**Introduction to Biomedical Imaging Systems**
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**Lecture - 46**
**MRI_Phys_S45_S52**

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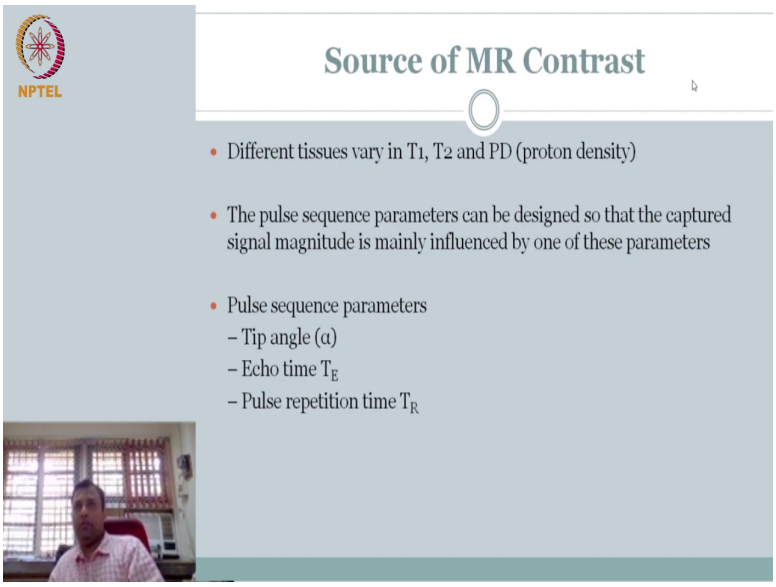


And here what we are going to do is look at the sources of contrast right that we come up in. So, what we have covered so far; we have covered starting with spin right we know what is the physics of the signal and how are we trying to convert this spin property or the characteristic the spin characteristics of the tissue material whatever we discussed. How is it converted to a voltage signal that is what we covered so far.

So, now, moving beyond this we are interested in magnetic resonance imaging; that means, we would like to see contrast between different locations right. And; that means, we talked about all work cell and we talked about the magnetization vector and how this magnetization

vector is the component in the transverse direction is measured and you get a voltage a free induction voltage right so that is the signal that we got.

So, now the question is if I have a distribution of this work cells right each one is having its own properties. If I take an image right the in one location how will I ensure that one location which has a different property what property we covered right, we will rehearse it now. How is it different from another location; that means, if you see a contrast from one location to another in our imaging parlance if some location is black the other location is white right you see a contrast black and white.

So, how does this come? What does this mean right? How is this related to the signal that we covered so far? That is going to be the coverage in this module it is going to be very short because I assume you went through all the video recordings before and you made your effort to read it from textbook multiple times. So, you have your own imagination of what is this fundamental signal and how we are going to measure it.

So, with that background I think you should be able to you know really appreciate the how the contrast is generated. So, to just before I list it rehearse yourself from whatever we covered why do you think the contrast come from. So, based on this course you know there is going to be first inherent contrast the physics based.

So, what is the inherent contrast we are interested here right think about it, what is it? Well, you might think ok where is the signal ok I am measuring something that is proportional to proton density. So, if I have different proton density then maybe the different locations will have were a different value of brighter dark ok.

So, inherent contrast would arise from proton density distribution of your proton density. Is that all is there any other intrinsic property? Well, we talked about proton density giving you magnetization vector and then we talked about the signal the rate at which it is losing the signal right. So, the transverse component is dephasing so we talked about inherent characteristics which is T2 or T2 star to be more you know have that detail as well.

So, nothing to do with dephasing and then we also associated some other material property in terms of time constant with which it comes back to equilibrium. So, inherent contrast that we are looking at of each of the tissue properties so far what we have covered has to do with difference in proton density, difference in time constant with which it is losing the signal due to dephasing and time constant with which the location is coming back to the equilibrium or the z component is building up these are the three inherent contrast ok.

