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Syventävä laboratoriotyö, Fysiikan laitos

Positional dependency of apparent diffusion coefficient

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May 2, 2018

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Abstract

The aim of this laboratory work is to directly measure whether the *Apparent diffusion coefficient* (ADC) has a positional dependency. The measurement is done on Skyra 3T by using the phantom described in [Viite Tonin artikkeliin].

1 Introduction

The existence of a positional dependency or measuring angle dependency has a large impact on measuring researches, since even small fluctuations depending on position might affect the result a lot. In this work we will be focusing on diffusion weighted imaging (DWI) and using phantom produced to investigate the ADC and DFC from [Viite Tonin artikkeli].

The diffusion measurement itself is an observation of Brownian motion of water particles in the tissue using the magnetic resonance. Modern DW sequences are taking their origin from "pulsed gradient spin echo (PGSE) technique" developed by Edward Stejskal and John Tanner in the mid-1960's. They adapted the T2-weighted spin-echo sequence by applying a symmetric pair of diffusion-sensitizing (bipolar) gradients around the 180° refocusing pulse. Their idea is illustrated in Figure 1.

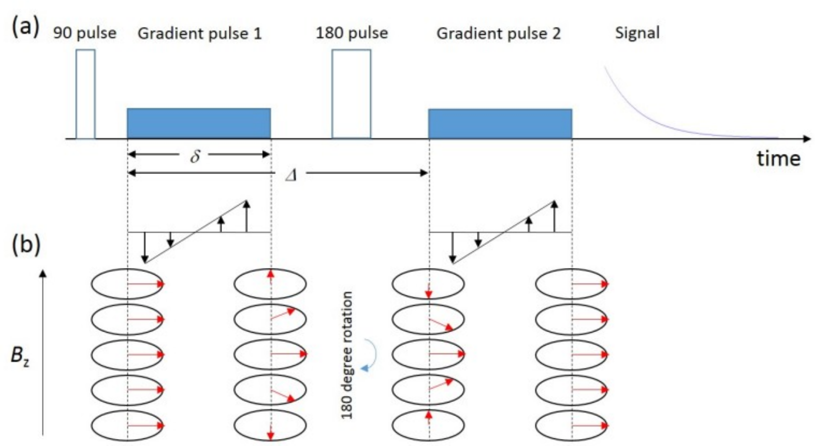


Figure 1: Scheme of DWI imaging process. Source [3]. a) section illustrates the sequence pulses used, while b) section demonstrates water attenuation state.

[http://mriquestions.com/making-a-dw-image.html]

Nu i tak dalee, aaaaaaaaaaaaaaaaaaaa

2 Theory

2.1 Diffusion equation

The diffusion coefficient measured in MR represent averages of the entire voxel over all measured dimensions.(In this case 3 dimensions are measured.)

Strength and timing of the gradients is represented with b-value. The higher b-value, the stronger are diffusion effects.

Depending on b-value using the Formula 1 the resulting intension I can be calculated from the signal at baseline I_0. The e is exponential and D is the diffusion coefficient.

$$I = I_0 * e^{b*D} \tag{1}$$

When 2+ DWI sequences with different b-values are obtained they can be plugged into above equation to solve D for each voxel. The map of D values for each voxel is called ADC-map. [5]

2.2 ADC

Apparent diffusion coefficient is used to measure the degree of diffusion of water molecules through different materials. Considering the head, the suitable values are in range of 670 – 1566. (10^{-6} $\frac{mm^2}{s}$) [1]

Therefore the phantom presented in [Tonin artikkeli] is suitable for measurements and will be used in this work.

2.3 FWHM connection to standard deviation

If considering the normal distribution the connection between Full Width Half Maximum and standard deviation is presented in equation 2

$$FWHM = 2\sqrt{2ln2} * \sigma \approx 2.355\sigma \tag{2}$$

where FWHM is Full Width Half Maximum = width of the peak at half of maximum, and σ is standard deviation.

