Absolute Quantification in $^1$H MRSI of the Prostate at 3 Tesla

Guillaume Lemaître
Supervisor: Paul M. Walker

Heriot-Watt University, Universitat de Girona and Université de Bourgogne

June 15th, 2011
Outline

1. Introduction
   - Motivations
   - MRSI of Prostate
   - Related Works

2. Project Goals

3. Methodology
   - Materials and Patients
   - Method

4. Results
   - ”Healthy” Metabolism
   - Cancer vs. Healthy Tissue

5. Conclusion
   - Considerations
   - Future Works
Introduction
Motivations - Anatomy

Peripheral Zone (PZ) is counting for 70% of the prostate. 70% of cancers occur in PZ. 30% of prostate cancers originate in Transitional Zone (TZ) and Central Zone (CZ). On MRI images, impossible to distinguish TZ and CZ.

Figure: Prostate anatomy
Introduction
Motivations - Anatomy

Figure: Prostate anatomy

Remarks

- Peripheral Zone (PZ) is counting for 70% of the prostate. 70% of cancers occur in PZ.
- 30% of prostate cancers originate in Transitional Zone (TZ) and Central Zone (CZ).
- On MRI images, impossible to distinguish TZ and CZ.
Introduction
Motivations - Anatomy

Figure: Prostate anatomy

Remarks
- Peripheral Zone (PZ) is counting for 70% of the prostate. 70% of cancers occur in PZ.
- 30% of prostate cancers originate in Transitional Zone (TZ) and Central Zone (CZ).
- On MRI images, impossible to distinguish TZ and CZ.
Introduction

Motivations - Anatomy

Peripheral Zone (PZ) is counting for 70% of the prostate. 70% of cancers occur in PZ.

30% of prostate cancers originate in Transitional Zone (TZ) and Central Zone (CZ).

On MRI images, impossible to distinguish TZ and CZ.
Introduction
Motivations - Statistics

(a) Estimated number cancers cases for both sexes and all ages.

(b) Estimated number cancers deaths for both sexes and all ages.

Figure: Cancer estimations in 2008 by the World Health Organization (WHO) [FSB^10]

Overview

- 2\textsuperscript{nd} most frequently diagnosed men cancer.
- Accounting for 7.1 % of overall cancers diagnosed.
- Accounting for 3.4 % of overall cancers death.
Introduction
Motivations - Statistics

(a) Estimated number cancers cases for both sexes and all ages.

(b) Estimated number cancers deaths for both sexes and all ages.

Figure: Cancer estimations in 2008 by the World Health Organization (WHO) [FSB+10]

Overview
- 2\textsuperscript{nd} most frequently diagnosed men cancer.
- Accounting for 7.1 % of overall cancers diagnosed.
- Accounting for 3.4 % of overall cancers death.
Introduction
Motivations - Statistics

(a) Estimated number cancers cases for both sexes and all ages.
(b) Estimated number cancers deaths for both sexes and all ages.

Figure: Cancer estimations in 2008 by the World Health Organization (WHO) [FSB+10]

Overview
- 2nd most frequently diagnosed men cancer.
- Accounting for 7.1 % of overall cancers diagnosed.
- Accounting for 3.4 % of overall cancers death.
Introduction

MRSI of Prostate - Overview

MRSI Examination

- Non-invasive technique using MRI allowing to study the metabolism of tissue.
- Each frequency corresponds to a different metabolite due of its number of proton.
- Peak integral is proportional to metabolite concentration.
Introduction

MRSI of Prostate - Overview

(a) Grid of MRSI

(b) Voxel Spectrum

MRSI Examination

- Non-invasive technique using MRI allowing to study the metabolism of tissue.
- Each frequency corresponds to a different metabolite due to its number of proton.
- Peak integral is proportionnal to metabolite concentration.
Introduction

MRSI of Prostate - Overview

MRSI Examination

- Non-invasive technique using MRI allowing to study the metabolism of tissue.
- Each frequency corresponds to a different metabolite due to its number of proton.
- Peak integral is proportional to metabolite concentrations.
Introduction
MRSI of Prostate - Pros & Cons

Pros

- Non-invasive technique.
- More sensitive than other MRI techniques.
- Better resolution than other common techniques (DRE, PSA).
Introduction
MRSI of Prostate - Pros & Cons

Pros

- Non-invasive technique.
- More sensitive than other MRI techniques.
- Better resolution than other common techniques (DRE, PSA).
Introduction
MRSI of Prostate - Pros & Cons

Pros

- Non-invasive technique.
- More sensitive than other MRI techniques.
- Better resolution than other common techniques (DRE, PSA).
Introduction
MRSI of Prostate - Pros & Cons

Pros
- Non-invasive technique.
- More sensitive than other MRI techniques.
- Better resolution than other common techniques (DRE, PSA).

Cons
- Relative recent technique.
- Lower resolution than other MRI methods.
Introduction
MRSI of Prostate - Pros & Cons

Pros
- Non-invasive technique.
- More sensitive than other MRI techniques.
- Better resolution than other common techniques (DRE, PSA).

