ISP Group

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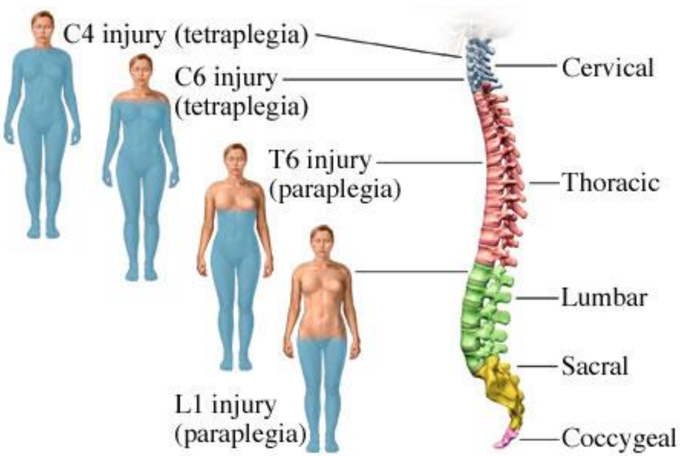
22/01/2014

You know certainly about some of these situations…

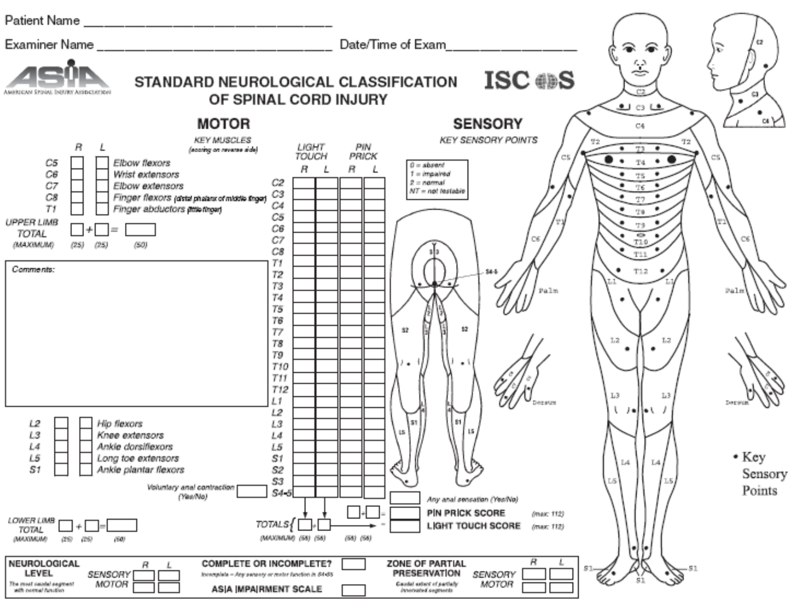
The falls are an important cause of spinal cord injuries

For now, only subjective tests are used to evaluate the functional damage



Consequences depends on the lesion site
but also on the extent of the damage

ASIA test
based on the feelings of the patient



Purves, *Neurosciences*, 3e édition
www.asia-spinalinjury.org

Could we objectively quantify the functional loss after spinal cord injury?

www.telegraph.co.uk

The technique should be able to…

… evaluate the degeneration of the nervous fibers

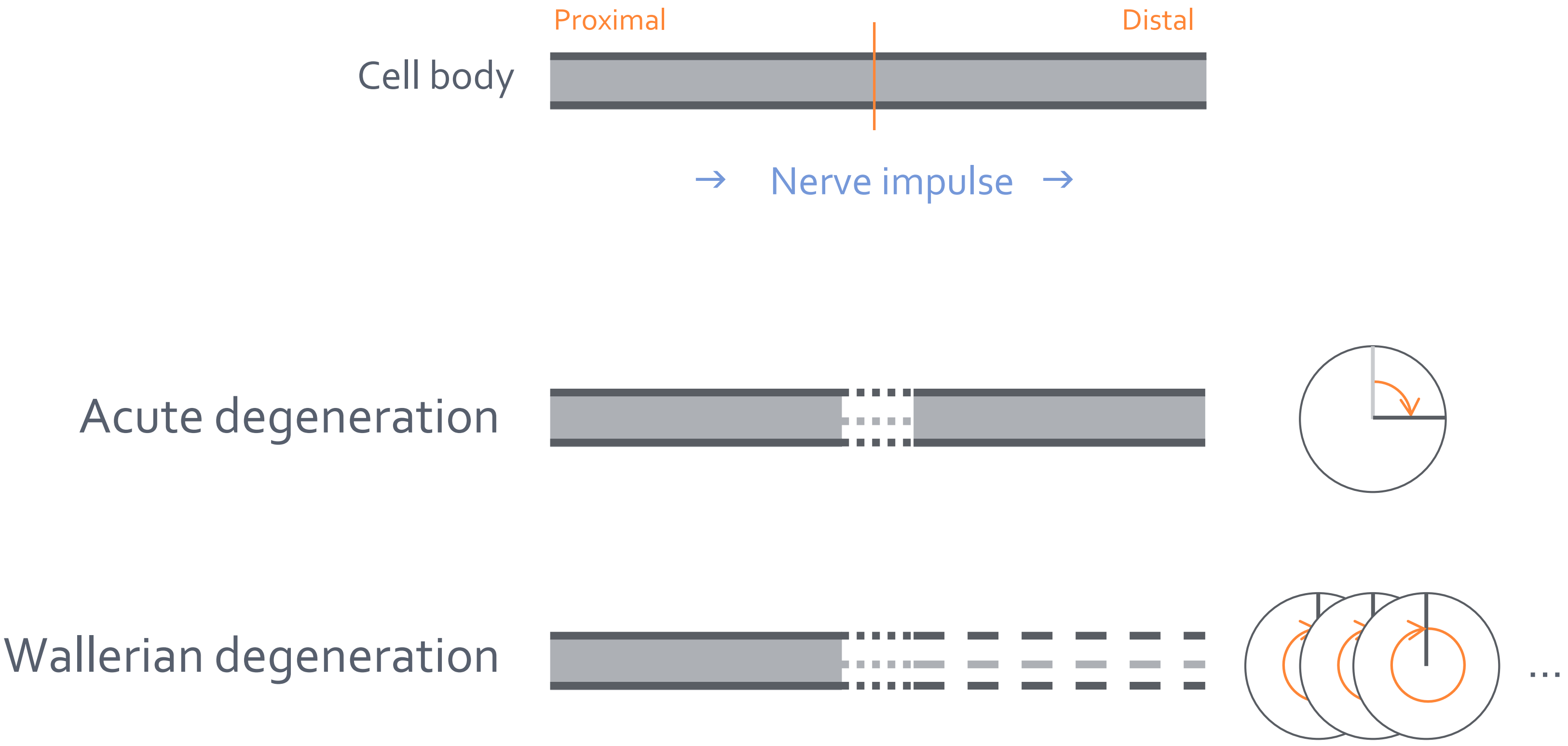
… give an objective measure of the functional loss

… provide longitudinal data of the patient

… consider the variability between subjects

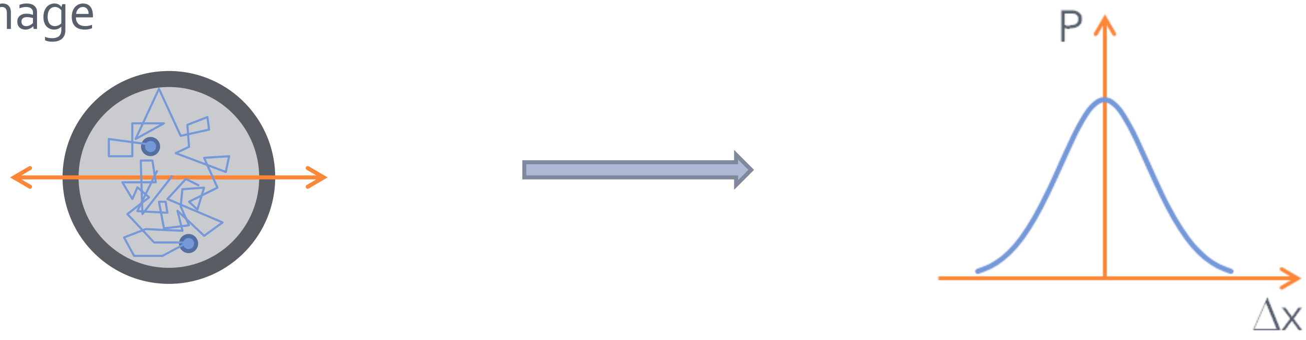
In vivo evaluation of the axonal degeneration
after spinal cord injury
using diffusion MRI and DKI

