Introduction to Biomedical Imaging Systems
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Lecture - 40
MRI_Intro_S1-S9

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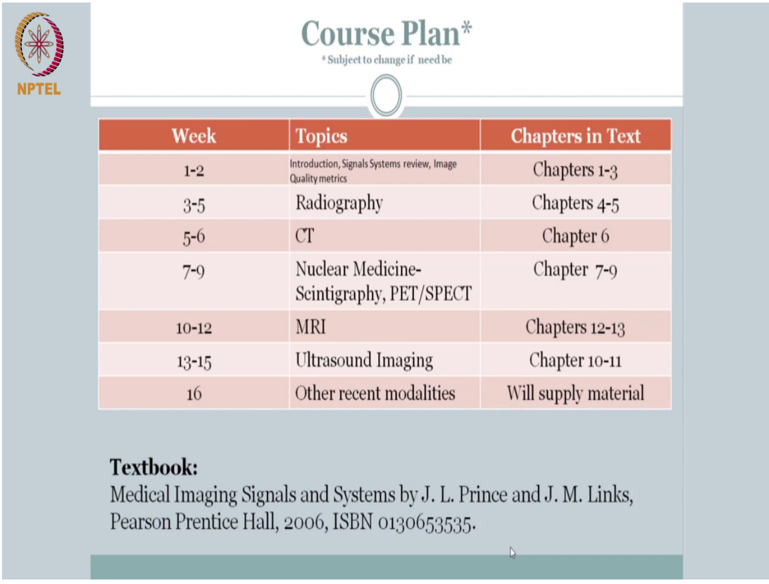

And we will follow the same textbook and I hope you all have the textbook and you will be able to read along, you know whenever you find time. And I just want to really caution you that this is a fantastic material MRI is very complicated, but yet it is very powerful and it is powerful because it is you know it is very multidisciplinary. And so I would request you to essentially use this video recording just to ensure that you get the you know feel for the subject feel for the concepts, I will try my best to show some animations you know give some vivid examples.

So, that the concept gets into your brain, after you get the concept you have a feel for the concept you have to read multiple times the textbook you know few other sources wherever you get a handle. You have to you know keep reading for multiple sources to have your own imagination of this of this of a concepts that come in MRI.

So, by no means we covering this in may be over 8 to 9 lectures that will squeezed down to may be 4 to 5, 6 hours or something like that this no means doing justice to the topic itself. Like it has been most other modules as well, so it is very introductory material ok.

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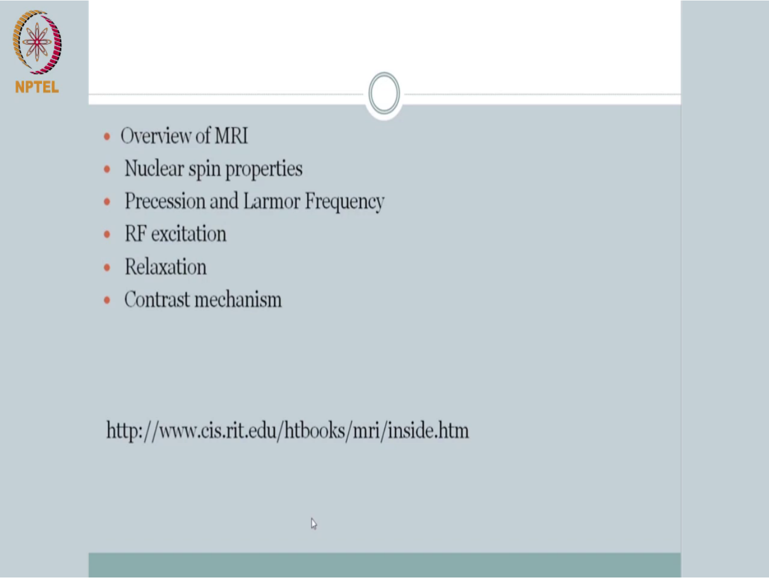

So let us move on we will quickly do an overview the overview will not span more than 2 3 slides and then we will get into the details of nuclear spin precession excitation relaxation and contrast mechanism. So, as you will notice this is not complete right this is just the block of the physics of MRI, right like we cover every other module that we have covered.

We have covered the physics we have covered the instrumentation reconstruction and then finally the image quality aspects. So, similarly here we will try to cover the MRI physics over maybe 3 lectures or something they are about 2 to 3 lectures or even slightly more and then we spend a lot more time on the imaging reconstruction image quality ok. I did pick several materials of several locations as far as possible I have tried to put list the references, so that you could go check it out yourself.