So, proton density T1 T2 changes from tissue one location to another location. So, is that all is there any other thing that we need to worry about before we talk about the contrast? Yes, remember this is just the physics now you have to measure this. So, did we have any parameter that is going to control how we are going to measure it, recall what are the parameters that we talked about that influences the signal right.

First thing is remember that alpha I have my signal here but I cannot measure that push it to the ground or the component in the transverse is what I am measuring. So; that means, the alpha is a parameter that you control right so how long you want to apply. So, that is your so alpha is one parameter that you can control depending on which your signal what you are measuring might be different then ok. So, alpha is under your control.

So, last class we talked one more other thing so after you push it you can allow it to dephase and then I can do an echo right. So, there is a time to echo that we talked about so that is under our control. Third one is oh similar thing after time to echo after the excitation is off then I have to repeat the experiment. So, how long do I wait before it all comes back to equilibrium and then I repeat the experiment so time to repeat right so that is under your control.

So, last time we talked about the sequence and diagram in there we talked about time to echo as a parameter that you control time to repeat as a parameter that you control and of course, alpha is a parameter that you control that essentially depends on how long you apply the excitation pulse. So, we have inherent contrast and three parameters that is under our control

during acquisition that may control the signal that you are measuring and therefore, the contrast ok.

So, pulse sequence parameters; pulse sequence parameters namely your tip angle echo time and pulse repetition right. So, now we are going to use these two concepts and see take a simple example case and see how does the difference in black, white, gray which we perceive as contrast. How does that relate to the tissue type and our pulse sequence parameters that is what we are going to cover.

Of course in the next module data acquisition reconstruction we will go about doing this. Now, we are understanding where is the contrast mechanism coming from over these parameters controlling the contrast that arises in MR. How we actually execute it will be in the instrumentation and reconstruction.

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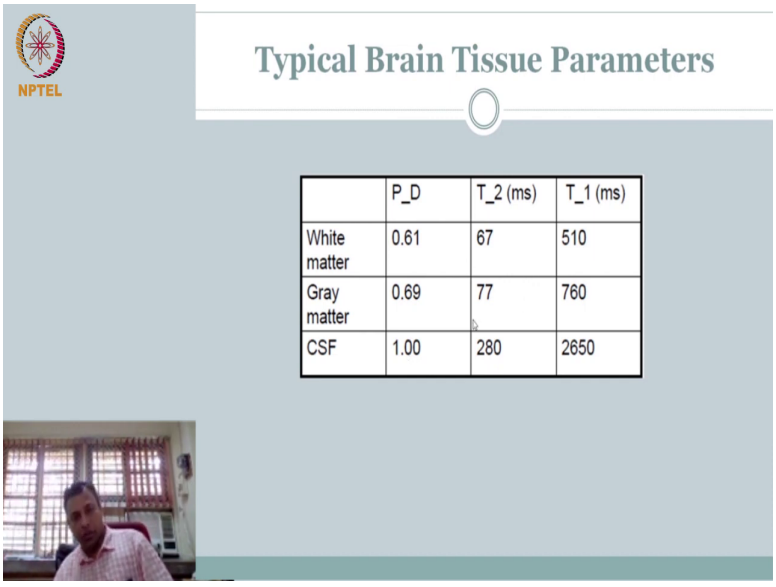

Take an example of a brain tissue right MRI you have seen several brain tissue. So, let us take a brain tissue we have three different types of tissues there gray matter white matter and fluid the cerebrospinal fluid. You notice these are the properties of proton density T 2 and T 1 the material property that is inherently different. So, this is the inherent contrast that you are expecting from different types of tissue that are there in the brain.