The axonal degeneration is a two-step process

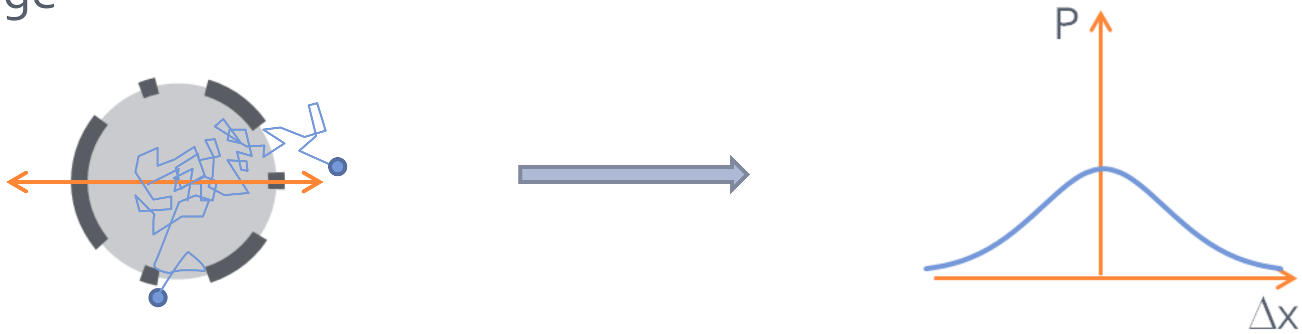


As a result, the diffusion of water molecules is altered

Before damage

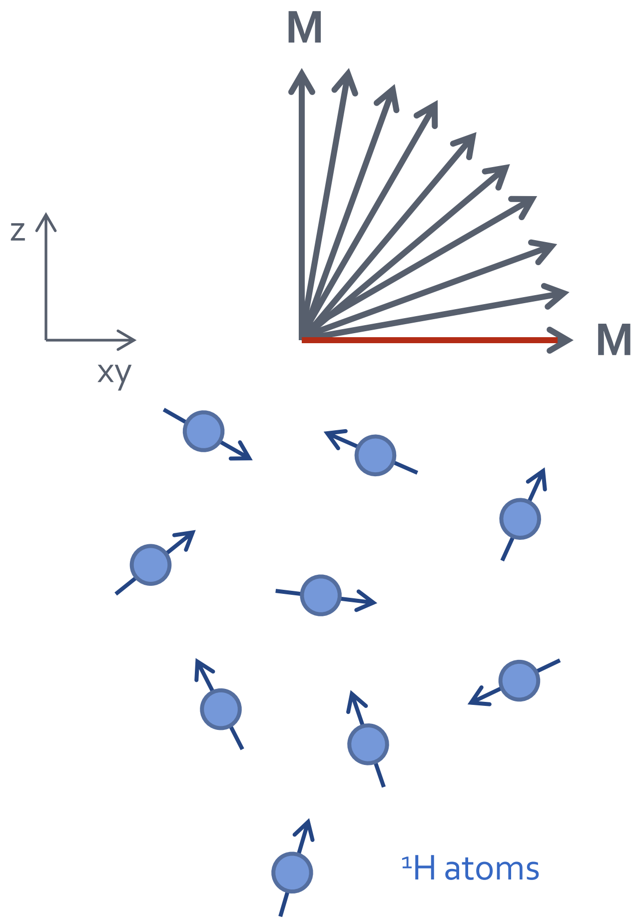


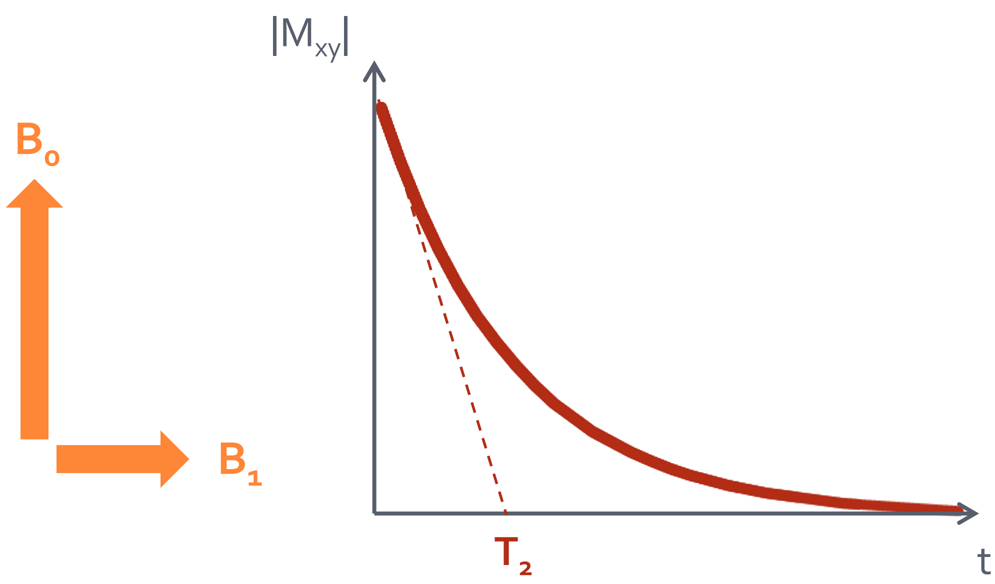
After damage



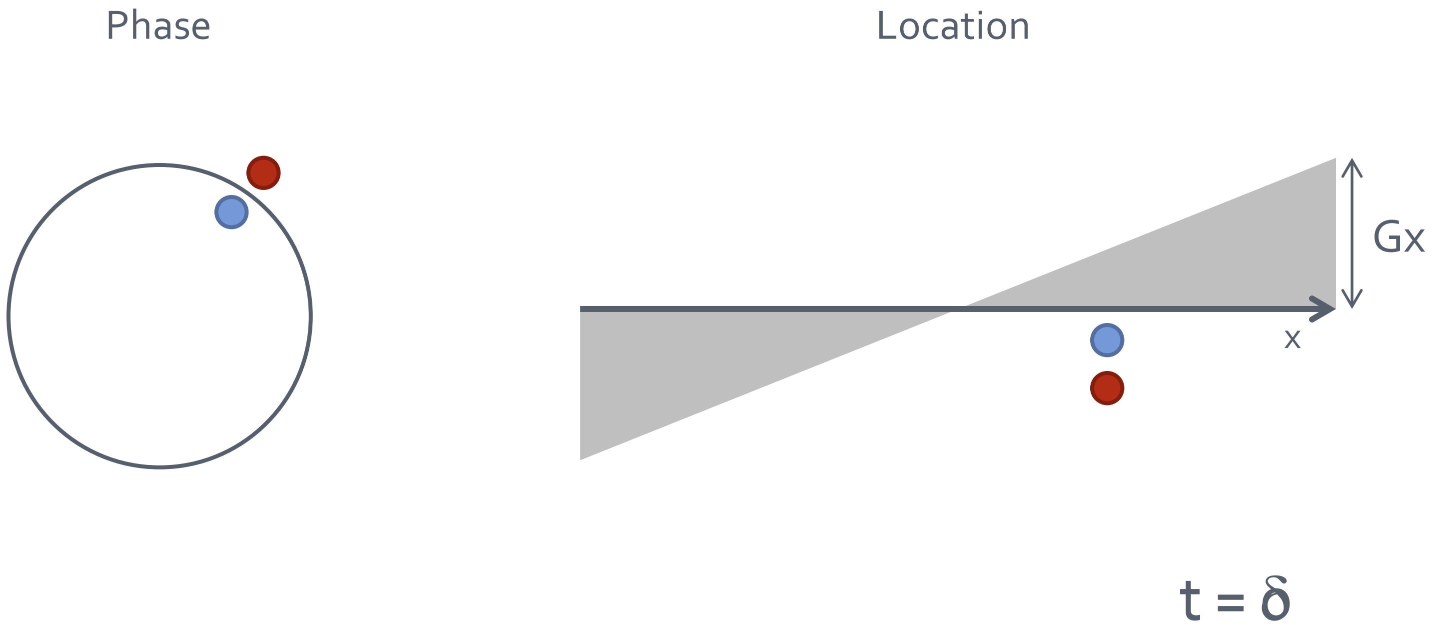
In vivo evaluation of the axonal degeneration after spinal cord injury using diffusion MRI and DKI