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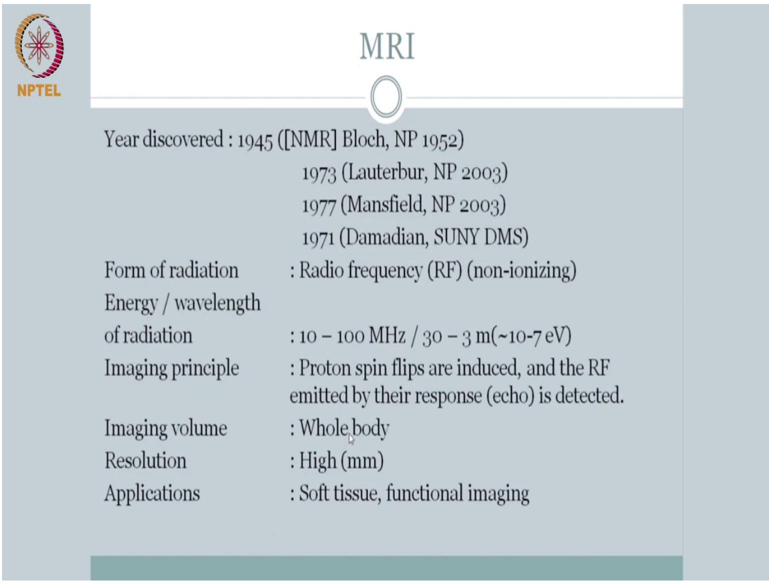

So, to start with the modality itself a grand overview the first thing that hopefully strikes you is you look at that you will see NP 1952 NP 2003 NP 2003. What is NP? NP is noble prize right. So, you can see as for as early as 1945 it was called nuclear magnetic resonance, this was about the before the World War 2 right, after World War 2 nuclear became word that is taboo.

So, instead of calling it nuclear magnetic resonance it became magnetic resonance and then it was adapted to imaging right and so it became magnetic resonance imaging imaging. And so first you have Bloch who got a noble prize for essentially coming up with the understanding of nuclear spins and how you can you know come up with scheme to characterize the spin properties and then Lauterbur and Mansfield they put a system together and they used the magnetic resonance principle the nuclear magnetic resonance property and convert that as an image.

Of course I did put one more Damadian there, just because there is some references that suggests that that Damadian also had the version before you know the others, but then he did not really get a Noble Prize. But yet probably also contributed a lot to demonstrate NMR for imaging. Of course, this is the non ionizing that is the big difference from what we have covered so far, we have covered ionizing radiation based projection radiography X-ray CT and then non-ionizing radiation based we were talked about ultrasound right.

So, this is another one which is non ionizing and one of the single most advantages if you actually look at it, it is compared to ultrasound which are also non ionizing here we could do whole body imaging right that is a big advantage. Of course apart from that it can do fantastic soft tissue imaging and functional imaging. Remember most of the ultrasound lectures that we covered topics we covered images that you would have seen we did not really see we could not penetrate bone and go into the skull and see the brain.

Most of it was abdomen surface MRI you know it is so powerful that you could actually do your head scans that is and that was functional imaging here is also a very powerful. I am sure you would have seen several in MRI applications, we will try to understand you know what is the versatility of this.

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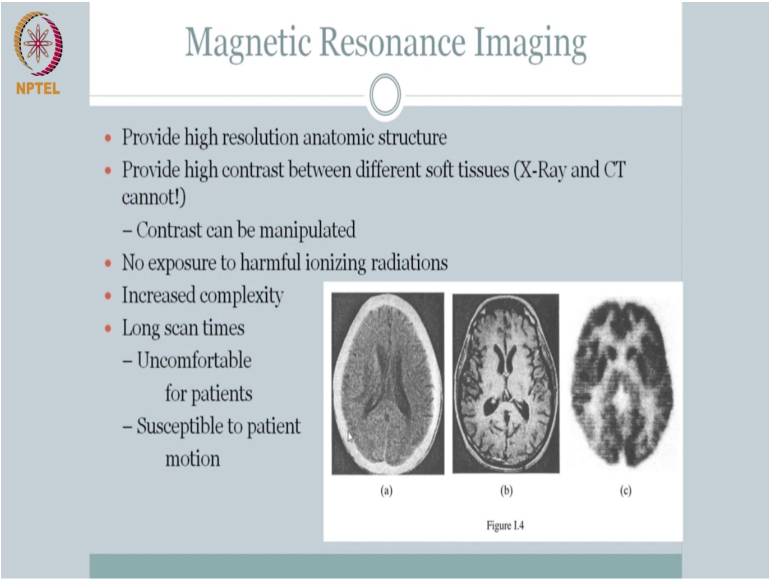

So, first it provides a high resolution anatomic structure and compared to your X-ray CT here you could also get very good soft tissue contrast, remember that figure 1.4 that is shown this is the same figure we started looking at. When we did X-ray CT as well as you know the introduction class we also talked about pet spect the C image that you see and of course the MRI.

