Acquisition and evaluation of dynamic contrast-enhanced MRI data

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Image acquisition

Slice orientation

Temporal resolution vs. spatial coverage

Choice of FA

Breathing or not?

FA accuracy

T_{10} measurement

AIF measurement

every tumour type is different!

Image acquisition
slice orientation

- coronal-sagittal oblique often preferred (instead of axial)
  - reduces wash-in effects in AIF (descending aorta)
  - movement correction easier (in plane)

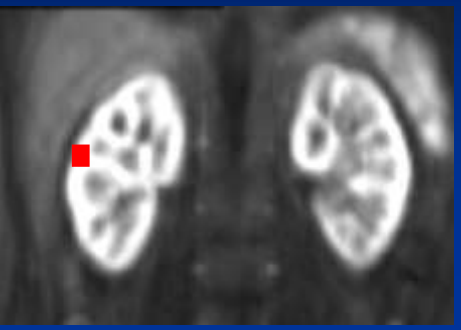
Image acquisition
Temporal resolution vs. spatial coverage

- Traditional Gd-enhanced image may take > 1 minute
  - Seeking high spatial resolution, complete coverage, good CNR
- Modern high SNR system can speed this up
  - Multi-array receive coils
- for DCE-MRI we want frame times 2-20 s
  - Depending on rate of enhancement in tumour of interest
  - Are we trying to capture first pass and estimate perfusion?
  - 3D (volume) acquisition preferred (better FA accuracy)
  - Use body coil transmission to reduce FA inhomogeneity
  - Scope for interleaving high spatial and high temporal resolution scans?
    - We can afford gaps in the later portion of the DCE curve

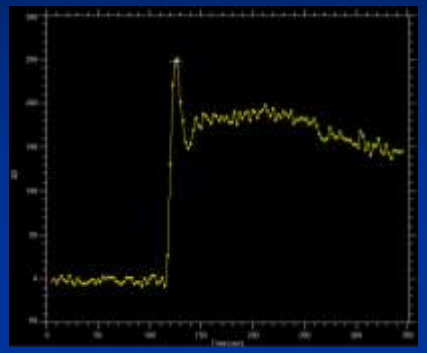
DCE imaging in the kidney
quantification of renal physiology

- Example shows:
  - Good temporal resolution (2.5s) and coverage
  - Good fitting of DCE curves
  - Reproducible renal physiological parameters
    - Repeats in controls
  - Accurate renal physiological parameters
    - Measured by other means e.g. Nuclear medicine

