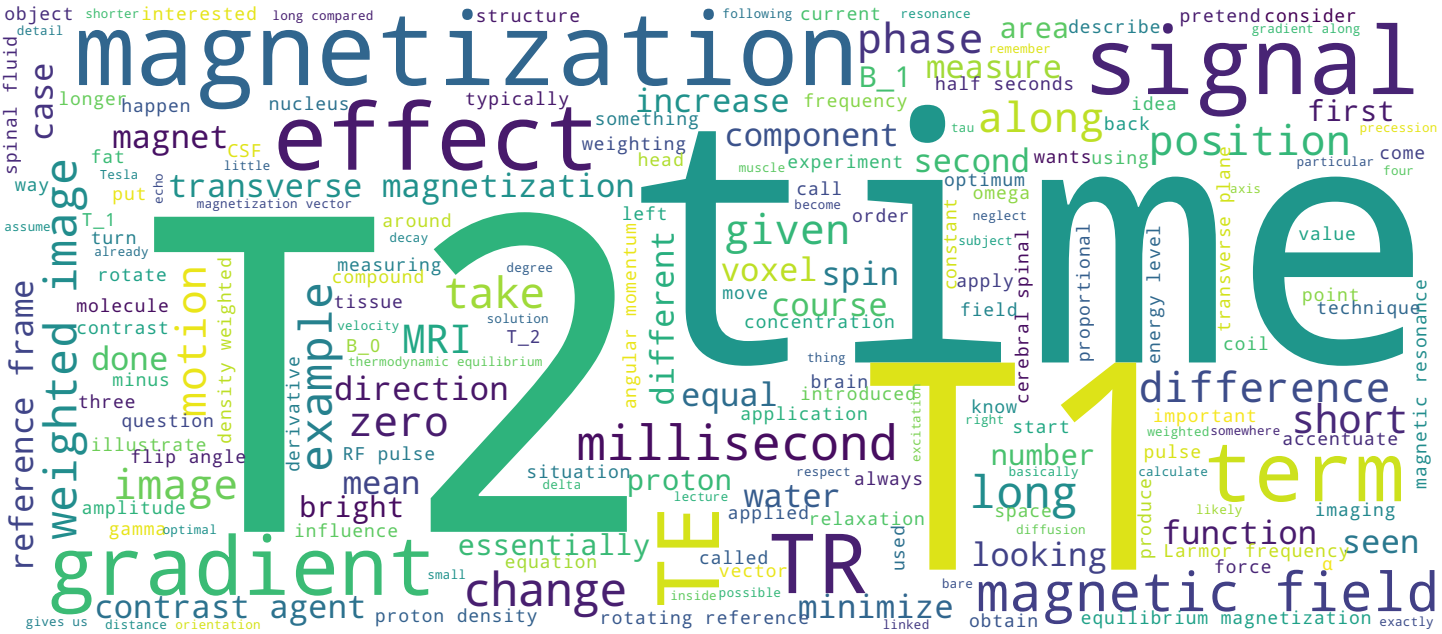
# 12.4 Basic MR contrasts

## Fundamentals of Biomedical Imaging

Prof. Rolf Gruetter

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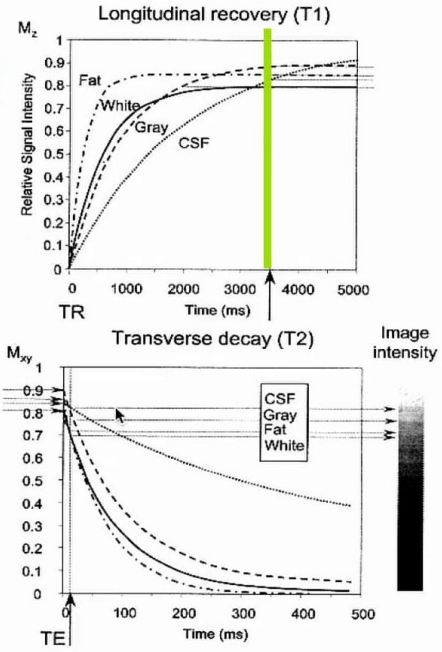
# 12-4. How are the basic MRI contrasts generated ?