So, now the objective is how do I get an image where I can see contrast predominantly due to, because material is same it is going to be brain which is going to have three materials. The contrast is going to be mainly due to differences in proton density or differences mainly due to T2 or T 1. Notice this material is undergoing PD T2 T1 is all happening simultaneously ok. So, now, the objective is how do I get an image that predominantly captures the difference here or the contrast due to proton density contrast due to T2 contrast due to T 1.

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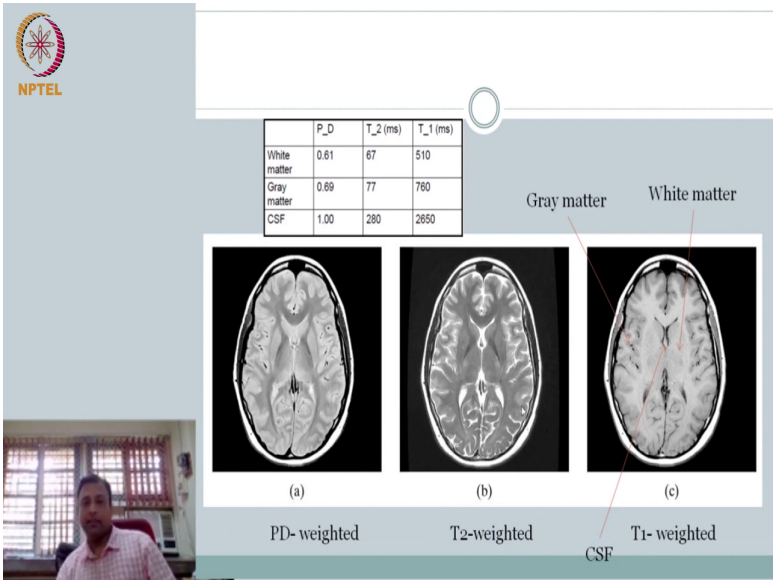

Clearly each image is going to look different right this is the same slice this is what we called as PD weighted image T2 weighted image and T1 weighted image this is the same table from last slide you have different material and different properties each of them have different property.

So, now you know or at least you guess that the white and black in each of this on the gray in between has to be related to or weighted more currently to use the language it is weighted towards one of the property. So, here the black and white and gray are all weighted based on the proton density parameter of the tissue here is likewise T2 weighted here is T1 weighted.

Notice qualitatively these images look different right so for example, here you see this hard glass shape right you see gray white black in between whereas, here you actually do not see you just see the cerebro CSF right, as a dark patch that is all you see here. So, clearly and here it is in between.

So, it depends on what you want to see the doctors are trained to see and if this is for normal if you have abnormal tumor growth that tissue may have a different T1 T2 PD property and therefore, that may start to show ok this is what is used. So, now, our objective is to understand what do we mean by PD weighted how do we get PD weighted how do we get T2 weighted how notice it is the same tissue it has all these three intrinsic properties.

Now, somehow I have to play with my you know parameters that is under my control to maximize PD or maximize T2 difference or maximize T1 different right. So, that is what we are going to see how are you going to get a PD weighted contrast T2 weighted contrast T1 weighted contrast that is going to be the task.

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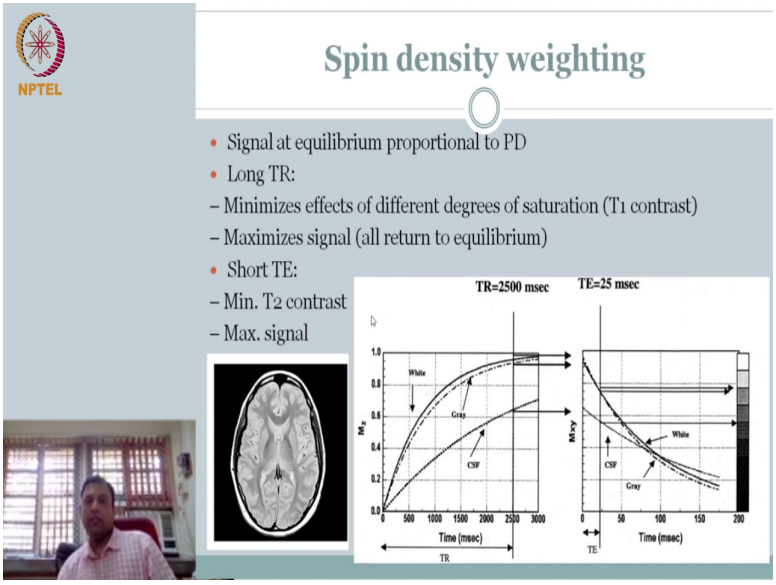


