Computational Approaches to Renal Function Assessment from DCE-MRI Time Series

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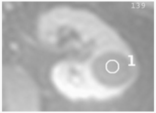
Cost B21 - Renal Working Group Meeting, Bergen
8 Dec. 2006

Kidney Disease

Secondary Renal Hypertension

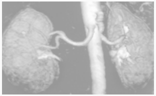
- presence of a stenosis which reduces renal blood flow
- assess the loss in renal function
- segmentation of functional compartments & perfusion parameters

Polycystic Kidney Disease



- cause functional loss in kidney
- growth of cysts can go along with a change of total kidney volume

Renal Transplants



- anastomotic stenosis and perfusion defects
- access to blood flow/ perfusion
- quantification of the status of the graft

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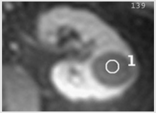

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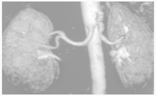

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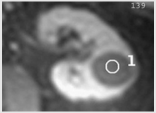

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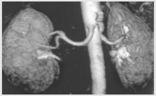

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Clinical Assessment of Renal Function of Human Kidney

Measurements

- creatinine level in blood (CL)
- change of blood urea nitrogen (BUN)
- creatinine clearance

Disadvantages

- significant change in BUN and CL only detectable until 60% function loss
- creatinine clearance overestimates actual glomerular filtration rate (GFR) up to 20%
- no split function between left or right kidney

→ indirect measures are rather imperfect, need for other assessment

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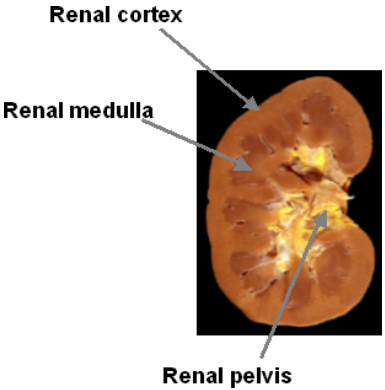
Standard Volume Estimations in Human Kidney

- kidney compartments: cortex, medulla, pelvis
- ultra-sound: method of choice to detect cysts
- imprecise estimates
  - high intra- and interobserver variations
  - manual perimeter drawing
  - semi-major/ semi-minor axis of one slice



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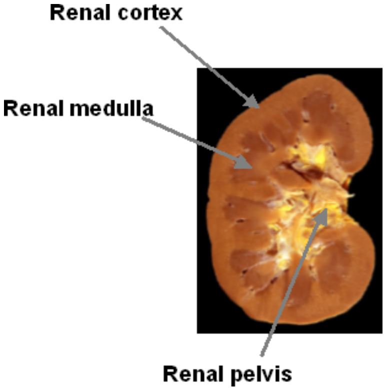

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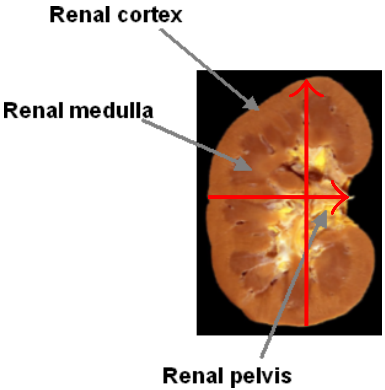

Assessment of Renal Function: MRI

Perfusion MRI

- noninvasive imaging of organs and tissue
- high resolution 3D, 4D data
- fast acquisition
- using contrast agents for perfusion study
- enables more accurate assessment of kidney function and volume

3T MR Scanner at Haukeland University Hospital

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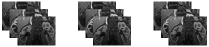
Clustering Volumetric MRI Perfusion Time Series



registered image data

- prerequisite: registered time series
- separate kidneys to estimate renal function for single kidneys
  - K-Means Clustering of short sequence ($\approx$ 20 frames)
  - initialise 3 classes, cosine distance function
  - separation based on intracluster distance $\rightarrow$ smallest value identifies cortex
- Clustering of single Kidneys
  - similar procedure as above
  - initialisation with 5 classes

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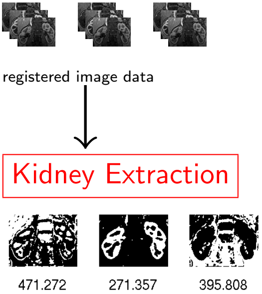

