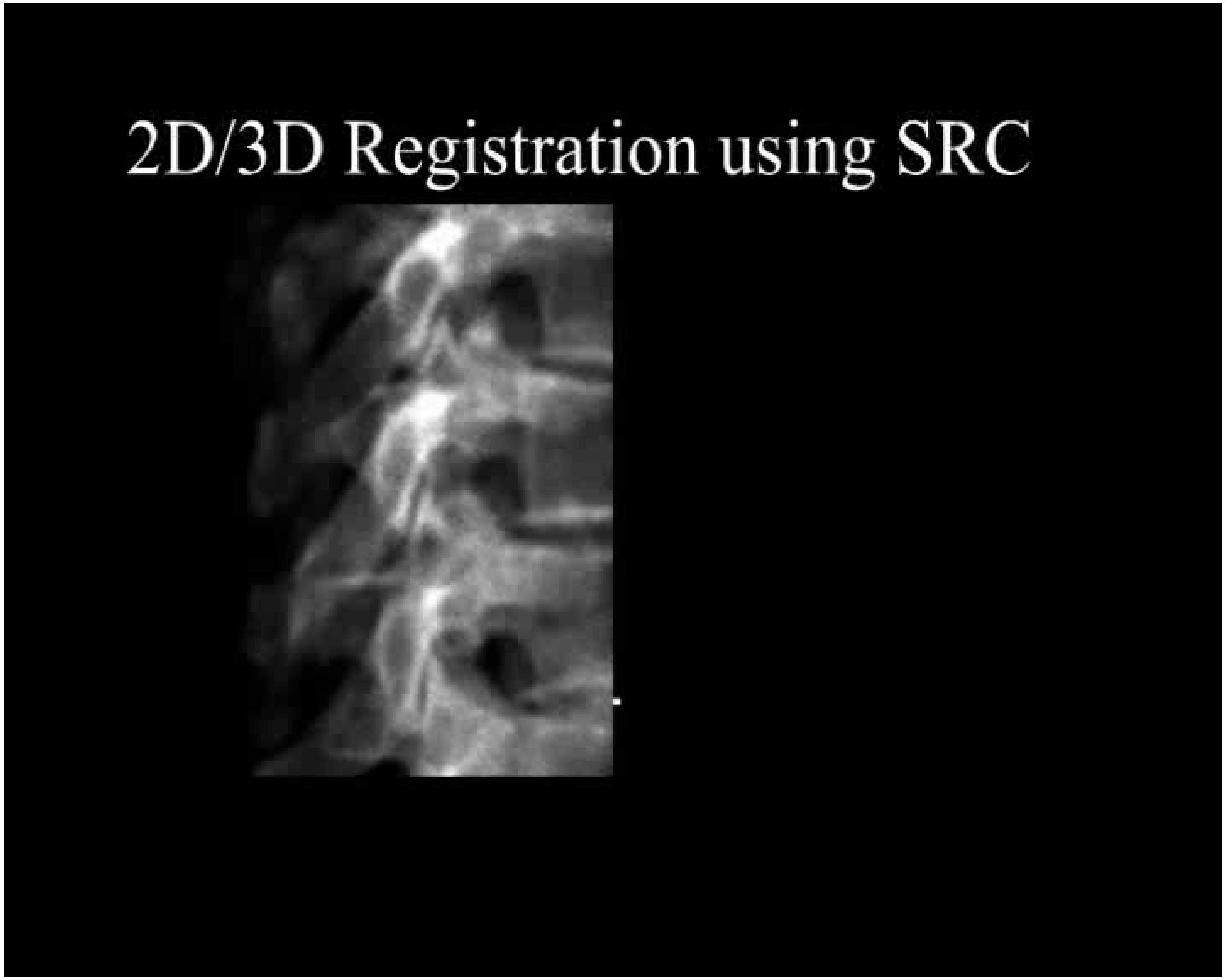
Compare the reformatted slice to the static slice - if no match is achieved, a new set of position parameters for the reformatting plane is chosen. Repeat this until the two images are identical.

Birkfellner W, Figl M, Kettenbach J et al.: Med Phys. 2007 Jan;34(1):246-55.
Frühwald L, Kettenbach J, Figl M et al.: Eur Radiol. 2009 Nov;19(11):2647-53.

Image Guided Radiotherapy – The Elekta Synergy LINAC

a.) Patient table
b.) MV-therapy unit
c.) kV imaging unit
d.) Flat Panel Imager
e.) EPID (=Electronic Portal Imaging Device)

2D/3D Registration of DRRs and X-ray image data



• Computation of digitally rendered radiographs (DRRs) from CT
• Iterative comparison with a reference X-ray image
• Convergence results in six degrees-of-freedom for rigid-body motion from planar 2D images

New Challenges

Up to the present, 2D/3D registration was considered a tool for patient setup. In IGRT, the introduction of LINACs capable of cone-beam CT have made this application to some extent obsolete. In order to use X-ray imaging for organ tracking, new challenges arise:

- Real-time performance
- Robustness against intensity changes and noise from scatter radiation
- Improved convergence behaviour for coping with jerky motion