## I. Proton density weighted MRI

Minimize effects of relaxation:

$$S(TE,TR) \propto \rho(1-e^{-TR/T_1})e^{-TE/T_2}$$

long TR:
minimize effect of $T_1$ differences




12-13

So how are the basic MRI contrasts generated? So we'll start out here with proton density weighted MRI. So for proton density, just to have proton density, one wants to minimize the effects of the relaxation. So take again the basic equation here that we have. The signal is a function of *TR*, *TE*, and *TR*. We want to minimize the effect of *T1*, so the *T1* here is for different tissues. We don't want to have the effect of *T1* on the signal, so essentially what this means is one wants to measure at a *TR* that is relatively long compared to *T1*. So it's a long *TR*, in this example here, it's three and a half seconds. That will minimize the effect of *T1* differences and let's pretend we've been good at that, so we can, by measuring here, neglect the effect of *T1*. So we'll just say this term here becomes one and we'll neglect its effect. So now we're left with the exponential decay here. This term here-- and I will look at the signal decaying as a function of *T2*. Again, we want to have no influence of *T2*, so to have no influence of *T2* we want this term to be essentially zero, *T* over *T2* is-- we can basically say *TE* zero then *T2* can be whatever it is, *E to the minus zero* is always one.

Notes

Summary

0m 04s

# 12-4. How are the basic MRI contrasts generated ?

## I. Proton density weighted MRI

Minimize effects of relaxation:

$$S(TE,TR) \propto \rho\left(1-e^{-TR/T_1}\right)e^{-TE/T_2}$$

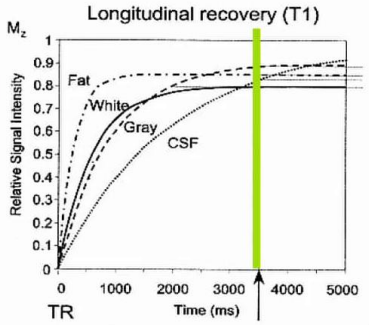
long TR:
minimize effect of $T_1$ differences

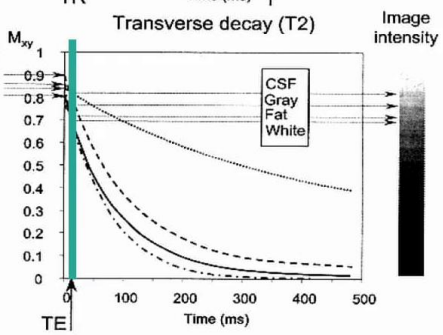
Short TE:
minimize influence of $T_2$

Imaging the number of protons per voxel

⇒ Tissues with higher spin density (e.g., fat, CSF) have higher image intensity

Water content: only ~70-100% (poor contrast)




12-13

So the goal here is to minimize the *TE*, so we'll use the *TE* as short as possible, that minimizes the effect of *T2* and so this term is gone and in this case one has an image that is essentially reflecting the equilibrium magnetization, which reflects-- as we have introduced in lecture eight-- which reflects a number of spins in a voxel. So we're imaging the number of protons per voxel, in this particular case, this is the Parameter Rho. So images with higher density, spin density like fat and CSF have a higher image intensity, however, if we consider the contrast that this can bare, we have to bare in mind that living tissue typically has water content that varies between 70 and 100%, so that is not a gigantic difference in contrast between the different tissues, so it's not a very good-- way to distinguish the tissues. Nonetheless it's the physical approach, we want to measure the density of protons, we're measuring a quantity, number of protons per voxel. This is for proton density MRI.

Notes

Summary

1m 29s

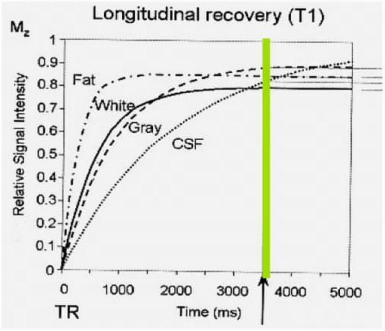
# II. How is $T_2$ contrast generated ?

## contrast based on differences in $T_2$

$$S(TE,TR) \propto \rho(1-e^{-TR/T_1})e^{-TE/T_2}$$

$T_2$ weighting: long TR → reduced $T_1$ effects

*longer* TE : accentuate $T_2$ differences




12-14

So second question: how is *T2* contrast produced now? We'll take again the same operational equation, that's our signal of our spinecall sequence and now we are looking at the *T1* effect. We are now interested in producing a contrast solely on the basis of *T2* and so in this case for *T2* weighting, we don't want to have the effect of *T1*. So we're going to use long *TR* to have a reduced effect of differences in *T1*. We are interested in exploiting just the effect of *T2* and so, again here, a three and a half seconds we have a fairly long *T1* to minimize the effect of *T2* and let's say this is sufficiently long that we are not measuring the influence of different *T1s* and so we can neglect this term for the following. Now to measure the effect of *T2*, one does not want to measure at a short *TE* because there they don't differentiate. One wants to use a longer *TE* to accentuate the differences in *T2*, so that's this term here, we want to accentuate the differences here, we pretended that this term is one-- and we don't need to consider it.

