Master‘s Program in Medical Physics

Biomedical Engineering

MRI Flow Measurements

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Overview

- Renal Artery Stenosis, Secondary Hypertension and their effect on kidney function
- Measuring Blood Flow with MRI
- Analysis and Quantification
- Conclusions
- Extensions to 4D Blood Flow Measurements

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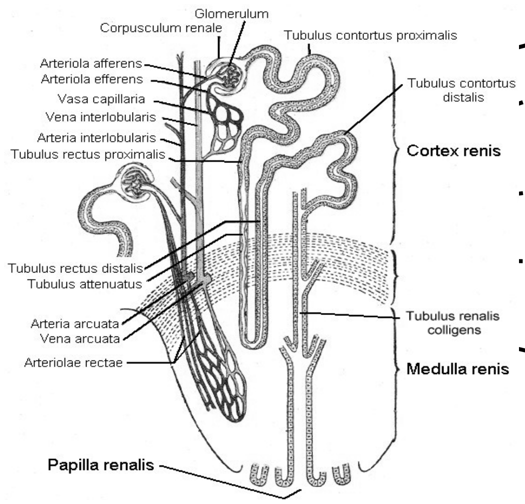
Renal Anatomy



- Cortex (*Cortex renalis*)
- Medulla (*Pyramides renales*)
- renal artery (*Arteria renalis*)
  renal vene (*Vena renalis*)
- Pelvis (*Pelvis renalis*)
- *Nephron* (*Papillae renales*)

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MIP Projection – Renal Artery

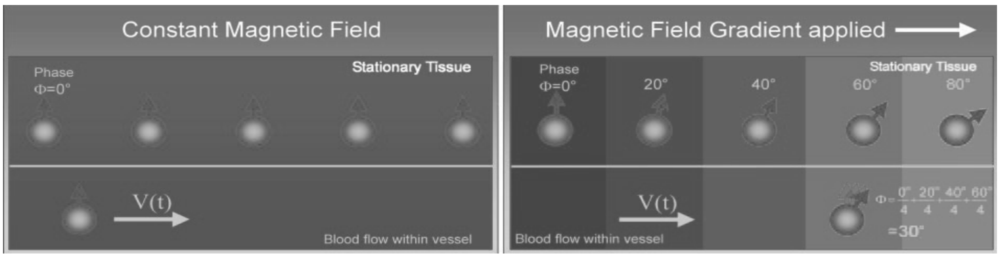
RAS, Secondary Hypertension, etc.

- RAS leading cause for secondary hypertension ➔ CKD
- Reduced flow triggers auto-regulation of systemic circulation
- Loss of renal parenchyma in the stenosed kidney
- Microangiopathy in the contralateral kidney

- Parameters to detect status:
  - Flow reduction
  - Flow velocity
  - Kidney size
  - Overall and split renal function

Allow for stenosis grading *and* better selection of patients for PTA

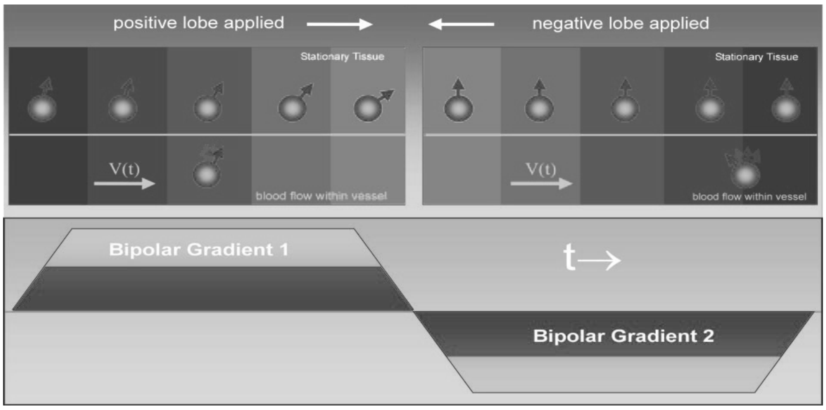
MR Blood Flow Measurements (1)