So, let us start proton density or spin density weighting this is how do you get this. Let us think about what is the meaning of proton density weighted. So, proton density you are sure there is the signal and you get proton density signal, recall go back fundamental you take the work cell you wait put it in the field you wait for a long time or a short time right you do not know the time wait for some time everything gets aligned.

So, the signal that you get now the equilibrium signal magnetization vector in equilibrium is essentially proportional to your proton density. So; that means, if I want to get proton density weighting, what do I need to do? I need to wait for a long time in our parameters what is a long time I have echo time I have a spin time oh sorry echo time I have alpha and I have time to repeat. So, let us assume every time I do I am going to apply enough excitation so that everything is alpha is 90 degree.

So, that is not a parameter I always apply alpha so that it is maximum. So, then what is the time that you have to wait? So, that it comes to equilibrium that mean my repeat time has to be very large. How large? I wait until all the different spins are all aligned in the z direction therefore, it will be only proportional to proton density clear.

So, if I want density I need to wait for a long time so that everything becomes in equilibrium so that is the first idea. So, if I want to do spin PD weighted image I know signal at equilibrium is proportional to PD and therefore, I will wait for all the signal to come to equilibrium. How can I do that? I can wait long TR I wait for a long time long repeat time TR is time to repeat.

So, when I do that what happens? The wait for a long time even if each of the tissue has different T 1 property I waited enough time that even the weakest guy the guy that will take the most time to come to equilibrium I have waited long enough than that guy, but now everything has come to saturation.

So, I do not have the effect of different T1 or the T1 contrast is minimized ok. So, everything comes back. So, now, the question is ok I minimize the influence of T1 what is the other influence T2. So, how do I minimize the influence of T2? What is T2? T2 is dephasing. So, if I have the signal that is predominantly PD weighted if I put it to flow because that is my measurement only the transverse component is measured.

So, the moment I put alpha equal to 90 degree the component comes to flow if I want to minimize T2 effect what should I do; that means, I shouldn't allow it to dephase right. If I do not allow it to dephase then initially whatever I measure is only based on PD of course, then what I can do repeated measurement here I can I do not allow it to dephase immediately I put 180 degree pulse time to echo right, I minimize that.

So, I am still not having the effect of T2, I am not allowed it to diphase. So; that means, to minimize the effect of T2 what should I do the parameter that is under control is TE, I have to minimize TE I have to, I have minimal TE. If I have minimal TE I would not have allowed it

to dephase and therefore, the effect of T2 will not come into picture. So, long TR short TE allows you to get a signal that is predominantly weighted towards the proton density ok.

So, to put it in picture these are the two M z and M xy the transverse component and the z component. So, if I wait for a long time what happens I have different materials each one has its own time constant T1 to build up so I am waiting for a long time that way I do not have to you know consider the effect of T1. I have allowed all each of them to reach their maximum equilibrium value.

Now, if I push this for TR is maximum. So, now, I push this guy to flow if I push it to flow this M z M z comes to the flow so the immediate skew signal I am going to start with the maximum signal and then it is going to dephase and therefore, go down. So, now I will do my time to echo as close as possible before the minimization starts if I do it long you see there the differences start T2 differences start to come.