Notes

Summary

2m 45s

# II. How is $T_2$ contrast generated ?

## contrast based on differences in $T_2$

$$S(TE,TR) \propto \rho(1-e^{-TR/T_1})e^{-TE/T_2}$$

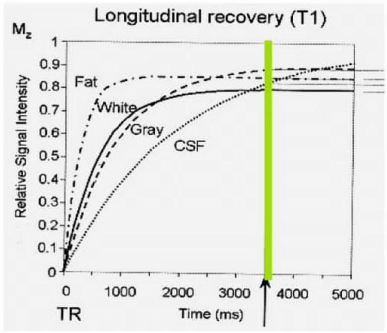
$T_2$ weighting: long TR → reduced $T_1$ effects

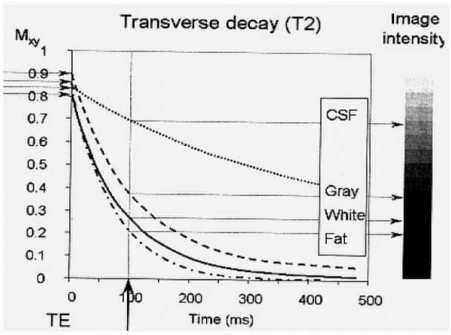
*longer* TE : accentuate $T_2$ differences

What TE is optimal?

1. Find TE at which $M_{xy}$ is most strongly affected by $T_2$ differences
2. Solution (variational calculus, Lecture 1):
3. Find TE at which $dM_{xy}/dT_2$=maximal

**TE = $T_2$**




12-14

So we'll just use a particular *T2* and now here the issue is: what is the optimal *TE* that we'll be using here to accentuate the *T2* differences? Clearly if we use a *TE = 0* we have no differentiation of the *T2* differences. If *TE* is very long compared to *T2* then we have no signal and we cannot differentiate, so there's somewhere in between this an optimum and this is done by-- the goal here is to find the echo time at which the transverse magnetization is most strongly effected by the *T2* differences. To do this we use the same kind of variational calculus or air propagation calculus that I introduced in lecture one to obtain this solution. So we'll do first-- and essentially what it is, we'll calculate the derivative of the transverse magnetization with respect to *T2* that tells us how much is the transverse magnetization sensitive to changes in *T2* and then we want to know at what *TE* is this derivative maximum. That's the approach. I'm not going to go through the details here. I'm just going to give you the result. The optimum *TE* here is -- at the value of *T2*.

Notes

Summary

4m 01s

# II. How is $T_2$ contrast generated ?

## contrast based on differences in $T_2$

$$S(TE,TR) \propto \rho(1-e^{-TR/T_1})e^{-TE/T_2}$$

$T_2$ weighting: long TR → reduced $T_1$ effects

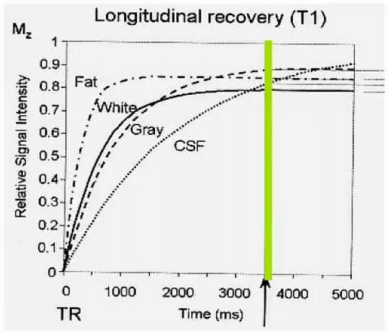
*longer* TE : accentuate $T_2$ differences

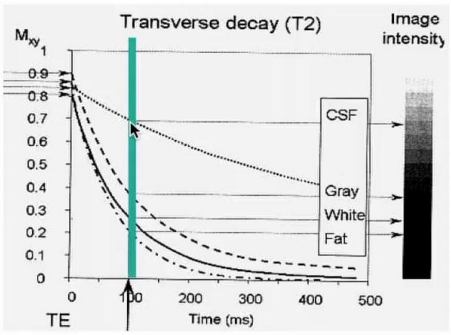
What TE is optimal?