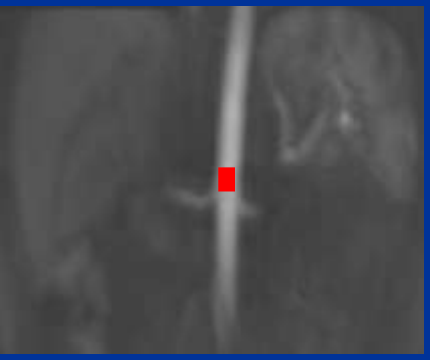
MRI Acquisition



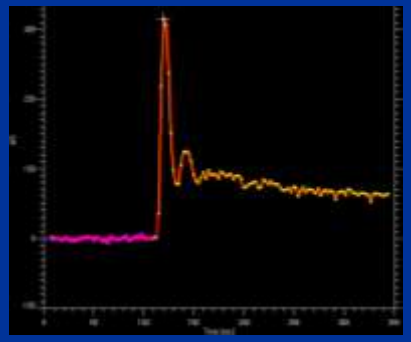
Cortical ROI



Time of peak



Arterial ROI

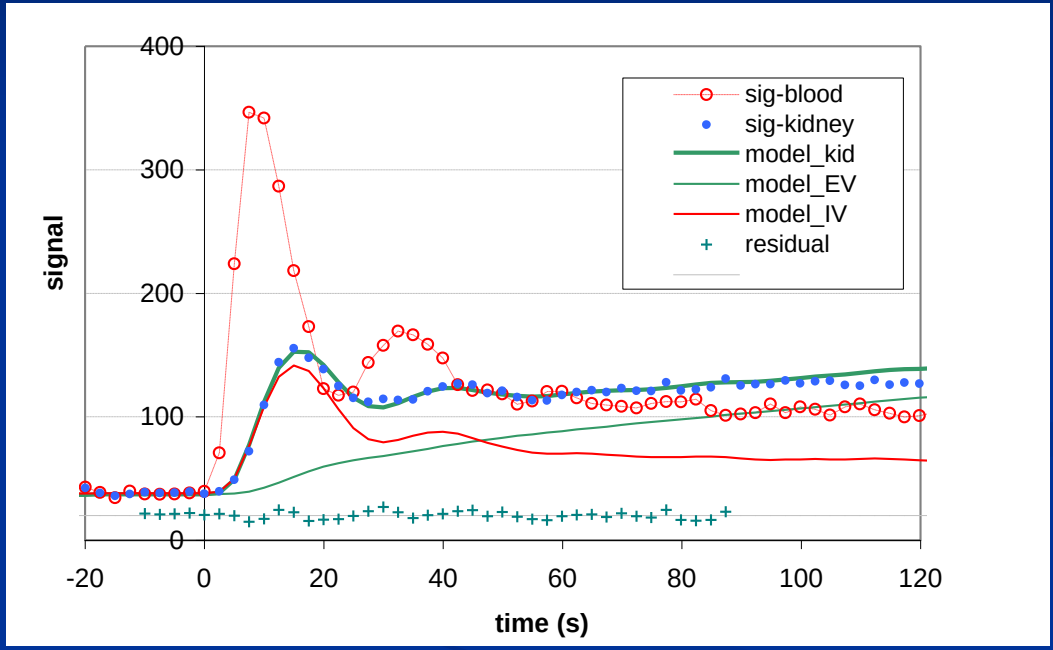


Arterial Input Function AIF

- Siemens Avanto 1.5 T scanner
- Abdominal TIM coil
- Gradient-echo 3D-FLASH pulse-sequence
- TR = 1.63 ms; TE = 0.53 ms
- Flip angle = 17°
- Strong fat saturation; PAT factor = 2 (GRAPPA)
- FOV = 400 x 325 mm^2
- 18 x 7.5 mm **coronal slices** covering entire kidney (no gap)
- Voxel size = 3.1 × 3.1 × 7.5 mm^3
- Frames acquired every 2.5 s
- Gd dose = 0.05 mmole/kg (**half dose**)

Fit parenchymal ROI
(uptake mode – no efflux)

- Spreadsheet implementation
  - uses solver; ROI fits in 5s
- blood and kidney signals
  - red circles; blue circles
- Fit up to 90s
  - green line
  - residuals RMS < 3%;
    - model errors are small
    - contributions from movement
    - contribution from blood signal noise?
  - efflux visible after 100s
    - kidney signal < model
- plot shows Gd in two compartments:
  - IV glomerular (red line; delayed AIF)
  - EV tubular (green line; shows uptake)



Normal values

parenchymal ROIs in uptake mode

		MRI mean±sd	instrumental sd	literature normal
filtration (min^{-1})	K^{trans}	0.25±0.05	0.04 (15%)	0.28(a)
blood volume (%)	v_b	34±8	6 (17%)	35 (c)
perfusion ml blood min^{-1} $(100\ ml)^{-1}$	F	219±53	26 (12%)	258(b)
filtration fraction (%)	FF	15.5±2.8	1.2 (8%)	15-20
Mean Arrival Time (s)	MAT	5.9±0.7	0.4 (6%)	6.5 (d)
absolute single kidney volume (ml)	V_{kid}	230±28	-	213
standardised kidney volume (ml)	V_{kid}^*	214±20		213
total GFR ($ml\ min^{-1}$)	GFR	115	27	120

Values in yellow are updated from abstract values (using F from peak of gaussian GIRF, and Hct^{small}=24%)

(a) = GFR/($2V_{kid}$*) (b) using RBF = 1.1 litre min^{-1} (c) from CT (d) Sourbron Invest Radiol 2008