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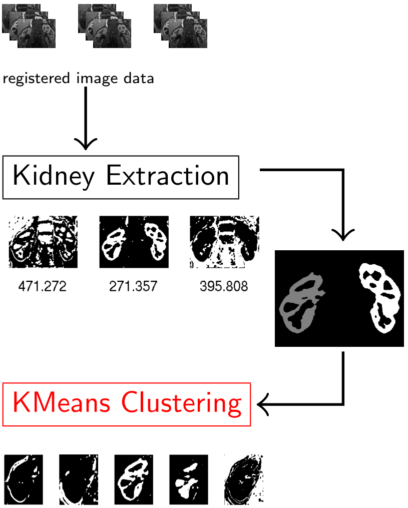

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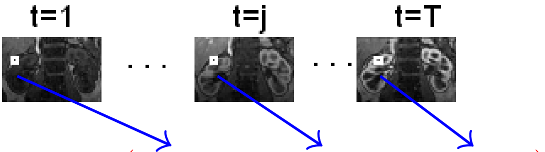
Independent Component Analysis of Kidney MRI Perfusion Data



$$\underline{I}(x,y) = (I_1(x,y), \ldots, I_j(x,y), \ldots, I_T(x,y))$$

↓

ICA

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$$IC_1, \ldots, IC_i, \ldots, IC_N$$

- find independent components in multidimensional data
- based on maximal non-gaussianity of ICs
- transform pixel intensities vectors into matrix
- apply fastICA algorithm
- transform back ICs into image space

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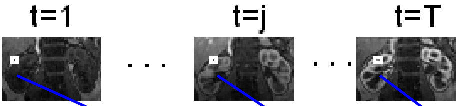

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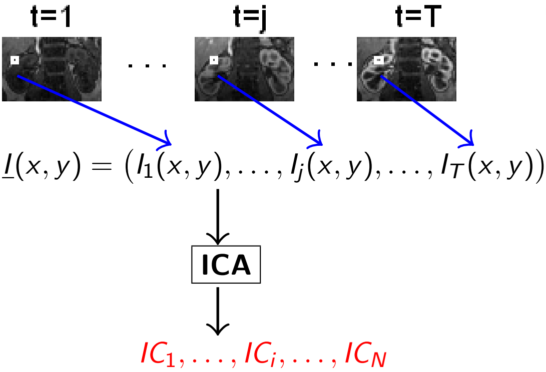

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Active Contours for Segmentation

Minimisation of the energy functional E^*_{snake} on the curve $\underline{v}(s)$:

$$E^*_{\text{snake}} = \int_0^l \left[\alpha E_{\text{cont}} + \beta E_{\text{curv}} + \gamma(E_{\text{dist}}) E_{\text{image}} + \delta(E_{\text{dist}}) E_{\text{dist}}\right] ds$$

- E_{cont} & E_{curv}: Continuity of the curve
- E_{image}: Result of time intensity vector correlation
- E_{dist}: Distance from initial contour
- α, β, γ & δ: Weights of the energy terms
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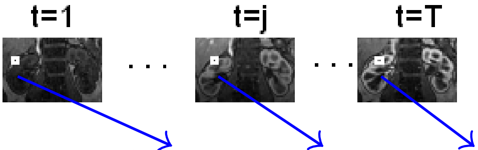
Deriving Gradient Information from Voxel Time Series



$$\underline{I}(x,y) = \left(I_1(x,y), \ldots, I_j(x,y), \ldots, I_T(x,y)\right)$$

$$c'(x,y) = \frac{1}{n} \sum_{(p,q)\in N^{(n)}(x,y)} c(I(x,y), I(p,q))$$

$$c(I(x,y), I(p,q)) = \frac{< I(x,y), I(p,q) >}{||I(x,y)||||I(p,q)||}$$

- perfusion data (3D+time)

  $\longrightarrow$ intensity vector for each pixel
- clustering time series: cosine distance function (angle between intensity vectors)

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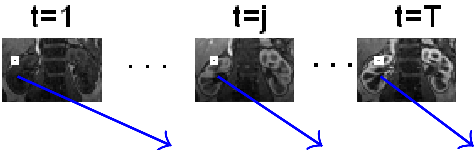

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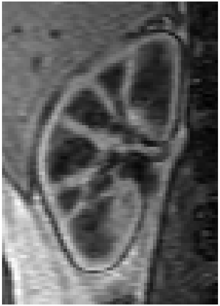

original image slice

after correlation

after k^{TH} and h-maxima transformation

Datasets

id	field	seq.	resolution(mm)	4D size	timing
1	1.5 T	FLASH	(1.48x1.48x3.00)	(256x256x20x20)	n.e.
2	1.5 T	VIBE	(1.48x1.48x3.00)	(256x256x20x118)	2.5
3	3.0 T	LAVA	(0.86x0.86x1.20)	(512x512x44x60)	3.0
4	3.0 T	LAVA	(1.72x1.71x2.4)	(256x256x20x60)	3.7

- scanner: 1.5 T Siemens Symphony, 3.0 T Signa Excite GE
- healthy volunteers
- all datasets have been registered before processing!