The MR signal measures the return to the equilibrium of the transverse magnetization after perturbation





The more the molecules diffuse, the more the signal is attenuated



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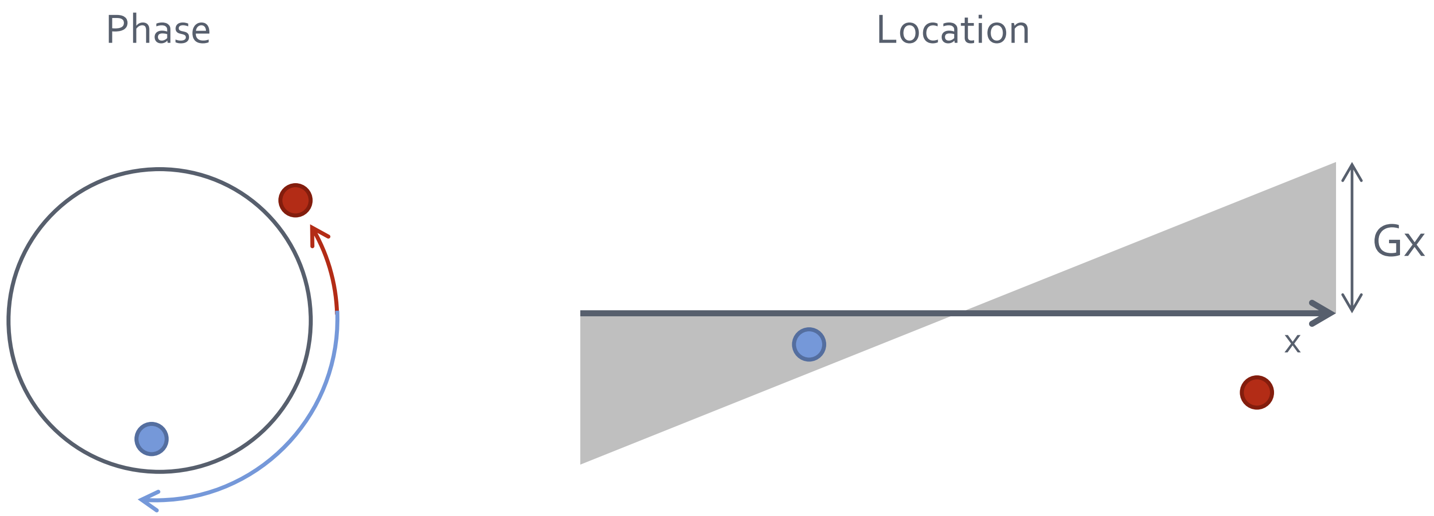
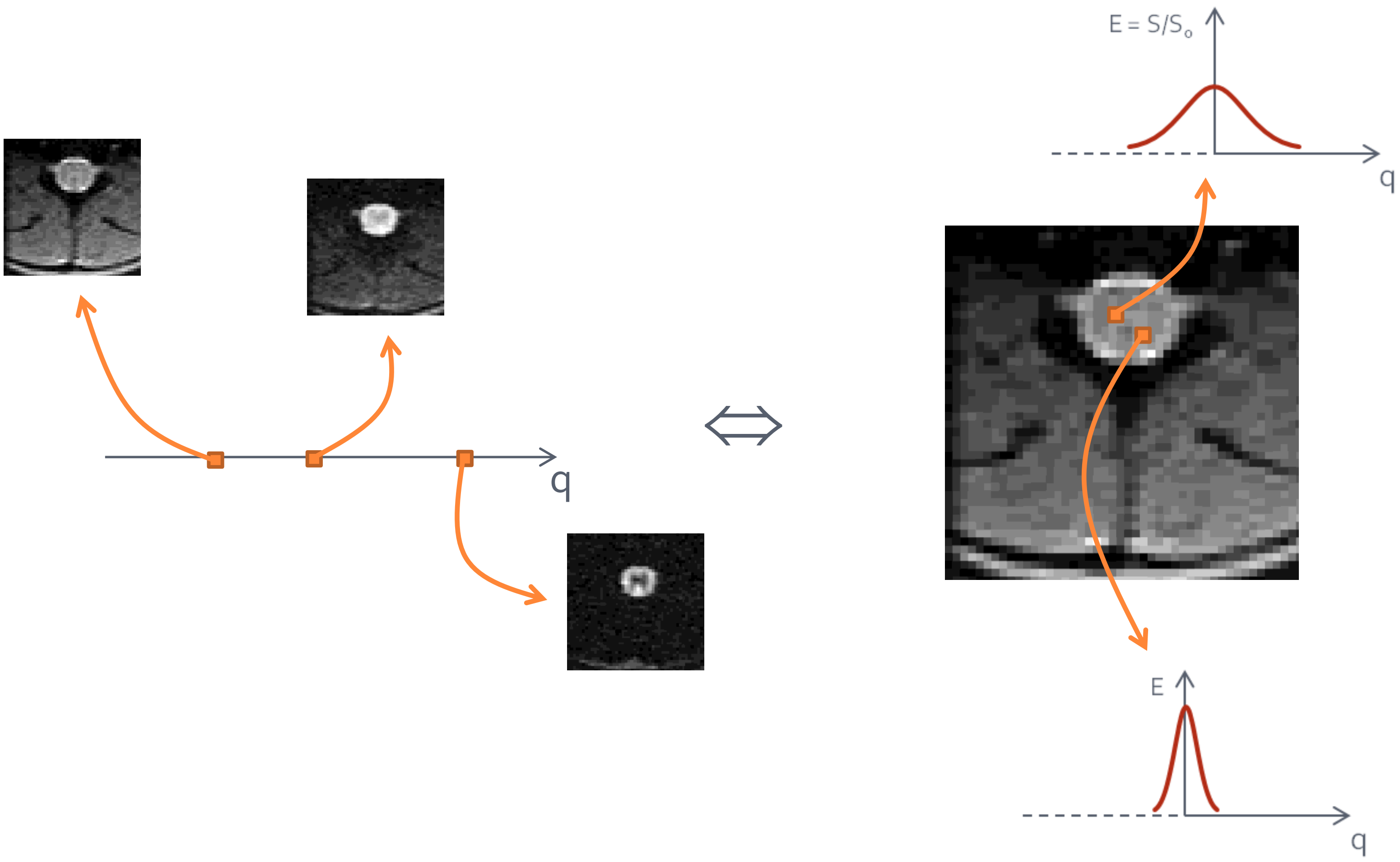