Speed: Coping with fast perspective DRR Rendering

- Classical raycasting is slow
- Reported runtime for iterative DRR-based 2D/3D registration ranges from 30 – 600 seconds in the literature
- Improvement is possible by implementing algebraic rendering methods

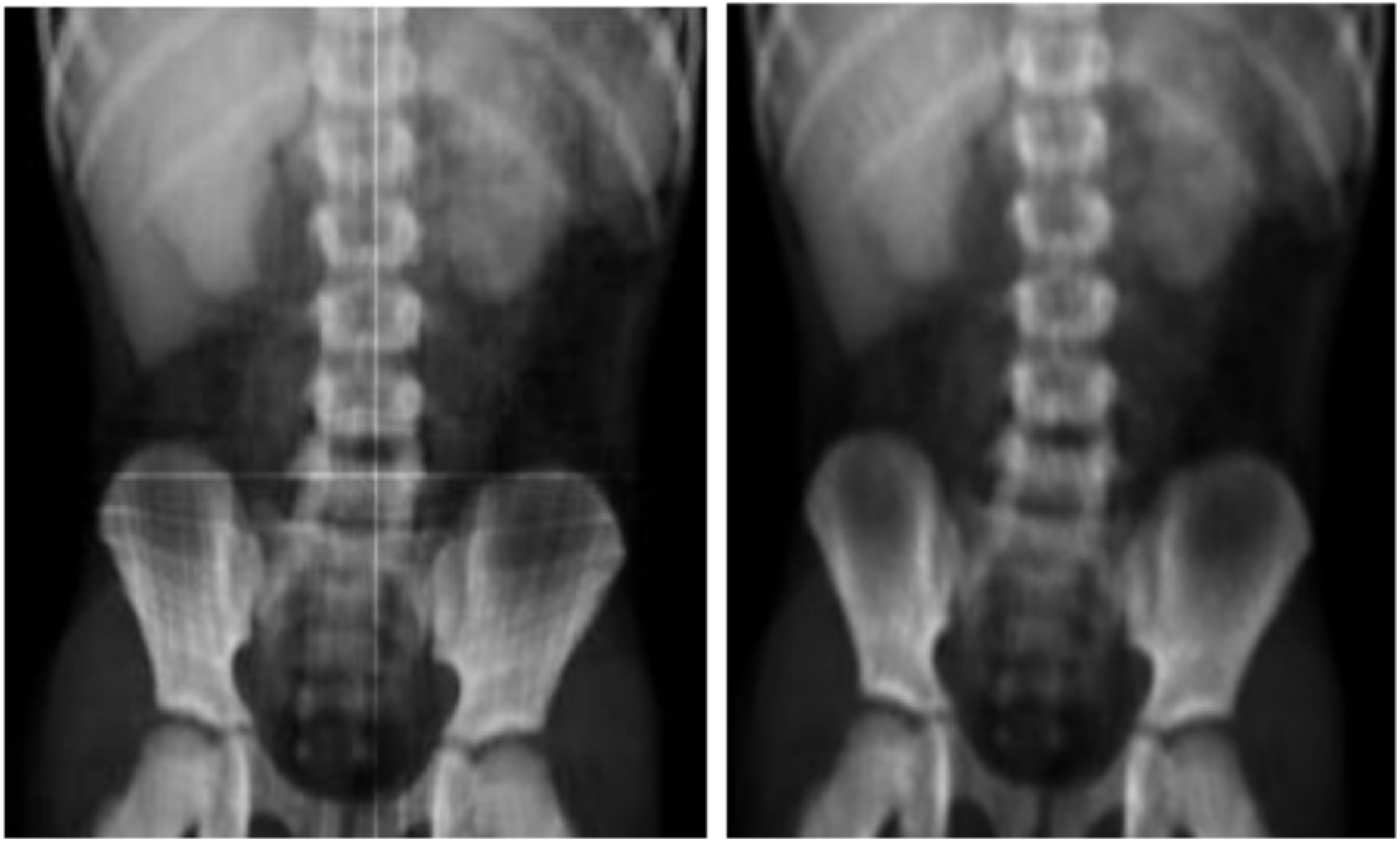
Splat rendering:

$$\mathbf{x}_p = P R_z R_y R_x T \mathbf{x}$$

where only voxel positions **x** within a defined density range are used

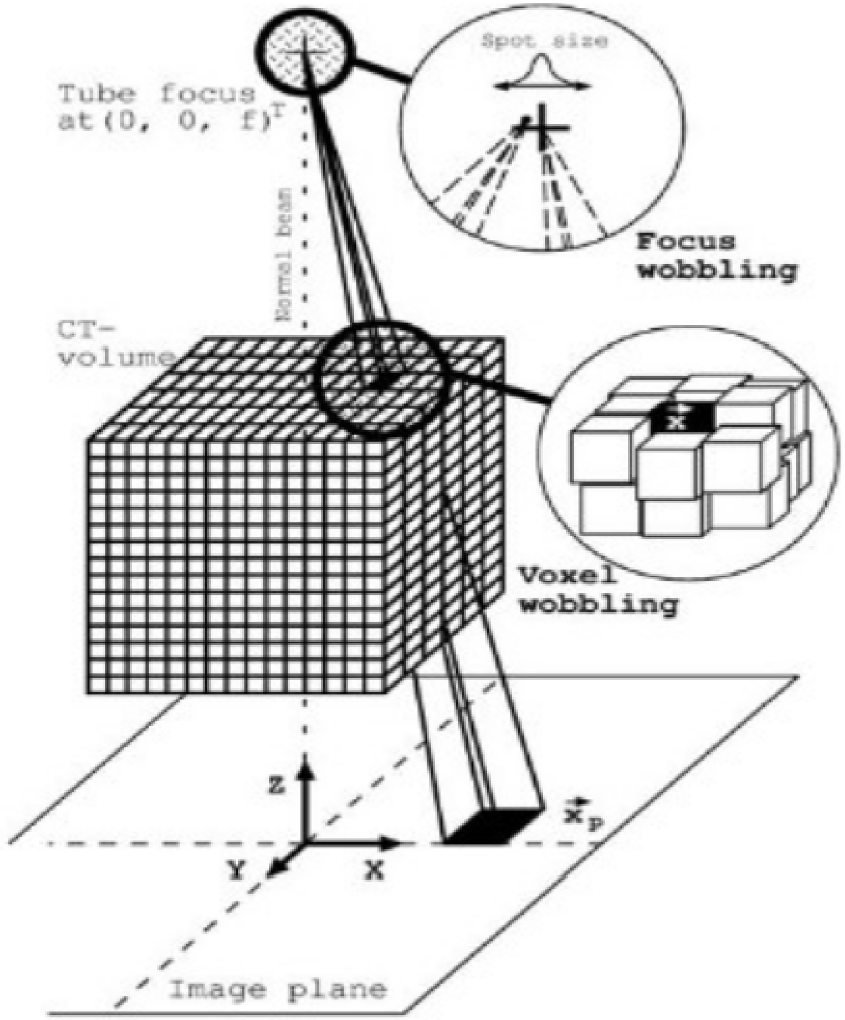
P = Projection matrix,
R = Rotation, T = Translation

Aliasing



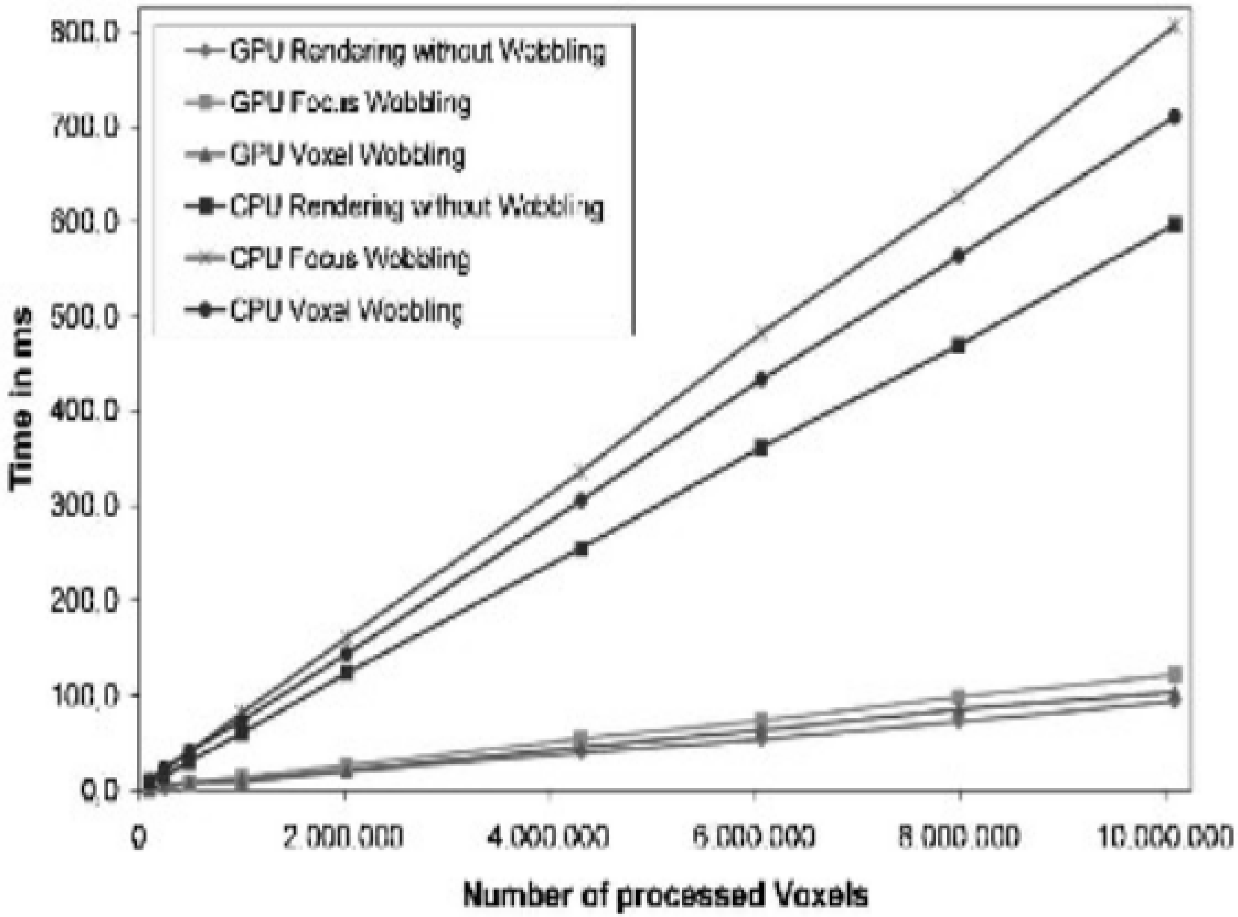
Classical Splatting vs. Wobbled Splatting