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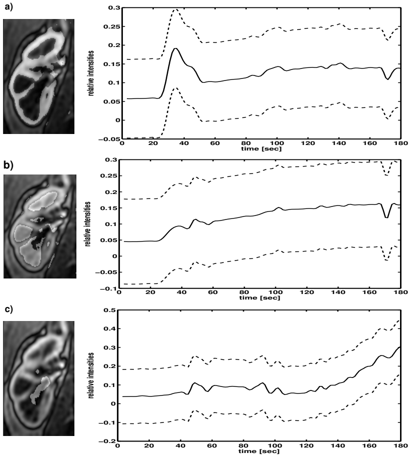
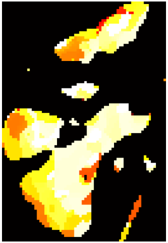
Results of Clustering Approach



- clusters depict functional compartments (cortex, medulla, pelvis) of the kidney
- derived time courses similar to descriptions from literature
- other clusters (2) represent background and partial volume effects (omitted)

Derived Parameter Maps



slice 22/44, dataset 3

- time to peak map (cortex, medulla)
- lighter color → later time point
- maximum slope
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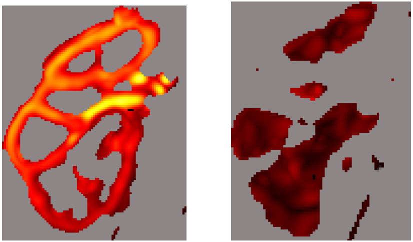

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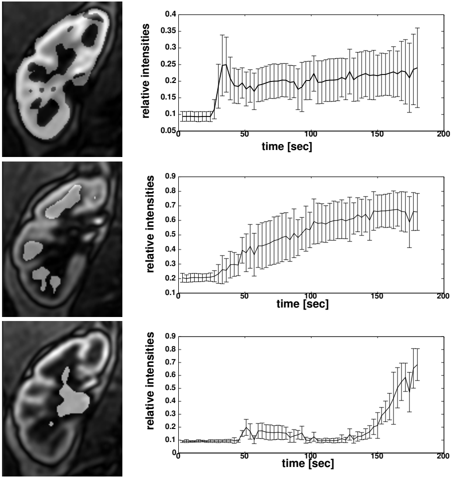
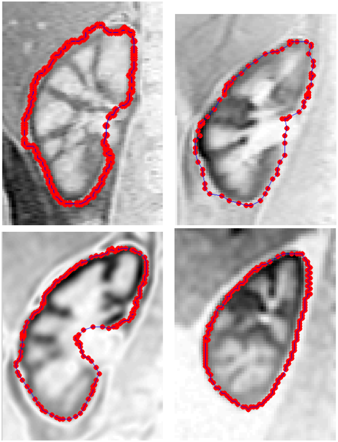
Results of Independent Component Analysis



- ICA can reveal functional compartments of the kidney
- derived time curves similar to those from K-Means clustering

Segmentation Results

- slice with the finally estimated contour of the left kidney for each dataset
- average segmentation accuracy for all slices/ dataset:
    1. 0.91
    2. 0.92
    3. 0.92
    4. 0.94



Segmentation Results

Volume rendering from segmentation results

Summary & Outlook

- presented several computational approaches to assess renal function (K-Means clustering, ICA analysis, volume segmentation)
- results are promising, functional compartments could be identified/ volume segmented
- based on time intensity curves, derivation of parameter maps

- test methods on data from non-healthy patients, and larger dataset
- transfer time intensity curves to concentration time curves ($\rightarrow$ pharmacokinetic modelling)
- calculate perfusion parameters like GFR

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Acknowledgements

Registration

- Rosario Sance, Technical University of Madrid, Spain
- Peter Rogelj, University of Ljubljana, Slovenia
- Andreea Anderlik, UiB

Visualisation

- Marek Kocinski, Technical University of Lodz, Poland

Imaging & Supervision

- Jarle Rørvik, UiB
- Arvid Lundervold, UiB

References

1. Zöllner FG, et al. Assessment of Renal Function from 3D Dynamic Contrast Enhanced MR images using Independent Component Analysis in *BVM 2007*.Informatik Aktuell,Springer 2007.accepted
2. Zöllner FG, et al. Towards quantification of kidney function by clustering volumetric MRI perfusion time series *MAGMA* 2006;19:103–104.
3. Zöllner FG, et al. Assessment of high field DCE-MRI of the kidneys using non-regid image registration and segmentation of voxel time-course *Inv Radiology.* 2006. submitted