CONCLUSION: our values for four physiological parameters are accurate (and FF and MAT are precise and could be useful)

ISMRM10 Stockholm

DCE imaging in the kidney
quantification of renal physiology

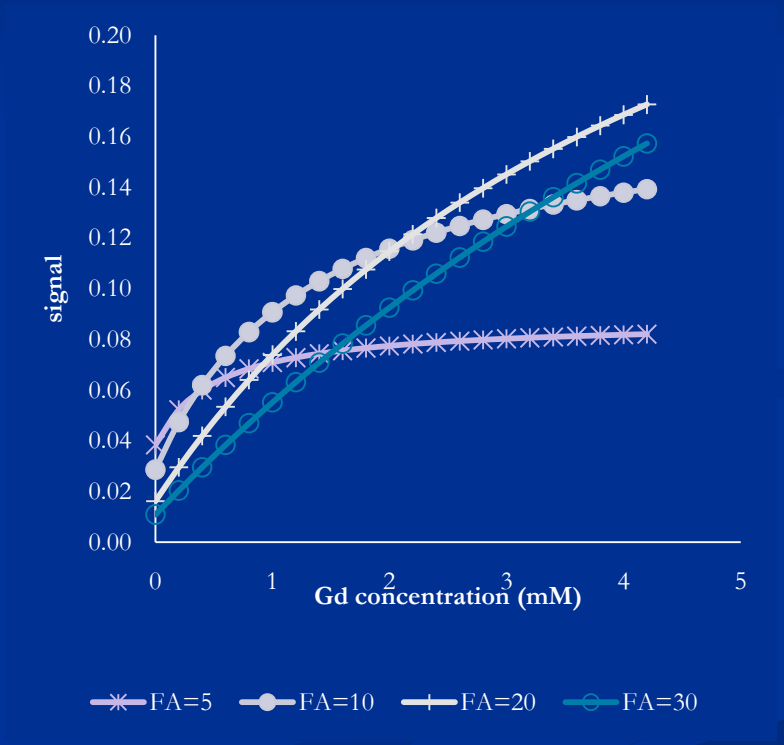
- End of Example
- Back to tumours

Image acquisition
Timing scheme

- Initial measurement of T_{10} (maybe)
- Start dynamic T_1w series ~3 frames before Gd
- Power injector Gd + saline flush
- Repeated T_1w imaging (fixed receiver gain)
- To estimate v_e should image for ~ 5min after bolus injection

Image acquisition
Choice of FA

- Higher FA (e.g. 30°)
  - gives linear signal vs Gd concentration,
  - higher dynamic range (e.g. for AIF)
  - Less signal at low concentration
- Lower FA (e.g. 10°)
  - Gives more signal at low concentration
  - But deal with signal non-linearity properly



T_1=1s; TR=3ms

Image acquisition
breathing or not?

- In body, respiratory motion can be major source of artefact.
- Total imaging time (~5 min) too long for a single breath hold
- Schemes
  - Free-breathing; hand above head to minimise motion of diaphragm
  - Breath-hold for first pass (~20s) then free breathe (but after breath-hold there can be a big gasp!)
  - Free breathe and throw away data at extreme of breath (using image or respiratory monitor to detect extrema)
  - Guided free breathing
- Still the subject of research

Image acquisition
FA accuracy

- FA accuracy on clinical MRI scanners is often poor
  - B_1 nonuniformity (inhomogeneity)
    - especially >1.5T; currently prefer 1.5T for quantification
    - especially in body imaging (head is better)
  - Which tissue is the setup procedure looking at to set up the flip angle? Volume, slice, ROI in the slice, tumour?
- Fast B_1 mapping sequences exist
- 'RF shimming' will improve B_1 uniformity – parallel transmit – TIM Tx trueform
- 3D acquisition usually better than 2D multi-slice (poor slice profile)
- Wrong FA value affects
  - calculation of Gd concentration from enhancement
  - measured AIF (if used)
  - measured T_{10} value (if used) (10% error in FA → 20% error in T_1)
  - some of this error may cancel out in the calculation of K^{trans} and v_e