- In classical splatting, aliasing artefacts are suppressed by rendering a Gaussian footprint (=slow)
- Wobbled splatting simulates a random motion of voxels or a blurred focus



W. Birkfellner et al., Phys Med Biol 50(9):N73-84, 2005

The next step: GPGPU



Since splat rendering is a completely algebraic process, it exploits the parallelization possibilities of modern graphics adapters to achieve rendering rates beyond 50 Hz for perspective volume rendering

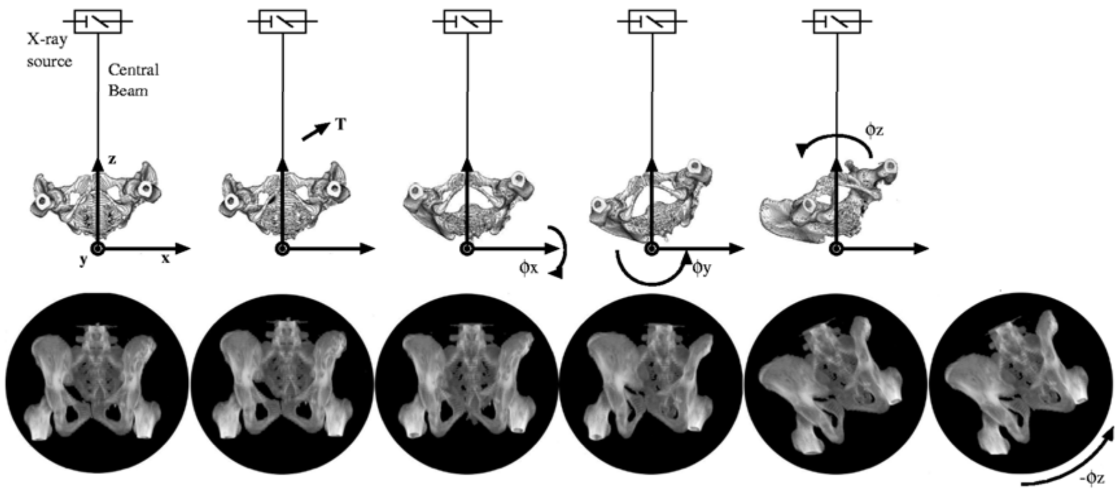
J. Spoerk et al., Med Phys. 34(11):4302-4308, 2007

Another plan of Attack – Similarity Measures

• Gains in Speed and Robustness are most likely to be achieved by designing dedicated merit functions