So, now, I push it to the flow and do the time to echo to be as short as possible then the contrast that I will get will be this will be white, this will be gray, this will be whatever this is my color bar with gray white to gray white to black. So, this is the contrast that you are going to get, clearly you see not much difference between these two guys which is white and grey.

Whereas, your CSF will be shown nicely that is what you see here the CSF is seen otherwise you do not really see too much of a difference between the other two material whatever little difference is there is what you see clear. So, now you know by manipulating the parameters the fundamental signal weightage is given to intrinsic signal of PD this is what you get from. How, we get it at different location and all we see in the next chapter, but you get a distribution by acquiring it in this sequence.

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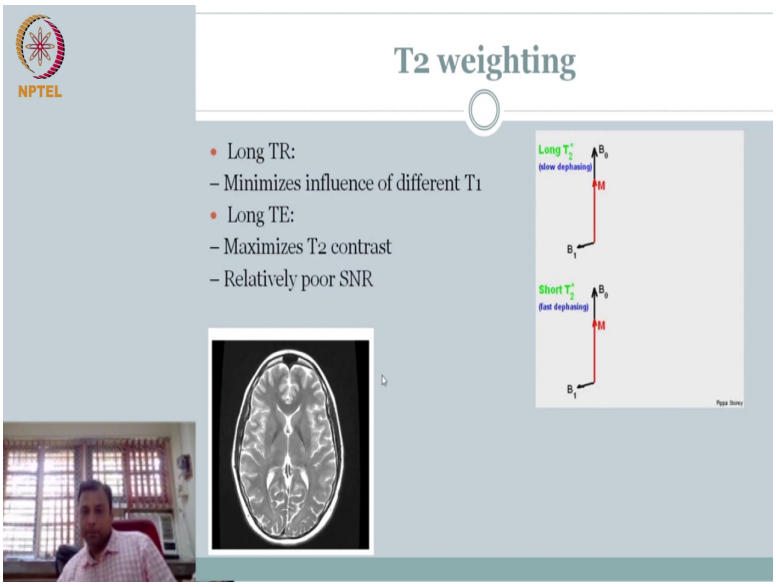


So, next is we need to root T2 weighting this is a T2 image. How do we get T2 weighting? Extending the same logic if you have a feel for so far what we have covered it should flow from there. So, what is T2 weighting oh? T2 has nothing to do with I mean it has to do with dephasing after you push it to the flow this is my signal how it dephases time to dephase is my signal of course, this is T2 star and T2 right. So, this dephasing is T2.

So, how do I get that? That means, one thing is clear if I do not allow too much time here then I will have I will not have T2 effect that is what we exploited in PD. We minimize the effect of T2, if I here I want to maximize the effect of T2. So, am I T echo right should be long enough so that I allow it to dephase the signal should go down. But how do we minimize the effect of T1 and proton density right that is the idea. How do I do that?

So, here also I do not care about how they start I am interested only after it falls to the flow how it is dephasing so; that means, different material I do not care about their T1 differences. So that means, I will allow it all of them to go back to equilibrium ok. So, here long TR I will do if I do long TR, I will minimize the influence of my T1 correct that is what we saw even in the proton density.

So, minimize the influence of different T1 by waiting for a long time, but instead of short T here I want long T TE so that I can measure T2. So, instead of short TE I am doing long TE it maximizes the T2 contrast which is what we want T2 weighting. So, you wait so that the dephasing happens, but the problem as you will notice is the signal is going weaker and weaker and I am measuring it as it drops down; that means, I am going to have a relatively poor signal to noise ratio ok. But this is how you get T2 weighting.