- Spins moving along a magnetic field gradient acquire a difference in the phase (right)
- Amount of phase difference proportional to the velocity of the moving spins

Lotz et al. , RadioGraphics 2002

MR Blood Flow Measurements (2)



- Flow encoding by means of difference in the bipolar gradients
- Acquisition of two images
- Phase difference by substraction

Lotz et al. , RadioGraphics 2002

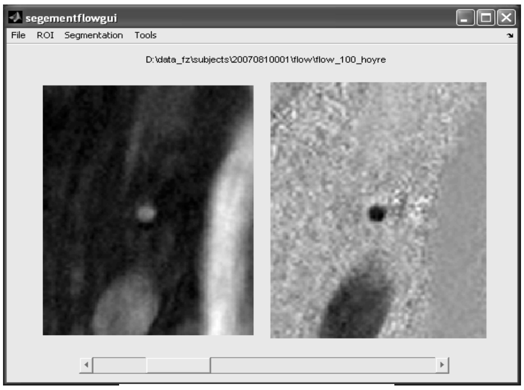
MR Blood Flow Measurements (3)

Phase difference expressed in formulars:

$$\Delta\Phi = \gamma \cdot \Delta m \cdot v$$

γ gyromagnetic ratio
Δm difference of the first moment of the gradient time curve

MR Blood Flow Measurements (4)



- receive 2 images
- Magnitude image with velocity
- Phase image with velocity *and* direction

$$v = \frac{\Delta\Phi}{\pi}$$

Flow encoding needs an operator defined value:
VENC [cm/sec]

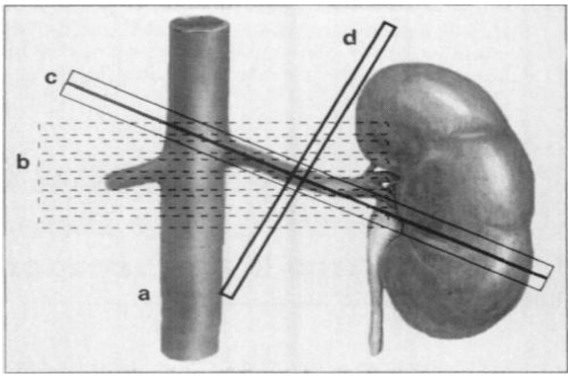
$-VENC < v < VENC$

Acquisition Protocol (1)

- ECG gated PC cine MR sequence with:
  - TE=4ms, TR=37ms, FA=30°
  - VENC=100 cm/s
  - ca. 20 images / cardiac cycle
  - Resolution 0.5 x0.5 mm
  - Slice thickness 6mm
- 1.5T Siemens Symphony Vision

Acquisition Protocol (2)

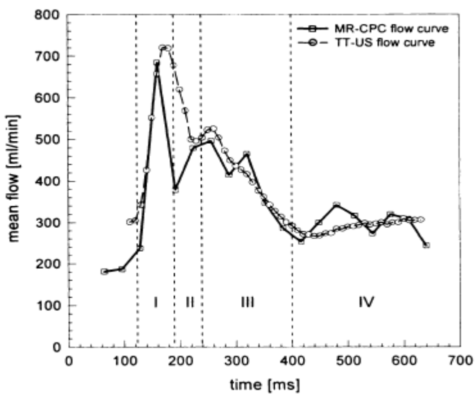
a. Abdominal aorta
b. Images acquired from MR angiography
c. Image slice through the vessel
d. Imaging plane for PC-MRI (perpendicular to c)