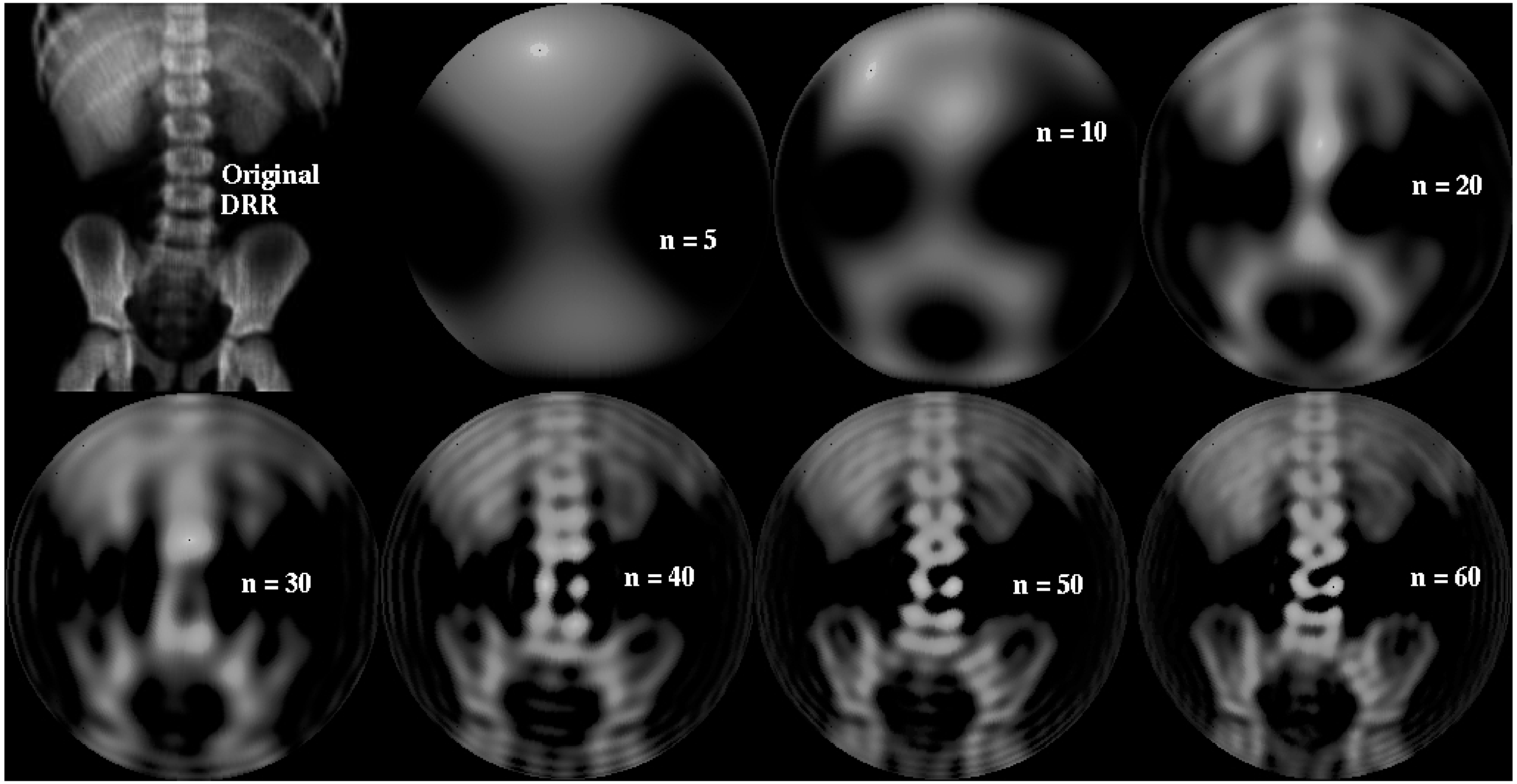
• Two novel approaches exploit either rotation invariance or specialised statistical measures

W. Birkfellner et al., Phys Med Biol 48, 2665-2679, (2003)



No volume transform applied to CT $\mathbf{V} = 1$ | Translation of CT, $\mathbf{V} = \mathbf{T}$, $t_x = 10$, $t_y = 10$, $t_z = 20$ | Rotation around x-axis and translation of CT $\mathbf{V} = \mathbf{R}_{\phi x}\mathbf{T}$, $\phi_x = 15°$ | Rotation around x- and y-axis, translation of CT $\mathbf{V} = \mathbf{R}_{\phi y}\mathbf{R}_{\phi x}\mathbf{T} = \mathbf{V}^*$, $\phi_x = 15°$, $\phi_y = 15°$ | Full transform in 6 dof of CT, $\mathbf{V} = \mathbf{R}_{\phi z}\mathbf{R}_{\phi y}\mathbf{R}_{\phi x}\mathbf{T}$, $\phi_x = 15°$, $\phi_y = 15°$, $\phi_z = 30°$ | Rotation around x- and y-axis, translation of CT $\mathbf{V} = \mathbf{R}_{\phi y}\mathbf{R}_{\phi x}\mathbf{T} = \mathbf{V}^*$, $\phi_x = 15°$, $\phi_y = 15°$. Full image rotated by $\alpha = -30° = -\phi_z$

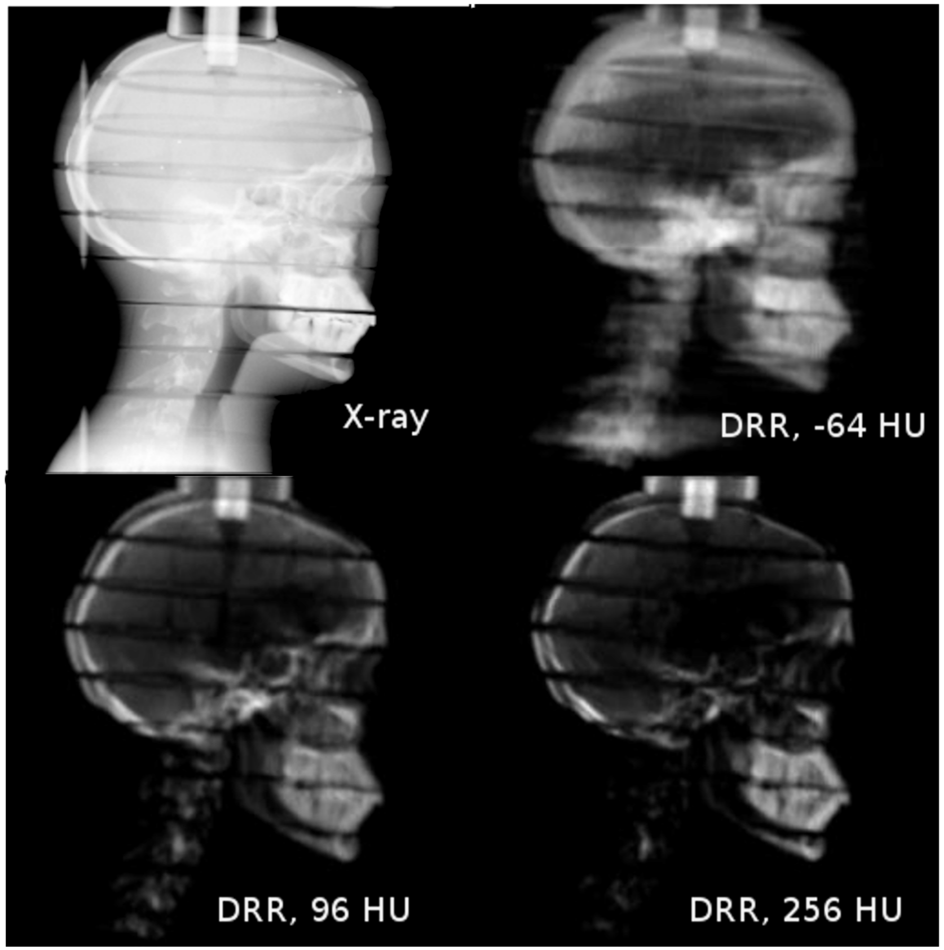
An not-so-harmonic in-plane rotation invariant measure