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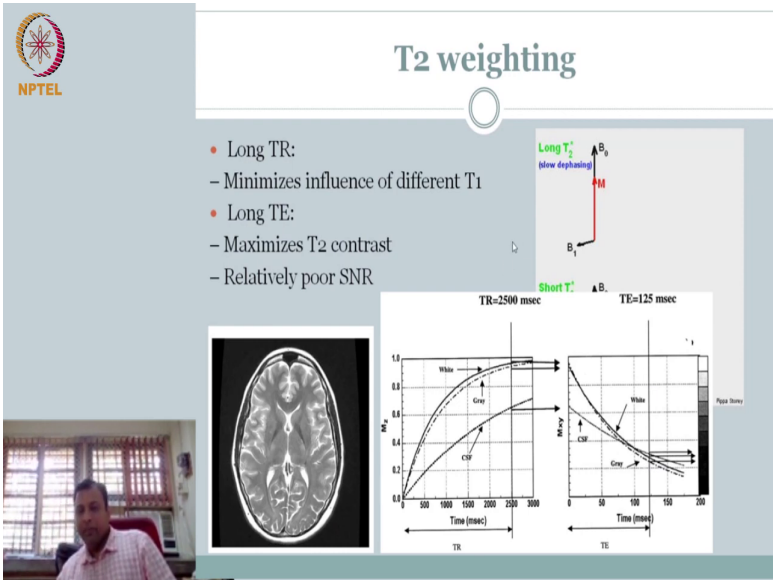

So, same thing wait for a long TR we maximize or minimize the effect of T1 then push it to the flow. So, this is where the signal each of them they start their saturation or equilibrium value and then start to dephasing therefore, signal is going down, but if I did TE I would not have captured T2 differences. So, now, I am waiting for T echo to be large enough such that I get to a region where I can differentiate different tissue based on their T2 differences ok clear. So, there is a neat animation here that I would like to show right.

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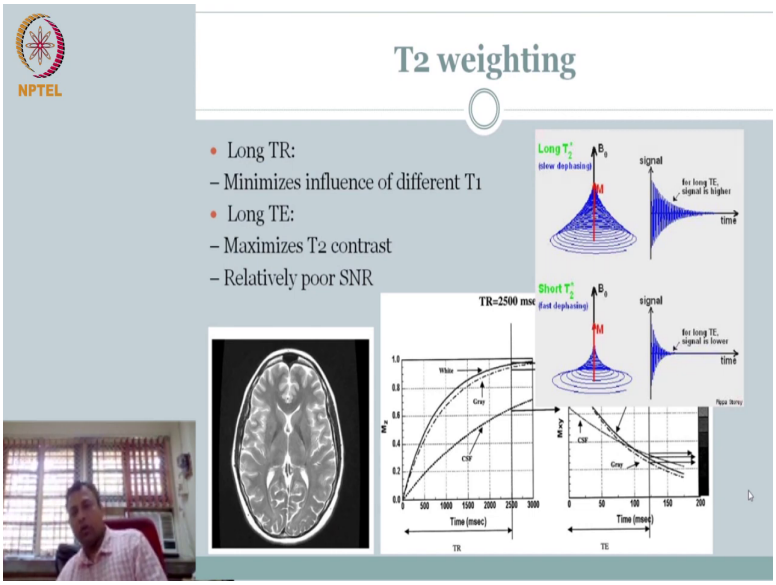


So, we covered T2 here, but the animation here shows long T2 star short T2 star notice the dephasing is both due to T2 star and T2, T2 star can be rapid it is the first part right. So, T2 almost always T2 is measured based on echo. That is what we saw that one of the sequence right we saw how the initial is T2 and T2 star and then you have T2 differences so here the same thing.

So, if it has a long T2 star then you might get good signal over a longer duration, if it is a short T2 star the signal will drop down abruptly so you will have a poor signal device ratio but we are interested in T2. So, the T2 signal to noise ratio depends also on the T2 star property at that location ok. Kepler animation remained it slow down and align it to your understanding let us stop here lets go to the next one is T2.