Cons
- Relative recent technique.
- Lower resolution than other MRI methods.
# Introduction

**MRSI of Prostate - Spectra Interpretation**

## Metabolite Localizations & Interpretations

<table>
<thead>
<tr>
<th>Metabolites</th>
<th>Concentration in cancer tissue</th>
<th>Concentration in healthy tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Choline</strong> (3.21 ppm)</td>
<td>Increasing concentration [KVH⁺96]</td>
<td>Low concentration [KVH⁺96]</td>
</tr>
<tr>
<td><strong>Citrate</strong> (2.64 ppm)</td>
<td>Decreasing concentration [KVN⁺95]</td>
<td>High concentration [KVN⁺95]</td>
</tr>
<tr>
<td><strong>Water</strong> (4.65 ppm)</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Figure:** Entire resonance spectrum
Introduction

MRSA of Prostate - Spectra Interpretation

Metabolite Localizations & Interpretations

<table>
<thead>
<tr>
<th>Metabolites</th>
<th>Concentration in cancer tissue</th>
<th>Concentration in healthy tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Choline</strong> (3.21 ppm)</td>
<td>Increasing concentration [KVH$^+96$]</td>
<td>Low concentration [KVH$^+96$]</td>
</tr>
<tr>
<td><strong>Citrate</strong> (2.64 ppm)</td>
<td>Decreasing concentration [KVN$^+95$]</td>
<td>High concentration [KVN$^+95$]</td>
</tr>
<tr>
<td><strong>Water</strong> (4.65 ppm)</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Spectra of the voxel: slice 12, row 9, column 10

(a) Spectrum representative of cancer tissue

Spectra of the voxel: slice 10, row 8, column 11

(b) Spectrum representative of healthy tissue
Peak Integration

→ Compute the numeric integral of the peak on a given range.
Peak Integration

→ Compute the numeric integral of the peak on a given range.

- Underestimation on squeeze peaks due of truncation of the peak wings.
Peak Integration

→ Compute the numeric integral of the peak on a given range.

**Underestimation on squeeze peaks due of truncation of the peak wings.**

⇒ Will be used in methodology.
Peak Fitting

Fit Gaussian, Lorentzian or Voigt curve (widely use in NMR) to the peak
consider and integrate the function fitted.
Peak Fitting

→ Fit Gaussian, Lorentzian or Voigt curve (widely use in NMR) to the peak consider and integrate the function fitted.

⇒ **Will be used in methodology.**
Introduction
Related Works - Data Analysis

Peak Fitting using Prior Knowledge

→ Fit an estimated curve to the entire signal using a data set based on prior observations.
  - LCMModel [Pro93].
  - MRUI [NCC⁺01].
Introduction

Related Works - Data Analysis

Peak Fitting using Prior Knowledge

→ Fit an estimated curve to the entire signal using a data set based on prior observations.

- LCMModel [Pro93].
- MRUI [NCC+01].

⇒ Problem of fitting our data.
Relative Quantification

- Ratios computation of discriminative metabolite concentrations:

\[
[ratio] = \frac{[Cho]}{[Cit]} \quad (1)
\]

or

\[
[ratio] = \frac{[Cho] + [Cre]}{[Cit]} \quad (2)
\]
Introduction
Related Works - Quantification Strategies

Relative Quantification

→ Ratios computation of discriminative metabolite concentrations:

\[ \text{[ratio]} = \frac{[\text{Cho}]}{[\text{Cit}]} \quad (1) \]

or

\[ \text{[ratio]} = \frac{[\text{Cho}] + [\text{Cre}]}{[\text{Cit}]} \quad (2) \]

Absolute Quantification

- External reference.
- Replace-and-match method.
- Principle of reciprocity.
- Water reference.
Introduction
Related Works - Quantification Strategies

Relative Quantification

→ Ratios computation of discriminative metabolite concentrations:

\[
[ratio] = \frac{[Cho]}{[Cit]} \quad (1)
\]

or

\[
[ratio] = \frac{[Cho] + [Cre]}{[Cit]} \quad (2)
\]

Absolute Quantification

- External reference.
- Replace-and-match method.
- Principle of reciprocity.
- Water reference.
Introduction
Related Works - Quantification Strategies

Relative Quantification

→ Ratios computation of discriminative metabolite concentrations:

\[
[ratio] = \frac{[\text{Cho}]}{[\text{Cit}]} \tag{1}
\]

or

\[
[ratio] = \frac{[\text{Cho}] + [\text{Cre}]}{[\text{Cit}]} \tag{2}
\]

Absolute Quantification

- External reference.
- Replace-and-match method.
- Principle of reciprocity.
- Water reference.
Related Works - Quantification Strategies

Relative Quantification

→ Ratios computation of discriminative metabolite concentrations:

\[
[ratio] = \frac{[\text{Cho}]}{[\text{Cit}]} \tag{1}
\]

or

\[
[ratio] = \frac{[\text{Cho}] + [\text{Cre}]}{[\text{Cit}]} \tag{2}
\]

Absolute Quantification

- External reference.
- Replace-and-match method.
- Principle of reciprocity.
- Water reference.
Relative Quantification

→ Ratios computation of discriminative metabolite concentrations:

\[
[ratio] = \frac{[Cho]}{[Cit]} \quad (1)
\]

or

\[
[ratio] = \frac{[Cho] + [Cre]}{[Cit]} \quad (2)
\]

Absolute Quantification

- External reference.
- Replace-and-match method.
- Principle of reciprocity.
- *Water reference.*
Introduction
Related Works - Quantification Strategies

Relative Quantification

→ Ratios computation of discriminative metabolite concentrations:

$$[ratio] = \frac{[Cho]}{[Cit]}$$ (1)

or

$$[ratio] = \frac{[Cho] + [Cre]}{[Cit]}$$ (2)

Absolute Quantification

• External reference.
• Replace-and-match method.
• Principle of reciprocity.
• Water reference.