So, now what we will attempt to do is yeah we knew from before MRI probably had very good contrast of distinguishing several different soft tissue, within soft tissue unlike CT which was very or X-ray test which was very good with the bones right especially then it has more exposure to a harmful radiations.

But most importantly it is very complex system and therefore you know access to it is very difficult, it needs dedicated setup that all pushes the access and cost. And of course, patients to go in you know go into that big gantry that you see it could be claustrophobic and so BP patients could feel uncomfortable because the data acquisition takes more time.

And this is not I mean this is being addressed at several levels it is becoming the data acquisition is coming down. But still it is one off we are not anywhere comparable to your ultrasound where we did the 30 frames per second or 40 frames per second frame rate.

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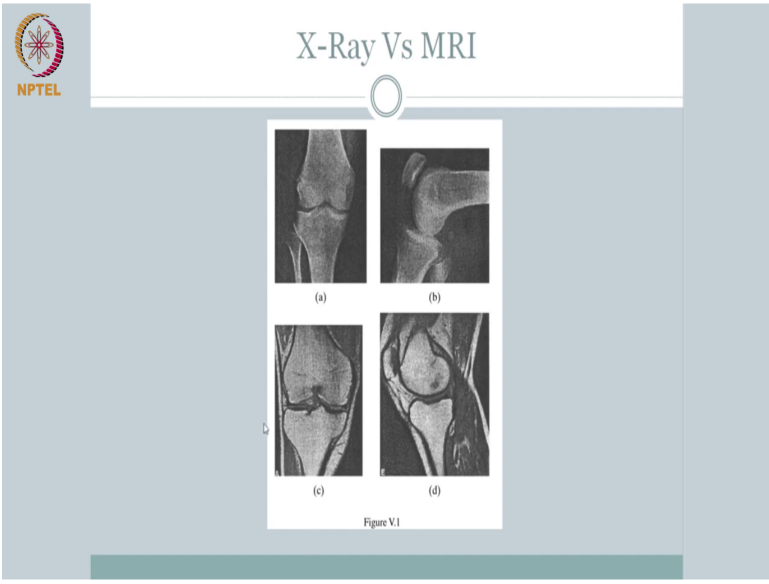

So, here is an example image that this you know top you see a and b you see the X-ray image bottom is your MRI. And what you see and what you do not see both tell a big story, what you see in the top row is if you see the bone nicely you could get the shape size, you could see the bone if there was a crack you could find out.

So, X-ray had it is role, but look at the images in c and d which is for the MRI not only do you see the bones, you also see the tendon you see the meniscus you see the muscle you see tissue you see a whole lot more than what you saw in the X-ray image and not only that the quality also seems to be very good.

So, what we would like to do is ok you do see a lot more, but you really do not know at this point of time. What it is right looking at the images yeah it is very good compared to the top a and b, c and d are good you are able to see much more. But what is that much more we really do not know in the sense that the top you know what is white, what is black, what is gray right.

You know the unit is nothing but related to the X-ray attenuation coefficient of the material at that location that is what you are seeing. Whereas here you really do not know what physically that white or gray or black means. So, the goal that we started asking ourselves at the beginning of the course is what do you see you see whatever you want to see what is that we want to see in MRI that is what we will cover the next several lectures ok.

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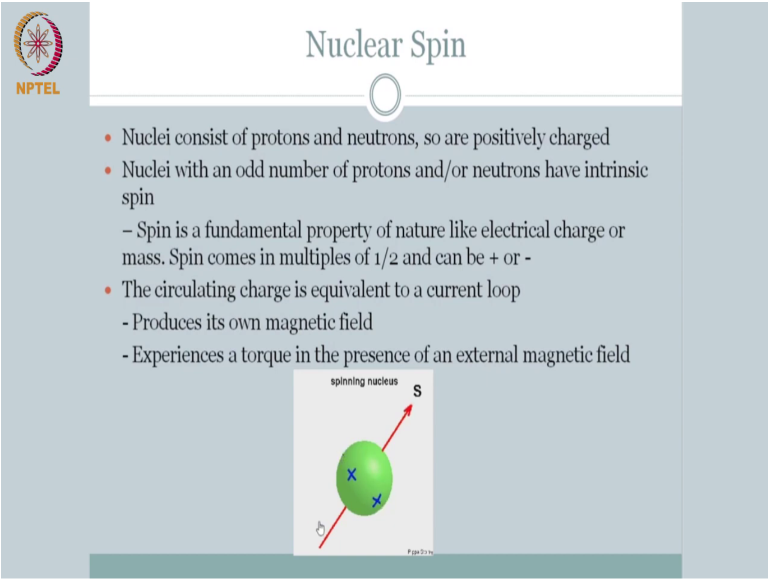

So, first and foremost we will start with the basic concept nuclear spin. What is a nuclear spin? We talked about atom nucleus electrons protons all of this we did in the X- ray physics that we started. So, we were restricted ourself to the electrons and the behaviour of the electromagnetic energy or X-ray energy with your electrons was exploited in X-ray based imaging and that time you mentioned about something about the nuclear right.

