Association between pathology and texture features of multi parametric MRI of the prostate

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Motivation

- Finding a correlation between imaging parameters (textures) derived from mpMRI and pathological verified tumor occurrence in the prostate
- Investigation of orthogonal partial least squares (OPLS) modelling approaches and the predictive power of parameter combinations
- Long-term goal: Usage of tumor prediction models as assistance during tumor delineation / diagnostic
Material & Methods: Dataset

- 25 Patient Data sets
  - T2 \((a)\)
  - DCE (70 timepoints)
    - DCE: 0s, 79s, 300s \((b-d)\)
    - AUC \((e)\)
    - kTrans \((f)\)
  - DWI (ADC map measured based on 4 b-values) \((g)\)
  - Pathology information after prostatectomy \((h)\)
    - Slice thickness 3-4 mm
Material & Methods: Delineation

- Registration of pathological slices and MR images is challenging
- Central Gland and Peripheral Zone were delineated on T2
- Based on histological information, Tumor was delineated by visual comparison and propagated to all image modalities
- In addition, geometrical substructures (PIRADS) were used and scored in accordance to pathological information (4 distinct scoring levels)
  - 6 substructures in CG and 16 substructures in PZ
Material & Methods: Delineation

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- PIRADS Structure 10p:
  - Score: 0.75 / 1
Material & Methods: Delineation

• In 24/25 cases the situation was more complex
Material & Methods: Workflow

T2

DCE 3 Timepoints

kTrans

AUC

Delineation

ADC

Extract Structures

Gray-level co-occurrence Matrices

GLCM (BinSize=8,16,32)

Calculate textual parameters

Tumor

Tumor-free

Data Matrix

X

Multivariate Image Analysis

PCA OPLS
Material & Methods: Workflow

**Material & Methods: Workflow**

- **Delineation**
  - T2
  - DCE
  - kTrans
  - AUC

- **Extract Structures**
  - Tumor
  - Tumor-free

- **Gray-level co-occurrence Matrices (GLCM)**
  - BinSize = 8, 16, 32

- **Calculate textual parameters**

- **Data Matrix**

- **Multivariate Image Analysis**
  - PCA
  - OPLS

**11 Histogramm based parameters per image modality**
Evaluation Parameters

- Textual Parameters
  - Autocorrelation, Cluster Prominence, Cluster Shade, Maximum Probability, Energy, Sum of Squares Variance, Sum Variance, Sum Entropy

- Gray-level co-occurrence matrixes (GLCM)
  - Bin Size (N=8,16 and 32)
  - 4 Orientations

- Histogram based parameters
  - Min, Max, 2%, 15%...85%, 98%, mean, median, standard deviation, skewness, kurtosis
Orthogonal partial least squares (OPLS) Modeling

• OPLS is a multivariate regression technique

• \( X \) data matrix:
  \( \rightarrow \) textures and histogram-based parameters of image modalities

• \( y \): response representing histological information

• OPLS removes variations in \( X, T_0P_0 \), that is orthogonal to response

• **Quality of Model:**
  \( \rightarrow R^2Y: \) goodness of model itself [0-1]
  \( \rightarrow Q^2Y: \) explaining the cross-correlation [0-1]

\[
X = \bar{x}' + tp' + T_0P_0 + E
\]
\[
y = \bar{y}' + tq' + F
\]
Preliminary Results: PCA on PIRADS structures

- Histograms of Score projections of ADC
  - Blue bars = distribution of tumor free PIRADS structures
  - Orange bars = PIRADS structures with tumor occurrence

![Histograms and ROC curves for different histoscores](image-url)
Preliminary Results: PIRADS using PCA

- Histograms of Score projections of ADC
  - Blue bars = distribution of tumor free PIRADS structures
  - Orange bars = PIRADS structures with tumor occurrence
Preliminary Results: OPLS modeling

<table>
<thead>
<tr>
<th>Imaging</th>
<th>Parameters</th>
<th>Q2Y</th>
<th>R2Y</th>
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<tr>
<td>ADC</td>
<td>Txt</td>
<td>0.491</td>
<td>0.544</td>
</tr>
<tr>
<td>ADC</td>
<td>Hist</td>
<td>0.624</td>
<td>0.643</td>
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<tr>
<td>ADC</td>
<td>Txt+Hist</td>
<td><strong>0.660</strong></td>
<td><strong>0.713</strong></td>
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<td>DCE (79s)</td>
<td>Txt</td>
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<td>0.529</td>
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<tr>
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<td>Hist</td>
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<tr>
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<td>Txt+Hist</td>
<td><strong>0.454</strong></td>
<td><strong>0.550</strong></td>
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<td>Txt</td>
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<td>0.435</td>
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<tr>
<td>T2</td>
<td>Hist</td>
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<tr>
<td>T2</td>
<td>Txt+Hist</td>
<td><strong>0.489</strong></td>
<td><strong>0.554</strong></td>
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<td>kTrans</td>
<td>Txt</td>
<td>0.282</td>
<td>0.351</td>
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<tr>
<td>kTrans</td>
<td>Hist</td>
<td>0.191</td>
<td>0.243</td>
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<tr>
<td>kTrans</td>
<td>Txt+Hist</td>
<td><strong>0.375</strong></td>
<td><strong>0.466</strong></td>
</tr>
</tbody>
</table>