$$t = \Delta + \delta$$

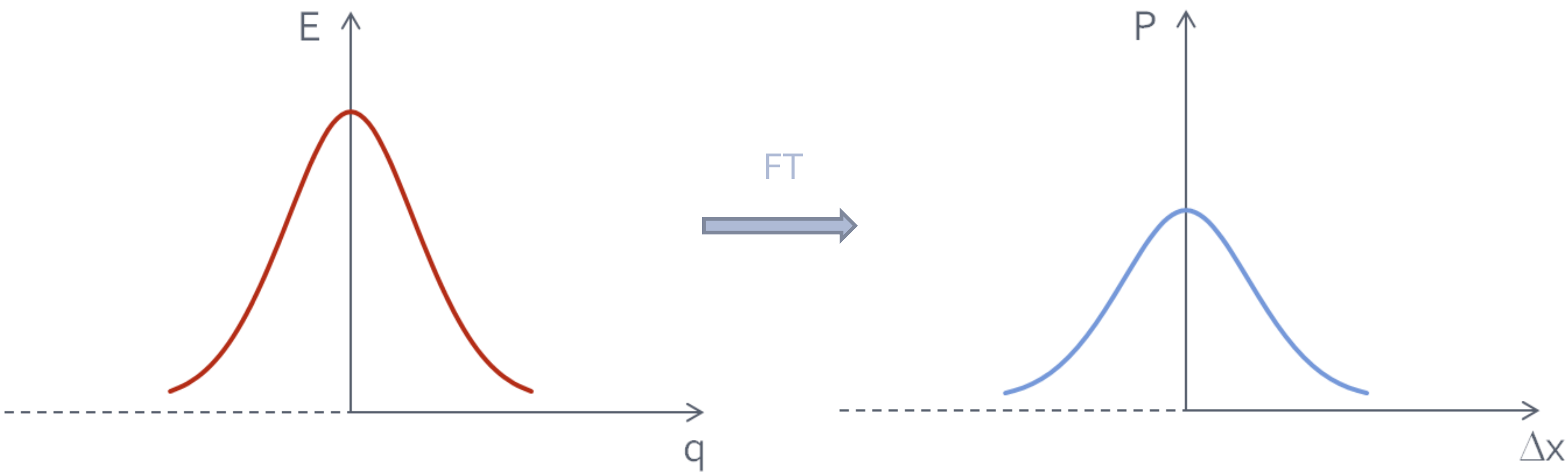
$$\mathbf{q} = \gamma / 2\pi \;\; \delta\, G \;\; \hat{\mathbf{I}}_{\mathbf{x}}$$

A diffusion weighted image is obtained for each q-value



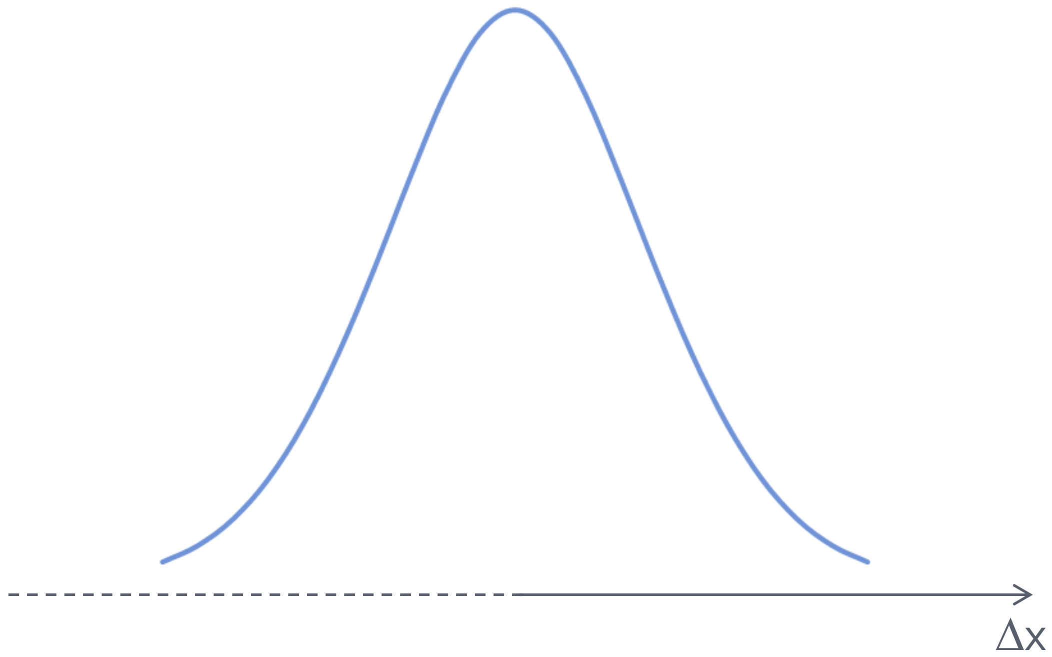
What is the relation between the signal attenuation and the probability density function of displacement?

The pdf is obtained applying a Fourier Transform to the signal attenuation curve



$$P(\Delta x) = \int_q E(q)\, e^{-i2\pi q \Delta x}\, dq$$

The diffusion can be characterized by different properties



Full Width at Half Maximum (FWHM)

Return to Origin Probability (RTOP)

Kurtosis

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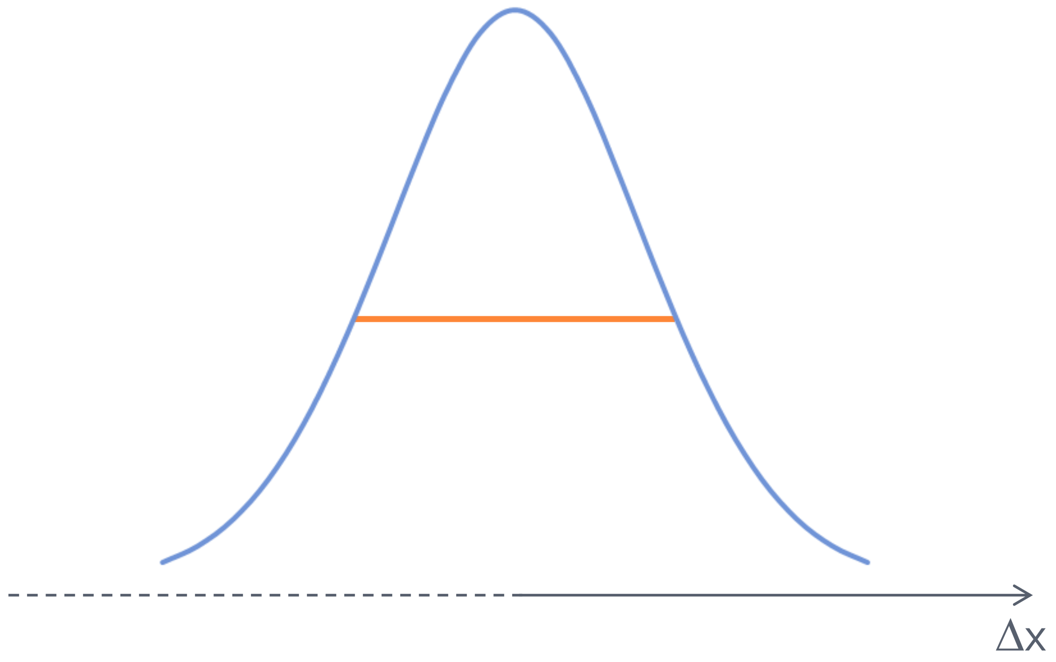