Image acquisition
T_{10} measurement

- T_1 measurement usually very vulnerable to FA errors
- Can use a standard value, but tumour values vary depending on pathology (~1-2s)
- Standard method is Variable Flip Angle
  - PD-w image (low FA)
  - T1-w image (higher FA)
  - Obviously sensitive to FA inaccuracy
  - Inversion Recovery methods much more robust, but take longer
- Inaccurate T_{10} gives inaccurate K^{trans} and v_e (though k_{ep} i.e. shape of curve is OK)
- Scanner Quality Assurance should demonstrate
  - stable signal (no Gd gives flat line) and
  - accurate T_1 measurement

Image acquisition
effect of T_{10} inaccuracy

- What T_{10} value for breast tumour should be used in model fitting?
- fitted values of K^{trans} and v_e
- Doubling tumour T_{10} reduces K_{trans} estimate by ~50% , v_e by more

Quantitative Analysis of Dynamic Gd-DTPA Enhancement in Breast Tumors Using a Permeability Model

Paul S. Tofts, Bruce Berkowitz, Mitchell D. Schnall

MRM 33:564–568 (1995)

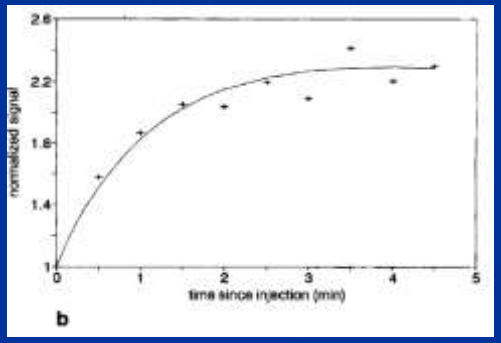
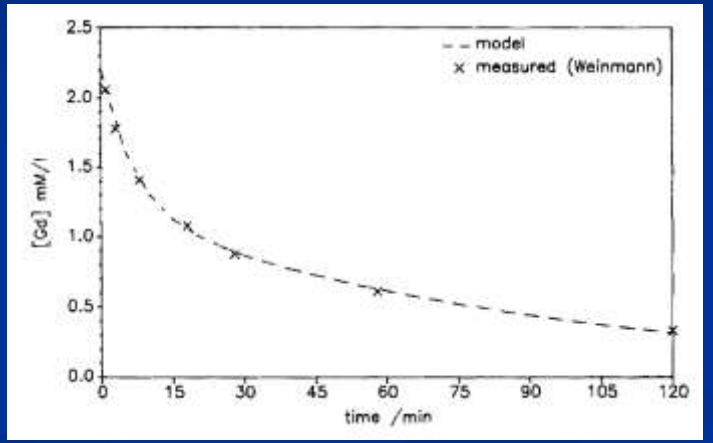


Table 1
Effects of the Assumed Tumor T_1 Value (T_{10}) on Fitted Values of Permeability k and Leakage Space v_i, for the Medium Permeability Data Shown in Fig. 1b (Measured at 1.5 T)

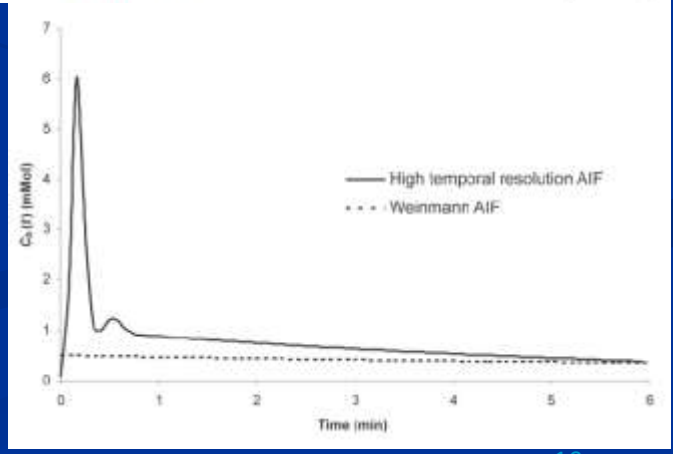
Tissue	T_{10} (s)	k (min^{-1})	v_i	RMS residual error in fit
Normal low risk fatty portion (18)	0.46	0.88	1.43	0.091
Tumor - low T_1 (20)	0.60	0.63	0.96	0.092
Normal high risk diffuse density portion (18)	0.71	0.51	0.76	0.093
Tumor - high T_1 (20)	1.3	0.26	0.36	0.095