OPLS Model including textual and histogram-based parameters for ADC

- **Blue dots** = tumor structures
- **Red dots** = tumor free structures
OPLS Modeling

- Histogram based parameters
- Textual Parameters
- Combined: Hist & Txt

- Q² values for different parameters:
  - ADC
  - T2
  - DCE (79s)
  - AUC
  - kTrans
  - DCE (0s)
  - DCE (300s)
OPLS Modeling
OPLS Modeling

Benefit from using all mpMRI image methods available

- R2Y
- Q2Y
- Linear (R2Y)
- Linear (Q2Y)
OPLS Modeling

Benefit from using all mpMRI image methods available

- R2Y
- Q2Y
- Linear (R2Y)
- Linear (Q2Y)
Conclusion

- Textual parameters proved to be an additional supplement to histogram-based parameters in mpMRI analysis
- Tumor prediction using OPLS shows encouraging results
- Best prediction value obtained were based on ADC
- PIRADS classification for tumor prediction is promising
  - But structure size is too large
  - Next step: voxel-based GLCM

Thanks for your attention!
Additonal Slides:
**Background: DIL boosting study**

*Andrzejewski et al 2015 Rad Oncol – in press*

- **Material and Methods:** DILs were defined based on multiparametric magnetic resonance imaging and fused with planning computed tomography images for twelve patients. VMAT, IMPT and HDR-BT treatment plans were created for each patient with the $\text{EQD}_{2\alpha/\beta}^2$ dose to the DIL escalated up to 111.6 Gy, $\text{PTV}_{\text{initial}} \ D_{\text{pres}} = 80.9$ Gy (EBRT) and $\text{CTV} \ D_{90\%} = 81.9$ Gy (HDR-BT). Hard dose constraints were applied to spare the OARs. Treatment plans were evaluated and compared between used techniques in CERR software.

- **Results:** Higher boost doses were achieved with IMPT compared to VMAT, keeping major OARs doses at similar level. HDR-BT was superior both in terms of OARs sparing and DIL boosting.
Outlook: Voxel-based GLCM

- Local texture around every voxel is analyzed
- A GLCM is generated for all voxels in image
- Data is assembled as X and subjected to multivariate methods
- Score values can be "refolded" to original image dimensions for visualization

Example from glioma data set
Outlook: Local Binary Patterns

- Analyzes the texture around a voxel
- Surrounded voxels are thresholded, which gives 0s and 1s
- Put together, these form a pattern, which is a binary number
- The LBP is the numerical number
- All LBPs from a ROI can be binned in a histogram, so the frequency of each pattern can be accessed
- The histograms can be subjected to multivariate data analysis

\[
\begin{align*}
\text{example} & \quad 6 & 5 & 2 \\
& \quad 7 & 6 & 1 \\
& \quad 9 & 8 & 7 \\
\text{thresholded} & \quad 1 & 0 & 0 \\
& \quad 1 & 1 & 1 \\
& \quad 128 & 8 & 8 \\
\text{weights} & \quad 1 & 2 & 4 \\
& \quad 64 & 32 & 16
\end{align*}
\]

LBP = 1 + 16 + 32 + 64 + 128 = 241
\[
C = \frac{(6+7+8+9+7)}{5} - \frac{(5+2+1)}{3} = 4.7
Multi parametric MR Images

ADC

T2

kTrans

PET

Histoscore:
Substructure 8p: 0.75
Sensitivity and Specificity of OPLS
Sensitivity and Specificity of OPLS

Image of a graph showing the sensitivity and specificity for different combinations of T2 and additional parameters.
Textual descriptors

- All:
  - autocorrelation, Cluster prominence, cluster shade, contrast, correlation, difference entropy, dissimilarity, energy, entropy, homogeneity 1 (as described by Soh et al.), homogeneity 2 (as implemented in MatLab 2014a, Image Processing Toolbox v. 9.0), information measure of correlations 1 and 2, inverse difference moment, normalized inverse difference moment, maximum probability, sum average, sum entropy, sum of squares, variance, sum variance

- Not included due to size dependency:
  - contrast, correlation, difference entropy, difference variance, dissimilarity, energy, entropy, homogeneity, inverse difference, information measures of correlation 1 and 2.

- Finally used textual parameters:
  - Autocorrelation, Cluster Prominence, Cluster Shade, Maximum Probability, Energy, Sum of Squares Variance, Sum Variance, Sum Entropy
Loading Plot – Size dependency of textual parameters

prostate_opls_model.M3 (OPLS)
Normalized to unit length
Colored according to model terms

\[ R2X[1] = 0.447 \quad R2Xo[1] = 0.183 \]

AutoCorrelation
- Healthy
- PIRADS-TumorScored(0.25-1)
- TumorOnly

Contrast.matlab
- Healthy
- PIRADS-TumorScored(0.25-1)
- TumorOnly
Zonal Segmentation

PCA Model - Scatter 2D (T)
N8_ADC

Peripheral
- 0.0
- 1.0

t[2] (26.4%)
t[1] (54.8%)