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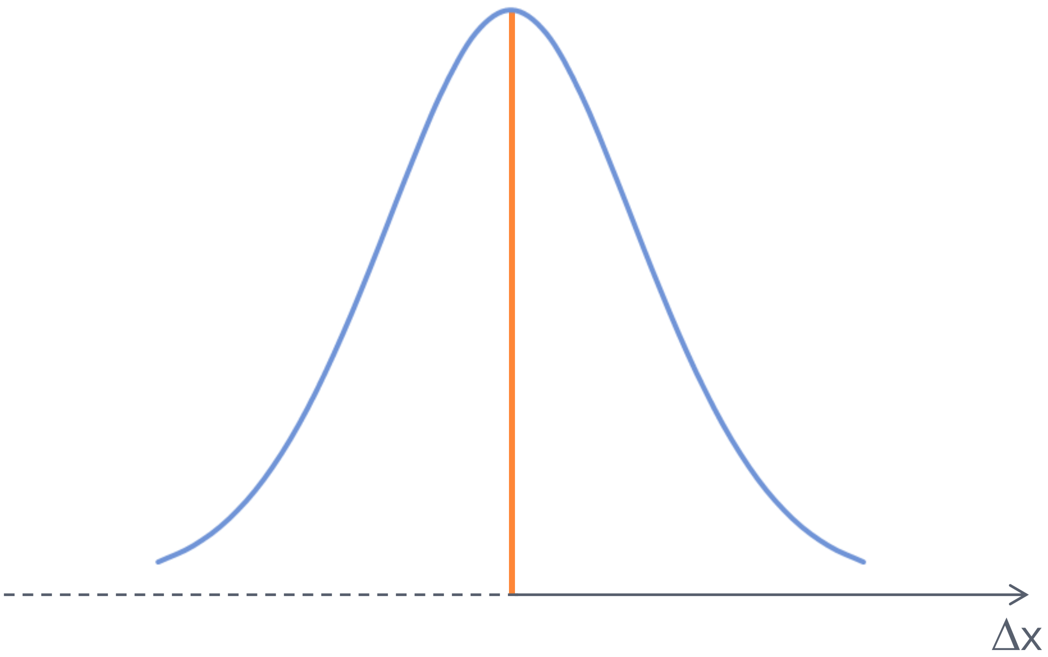

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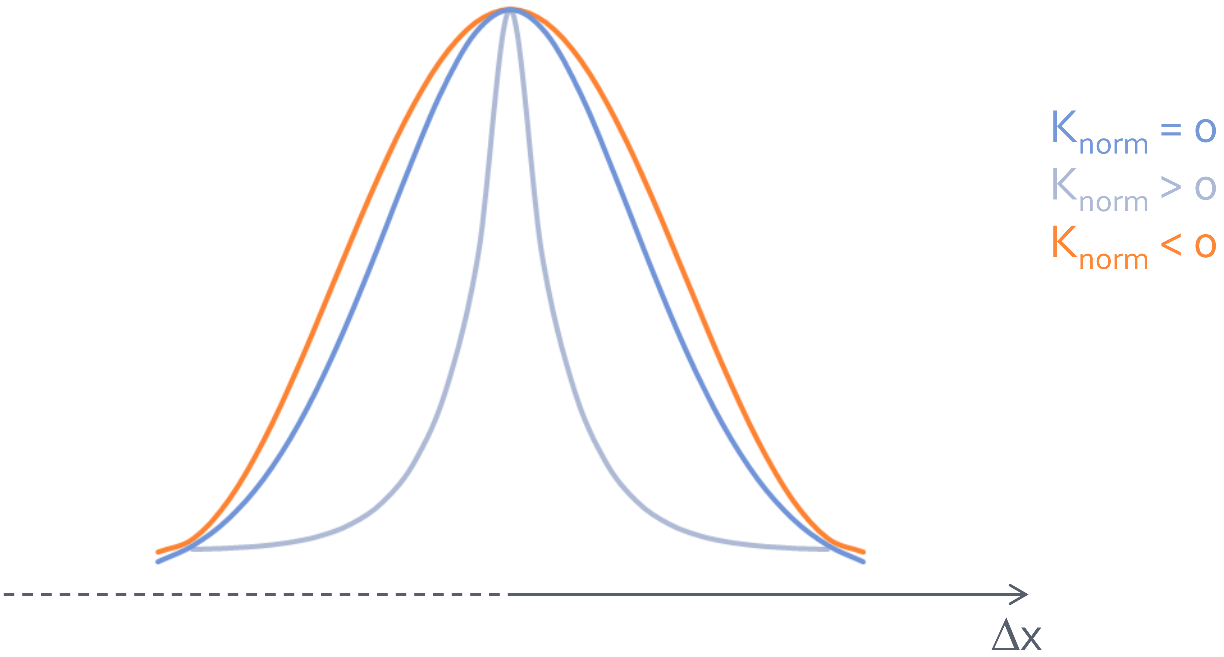
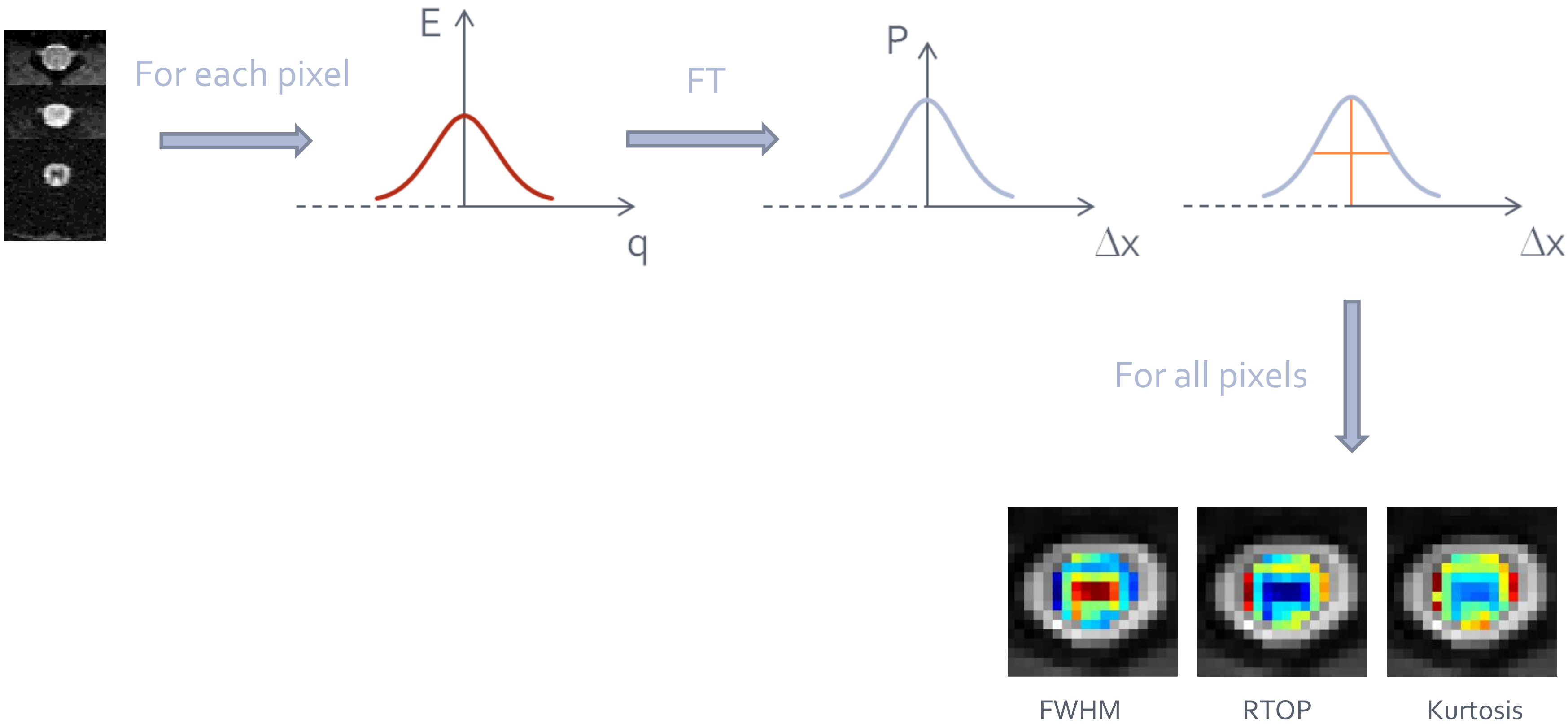


Full Width at Half Maximum (FWHM)