Image acquisition
AIF measurement

- Ideally measure AIF for each subject
  - But can introduce extra variation that degrades within-subject reproducibility
- AIF measurement can be hard!
  - Wash-in effect increases signal, gives too high estimate of Cp
  - To capture first pass needs good temporal resolution (1-3 s)
- Alternative is population based AIF
  - Weinmann (slow, from blood samples)
  - Fritz-Hansen (numerical, fast)
  - Parker (analytic, has first pass)



Magnetic Resonance in Medicine 56:993–1000 (2006)



Magnetic Resonance in Medicine 56:993–1000 (2006)

Experimentally-Derived Functional Form for a Population-Averaged High-Temporal-Resolution Arterial Input Function for Dynamic Contrast-Enhanced MRI

Geoff J.M. Parker,[1]* Caleb Roberts,[1] Andrew Macdonald,[1] Giovanni A. Buonaccorsi,[1] Sue Cheung,[1] David L. Buckley,[1] Alan Jackson,[1] Yvonne Watson,[1] Karen Davies,[1] and Gordon C. Jayson[2]

Image analysis

Spatial registration

Choice of AIF

v_p or not?

How least squares fitting works

histograms

Examples from Tissue4D

every tumour type is different!

Image analysis
Spatial registration

- In-plane movement (coronal-sagittal slice) relatively easy
- mostly 1D
- General problem is hard (non-rigid body motion)
- Depends on tumour location
- Ongoing research

- every tumour type is different!

Image analysis
Choice of AIF

User measured or population average

every tumour type is different!

Image analysis
v_p or not?

Plasma term if tumour is vascular

Try it in the fit; do you get $v_p > 0$?

every tumour type is different!

Image analysis
How least squares fitting works

- To fit a model to the data:
  - model signal curve depends on
    - free parameters K^{trans} v_e (v_p) ; these are to be determined by the fitting process
    - fixed parameters FA T_{10} r_1 (Hct...) ; these are preset
  - Calculate difference between model curve and measured curve (from ROI)
    - Actually the sum of the squares of the differences
  - Adjust the free parameters over all possible values
    - find which combination of these gives the minimum difference
  - This combination is the Last Squares Fit
    - The free parameter values are the 'fitted values'
  - Fit failures can occur
    - No minimum could be found (e.g. very noisy data), or
    - Unrealistic value of a parameter (often v_e>1, often caused by incomplete data or wrong T_{10})
- Give confidence limits on fitted parameters

Image analysis
ROI analysis and voxel mapping

- ROI analysis
  - Generate a curve; high SNR
  - Can see realism of model
  - Can adjust ROI if in-plane movement