Schönberg et al. , Radiology 1997

Clinical Interpretation of Flow Profile

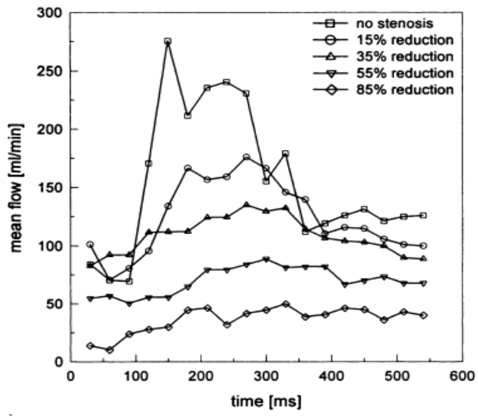
- 4 section within RR interval
- Systolic peak (I)
- Incision (II) followed by midsystolic peak (III)
- Diastolic phase (IV)



Schönberg et al. , Radiology 1997

Flow Profile in Stenoic Patient

- First systolic peak and incision disappear with increasing degree of stenosis



Schönberg et al. , Radiology 1997

MR Blood Flow Data Analysis

- Common:
  manual delineation of vessel (Florez et al., MAGMA 2006, Bax et al., J Vasc Interv Radiol 2005)
- Active contours (Kozerke et al., JMRI 1999, Mansard et al., MRM 2004)
- Correlation and thresholding (Alperin et al., MRM 2003)

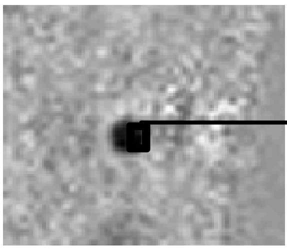
K-Means Clustering (1)

- iterative process, minimize the objective function across all clusters $C_1, \ldots, C_K$,
  - K is the number of predefined clusters,
  - m_k is the centroid of cluster C_k,
  - and are the data points.
  - d() distance metric
- partition of the data into K clusters

Distance measures:
Euclidian
Correlation
Cosine

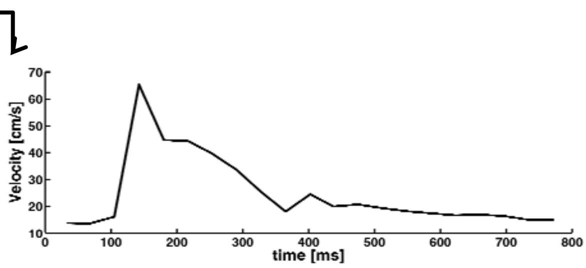
$$E = \sum_{k=1}^{K} \sum_{x \in C_k} d(\vec{x}, \vec{m}_k)$$

K-Means Clustering (2)



Phase image

Each pixel has a velocity profile



Velocity profile

Velocity profiles input to clustering algorithm

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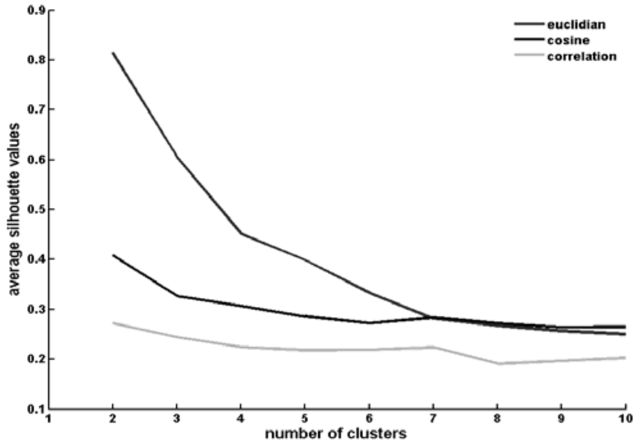
Results – Distance Metric



$$s(i) = \frac{(b(i) - a(i))}{\max\{a(i), b(i)\}}$$

a(i): average distance between the i-th sample and all samples in C_i

b(i): minimum average distance of the i-th sample and all samples in cluster C_j, $i \neq j$