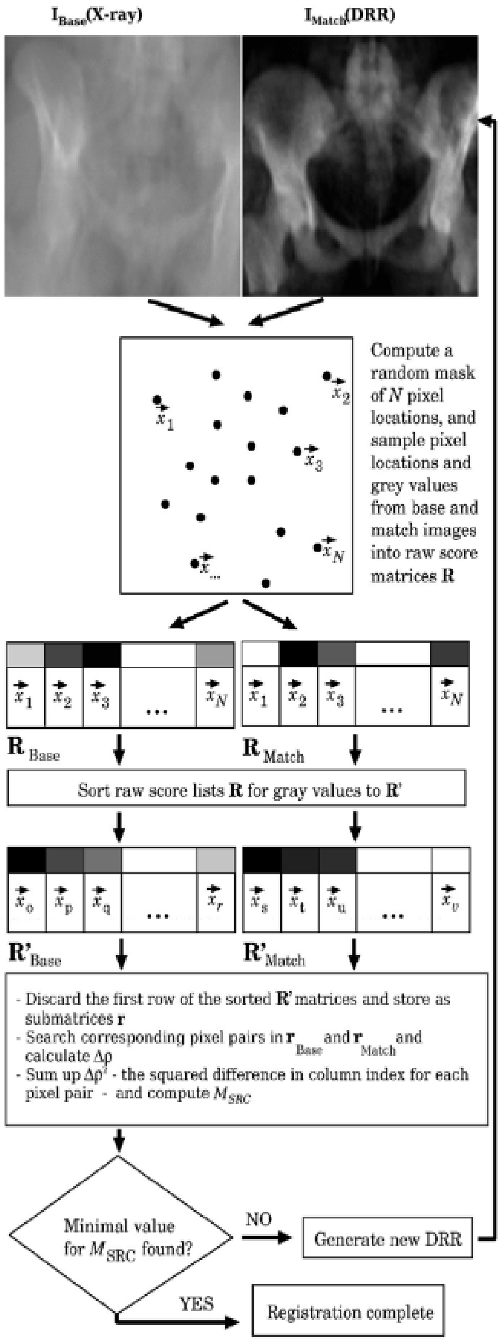


S. Dong et al., Proceedings of MICCAI, 2008

A measure invariant to intensity transforms - SRC

Another problem in IGRT is the different photon energy used for diagnostic CT imaging and kV imaging in the presence of massive scatter radiation