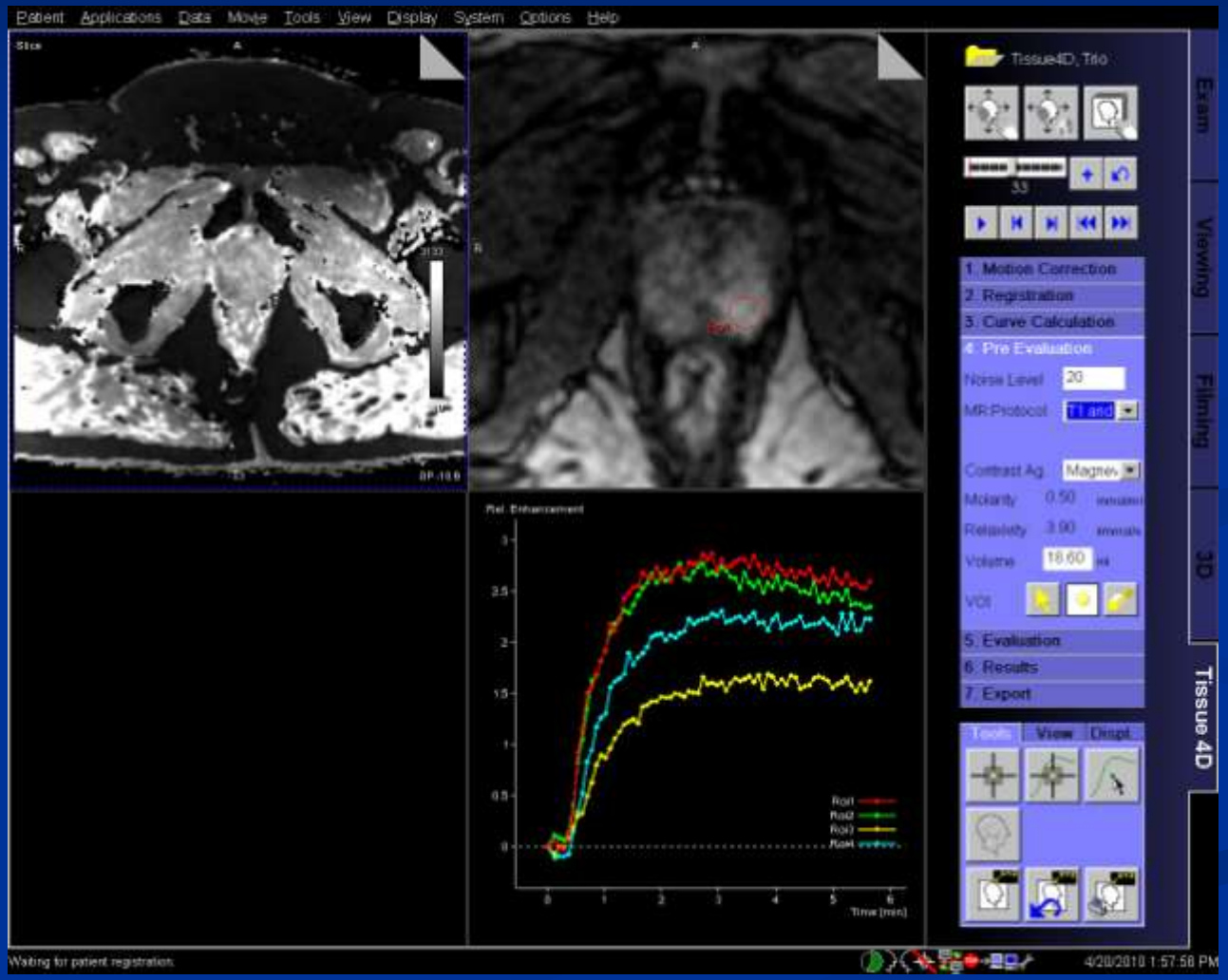
- Voxel mapping
  - Unbiased examination of whole tumour
  - Needs good registration of slices
  - Needs good SNR
  - Can generate histograms