1. Find TE at which $M_{xy}$ is most strongly affected by $T_2$ differences
2. Solution (variational calculus, Lecture 1):
3. Find TE at which $dM_{xy}/dT_2$=maximal

$$TE = T_2$$

4. For tissues with different $T_{2a}$ and $T_{2b}$: Use TE between the two $T_2$ values.



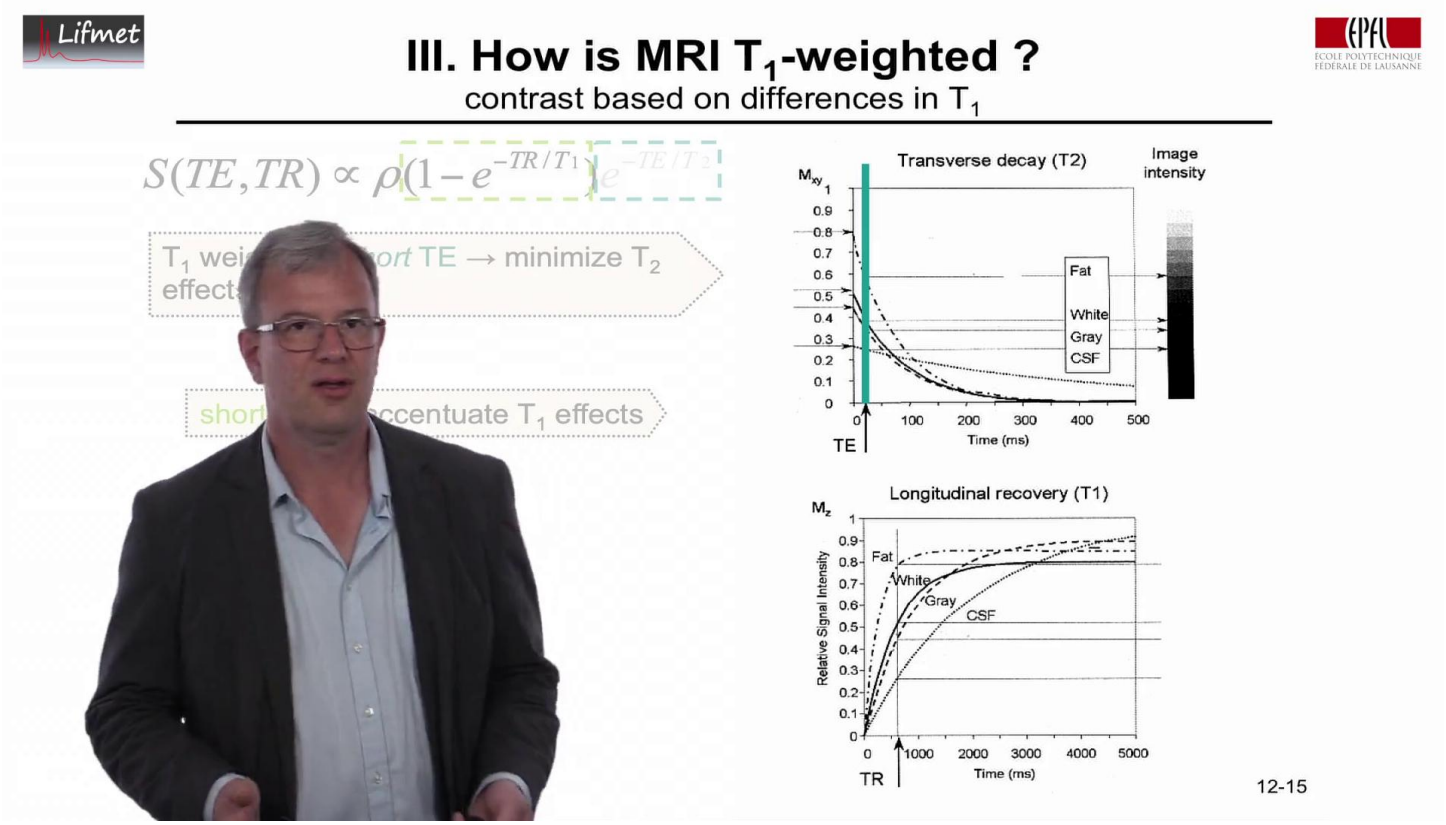

12-14

If we have tissues with different *T2*, so *T2a* and *T2b* then most likely the optimum *TE* to use for differentiating those two tissues is the *TE* that's between the two *T2* values so somewhere in between. So it's automatic -- A crucial requirement, if your *T2s* are on the order of 100 milliseconds, there's no point in measuring it at 200 milliseconds, so you set it to 100 milliseconds. However, if you're in a situation where the *T2s* are 50 milliseconds, the 100 milliseconds are perhaps not the optimum choice *T2* weighting. Okay, so in this case *TE* here is 100 milliseconds.