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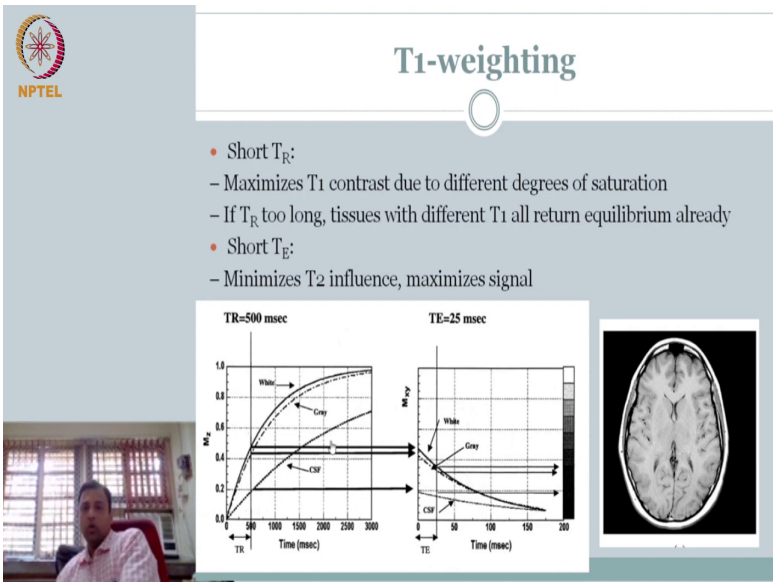


So, what do we do for T? Sorry T1. From whatever we covered this should be straightforward, I want to minimize the effect of T2 here I want to minimize the effect of PD here. So, if you want to minimize the effect of PD; that means, what was favoring PD, so allow it to come long TR favored PD.

So, that means here you want to minimize the effect of PD and maximize the effect of T1 differences in resistant then I should not wait for long if I wait for too long for repeating

everything would have come the different properties of T1 you will not be able to differentiate everything would have come to the maximum.

So, clearly if I want to do T1 from whatever we know common sense dictates that my time to repeat should not be too long if it is too long all the T1 properties of each of the tissue I will not be able to distinguish because everything would become saturated ok. So, first logic is your time to repeat should not be maximum so, it should be short that previous two sequences we had long TR now we have to do short TR because I want to exploit the difference in T1. So, maximizes T1 contrast due to different degrees of saturation

So, if T TR is too long everything will become equilibrium. So, you will not be able to differentiate one location from another location. So, next is of course, you have to minimize the effect of T2. How do you minimize the effect of T2? Like proton density short TE, if I if I do not have time for echo then this T2 effect that will be minimized when we wanted T2 effect we wanted long TE.

So, if I do not want T2 effect I want short T right natural extension for what we cover minimizes T2. So, advantage here is minimizes T2 means your signal is also going to be good ok. So, same plots like before instead of waiting for saturation now I am exploiting the difference here in T1.

So, here I have differences that I want to allow the rate at which it goes down right goes up in this case right that is the T1, this contrast I want. So I am going to start at a lower level. So, I waited here I have got the maximum signal, but I am stopping in between. So, I have some signal I start from that location and allow it to go down, but I do not allow it to go down too much because then it is T2. So, I wait and immediately whatever short TE possible I am taking the signal so now, I will be able to differentiate based on T1 right here white matter gray matter CSF clear.