- Both are in Tissue4D

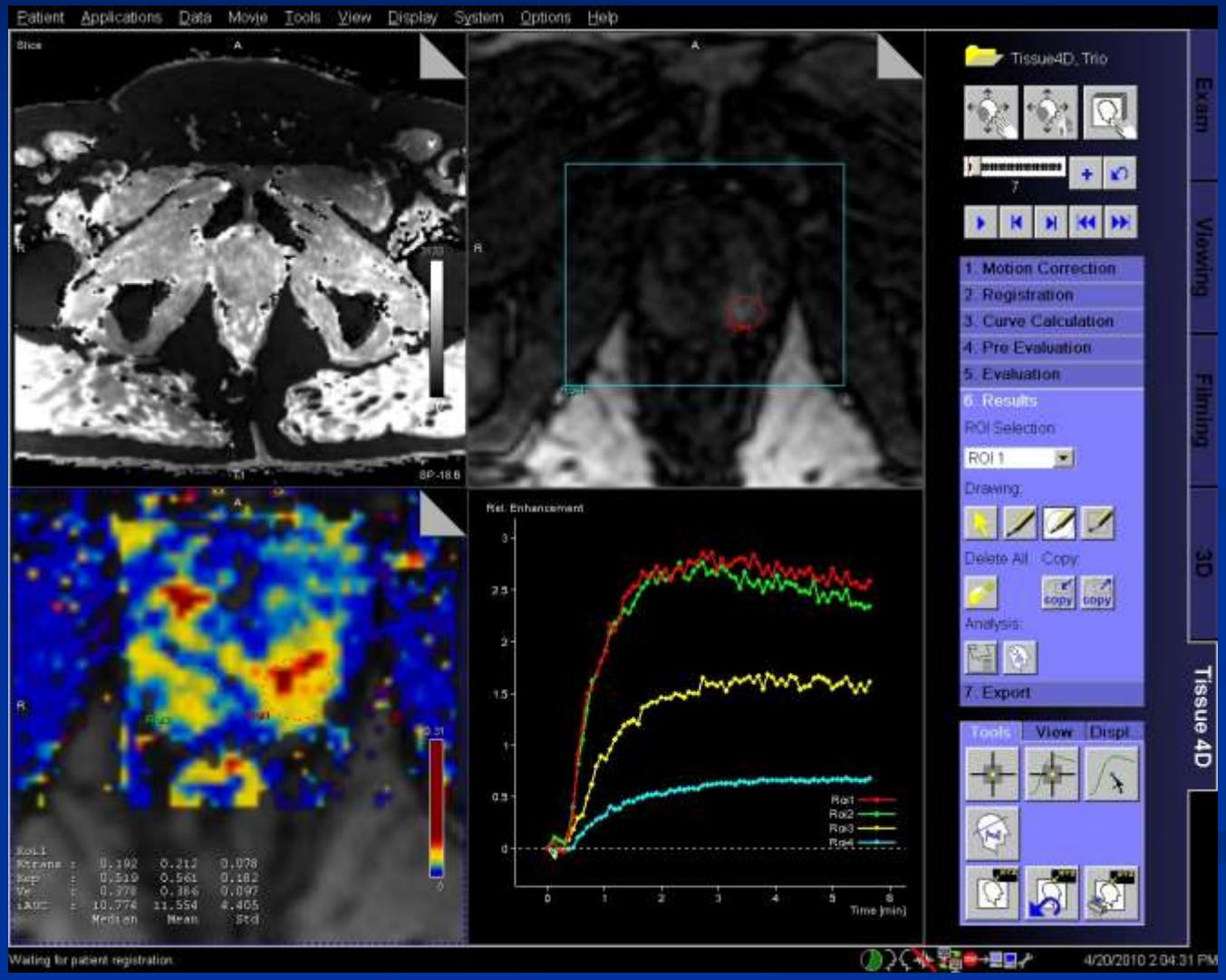
Image analysis
histograms

- Histograms can display information from a whole ROI or VOI
- Use relative volume or absolute volume
- Standardised histogram architecture for multi-centre comparison:
  - Normalise for bin width
  - Area under histogram is then 100% or total tumour volume (mL)
  - More in Tofts PS MAGMA. 2006; 19:209-22. Sources of variation in multi-centre brain MTR histogram studies: body-coil transmission eliminates inter-centre differences.
- Extract features:
  - Peak location (mode) median mean
  - Peak height
  - Characterise tails (volume or percentile)
    - Can predict malignant transformation (Tofts PS JMRI 2007; 25:208)
  - Principle components analysis is more general (Dehmeshki MRM 2001;46:600)