Notes

Summary

5m 21s




Okay and finally, let's discuss *T1* weighting. So we are looking, again, at the operational equation here for the spinecall sequence, 91/80 degree but now we're not interested in having the effect of *T2*. So we want to minimize the effect of *T2* and to do this, like with proton density weighted imaging, we want to have a *TE* that is as short as possible. So while using a short *TE* to minimize the effects of *T2*, so we'll use something here like 20 milliseconds in this particular example. And then let's pretend that we've been successful and that our *TE* is sufficiently shorter, we can largely neglect the effects of *T2*, so we'll pretend that this factor here is one and we'll just grey it out here and it's no longer observable. So now we're interested in optimizing or looking at this term here and so the effect to accentuate *T1* effects, one uses a relatively short *TR*. If we use a *TR* that's very long compared to *T1*, we won't have an effect of *T1*. If *TR* is very short compared to *T1*, we're using 90/80 pulses here then we have no signal. So there's most likely also here an optimum for the *TR*.

Notes

Summary

6m 04s

# III. How is MRI $T_1$-weighted ?

contrast based on differences in $T_1$

$$S(TE,TR) \propto \rho(1-e^{-TR/T_1})e^{-TE/T_2}$$

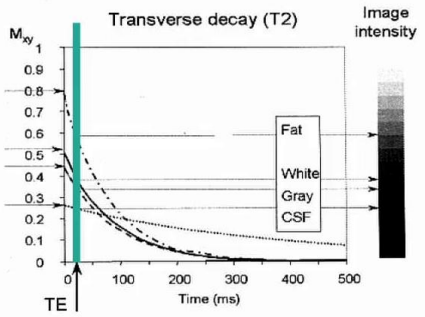
$T_1$ weighting: *short* TE → minimize $T_2$ effects

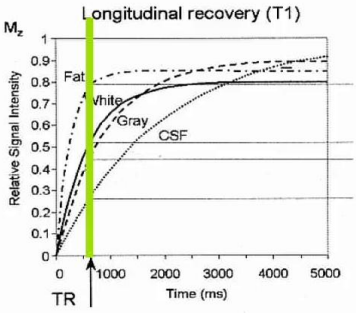
short TR → accentuate $T_1$ effects

1. use short TR to maximize the differences in longitudinal magnetization during the return to equilibrium
2. Tissues with shorter $T_1$ have higher image intensity
3. **Question:** When is the signal maximally sensitive to changes/differences in $T_1$?

   Answer: TR=$T_1$

   (see 9-17)




12-15

So the idea is to use a short *TR* to maximize the differences in longitudinal magnetization as they are returning to thermodynamic equilibrium, so we have CSF here going slow and we have white matter going much faster. So we'll have some differences here and in this particular example the *TR* chosen here is 600 milliseconds. As a consequence, tissues with short *T1* have a higher image intensity because they are the ones who are much further along in their return to thermodynamic equilibrium than the tissues with long *T1* such as CSF. So CSF appears dark. Now again we can ask what is the good choice of *TR*. That's the question. And I'll give you the answer because we have actually dealt with this already in course nine, and it's a similar calculation that I introduced in lecture one, and we just used on the preceding slide, and the answer here is not surprising, we're dealing with an exponential return, that the optimal *TR* to see *T1* changes is at the *TR* = *T1* We're not going to go into much of the details here. Let's illustrate in the following-- we'll illustrate these different contrasts.