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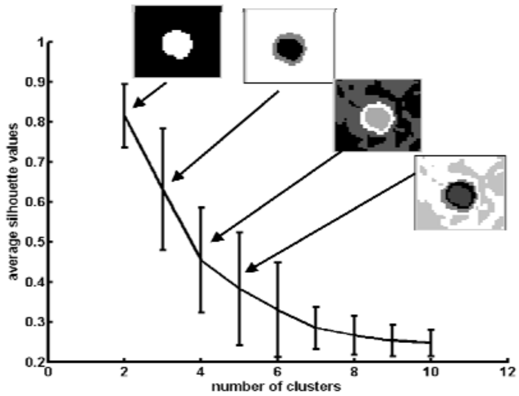
Results – Number of Clusters



- K=2 best average silhouette width
- For higher K subdivision of vessel region and background

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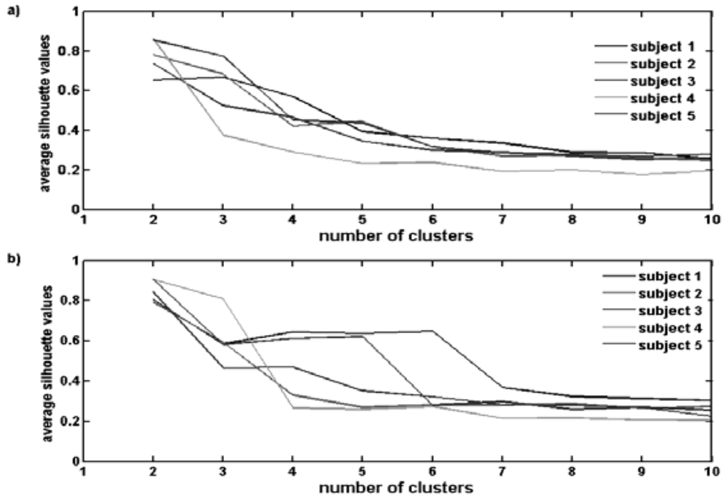
Results – Number of Clusters (2)



a) Left renal arteries, b) right renal arteries

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Results – Comparison to Manual Delineations

Differences due to aliasing →

overestimation →

Similar area sizes →

datasets	k-means clustering		Manual delineation
	optimal number of clusters (K)	area (mm²)	area (mm²)
1 right	3	15.68	28.86 (±2.39)
1 left	3	48.66	36.73 (±0.21)
2 right	3	17.64	16.05 (±1.02)
2 left	3	20.37	29.89 (±0.00)
3 right	3	44.10	38.16 (±0.19)
3 left	3	30.65	21.36 (±1.76)
4 right	2	22.98	22.35 (±0.14)
4 left	2	21.29	20.08 (±0.33)
5 right	3	18.86	21.64 (±0.90)
5 left	2	30.57	32.03 (±0.35)

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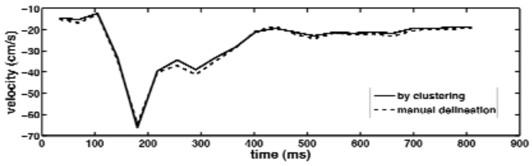
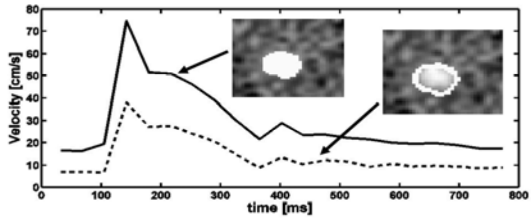
Results – Comparison of Velocity Profiles

- High correlation between velocity profiles (r=0.996, +/- 0.002)
- Similar for flow profiles (r=0.994, +/- 0.005)





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Conclusions

- Clustering of PC cine MR images for blood flow measurements feasible
- Differences in area to manual delineations
- But: high correlation of the velocity and flow profiles
- Number of cluster k=2,3 dependent on subject
- Easy and fast method, nearly no manual interaction