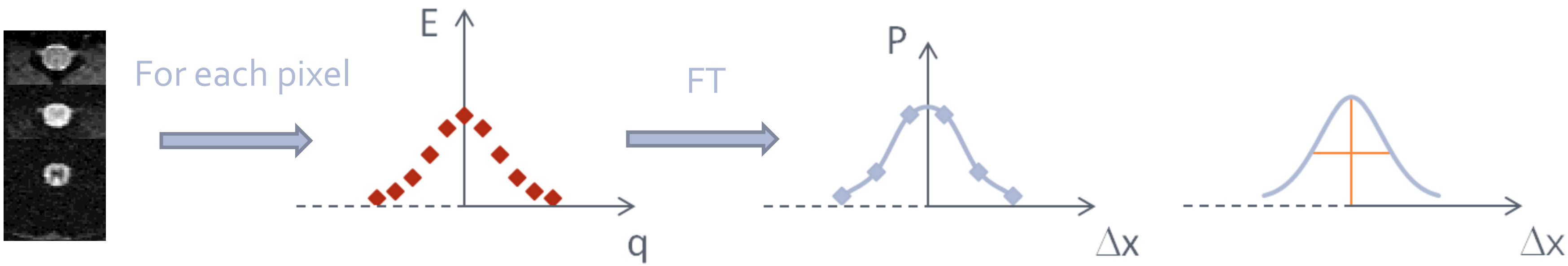
Return to Origin Probability (RTOP)

Kurtosis

From acquisitions to diffusion maps: the ideal case



In practice, the signal is measured only for several q-values



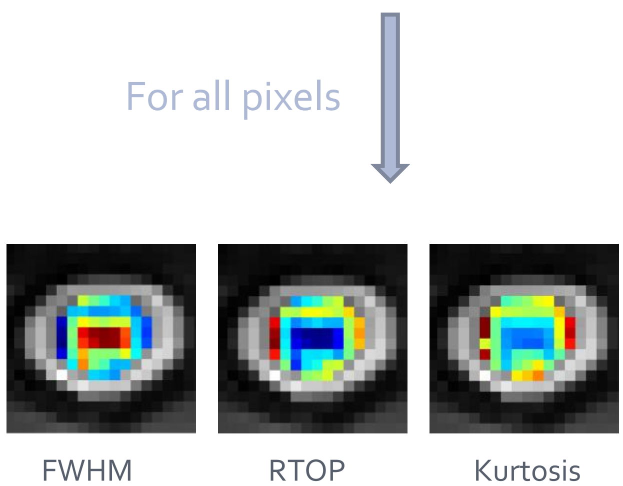
In real conditions…

Observations corrupted by noise

Finite number of observations and limited resolution in the spatial domain

Artifacts (movements, partial volume effect, etc.)

…



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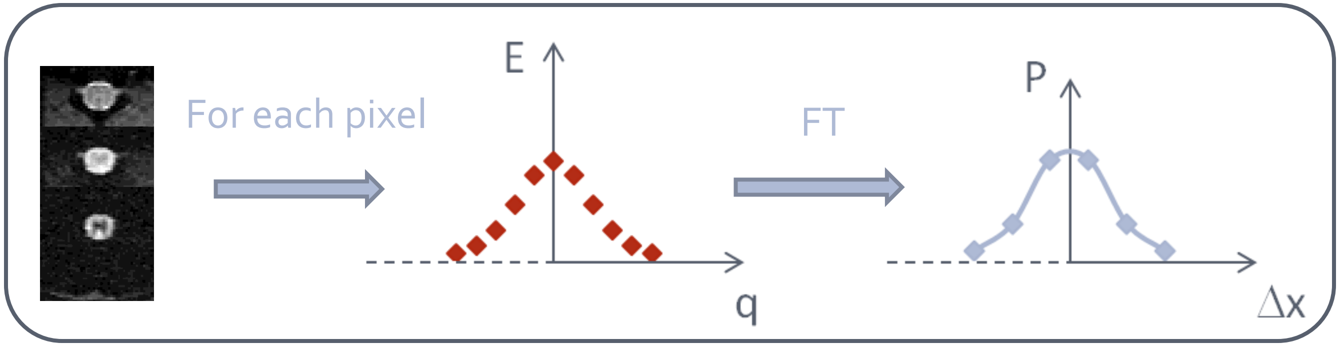


In real conditions…

Observations corrupted by noise

Noise correction and filter applied on magnitude images

Finite number of observations and limited resolution in the spatial domain

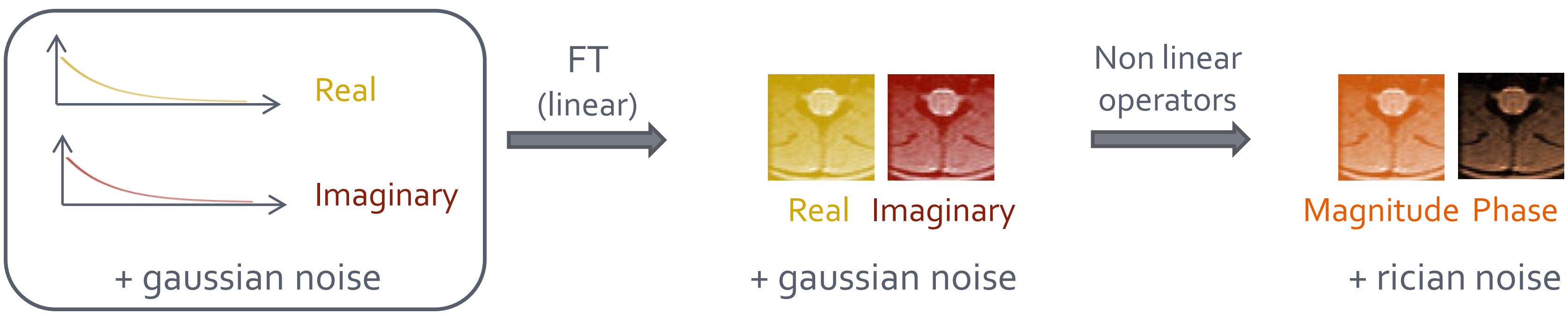
Approximation of the attenuation signal by diffusion models

Artifacts (movements, partial volume effect, etc.)

Main corrections during acquisition

…

Three methods were used to improve the SNR



1. **Averaging during acquisitions**

Averaging n times → σ^2 decreased by a factor $\sqrt{n}$

Three methods were used to improve the SNR

2. Correction based on variance estimation from the background pixels

$$p_M(M) = \frac{M}{\sigma^2} e^{-\frac{(M^2+A^2)}{2\sigma^2}} I_0\left(\frac{A \cdot M}{\sigma^2}\right)$$

M : measured intensity
A : real intensity

if A ≈ 0 $\quad p_M(M) = \frac{M}{\sigma^2} e^{-\frac{-M^2}{2\sigma^2}} \qquad \hat{\sigma} = \sqrt{\frac{1}{2N}\sum_{i=1}^{N} X_i^2}$

if SNR > 3 $\quad$ Gaussian distribution of mean $\overline{M} = \sqrt{A^2 + \sigma^2}$

$$\tilde{A}_i = \sqrt{\left|M_i^2 - \hat{\sigma}^2\right|}$$

Three methods were used to improve the SNR

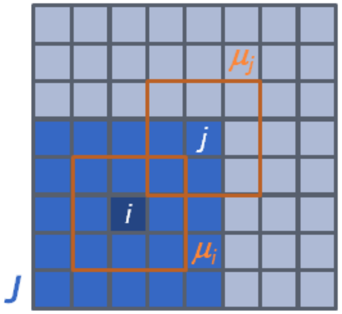
3. Non-Local Mean (NLM) Filter (Buades et Morel)

Smoothing filter that preserves borders and details

$$NL\left(\tilde{A}_i\right) = \sum_{j \in I} w(i,j)\tilde{A}_j \quad \text{with} \quad \sum_{j \in I} w(i,j) = 1$$