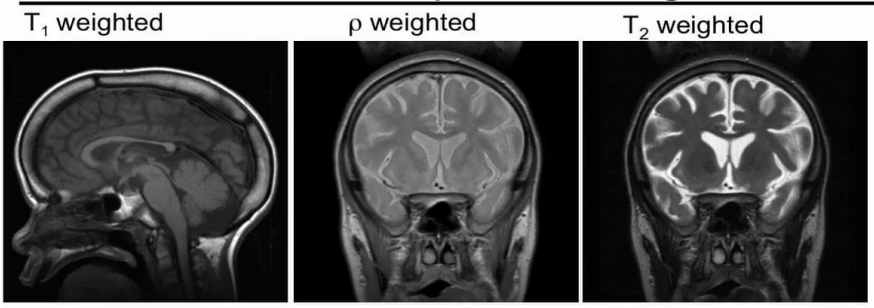
Notes

Summary

7m 26s

# Ex. ρ, $T_1$ and $T_2$ weighted MRI

Spin echo images



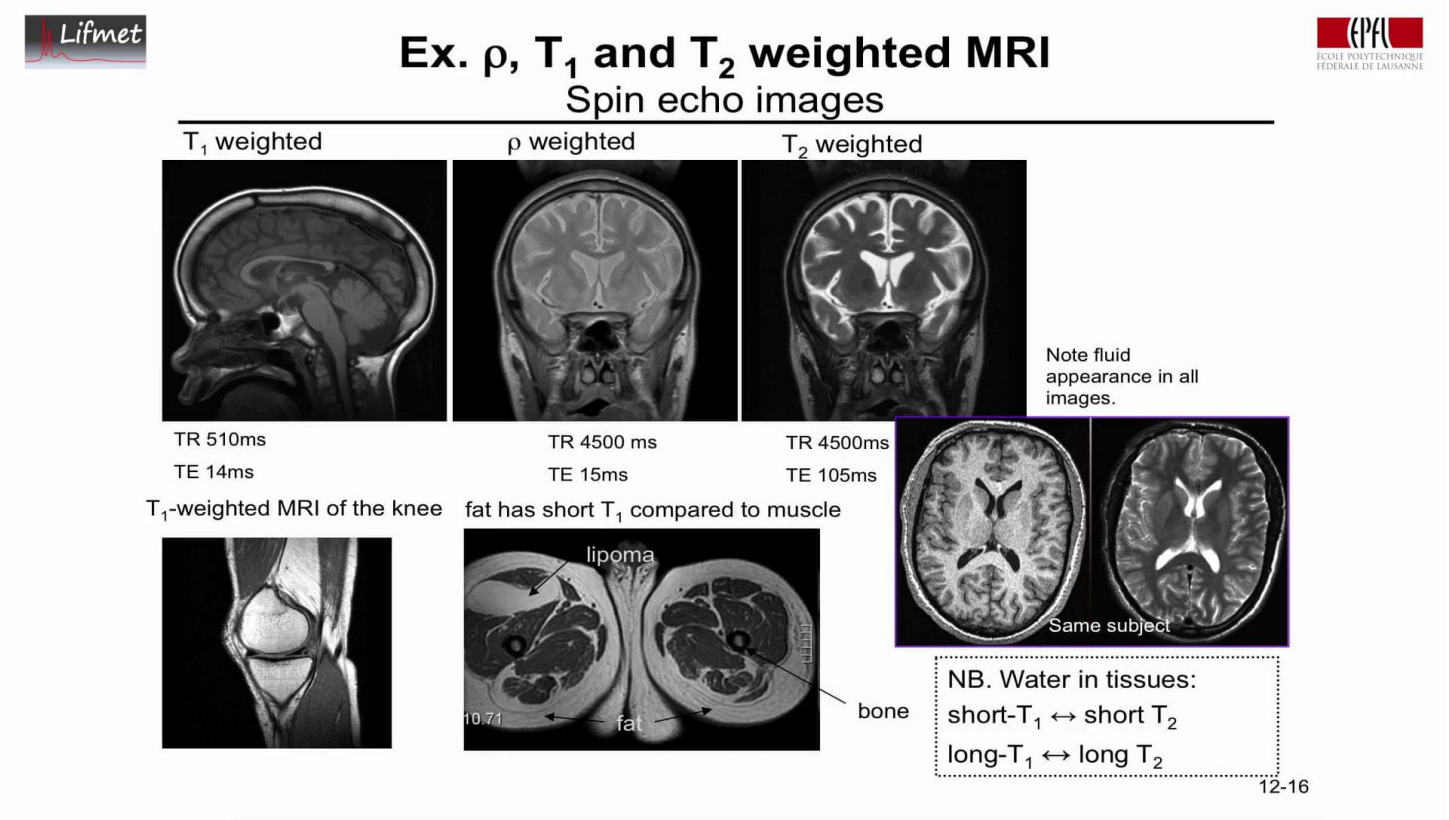

12-16

So here's a *T1* weighted image of the head. We can see the tongue here, the nose, this is a sectional cross, so here is the back of the head where we have the little bump back here. To give you an idea what the *TRs* and *Ts* are, I've put them in here, so this is a *TR* of 510 milliseconds and a *TE* of 40 milliseconds. Here's now a density weighted, proton density weighted image. So it is a *TR* of four and a half seconds and a *TE* of 50 milliseconds. This is a cut through the head coronally, so we can see the ventricles very bright, the CSF bright because this is 100% water. It's not very bright but it's bright. It's a greyish image. And *T2* weighted here now, the *TR* is four and a half seconds and the *TE* is 100 milliseconds. We can see the liquid filled spaces, the CSF, cerebral spinal fluid has long *T2*. There's no proteins, no membranes in there or very little, so *T2* is long, they show up as bright. And so notice here that we have the fluid, cerebral spinal fluid here, here, and here.