⇒ Widely used for MRSI of brain [JBNK06]. Only one study for MRSI of prostate [MBG+11].
Outline

1 Introduction
   - Motivations
   - MRSI of Prostate
   - Related Works

2 Project Goals

3 Methodology
   - Materials and Patients
   - Method

4 Results
   - "Healthy" Metabolism
   - Cancer vs. Healthy Tissue

5 Conclusion
   - Considerations
   - Future Works
Project Goals

Objectives

- Design a customize method to analyse the data.
- Compute absolute concentrations of choline and citrate using water as reference.
- Study variations of choline and citrate concentrations
Objectives

- Design a customize method to analyse the data.
- Compute absolute concentrations of choline and citrate using water as reference.
- Study variations of choline and citrate concentrations.
Objectives

- Design a customize method to analyse the data.
- Compute absolute concentrations of **choline** and **citrate** using **water as reference**.
- Study variations of **choline** and **citrate** concentrations.
### Outline

<table>
<thead>
<tr>
<th></th>
<th>Introduction</th>
<th>Project Goals</th>
<th>Methodology</th>
<th>Results</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Motivations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- MRSI of Prostate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Related Works</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Project Goals</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Methodology</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Materials and Patients</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Method</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- &quot;Healthy&quot; Metabolism</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Cancer vs. Healthy Tissue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Conclusion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Considerations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Future Works</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Methodology

MRSI Protocol

Water Reference Series

- Unsuppressed water acquisition at $TE = 30\, ms$
- Unsuppressed water acquisition at $TE = 80\, ms$
- Unsuppressed water acquisition at $TE = 140\, ms$

$\Rightarrow$ Used to normalize and obtain absolute concentration.
Methodology

MRSI Protocol

Water Reference Serie

- Unsuppressed water acquisition at $\text{TE} = 30 \text{ ms}$.
- Unsuppressed water acquisition at $\text{TE} = 80 \text{ ms}$.
- Unsuppressed water acquisition at $\text{TE} = 140 \text{ ms}$.

$\Rightarrow$ Used to normalize and obtain absolute concentration.
Methodology
MRSI Protocol

Water Reference Serie

- Unsuppressed water acquisition at TE = 30 ms.
- Unsuppressed water acquisition at TE = 80 ms.
- Unsuppressed water acquisition at TE = 140 ms.

⇒ Used to normalize and obtain absolute concentration.
**Methodology**

**MRSI Protocol**

- **Water Reference Series**
  - Unsuppressed water acquisition at TE = 30 ms.
  - Unsuppressed water acquisition at TE = 80 ms.
  - Unsuppressed water acquisition at TE = 140 ms.

⇒ Used to normalize and obtain absolute concentration.
Methodology

MRSI Protocol

Metabolites Signal

- Water and lipid suppressed sequence at $TE = 140$ ms and $TR = 720$ ms.
Methodology

Study Population

"Healthy" Patients

- 8 patients.
- Mean age of 61.8 (range 57.8-71.1).
- Mean PSA 8.0 $ng.mL^{-1}$ (range 2.7-15.0 $ng.mL^{-1}$).
- Negative biopsies.
Methodology

Study Population

"Healthy" Patients

- 8 patients.
- Mean age of 61.8 (range 57.8-71.1).
- Mean PSA $8.0 \text{ ng.mL}^{-1}$ (range 2.7-15.0 $\text{ng.mL}^{-1}$).
- Negative biopsies.
Methodology
Study Population

"Healthy" Patients

- 8 patients.
- Mean age of 61.8 (range 57.8-71.1).
- Mean PSA 8.0 ng.mL$^{-1}$ (range 2.7-15.0 ng.mL$^{-1}$).
- Negative biopsies.
Methodology
Study Population

"Healthy" Patients

- 8 patients.
- Mean age of 61.8 (range 57.8-71.1).
- Mean PSA 8.0 ng.mL$^{-1}$ (range 2.7-15.0 ng.mL$^{-1}$).
- Negative biopsies.
Methodology

Study Population

"Healthy" Patients

- 8 patients.
- Mean age of 61.8 (range 57.8-71.1).
- Mean PSA 8.0 $ng.mL^{-1}$ (range 2.7-15.0 $ng.mL^{-1}$).
- Negative biopsies.

Patients with Cancers

- 8 patients.
- Mean age of 70.9 (range 57.8-82.3).
- Mean PSA 15.8 $ng.mL^{-1}$ (range 0.4-74.0 $ng.mL^{-1}$).
- Biopsy proven cancer.
- Gleason score between 6 and 7.
Methodology

Study Population

"Healthy" Patients

- 8 patients.
- Mean age of 61.8 (range 57.8-71.1).
- Mean PSA 8.0 $ng.mL^{-1}$ (range 2.7-15.0 $ng.mL^{-1}$).
- Negative biopsies.

Patients with Cancers

- 8 patients.
- Mean age of 70.9 (range 57.8-82.3).
- Mean PSA 15.8 $ng.mL^{-1}$ (range 0.4-74.0 $ng.mL^{-1}$).
- Biopsy proven cancer.
- Gleason score between 6 and 7.
"Healthy" Patients

- 8 patients.
- Mean age of 61.8 (range 57.8-71.1).
- Mean PSA 8.0 \(\text{ng.mL}^{-1}\) (range 2.7-15.0 \(\text{ng.mL}^{-1}\)).
- Negative biopsies.

Patients with Cancers

- 8 patients.
- Mean age of 70.9 (range 57.8-82.3).
- Mean PSA 15.8 \(\text{ng.mL}^{-1}\) (range 0.4-74.0 \(\text{ng.mL}^{-1}\)).
- Biopsy proven cancer.
- Gleason score between 6 and 7.
Methodology

Study Population

"Healthy" Patients

- 8 patients.
- Mean age of 61.8 (range 57.8-71.1).
- Mean PSA 8.0 $ng.mL^{-1}$ (range 2.7-15.0 $ng.mL^{-1}$).
- Negative biopsies.