3 Methodology

3.1 Imaging device and sequence parameter

Imaging device: Siemens Skyra (Erlangen, Germany)
Coil: 30 channel body matrix coil
b-value: 0 – 800

3.2 Structure of the phantom and ROI definition

The phantom has 4 cylindrical objects filled with different materia, while the space between them is filled with room temperature water. The T1 axial scan is presented in Figure 2. The circular areas are the cylindric objects filled with (KATSO tonin artikkeli), and area in between is water.

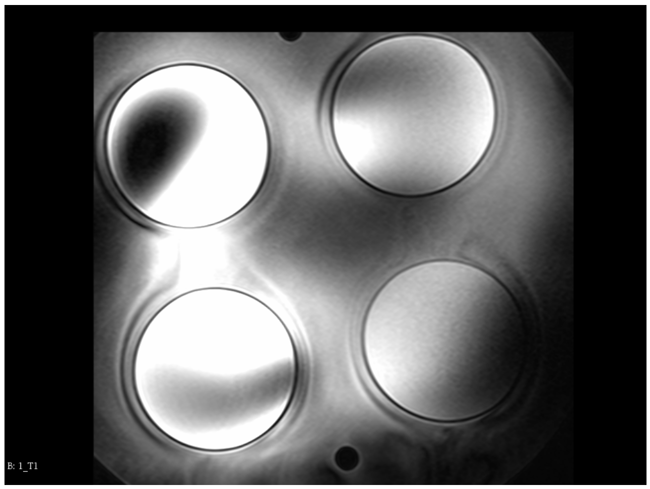


Figure 2: The T1 axial slide of phantom. Circular object are pattern filled with different materia, while the area in between is water. All those darkening and lighter spots are imaging artifacts.

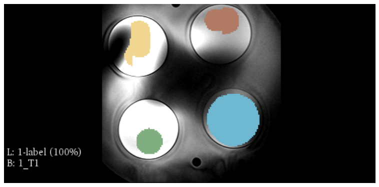
The circular areas in a scan are supposed to be homogeneous, therefore the artifacts are causing a lot of divergence. To avoid such the ROI is defined by two ways: manually from flat area, and semi-automatically assuming that there is only one major peak and the image's defects are not producing significant peaks in histogram. Such assumption is possible to do relying on the phantoms structure.

3.3 Sequences

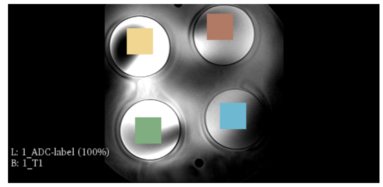
During the measurement the following 3 sequences are imaged:

1. Haste localizer
2. ADC sequence
3. ADC_DFC sequence

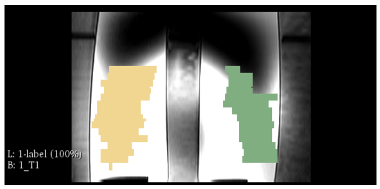
Haste localizer allows preview on how object is aligned. In our research the idea is to observe 4 rotationally dependent positions, so localizer sequence will allow to ensure the almost same position.



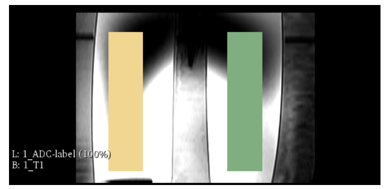
(a) roiManualAxial



(b) ROI by semi-automated method



(c) roiManualSagittal



(d) roi Autom Sagittal

Figure 3: Illustration of ROI definition manually and automatically. Green is ROI for ADC-1, Yellow – ADC-2, Red – ADC-3 and Teal – ADC-4.

Values produced by ADC sequences are recorded in Table 6. The ADC-DFC sequence is produced simultaneously by the protocol without bringing any additional information, so will be ignored.

3.4 Peak definition from histogram

Since ROI defined by user are time consuming and hardly repeatable a semiautomatic algorithm was developed. Its' structure is presented in Figure **??**.