Notes

Summary

8m 46s



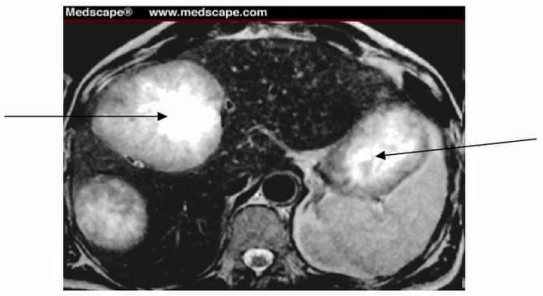

We have long *T2* for cerebral spinal fluid and long *T1* but the cerebral spinal fluid is darker *T1* because the weighting there favors the shorter *T1* components whereas a *T2* weighted the imaging, the weighting favors of the long *T2* components. So this is, again, a comparison of *T1* and *T2* images in the brain of the same subject we have tissue filled ventricles, dark on *T1* weighted, and bright on the *T2* weighted image. Here's an example of a *T1* weighted image of the knee and this is of the muscle, also *T1* weighted fat typically has a shorter *T1* compared to muscle, so we get good contrast. This is fat. This is the bone. And here we have the lymphoma in this unfortunate patient, so this is showing the fat signal. So we have to remember for water that a short *T1* typically implies a short *T2* and a long *T1* implies a long *T2*. So even though this is long *T2* and this is long *T1* the contrast, the way it appears is different and this is important because the way the contrast generate the MRI changes the appearance of the same signal or the same mechanism.

Notes

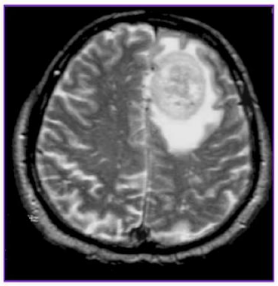
Summary

9m 54s

# Ex. $T_2$-weighted MRI of cancer
(cancer tissue water has long $T_2$)

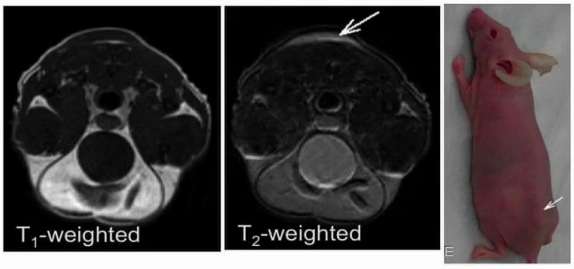



Colon carcinoma metastases (liver)



$T_2$-weighted

nude mouse with xenograft tumor (D282 tumor)




TR = 500 ms
TE = 14 ms

TR = 2 s
TE = 40 ms




12-17

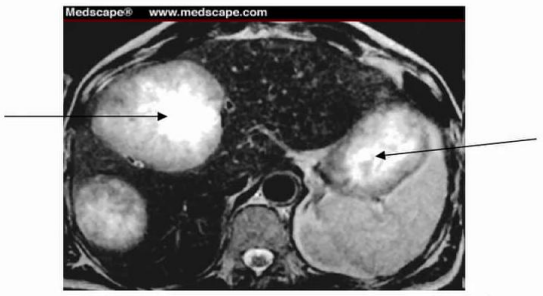
The second example on this is *T2* weighted imaging of MRI of cancer and one of the features is that cancer tissue has a long *T2*. This is a metastases of colon carcinoma here on this *T2* weighted image of the abdomen. They are hyper intense, very brightly visible. Here's a *T2* weighted image of the brain tumor. One can see the bright area here but it shouldn't be and there's even some different within that, that it looks peculiar. Here's an example of -- a mouse with xenograft tumor, so the tumor is implanted here on the surface. This is the *T1* weighted image, just to give you an idea what the perimeters are 500 milliseconds *TR*, 14 milliseconds *TE*. This is *T2* weighted here and again, *TE* is not 40 milliseconds, *TR* is two seconds. And on the *T2* weighted image one can see the xenograft tumor is much harder to see on the *T1* weighted image, so *T2* weighted images are very often used to detect tumor tissue. Here's again, for a mouse implanted with tumor baring cells, non-tumor baring cells in the *T2* weighted image clearly the tumor that has grown is very visible.