Patients with Cancers

- 8 patients.
- Mean age of 70.9 (range 57.8-82.3).
- Mean PSA 15.8 $ng.mL^{-1}$ (range 0.4-74.0 $ng.mL^{-1}$).
- Biopsy proven cancer.
- Gleason score between 6 and 7.
Methodology

Study Population

"Healthy" Patients

- 8 patients.
- Mean age of 61.8 (range 57.8-71.1).
- Mean PSA 8.0 $ng.mL^{-1}$ (range 2.7-15.0 $ng.mL^{-1}$).
- Negative biopsies.

Patients with Cancers

- 8 patients.
- Mean age of 70.9 (range 57.8-82.3).
- Mean PSA 15.8 $ng.mL^{-1}$ (range 0.4-74.0 $ng.mL^{-1}$).
- Biopsy proven cancer.
- Gleason score between 6 and 7.
Methodology

Method - Baseline Detection

Xi et al. [XR08]

⇒ Maximizing the following cost function:

\[ F(b) = \sum_i b_i - A \sum_i (b_{i+1} + b_{i-1} - 2b_i)^2 - B \sum_i (b_i - \gamma_i)^2 g(b_i - \gamma_i) \] (3)
Methodology
Method - Baseline Detection

Xi et al. [XR08]

⇒ Maximizing the following cost function:

\[ F(b) = \sum_i b_i - A \sum_i (b_{i+1} + b_{i-1} - 2b_i)^2 - B \sum_i (b_i - \gamma_i)^2 g(b_i - \gamma_i) \] (3)

Smoothness Penalty

→ The baseline have to be smooth without to be flat.
Methodology
Method - Baseline Detection

Xi et al. [XR08]

Maximizing the following cost function:

\[ F(b) = \sum_{i} b_i - A \sum_{i} (b_{i+1} + b_{i-1} - 2b_i)^2 - B \sum_{i} (b_i - \gamma_i)^2 g(b_i - \gamma_i) \] (3)

Negative Penalty

The baseline have to lie on the middle of the data on noisy portions.
Methodology

Method - Baseline Detection

Xi et al. [XR08]

⇒ Maximizing the following cost function:

\[
F(b) = \sum_i b_i - A \sum_i (b_{i+1} + b_{i-1} - 2b_i)^2 - B \sum_i (b_i - \gamma_i)^2 g(b_i - \gamma_i)
\]  

Parameters - Theory

\[
A = \frac{5 \times 10^{-9} n^4}{\sigma}
\]  

\[
B = \frac{1.25}{\sigma}
\]

- Standard deviation \( \sigma \) of the noise is estimate using LOWESS regression.
Crop the signal between range 3.96-5.94 ppm.

Compute rough approximation → Wavelet decomposition.

Detect valleys using Lavielle’s algorithm [Lav99].

Find real local minima.

Detection and substraction of baseline [XR08].

Computation of numeric integral using Simpson’s rule.

\[
\int_{b}^{a} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\]
Methodology
Method - Water Quantification

- Crop the signal between range 3.96-5.94 ppm.
- Compute rough approximation → Wavelet decomposition.
- Detect valleys using Lavielle’s algorithm [Lav99].
- Find real local minima.
- Detection and substraction of baseline [XR08].
- Computation of numeric integral using Simpson’s rule.

\[
\int_a^b f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\]
Methodology
Method - Water Quantification

- Crop the signal between range 3.96-5.94 ppm.
- Compute rough approximation → Wavelet decomposition.
- Detect valleys using Lavielle’s algorithm [Lav99].
- Find real local minima.
- Detection and substraction of baseline [XR08].
- Computation of numeric integral using Simpson’s rule.

\[
\int_{a}^{b} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\]  

(6)
Methodology

Method - Water Quantification

- Crop the signal between range 3.96-5.94 ppm.
- Compute rough approximation → Wavelet decomposition.
- Detect valleys using Lavielle's algorithm [Lav99].
- Find real local minima.
- Detection and substraction of baseline [XR08].
- Computation of numeric integral using Simpson's rule.

\[
\int_{b}^{a} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\]  (6)
Methodology
Method - Water Quantification

- Crop the signal between range 3.96-5.94 ppm.
- Compute rough approximation $\rightarrow$ Wavelet decomposition.
- Detect valleys using Lavielle's algorithm [Lav99].
- Find real local minima.
- Detection and substraction of baseline [XR08].
- Computation of numeric integral using Simpson's rule.

$$\int_{b}^{a} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]$$

(6)
Methodology
Method - Water Quantification

- Crop the signal between range 3.96-5.94 ppm.
- Compute rough approximation $\rightarrow$ Wavelet decomposition.
- Detect valleys using Lavielle’s algorithm [Lav99].
- Find real local minima.
- Detection and substraction of baseline [XR08].
- Computation of numeric integral using Simpson’s rule.

\[
\int_b^a f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\]  \hspace{1cm} (6)
**Methodology**

**Method - Prostate Segmentation**

---

**Segmentation**

- K-means to segment using $K = 2$ on water concentrations found at $TE = 30$ ms.
Methodology
Method - Choline Quantification

- Crop the signal between range 3.17-3.29 ppm.
- Detect maxima then iteratively find the valleys.
- Detection and substration of baseline [XR08].
- Fit a Gaussian $G(x)$ and a Lorentzian $L(x)$.
- Compute the convolution between $G(x)$ and $L(x)$ to obtain the Voigt function $V(x)$.
- Computation of numeric integral of $V(x)$ using Simpson’s rule.

$$\int_{b}^{a} f(x) \, dx = \frac{b-a}{6} \left[ f(a) + 4f \left( \frac{a+b}{2} \right) + f(b) \right] \tag{7}$$
Methodology
Method - Choline Quantification