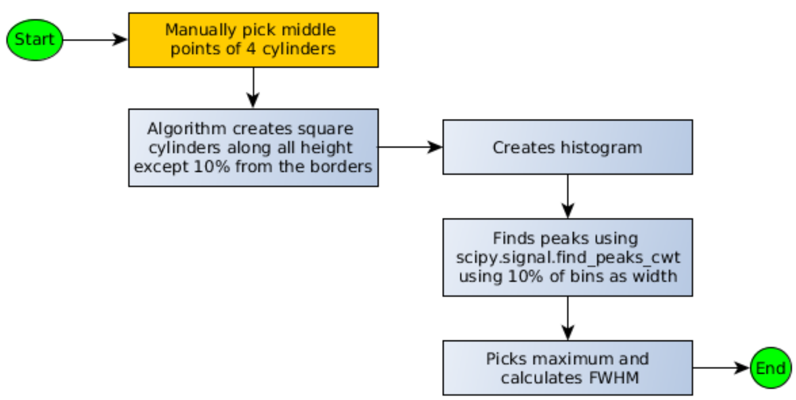


Figure 4: The structure of semiautomatic algorithm. The yellow parts are user defined, rest automated.

Algorithm starts by user defining the middle points of each observed cylinder.

After the definition algorithm generates square cylindrical ROI over the height of phantom. For each ROI a histogram is generated and its' maximal peaks are found using $scipy.signal.find\_peaks\_cwt$ and initiated with 100 bins and 10% width.

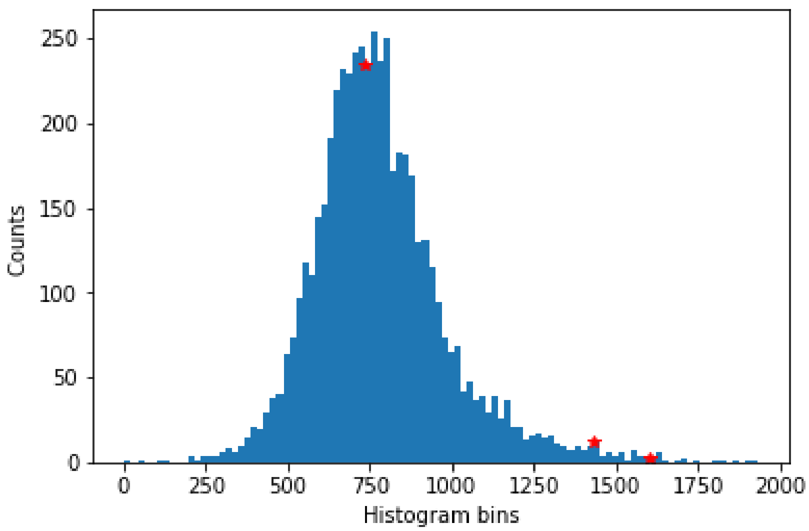


Figure 5: An example histogram for a ROI. The red stars show the peaks found within the width condition. As it can be seen the scipy method allows to ignore the single peaks and finds global peak.

A typical histogram is presented in Figure 5. The x-axis presents the binned values inside the ROI, while y-axis shows how many voxels of each intensity is inside ROI.

4 Results

The axial slice of phantom without anything is presented in Figure 2. As already mentioned in Methodology chapter, the defects of an image are forcing to use manual area definition, like presented in Figure 3, or benefit use an additional information of what type of peak is expected, so it can be analyzed using semiautomated methods.

Manually defined ROI results are presented in Figure 6. The visualization of the situation is shown in the Figure 8a. As it can be seen the variance inside each position is high, covering all value differences between positions.

However, the semiautomatic result has less variance due to peak filtering, so it is more conclusion suitable. The raw output for all datasets are presented in Attachments in Table 7.1. By grouping them according to positions as already done for manual results, the Figure 7 is visualizing the observed results