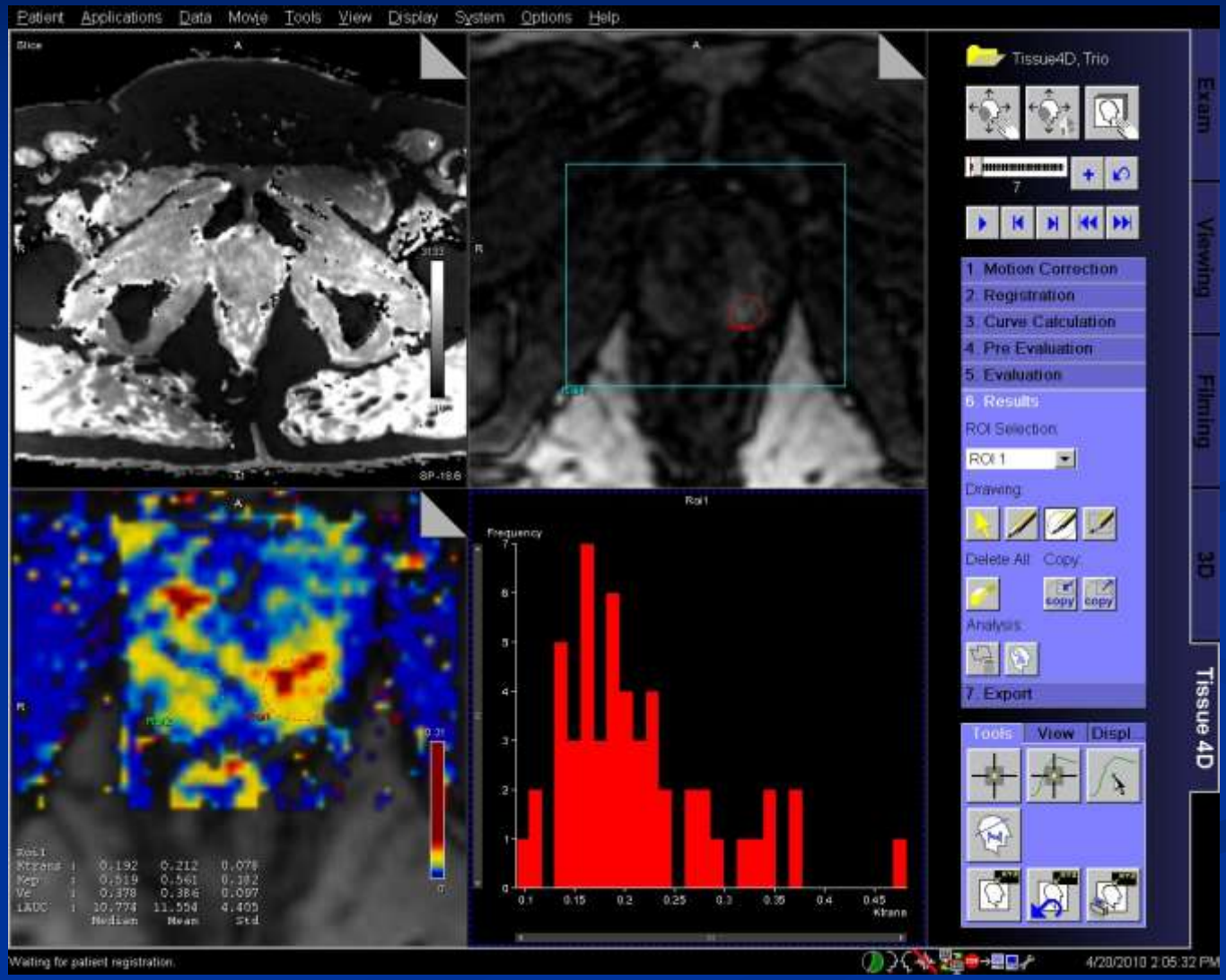
Tissue4D - ROI and maps of K^{trans}



Tissue4D - ROI and maps of K^{trans}



Tissue4D - ROI and maps of K^{trans}



summary

- Principle physiological parameters are K^{trans} and v_e
- Beware of FA and T_{10} problems
- Is a v_p term needed in the modelling?

- every tumour type is different!

- Acknowledgements:
  - UK Experimental Cancer Medicine Committee group on cancer imaging (Martin Leach, David Collins and many more)
  - Silke Quick, Peter Gall (Siemens Erlangen) for tissue4D examples