- Crop the signal between range 3.17-3.29 ppm.
- Detect maximum then iteratively find the valleys.
- Detection and substraction of baseline [XR08].
- Fit a Gaussian $G(x)$ and a Lorentzian $L(x)$.
- Compute the convolution between $G(x)$ and $L(x)$ to obtain the Voigt function $V(x)$.
- Computation of numeric integral of $V(x)$ using Simpson’s rule.

\[
\int_b^a f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right] 
\]

(7)
Methodology
Method - Choline Quantification

- Crop the signal between range 3.17-3.29 ppm.
- Detect maximum then iteratively find the valleys.
- Detection and substraction of baseline [XR08].
- Fit a Gaussian $G(x)$ and a Lorentzian $L(x)$.
- Compute the convolution between $G(x)$ and $L(x)$ to obtain the Voigt function $V(x)$.
- Computation of numeric integral of $V(x)$ using Simpson’s rule.

$$\int_{b}^{a} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]$$

(7)
Methodology
Method - Choline Quantification

- Crop the signal between range 3.17-3.29 ppm.
- Detect maximum then iteratively find the valleys.
- Detection and substraction of baseline [XR08].
- Fit a Gaussian $G(x)$ and a Lorentzian $L(x)$.
- Compute the convolution between $G(x)$ and $L(x)$ to obtain the Voigt function $V(x)$.
- Computation of numeric integral of $V(x)$ using Simpson's rule.

\[
\int_{b}^{a} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\] (7)
Methodology
Method - Choline Quantification

- Crop the signal between range 3.17-3.29 ppm.
- Detect maximum then iteratively find the valleys.
- Detection and substraction of baseline [XR08].
- Fit a Gaussian $G(x)$ and a Lorentzian $L(x)$.
- Compute the convolution between $G(x)$ and $L(x)$ to obtain the Voigt function $V(x)$.
- Computation of numeric integral of $V(x)$ using Simpson’s rule.

$$\int_{a}^{b} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]$$ (7)
Methodology
Method - Choline Quantification

- Crop the signal between range 3.17-3.29 ppm.
- Detect maximum then iteratively find the valleys.
- Detection and substraction of baseline [XR08].
- Fit a Gaussian \( G(x) \) and a Lorentzian \( L(x) \).
- Compute the convolution between \( G(x) \) and \( L(x) \) to obtain the Voigt function \( V(x) \).
- Computation of numeric integral of \( V(x) \) using Simpson’s rule.

\[
\int_{b}^{a} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\]
Methodology

Method - Citrate Quantification

- Smooth signal using cubic spline.
- Find minimum between 2.75-2.95 ppm and 2.40-2.50 ppm.
- Compute the baseline of absolute signal.
- Iteratively, find the limits the nearest of the baseline.
- Subtract the baseline.
- Computation of numeric integral using Simpson’s rule.

\[
\int_{a}^{b} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\]
Methodology
Method - Citrate Quantification

- Smooth signal using cubic spline.
- Find minima between 2.75-2.95 ppm and 2.40-2.50 ppm.
- Compute the baseline of absolute signal.
- Iteratively, find the limits the nearest of the baseline.
- Substract the baseline.
- Computation of numeric integral using Simpson’s rule.

\[
\int_{a}^{b} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\]

(8)
Methodology

Method - Citrate Quantification

- Smooth signal using cubic spline.
- Find minima between 2.75-2.95 ppm and 2.40-2.50 ppm.
- Compute the baseline of absolute signal.
- Iteratively, find the limits the nearest of the baseline.
- Substract the baseline.
- Computation of numeric integral using Simpson’s rule.

\[
\int_{b}^{a} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\]

(8)
Methodology
Method - Citrate Quantification

- Smooth signal using cubic spline.
- Find minima between 2.75-2.95 ppm and 2.40-2.50 ppm.
- Compute the baseline of absolute signal.
- Iteratively, find the limits the nearest of the baseline.
- Substract the baseline.
- Computation of numeric integral using Simpson’s rule.

\[
\int_{a}^{b} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\] 

(8)
Methodology

Method - Citrate Quantification

- Smooth signal using cubic spline.
- Find minima between 2.75-2.95 ppm and 2.40-2.50 ppm.
- Compute the baseline of absolute signal.
- Iteratively, find the limits the nearest of the baseline.
- Subtract the baseline.
- Computation of numeric integral using Simpson’s rule.

\[
\int_{b}^{a} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4 f \left( \frac{a + b}{2} \right) + f(b) \right]
\]  

(8)
Methodology

Method - Citrate Quantification

- Smooth signal using cubic spline.
- Find minima between 2.75-2.95 ppm and 2.40-2.50 ppm.
- Compute the baseline of absolute signal.
- Iteratively, find the limits the nearest of the baseline.
- Subtract the baseline.
- Computation of numeric integral using Simpson’s rule.

\[
\int_{b}^{a} f(x) \, dx = \frac{b - a}{6} \left[ f(a) + 4f \left( \frac{a + b}{2} \right) + f(b) \right]
\] (8)
Absolute Concentrations

→ Fully relaxed signal is proportionnal to the number of moles of the molecules in the voxel.

\[
[\text{met}] = \frac{2 \times [H_2O] \times S_{0\text{met}}}{n_{H\text{met}} \times S_{0H_2O}}
\]  

(9)
Methodology - Absolute Quantification

Absolute Concentrations

$\rightarrow$ Fully relaxed signal is proportionnal to the number of moles of the molecules in the voxel.

$$[\text{met}] = \frac{2 \times [\text{H}_2\text{O}] \times S_{0\text{met}}}{n_{\text{Hmet}} \times S_{0\text{H}_2\text{O}}} \quad (9)$$