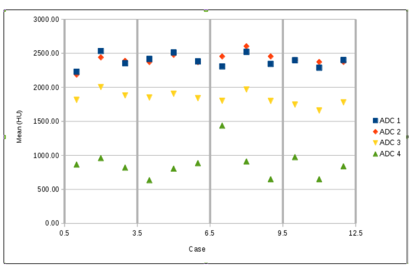
Position 1	ADC				**Mean**	**std**
2186.12	2439.51	2388.35			2337.99	133.99
2227.80	2533.35	2352.92			2371.36	153.61
1815.27	2002.87	1880.28			1899.47	95.26
864.51	959.44	819.91			881.28	71.26
Position 2						
635.18	805.18	886.09			775.48	128.06
2370.92	2476.99	2370.92			2406.28	61.24
2416.52	2512.07	2381.61			2436.73	67.54
1849.75	1904.19	1840.03			1864.66	34.58
Position 3						
1800.59	1968.55	1798.68			1855.94	97.53
1436.80	910.51	650.10			999.14	400.77
2453.25	2602.65	2453.43			2503.11	86.20
2305.82	2520.33	2343.38			2389.84	114.56
Position 4						
2397.50	2287.72	2400.00			2361.74	64.12
1745.76	1659.07	1778.78			1727.87	61.83
974.45	649.76	839.53			821.25	163.12
2399.86	2371.64	2373.08			2381.53	15.89

Figure 6: ADC results. Each column represents a separate measurement at almost same position, minimal fluctuations are possible due to rotation uncertainty.

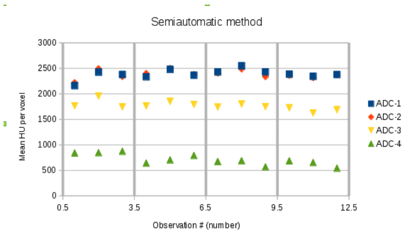
Semiautomatic					
Position 1				**Mean**	**Std**
2160.96	2425.44	2378.14		2321.51	141.04
2215.84	2488.66	2340.42		2348.31	136.58
1764.66	1956.38	1743.44		1821.49	117.30
841.48	847.48	874.8		854.59	17.76
Position 2					
642.33	705.65	792.4		713.46	75.34
2332.68	2479.2	2363.86		2391.91	77.18
2395.78	2496.19	2374.54		2422.17	64.98
1761.58	1852.6	1790.75		1801.64	46.48
Position 3					
1740.69	1799.42	1746.6		1762.24	32.34
674.65	689.78	568.62		644.35	66.02
2427.76	2548.41	2428.78		2468.32	69.36
2408.34	2488.42	2337.04		2411.27	75.73
Position 4					
2365	2318.36	2375.52		2352.96	30.42
1725.7	1623.92	1688.6		1679.41	51.51
687.76	654.56	542.6		628.31	76.06
2384.6	2342.25	2376.86		2367.90	22.55

Figure 7: Semiautomatic ADC results. Each column represents a separate measurement at almost same position, minimal fluctuations are possible due to rotation uncertainty.

numerically, and Figure 8b graphically.



(a) Manually defined ROI.



(b) Semiautomatic ROI.

Figure 8: ADC results plotted by cylinder. Each 3 results belong to same position. As it can be noticed the semi-automatic method that uses peak finding in histogram produces more stable results, in particular with the 4th cylinder.

It can be seen that even in more precise semiautomatic method the variance between the rotations is high enough to remove all possibilities to conclude anything about positional dependency.

4.1 Errors expected

Liquid flow : Flowing liquids are causing artificially strong diffusion therefore lowering ADC values. This is addressed by letting a phantom stay still after rotation for 1 minute.

Temperature dependency : Pure water diffusion coefficient is temperature dependent and can be even x3 if temperature increases around 30 degrees. To address this phantom was filled with room temperatured water, with low amount of humans participating and all imaged in one session.

4.2 Additionally observed errors

In some situations the imaging artifacts have generated an significant additional peaks into figures. This lead to

(a) Histogram from data 7, ROI 4.

(b) Axial data 7, manual ROI 4 as contour. (c) Axial data 7, manual ROI 4 as contour.

Figure 9: Artifacts affecting the result.

5 Discussion

Semiautomatic method produced better results in sense of variance and result certainty than manual. However, they still lead to the variance between the results. The positioning was in right direction, but in some cases the variance in positioning was visible with bare eyes. For future research the position of phantom can be made more certain by using several lasers from different directions which combined with marks on a phantom will create landmarks for the phantom.

The obtained images gave a hint that cylinders inside the phantom were not exactly parallel or symmetrically placed, so this error should be addressed aswell.

An optional line of interest is to research the variation between the researchers.

6 Conclusion

By comparing the mean values of rotational symmetric positions, there are some variating noticeable. However, the uncertainty of mean value definition negates all shift. Therefore location based dependency can be proved.