Notes

Summary

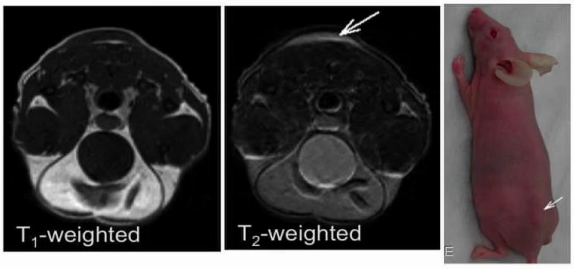
11m 21s

# Ex. $T_2$-weighted MRI of cancer
(cancer tissue water has long $T_2$)



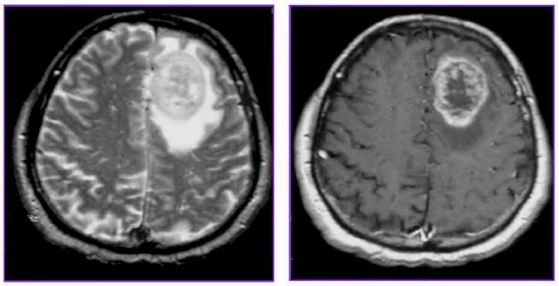

Colon carcinoma metastases (liver)

nude mouse with xenograft tumor (D282 tumor)

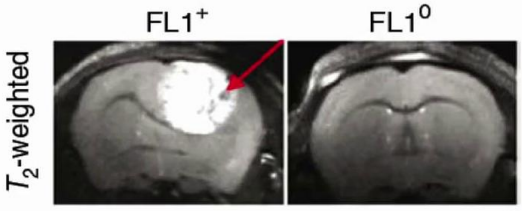



TR = 500 ms
TE = 14 ms

TR = 2 s
TE = 40 ms



$T_2$-weighted $T_1$-weighted post-contrast




12-17

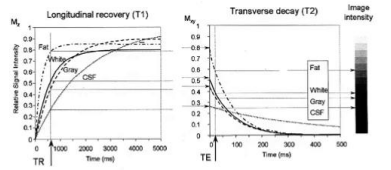
And now on the *T2* weighted image, one has very often a contrast that is not homogeneous for a tumor and what is often done is the application of contrast agents. Contrast agents which depict the breakdown of blood-brain barrier or vasculature and this is now the same patient here, *T1* weighted image after the application of a contrast agent. And that bares now the question on what are MRI contrast agents, which we'll discuss next.

Notes

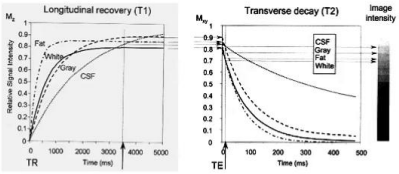
Summary

12m 46s

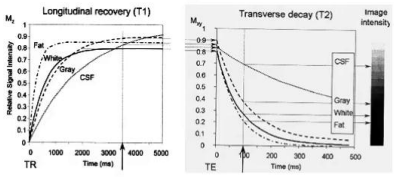
# Credits (1/2)




**"The Essential Physics of Medical Imaging"**
Fig. 14-21, from Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholt, John M. Boone




**"The Essential Physics of Medical Imaging"**
Fig. 14-22, from Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholt, John M. Boone



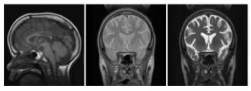

**"The Essential Physics of Medical Imaging"**
Fig. 14-23, from Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholt, John M. Boone

Notes

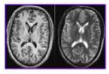
Summary

13m 21s

# Credits (2/2)

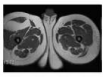


**''M R I Pulse Sequences''Jerry Allison Ph.D. (2004)**
https://radiologyphp.gru.ede/radiologyphysics/CatCourse/Allison/MRIPulseSequences.ppt

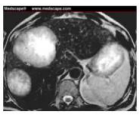


**"Neuroimaging with MRI : some of the things we can see", Robet W. Cox, 2007**
https://afni.nimh.nih.gov/pub/dist/edu/2007_12_MRIanat/MRIanat.ppt

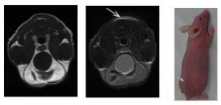
**Imagerie Diagnostique en Chiropratique Partie 2 André J. Cardin DC,**
http://slideplayer.fr/slide/1803082/



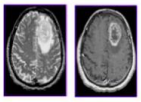
**Intramuscular lipoma, From the collection of Dr Kimberly Moore Dalal and Dr Steven D. DeMartini**
https://online.epocrates.com/diseases/981/Lipoma



**Evaluation of the Liver for Metastatic Disease, fig 15.**
**Erik K. Paulson, MD1, 1Department of Radiology, Duke University Medical Center, Durham, North Carolina**
http://www.medscape.com/viewarticle/410855_11



**Donghoon Lee et al. *J. Vis. Exp. 2009;***



**Supratentorial brain neoplasm. Noll MRI Physics I: Spins, Excitation, Relaxation Douglas C. Noll**
http://slideplayer.com/slide/5272436/

Notes

Summary

13m 25s