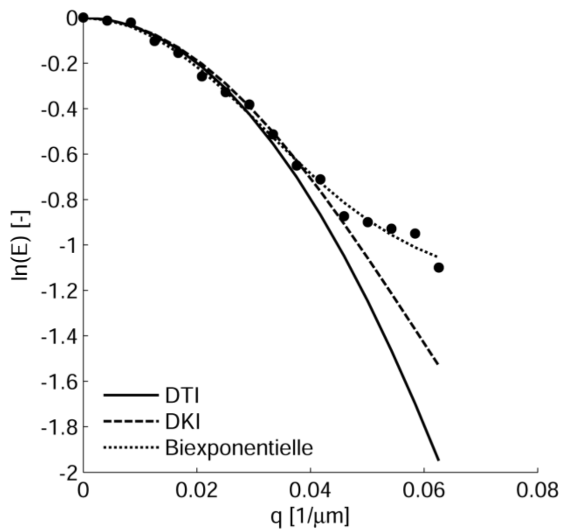
w(i,j) : weighting function depending on the similarity between voxels i and j

$$w(i,j) = \frac{1}{Z(i)} e^{-\left\|\tilde{A}_{\mu_i} - \tilde{A}_{\mu_j}\right\|_{2,a}^2 / h^2}$$

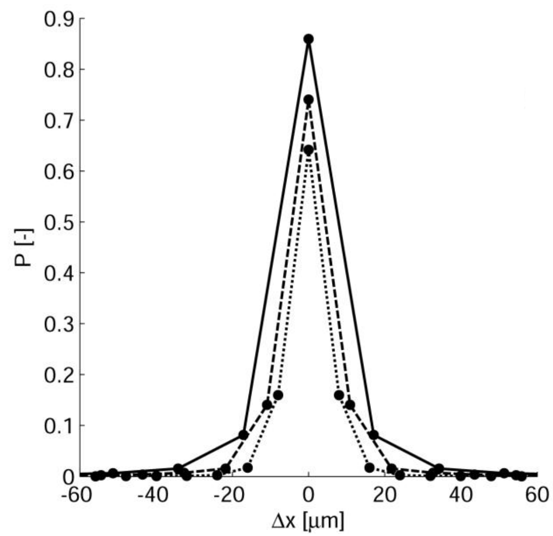


In vivo evaluation of the axonal degeneration
after spinal cord injury
using diffusion MRI and DKI

The DTI and the DKI are two diffusion models



FT



$$E(q) = e^{-Aq^2D} + Bq^4D^2K + O(q^6)$$

Diffusion Tensor Imaging

Diffusion Kurtosis Imaging

DTI provides a first estimation of the parameters

$$E(q) = e^{-Aq^2D + Bq^4D^2K + O(q^6)}$$

Diffusion Tensor Imaging

Diffusion Kurtosis Imaging

$$\ln(E(q)) = -Aq^2D$$

$$\ln(E(q)) = -Aq^2D + Bq^4D^2K$$

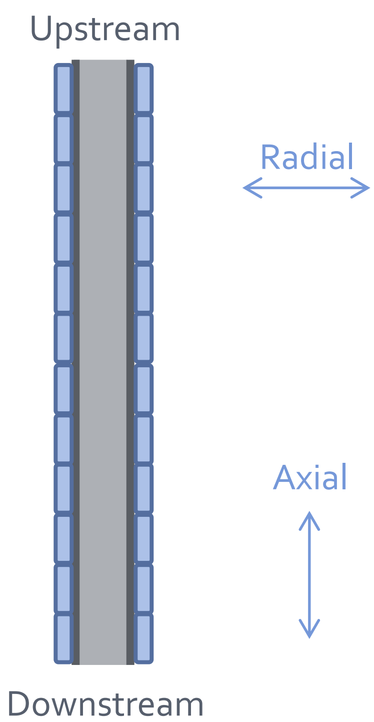
Simple linear regression
(least squares)

Non linear optimization
using trust-region-reflective algorithm
implemented in Matlab

$D, K > 0$

$D_0 = D_{DTI}$
$K_0 = 0$

The final step is the extraction of parameters of the pdf



$FWHM_{\perp}$ $RTOP_{\perp}$ $D_{\perp}$ $K_{\perp}$

$D_{average}$
+
Fractional Anisotropy

$FWHM_{//}$ $RTOP_{//}$ $D_{//}$ $K_{//}$

DTI ($FWHM_{//}$, $RTOP_{//}$, $D_{//}$)

DKI ($FWHM_{//}$, $RTOP_{//}$, $D_{//}$, $K_{//}$)