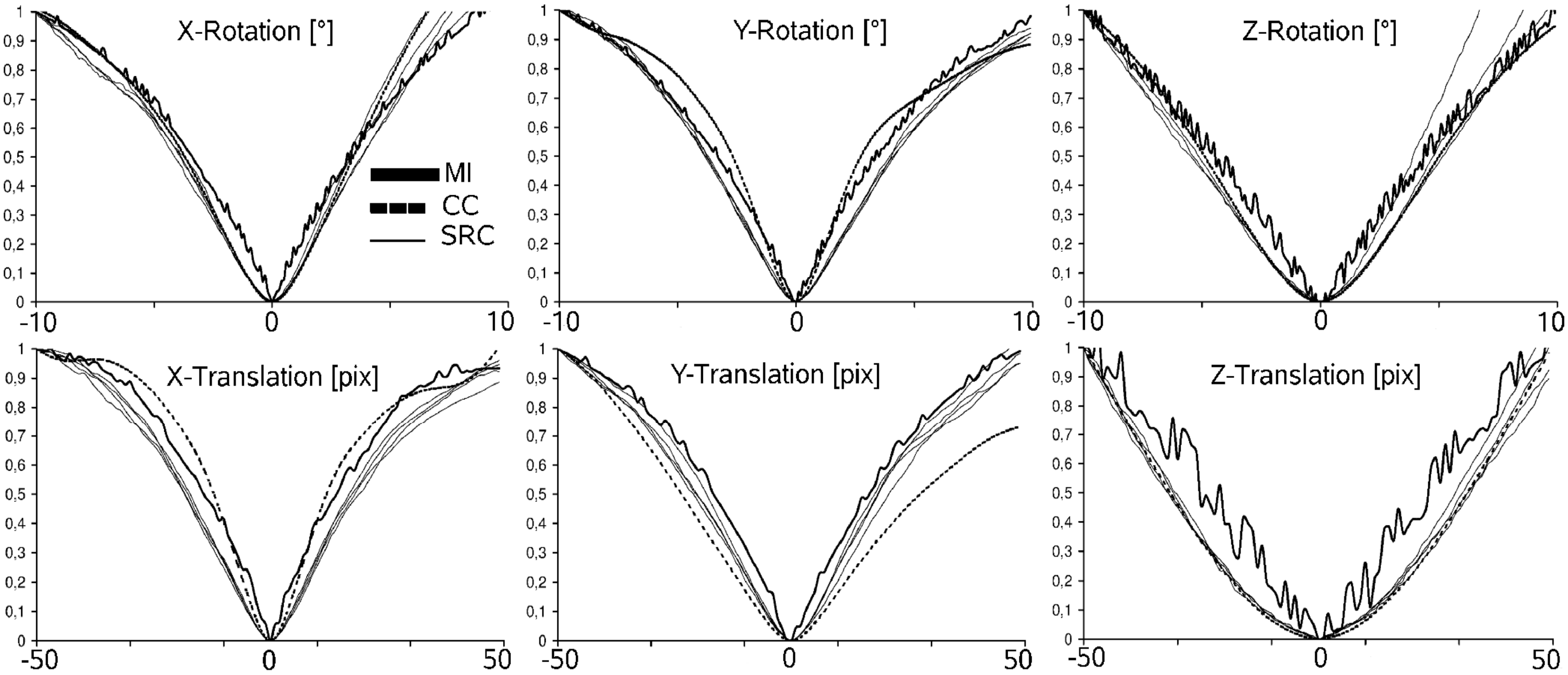




Stochastic Rank Correlation

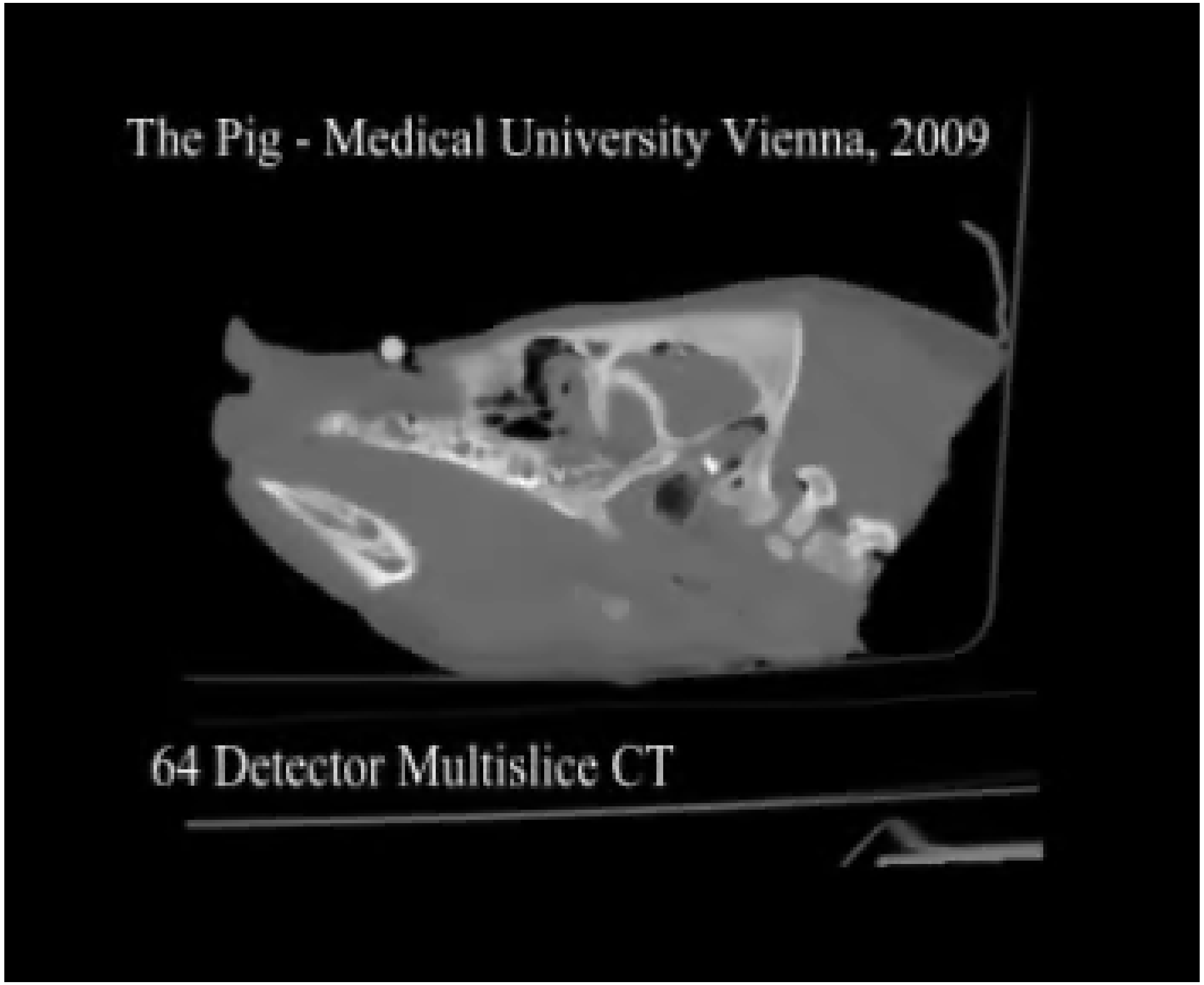
- Compute Spearmans Rank-Correlation Coefficient for two images
- RC is independent of gray values since it correlates the rank of a pixel in sorted lists
- RC is robust against outliers
- **Stochastic rank correlation** reduces the time-intensive sorting by sampling the histogram via a random selection of pixels
- Works for images with a steady and monotonic relationship between pixels