Unknown Parameters

- Fully relaxed water signal: $S_{0\text{H}_2\text{O}}$.
- Fully relaxed metabolite signal: $S_{0\text{met}}$. 
Methodology - Absolute Quantification

Water Signal: $S_{0H_2O}$

$$S_{0H_2O} = \frac{S^*_{0H_2O} \exp\left(-\frac{TE}{T_2}\right)}{1 - \exp\left(-\frac{TR}{T_1}\right)}$$  \hspace{1cm} (10)
Methodology - Absolute Quantification

Water Signal: $S_{0H_2O}$

\[
S_{0H_2O} = \frac{S^*_{0H_2O} \exp(-\frac{TE}{T_2})}{1 - \exp(-\frac{TR}{T_1})}
\] (10)
Methodology - Absolute Quantification

Water Signal: $S_{0H_2O}$

$$S_{0H_2O} = \frac{S^*_{H_2O} \exp(-\frac{TE}{T_2})}{1 - \exp(-\frac{TR}{T_1})}$$ (10)
Methodology - Absolute Quantification

Water Signal: $S_{0H_2O}$

$$S_{0H_2O} = \frac{S_{0H_2O}^* \exp\left(-\frac{TE}{T_2}\right)}{1 - \exp\left(-\frac{TR}{T_1}\right)} \tag{10}$$

Denominator

- $TR = 720$ ms.
- $T_1 = 1600$ ms.
Methodology - Absolute Quantification

Metabolite Signal: $S_{0\text{met}}$

$$S_{0\text{met}} = \frac{S^*_{\text{met}} \exp\left(-\frac{TE}{T_2}\right)}{1 - \exp\left(-\frac{TR}{T_1}\right)}$$  (11)
Methodology - Absolute Quantification

Metabolite Signal: $S_{0\text{met}}$

\[
S_{0\text{met}} = \frac{S^*_{0\text{met}} \exp\left(-\frac{TE}{T_2}\right)}{1 - \exp\left(-\frac{TR}{T_1}\right)}
\]  \hspace{1cm} (11)

Numerator

- $S^*_{0\text{met}}$: Choline or citrate concentration.
- $TE = 140$ ms.
- $T_2 = 180$ ms for citrate and 220 ms for choline.
Methodology - Absolute Quantification

Metabolite Signal: $S_{0\text{met}}$

$$S_{0\text{met}} = \frac{S^*_{0\text{met}} \exp\left(-\frac{TE}{T_2}\right)}{1 - \exp\left(-\frac{TR}{T_1}\right)}$$  \hspace{1cm} (11)

Denominator

- $TR = 720$ ms.
- $T_1 = 600$ ms for citrate and $1500$ ms for choline.
1 Introduction
   • Motivations
   • MRSI of Prostate
   • Related Works
2 Project Goals
3 Methodology
   • Materials and Patients
   • Method
4 Results
   • ”Healthy” Metabolism
   • Cancer vs. Healthy Tissue
5 Conclusion
   • Considerations
   • Future Works
Results
”Healthy” Metabolism - Position Behaviour - Peripheral Zone

”Healthy” Tissue in healthy patients

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.70 ± 0.40</td>
<td>33.41 ± 10.10</td>
</tr>
</tbody>
</table>
Results

"Healthy" Metabolism - Position Behaviour - Peripheral Zone

"Healthy" Tissue in healthy patients

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.70 ± 0.40</td>
<td>33.41 ± 10.10</td>
</tr>
<tr>
<td>Median</td>
<td>2.28 ± 0.56</td>
<td>45.67 ± 14.05</td>
</tr>
</tbody>
</table>
Results

"Healthy" Metabolism - Position Behaviour - Peripheral Zone

"Healthy" Tissue in healthy patients

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.70 ± 0.40</td>
<td>33.41 ± 10.10</td>
</tr>
<tr>
<td>Median</td>
<td>2.28 ± 0.56</td>
<td>45.67 ± 14.05</td>
</tr>
<tr>
<td>Base</td>
<td>2.60 ± 0.60</td>
<td>54.28 ± 12.94</td>
</tr>
</tbody>
</table>
Results

"Healthy" Metabolism - Position Behaviour - Peripheral Zone

"Healthy" Tissue in biopsy proven cancer

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>$1.66 \pm 0.32$</td>
<td>$23.67 \pm 10.73$</td>
</tr>
</tbody>
</table>
Results

"Healthy" Metabolism - Position Behaviour - Peripheral Zone

"Healthy" Tissue in biopsy proven cancer

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.66 ± 0.32</td>
<td>23.67 ± 10.73</td>
</tr>
<tr>
<td>Median</td>
<td>1.80 ± 0.48</td>
<td>35.01 ± 11.52</td>
</tr>
</tbody>
</table>
Results

"Healthy" Metabolism - Position Behaviour - Peripheral Zone

"Healthy" Tissue in biopsy proven cancer

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.66 ± 0.32</td>
<td>23.67 ± 10.73</td>
</tr>
<tr>
<td>Median</td>
<td>1.80 ± 0.48</td>
<td>35.01 ± 11.52</td>
</tr>
<tr>
<td>Base</td>
<td>2.02 ± 0.82</td>
<td>39.20 ± 20.82</td>
</tr>
</tbody>
</table>
**Results**

"Healthy" Metabolism - Position Behaviour - Peripheral Zone

![Box plot of the absolute concentration Citrate in Peripheral Zone](image1)
![Box plot of the absolute concentration Choline in Peripheral Zone](image2)

(a) Citrate concentration  
(b) Choline concentration

**Summarize**

- Increasing concentration of citrate.
Results

"Healthy" Metabolism - Position Behaviour - Peripheral Zone

(a) Citrate concentration

(b) Choline concentration

Summarize

- Increasing concentration of citrate.
- Increasing concentration of choline.
Results