7 Attachments

7.1 Raw semiautomated results

Peak value	**FWHM**	**σ, std**
2160.96	21.16	8.985138
2215.84	23.64	10.03821656
1764.66	21.57	9.15923567
841.48	27.12	11.51592357
642.33	21.77	9.24416136
2332.68	25.78	10.94692144
2395.78	25.78	10.94692144
1761.58	20.58	8.7388535
1740.69	21.81	9.2611465
674.65	27.71	11.76645435
2427.76	22.92	9.73248408
2408.34	25.26	10.72611465
2365.	25.	10.61571125
1725.7	20.06	8.51804671
687.76	47.98	20.37367304
2384.6	24.91	10.57749469
2425.44	25.74	10.92993631
2488.66	27.29	11.5881104
1956.38	39.78	16.89171975
847.48	26.16	11.10828025
705.65	17.35	7.36730361
2479.2	24.92	10.58174098
2496.19	26.79	11.37579618
1852.6	23.8	10.10615711
1799.42	20.62	8.75583864
689.78	29.62	12.57749469
2548.41	19.01	8.07218684
2488.42	25.22	10.70912951
2318.36	28.76	12.21231423
1623.92	22.93	9.73673036
654.56	20.76	8.81528662
2342.25	38.95	16.53927813
2378.14	28.97	12.3014862
2340.42	26.14	11.09978769
1743.44	20.82	8.84076433
874.8	37.34	15.85562633
792.4	28.2	11.97452229
2363.86	25.98	11.03184713
2374.54	25.01	10.61995754

1790.75	29.45	12.50530786
1746.6	32.16	13.65605096
568.62	22.94	9.74097665
2428.78	25.78	10.94692144
2337.04	30.61	12.99787686
2375.52	29.01	12.31847134
1688.6	24.2	10.27600849
542.6	26.98	11.45647558
2376.86	25.53	10.84076433
2391.08	29.97	12.72611465
2481.62	26.39	11.2059448
1774.56	18.86	8.00849257
870.28	54.08	22.96390658
807.39	28.57	12.13163482
2387.28	22.66	9.62208068
2362.02	24.86	10.55626327
1763.2	39.16	16.62845011
1754.57	25.07	10.64543524
735.26	38.54	16.36518047
2474.83	25.37	10.77282378
2382.3	23.85	10.12738854
1788.96	28.62	12.15286624
720.3	37.9	16.09341826
2461.68	27.24	11.56687898
2390.34	27.49	11.67303609
1782.4	25.7	10.91295117
745.24	35.18	14.93842887
2484.5	27.25	11.57112527
2405.51	28.77	12.21656051
1797.52	28.28	12.00849257
716.44	19.42	8.2462845
2460.2	25.77	10.94267516
2396.8	30.12	12.78980892
1768.24	24.92	10.58174098
734.96	17.36	7.37154989
2474.8	25.6	10.87048832
2385.6	30.6	12.99363057
1804.75	28.75	12.20806794
725.2	18.44	7.83014862
2442.8	26.98	11.45647558
2378.08	28.47	12.08917197
1801.74	26.26	11.1507431
748.05	19.23	8.1656051

2423.68	25.96	11.02335456
2373.16	28.68	12.17834395

7.2 ROI creation using Slicer

Note: User has to load the volume, create labelmap and mark 4 fiducial.

```
#!/usr/bin/env python2
# -*- coding: utf-8 -*-
"""
@author: sofiev
"""

import slicer
import vtk
import numpy

nFiducial=slicer.util.getNodesByClass('vtkMRMLMarkupsFiducialNode')[0]
nVolume=slicer.util.getNodesByClass('vtkMRMLScalarVolumeNode')[0]

aVolume=slicer.util.array(nVolume.GetName())
aLabelMap=slicer.util.array(nVolume.GetName()+'-label')

aLabelMap[:]=0.0;

for iFidu in range(4):
    coord=numpy.zeros(4)
    nFiducial.GetNthFiducialWorldCoordinates(iFidu,coord)
    ijkToRAS = vtk.vtkMatrix4x4()
    nVolume.GetIJKToRASMatrix(ijkToRAS)
    RAS2IJK = vtk.vtkMatrix4x4()
    nVolume.GetRASToIJKMatrix(RAS2IJK)
    newCoord=numpy.array(RAS2IJK.MultiplyFloatPoint(coord))
    newCoord[0]=int(newCoord[0])
    newCoord[1]=int(newCoord[1])
    newCoord[2]=int(newCoord[2])
    #newCoord --     x, y, z
    # default system -- z, x, y
    aKoko=aLabelMap.shape
    aLabelMap[int(0.1*aKoko[0]):int(0.9*aKoko[0]),newCoord[1]-10:newCoord[1]+10,
```

```
slicer.util.saveNode(slicer.util.getNode(nVolume.GetName()+'-label'),'/home/sofi
```