In vivo evaluation of the axonal degeneration
after spinal cord injury
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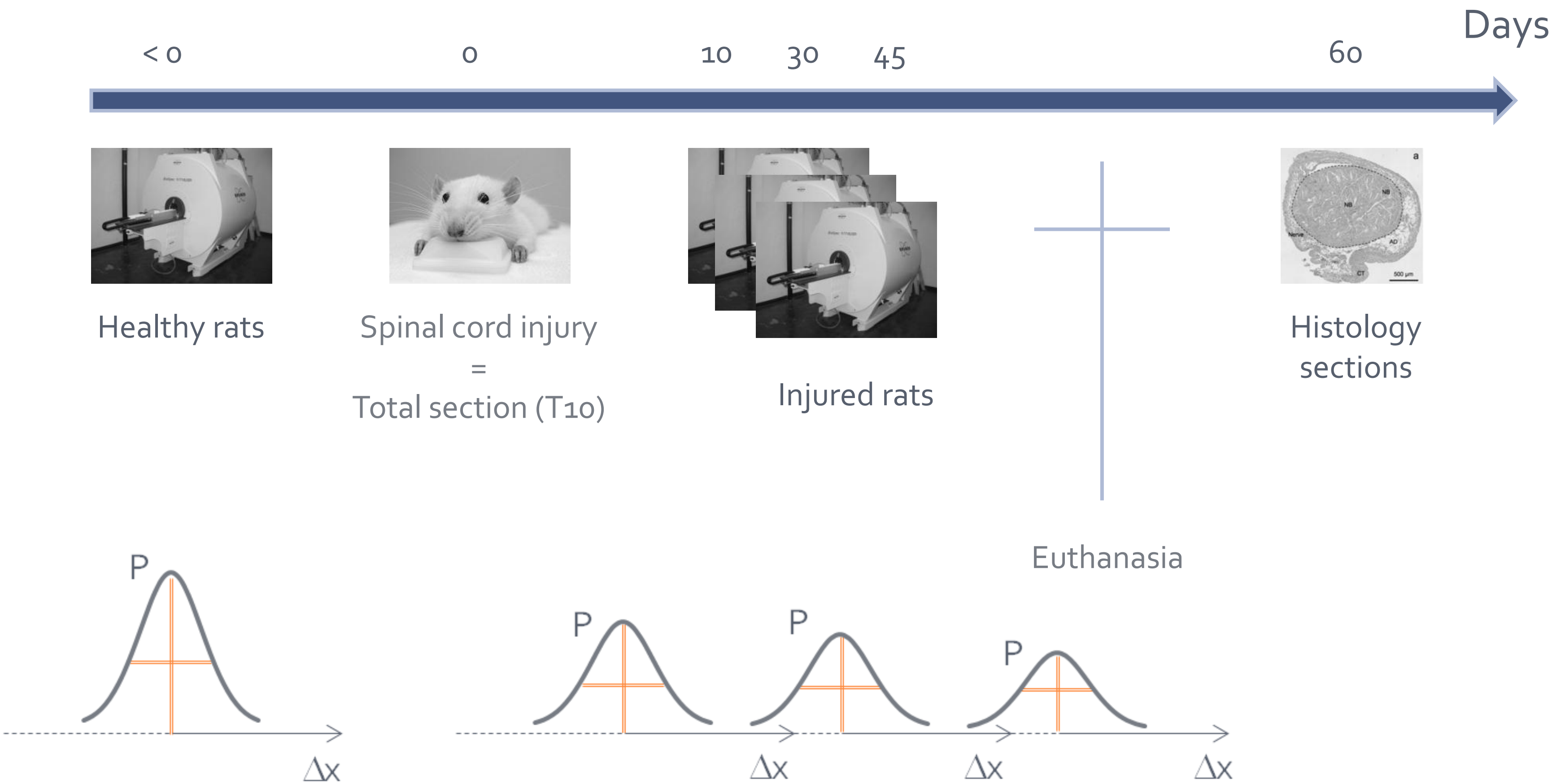
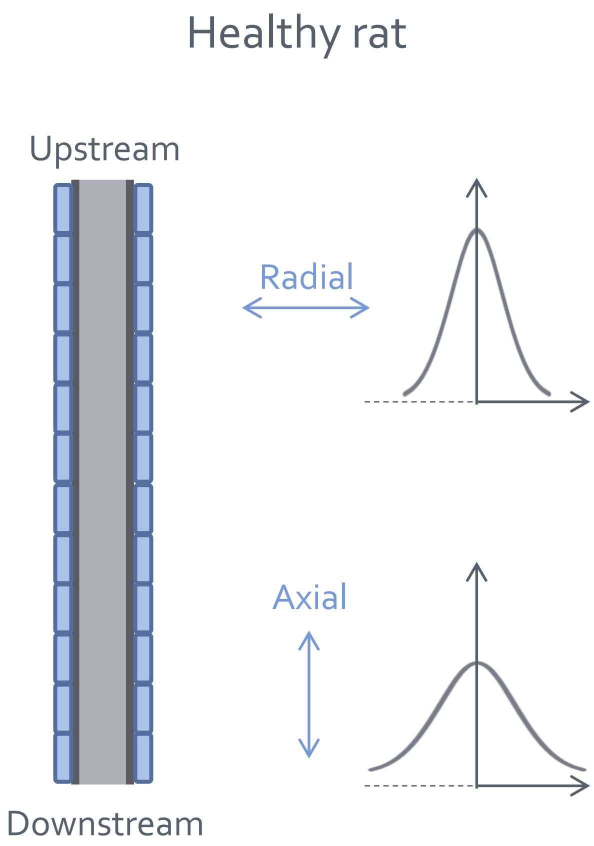
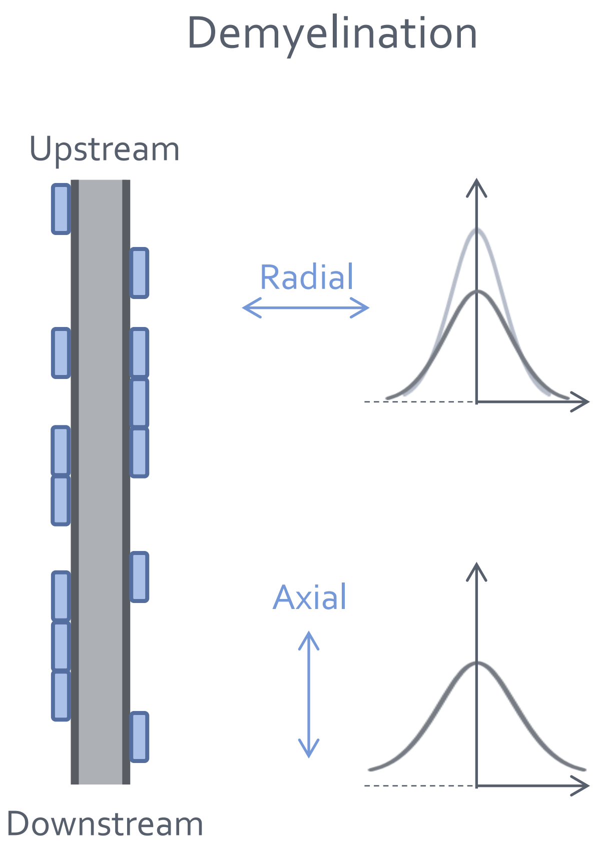
The technique is adapted for longitudinal studies



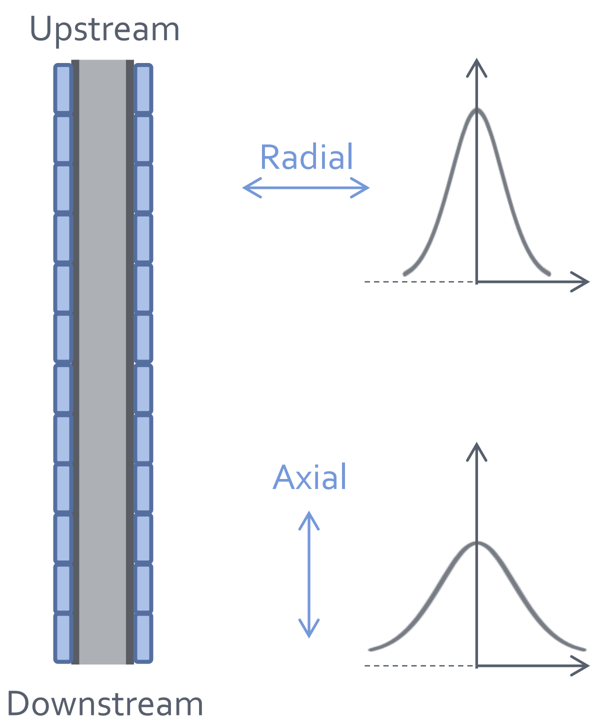
The evolution of the pdf shape gives information on the neuropathology



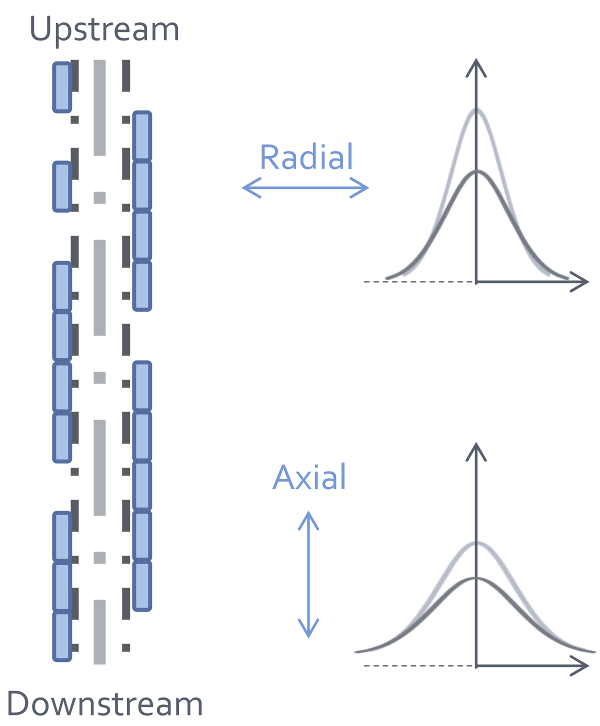


The evolution of the pdf shape gives information on the neuropathology

Healthy rat



Wallerian degeneration after section
(distal part)



Further analysis of the results is based on diffusion maps

... comparison between the four different acquisition times

... comparison between the upstream and the downstream parts of the lesion site

... comparison with histological sections

... estimation of good indicator(s) of the axonal degeneration

Falls can be tragic… so, be careful!

F1 STAR SCHU FIGHTS FOR LIFE AFTER SKI HORROR

BY JOSH LAYTON

F1 legend Michael Schumacher was fighting for life in a coma last night after a horrific skiing fall.

Schumacher, 44, hit his head on a rock and was in a "critical state" after surgery on a brain haemorrhage.

He was flown to hospital and was unconscious when he arrived. His wife and children are with him in France.

FULL STORY: PAGES 4&5

CRITICALLY ILL Ski fan Michael Schumacher

Wife & kids at bedside after brain haemorrhage leaves him in coma

Any questions ?