"Healthy" Metabolism - Position Behaviour - Central Zone

"Healthy" Tissue in healthy patients

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.71 ± 0.34</td>
<td>21.34 ± 6.42</td>
</tr>
</tbody>
</table>
Results

"Healthy" Metabolism - Position Behaviour - Central Zone

"Healthy" Tissue in healthy patients

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.71 ± 0.34</td>
<td>21.34 ± 6.42</td>
</tr>
<tr>
<td>Median</td>
<td>1.87 ± 0.44</td>
<td>23.87 ± 9.38</td>
</tr>
</tbody>
</table>
Results

"Healthy" Metabolism - Position Behaviour - Central Zone

"Healthy" Tissue in healthy patients

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.71 ± 0.34</td>
<td>21.34 ± 6.42</td>
</tr>
<tr>
<td>Median</td>
<td>1.87 ± 0.44</td>
<td>23.87 ± 9.38</td>
</tr>
<tr>
<td>Base</td>
<td>2.00 ± 0.45</td>
<td>26.42 ± 9.52</td>
</tr>
</tbody>
</table>
"Healthy" Tissue in biopsy proven cancer

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.30 ± 0.29</td>
<td>19.70 ± 7.44</td>
</tr>
</tbody>
</table>
"Healthy" Tissue in biopsy proven cancer

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.30 ± 0.29</td>
<td>19.70 ± 7.44</td>
</tr>
<tr>
<td>Median</td>
<td>1.45 ± 0.19</td>
<td>16.77 ± 3.82</td>
</tr>
</tbody>
</table>
### Results

"Healthy" Tissue in biopsy proven cancer

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apex</td>
<td>1.30 ± 0.29</td>
<td>19.70 ± 7.44</td>
</tr>
<tr>
<td>Median</td>
<td>1.45 ± 0.19</td>
<td>16.77 ± 3.82</td>
</tr>
<tr>
<td>Base</td>
<td>1.50 ± 0.41</td>
<td>16.16 ± 4.52</td>
</tr>
</tbody>
</table>
Results

"Healthy" Metabolism - Position Behaviour - Central Zone

(a) Citrate concentration
(b) Choline concentration

Summarize

- Constant concentration of citrate.
"Healthy" Metabolism - Position Behaviour - Central Zone

(a) Citrate concentration

(b) Choline concentration

Summarize

- Constant concentration of citrate.
- Constant concentration of choline.


**Results**

"Healthy" Metabolism - Zonal Behaviour

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral Zone</td>
<td>2.25 ± 0.64</td>
<td>45.34 ± 14.83</td>
</tr>
</tbody>
</table>
## Results

"Healthy" Metabolism - Zonal Behaviour

<table>
<thead>
<tr>
<th>Zone</th>
<th>Choline</th>
<th>Citrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral Zone</td>
<td>2.25 ± 0.64</td>
<td>45.34 ± 14.83</td>
</tr>
<tr>
<td>Central Gland</td>
<td>1.87 ± 0.42</td>
<td>24.00 ± 8.76</td>
</tr>
</tbody>
</table>
Results

"Healthy" Metabolism - Zonal Behaviour

(a) Citrate concentration

(b) Choline concentration

Summarize

- Higher concentration of citrate in PZ than CG.
Results

"Healthy" Metabolism - Zonal Behaviour

(a) Citrate concentration

(b) Choline concentration

Summarize

- Higher concentration of citrate in PZ than CG.
- Higher concentration of choline in PZ than CG.
# Results

Cancer vs. Healthy Tissue - Citrate Concentration

<table>
<thead>
<tr>
<th>Zone</th>
<th>No Cancer</th>
<th>Cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral Zone</td>
<td>45.34 ± 14.83</td>
<td>32.97 ± 15.45</td>
</tr>
</tbody>
</table>
## Results

Cancer vs. Healthy Tissue - Citrate Concentration

<table>
<thead>
<tr>
<th>Zone</th>
<th>No Cancer</th>
<th>Cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral Zone</td>
<td>45.34 ± 14.83</td>
<td>32.97 ± 15.45</td>
</tr>
<tr>
<td>Central Gland</td>
<td>24.00 ± 8.76</td>
<td>17.43 ± 5.31</td>
</tr>
</tbody>
</table>
Results
Cancer vs. Healthy Tissue - Citrate Concentration

<table>
<thead>
<tr>
<th>Zone</th>
<th>No Cancer</th>
<th>Cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral Zone</td>
<td>45.34 ± 14.83</td>
<td>32.97 ± 15.45</td>
</tr>
<tr>
<td>Central Gland</td>
<td>24.00 ± 8.76</td>
<td>17.43 ± 5.31</td>
</tr>
<tr>
<td>Cancer Zone</td>
<td>NA</td>
<td>14.24 ± 5.28</td>
</tr>
</tbody>
</table>
Results
Cancer vs. Healthy Tissue - Citrate Concentration

Summarize
- High decrease of citrate concentration in cancer zone compared to peripheral zone.
Results
Cancer vs. Healthy Tissue - Citrate Concentration

Summarize
- High decrease of citrate concentration in cancer zone compared to peripheral zone.
- No distinction between cancer zone and central gland.
**Results**

Cancer vs. Healthy Tissue - Citrate Concentration

**Healthy Patient**

![Image of Healthy Patient](image-url)
Results

Cancer vs. Healthy Tissue - Citrate Concentration

Patient with Cancer
Results
Cancer vs. Healthy Tissue - Choline Concentration

<table>
<thead>
<tr>
<th>Zone</th>
<th>No Cancer</th>
<th>Cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral Zone</td>
<td>2.25 ± 0.64</td>
<td>1.82 ± 0.57</td>
</tr>
</tbody>
</table>
Results
Cancer vs. Healthy Tissue - Choline Concentration