7.3 Histogram analysis and FWHM calculations

Note: This can be used to any ROI volume, even user defined one.

```
#!/usr/bin/env python2
# -*- coding: utf-8 -*-
"""
@author: sofiev
"""
import numpy as np
import numpy

import matplotlib.pyplot as plt
import nibabel as nib
import scipy, os, cv2
import scipy.signal

import string
import skimage
import skimage.measure


print "------------------------------------------------"
aFinalResults=numpy.zeros([22*4,3])
for iFilu in range(1,22):
    print "------------------------------------------------"
    print iFilu
    print "------------------------------------------------"
    sImgFilename="/home/sofiev/University/SyventavatLabrat/DWI/nifti_files/"+str

    sLabelFilename="/home/sofiev/University/SyventavatLabrat/DWI/rois/"+str(iFilu

    imgADC =nib.load(sImgFilename)
    imgLabel=nib.load(sLabelFilename)

    dataADC = imgADC.get_data()
    dataLabel=imgLabel.get_data()

    iNumBins=100
    for iRunningLabel in range(1,5):
        print iRunningLabel
        aTempLabel=(dataLabel==iRunningLabel)

```

```
            aTemp=dataADC.reshape(-1)*aTempLabel.reshape(-1)
            aTemp=aTemp[aTemp>0]

            plt.hist(aTemp, iNumBins)


            hist, bins=np.histogram(aTemp, iNumBins)

            peakind=scipy.signal.find_peaks_cwt(hist, np.arange(1,int(0.1*iNumBins))
            plt.plot(bins[peakind], hist[peakind], 'r*')
            plt.ylabel('Counts ')
            plt.xlabel('Histogram bins')

            plt.show()

            iMaxPeak=peakind[numpy.where(hist[peakind]==hist[peakind].max())]
            iMaxValue=hist[iMaxPeak]

            aTemp=numpy.where(hist>iMaxValue/2)
            aTemp[0][0]

            print "iMaxPeak:", iMaxValue, bins[iMaxPeak], bins[aTemp[0][0]], bins[aT
            aFinalResults[(iFilu-1)*4+iRunningLabel,:]=[bins[iMaxPeak], bins[aTemp[0
            #print aTemp[0][0],aTemp[0][-1]


print aFinalResults
aTemp= aFinalResults
aTemp[:,1]=aTemp[:,2]-aTemp[:,1] # width distance
aTemp[:,2]=aTemp[:,1]/2.355 # sigma

print aTemp
```

References

[1] *Apparent diffusion coefficient*, `https://radiopaedia.org/articles/apparent-diffusion-coefficient-1`, Dr Henry Knipe and Dr Mohammad Taghi Niknejad et al., *checked: 2017*

[2] *TonynArtikkeli*, `https://radiopaedia.org/articles/apparent-diffusion-coefficient-1`, Dr Henry Knipe and Dr Mohammad Taghi Niknejad et al., *checked: 2017*

[3] *Image*, `http://www.magritek.com/2016/07/18/gradients-in-nmr-spectroscopy-part-5-the-pulsed-gradient-spin-echo-pgse-experiment/`, *checked: 2017*

[4] *DWI b-Value*, `http://mriquestions.com/what-is-the-b-value.html`, *checked: 2018*

[5] *MRI Physics: Diffusion-Weighted Imaging*, `http://xrayphysics.com/dwi.html#adc`, *checked: 2018*