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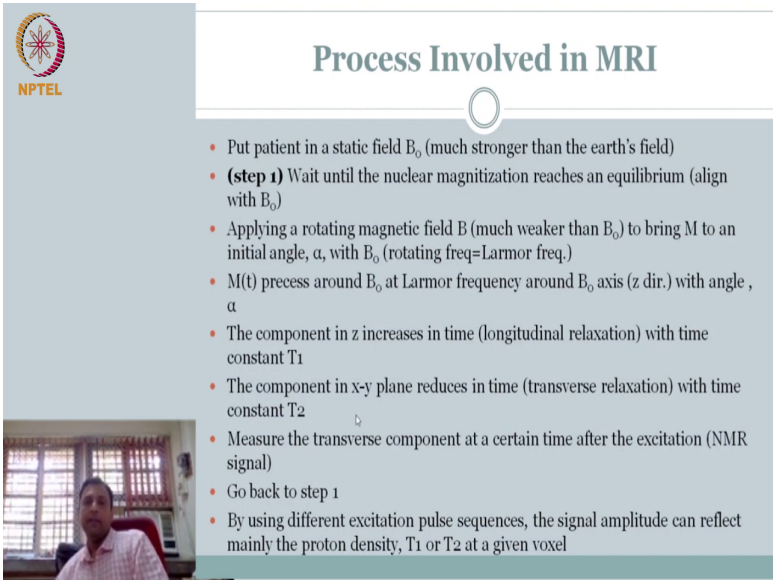


So, let us summarize put everything in the context of what we have covered so far. Process involved in MRI, what do you think? First and foremost take a sample we started with what put it in the static field, put the patient in the static field and then you wait until the magnetization reaches equilibrium. Once the equilibrium is reached you apply another magnetic field, but this time it is going to be rotating magnetic field right.

And what is the rotation frequency you are going to have Larmor; Larmor frequency. Once you do this what happens? You push it to the flow so your signal comes from M of t precesses around B naught with Larmor frequency. And then you are talking about longitudinal relaxation and transverse relaxation.

And where is your signal coming from essentially your transverse component when its spinning you put a coil magnetic field cuts the coil in a loop and therefore, you are going to

get free induction decay so your signal is coming from here. So, finally we do this by exploiting different pulse sequence and we introduced the sequence diagram pulse sequence diagram also ok.

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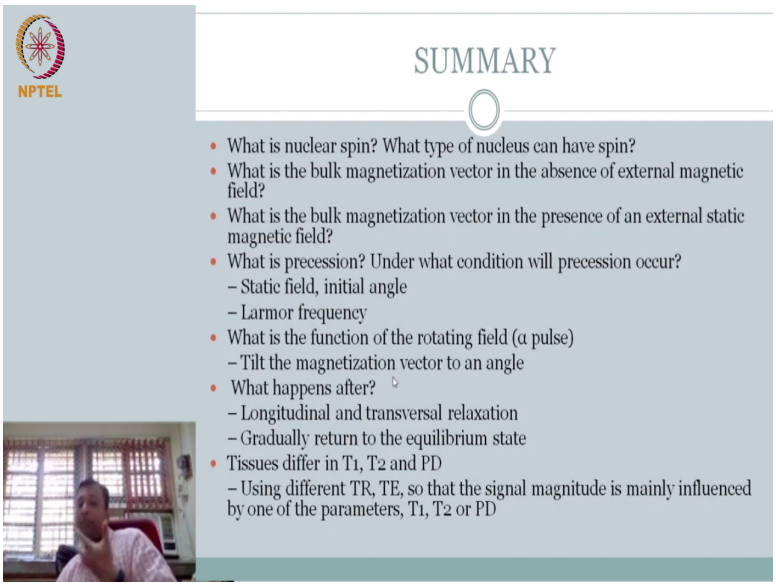


So, finally to summarize concept wise we talked about nuclear spin for nuclear spin we went on to bulk when you put many of them in a static field right. So, what is bulk magnetization the absence of external field bulk magnetization the presence of it the presence of external field what did we notice you talked about the concept of precision right and Larmor frequency.

So, once we did that what concept did we introduce applying another one pushing it to the floor ok. So, we talked about alpha pulse and the rotating field tip angle. Finally, we talked about after you finish excitation the two relaxation processes after the relaxation process we

talked about contrast mechanism. How to get different contrast exploiting T1 T2 and PD using the time to relax and time to echo clear?

So, the next module we will talk about the instrumentation, how do we how do we realize this right instrumentation and finally, about after you get the data how I am going to say that this signal is from this location right imaging how do we do that.

Thank you.