<table>
<thead>
<tr>
<th>Zone</th>
<th>No Cancer</th>
<th>Cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral Zone</td>
<td>2.25 ± 0.64</td>
<td>1.82 ± 0.57</td>
</tr>
<tr>
<td>Central Gland</td>
<td>1.87 ± 0.42</td>
<td>1.42 ± 0.30</td>
</tr>
</tbody>
</table>
## Results

### Cancer vs. Healthy Tissue - Choline Concentration

<table>
<thead>
<tr>
<th>Zone</th>
<th>No Cancer</th>
<th>Cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral Zone</td>
<td>2.25 ± 0.64</td>
<td>1.82 ± 0.57</td>
</tr>
<tr>
<td>Central Gland</td>
<td>1.87 ± 0.42</td>
<td>1.42 ± 0.30</td>
</tr>
<tr>
<td>Cancer Zone</td>
<td>NA</td>
<td>1.47 ± 0.40</td>
</tr>
</tbody>
</table>

Guillaume Lemaître

Absolute Quantification in $^1$H MRSI of the Prostate at 3 Tesla
Summarize

- No significant variations of choline concentrations between healthy and cancer tissues.
Outline

1 Introduction
   • Motivations
   • MRSI of Prostate
   • Related Works

2 Project Goals

3 Methodology
   • Materials and Patients
   • Method

4 Results
   • ”Healthy” Metabolism
   • Cancer vs. Healthy Tissue

5 Conclusion
   • Considerations
   • Future Works
Considerations

- Build a method adapted to the given data.
Considerations

- Build a method adapted to the given data.
- Compute absolute concentration of citrate and choline:
Considerations

- Build a method adapted to the given data.
- Compute absolute concentration of citrate and choline:
  - Increasing citrate concentration between healthy and cancer tissue as in the literature.
Conclusion

Considerations

- Build a method adapted to the given data.
- Compute absolute concentration of citrate and choline:
  - Increasing citrate concentration between healthy and cancer tissue as in the literature.
  - No significant variations of choline concentration between healthy and cancer.
Considerations

- **Build a method adapted to the given data.**
- **Compute absolute concentration of citrate and choline:**
  - Increasing citrate concentration between healthy and cancer tissue as in the literature.
  - No significant variations of choline concentration between healthy and cancer.
- **Absolute concentration of citrate has been shown to be a discriminative to diagnose prostate cancer in PZ.**
Future works

- Acquisition of phantom (groundtruth) to evaluate the method.
Future Works

- Acquisition of phantom (groundtruth) to evaluate the method.
- Combination of features from functional MRI (Perfusion, Diffusion, MRSI, $T_2$ weighted) to implement a framework to detect automatically prostate cancer.


Functional MR imaging of prostate cancer.


Geckomedia.
Natom anatomy, 2011.
Use of tissue water as a concentration reference for proton spectroscopic imaging.

In vivo proton magnetic resonance spectroscopy of diseased prostate: spectroscopic features of malignant versus benign pathology.
MR imaging of the prostate gland: normal anatomy.

1H MR spectroscopy of the brain: absolute quantification of metabolites.

M. Kanowski, J. Kaufmann, J. Braun, J. Bernarding, and C. Tempelmann.
Quantitation of simulated short echo time 1H human brain spectra by LCModel and AMARES.
Automated estimation of tumor probability in prostate magnetic resonance spectroscopic imaging: pattern recognition vs quantification.

Three-dimensional H-1 MR spectroscopic imaging of the in situ human prostate with high (0.24-0.7-cm³) spatial resolution.
Citrate as an in vivo marker to discriminate prostate cancer from benign prostatic hyperplasia and normal prostate peripheral zone: detection via localized proton spectroscopy.  

M. Lavielle.  
Detection of multiple changes in a sequence of dependent variables.  
Quantification of citrate concentration in the prostate by proton magnetic resonance spectroscopy: zonal and age-related differences.

C. A. Lieber and A. Mahadevan-Jansen.
Automated method for subtraction of fluorescence from biological Raman spectra.

Vincent Mazet.
*Développement de méthodes de traitement de signaux spectroscopiques : estimation de la ligne de base et du spectre de raies.*

Prostate cancer metabolite quantification relative to water in 1H-MRSI in vivo at 3 Tesla.

J. E. McNeal.
The zonal anatomy of the prostate.
*Prostate, 2:35–49, 1981.*


S. Parfait, J. Miteran, and P.M. Walker.  
*Classification de spectres et recherche de biomarqueurs en spectroscopie par résonance magnétique nucléaire du proton dans les tumeurs prostatiques.*  

S. W. Provencher.  
Estimation of metabolite concentrations from localized in vivo proton NMR spectra.  

A. Rajesh, F. V. Coakley, and J. Kurhanewicz.  
3D MR spectroscopic imaging in the evaluation of prostate cancer.  
Christian H. Reinsch.
Smoothing by spline functions.

H. Ratiney, M. Sdika, Y. Coenradie, S. Cavassila, D. van Ormondt, and D. Graveron-Demilly.
Time-domain semi-parametric estimation based on a metabolite basis set.

Optimal timing for in vivo 1H-MR spectroscopic imaging of the human prostate at 3T.


Wikipedia.
Prostate — wikipdia, l’encyclopdie libre, 2011.
[En ligne; Page disponible le 17-mai-2011].

Y. Xi and D. M. Rocke.
Baseline correction for NMR spectroscopic metabolomics data analysis.