SRC, CC, and NMI



Birkfellner W, Stock M, Figl M et al.: Med Phys. 2009 Aug;36(8):3420-8.
Figl M, Bloch C, Gendrin C et al.: Phys Med Biol. 2010 Oct 7;55(19):N465-71.

Validation



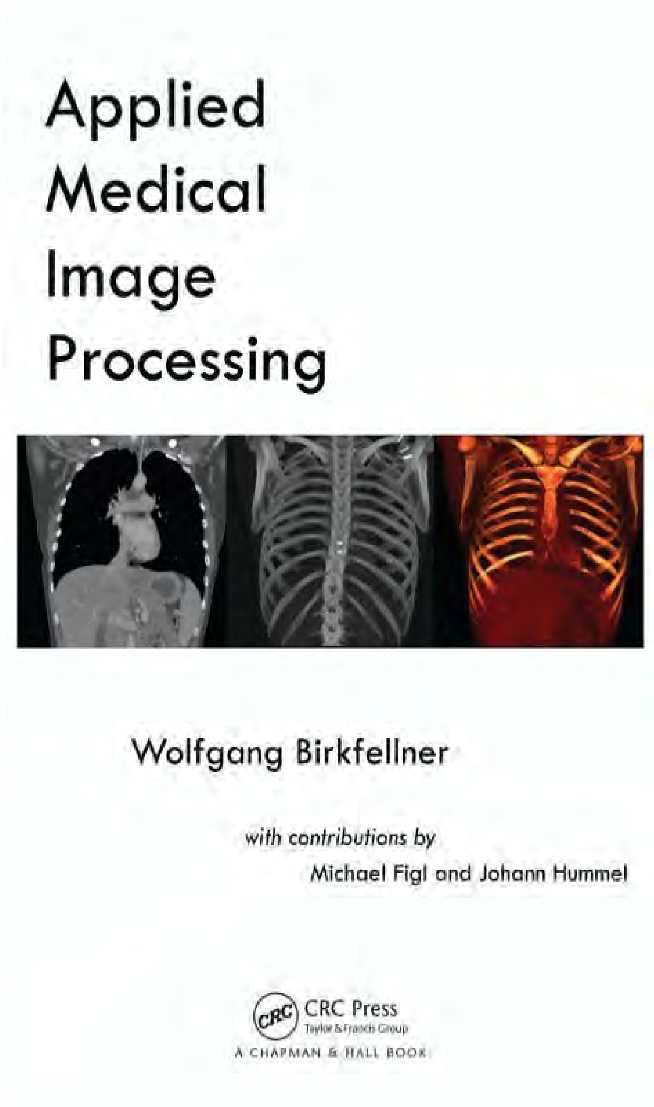
Pawiro SA, Markelj P, Pernus F et al.: Med Phys. 2011 Mar;38(3):1481-90.
Gendrin C, Markelj P, Pawiro SA et al.: Med Phys. 2011 Mar;38(3):1491-502

… and some preliminary results for IGRT of the lung …

- Update rate: 5 Hz
- Full retrieval of 6 degrees of freedom in motion of the CTV

Gendrin C, Furtado H, Weber C et al.: Radiother Oncol. 2011 Aug 30. - Epub ahead of print

Finally – Medical Physicists do also teach ...



Conclusions

- Medical image processing is an application – driven, interdisciplinary area of research in Medical Physics, Applied Mathematics, and Computer Science

- Scientific impact can only be achieved if a close cooperation with clinical partners can be established

- Visibility of the field for undergraduate students of physics, mathematics, and computer science/engineering should be improved

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Dept. of Radio-Oncology

Dept. of Diagnostic Radiology

Excellence Center for High Field MR

Dept. of Cranio-Maxillofacial Surgery

Dept. of Orthopaedic Surgery

Dept of Trauma Surgery

... & my Colleagues at the CBMTP

wolfgang.birkfellner@meduniwien.ac.at
http://www.meduniwien.ac.at/mip