We said nuclear medicine right spect, where we talked about radioactivity essentially the signature comes from the radioactive decay that happens at the nuclear. So, that was nuclear medicine, here also we are talking about nuclear spin. So that means, it gives you a clue nuclear when we talk about here we are interested in the nucleus part of the atom. What is there in the nucleus you know that what is that it is neutron and protons neutron do not have any charge, so protons has positive charge.

So, when we talked about electrons we talked about electrons spinning around the nucleus in shells k shell l shell m shell n shell all those things. What happens to the proton itself is it just standing there no the protons which are positively charged are also spinning about it is axis. So, to just recollect we know nuclei consists of protons and neutrons and so nucleus is actually positively charged and we know and the spinning is a intrinsic property like you have charge you have mass spin is also a very fundamental property.

And it turns out that spins can be in multiples of half; that means, it can be multiples half it gets it have a positive spin or a negative spin. What does it mean? You can have clockwise spin or anticlockwise spin right. So, when you have a charge that is spinning around you can start to imagine that is nothing but the a current loop a current loop right.

What happens why are we interested in imagining this to be a equivalent of current loop. The moment you have current loop that is you have a charge that is moving around in circles then you would expect to you will have a magnetic field associated with it. So, this is the key, so you have nucleus the nucleus has protons which are positively charged the protons are now spinning.

So, if you view that as a charge that is doing in circular loop that is nothing but a current loop; that means, you would expect to have a magnetic field that is there present along with this charged particle that is spinning. So, it produces its own magnetic field however small it is right. So, what happens when you have a magnetic field and you subject that to a external magnetic field well you may not the expect anything if you really do not collect it right.

So, where else have you been exposed to the magnetic field and external magnetic field, a simple bar magnets take your magnets you would have seen the 8th standard 9 standard the experiments you take a magnet and place it on a table. Where will what will happen we will try to align to an external field what is the external field here you know its magnetic field.

So, you have a magnet you leave it in the presence of external magnetic field which is the Earth’s magnetic field. What do you see it is actually rotating right it is experiencing a torque, so that it now aligns itself to the Earth's magnetic field. So, naturally that means, if you imagine all your nucleuses are having spin it is charged and it is spinning.

Therefore, it has a tiny magnetic field if you subject this tiny magnetic field to an external field you would expect the same thing that is the spins should experience a torque. So, that it becomes in alignment with the external field ok. So, before we proceed just imagine, so this is what we are talking about we have multiple of these many of these in our tissues we have a spin charged particle. So, you have a magnetic field ok a vector.

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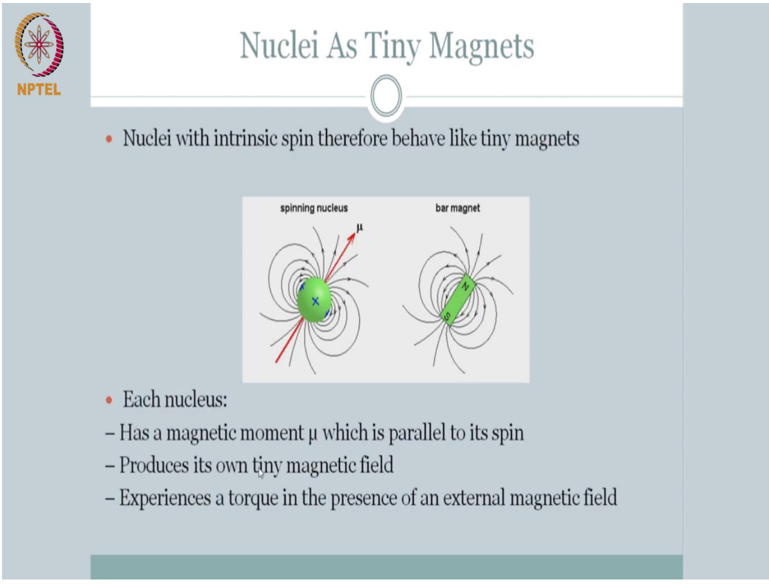

So, I said you could imagine that it is very similar to a bar magnet a bar magnet has a North Pole South Pole it has magnetic flux lines. So, it will align itself to the Earth's magnetic field like this you have your charged particles that is spinning. So, you have a magnetic moment vector mu.

So, each nucleus has a magnetic moment mu which is parallel to its spin axis right. So, you have if you want to really imagine you imagine like we always say right I have been saying the X-ray part I told imagine yourself as nothing but distribution of mu, mu there was your X-ray attenuation coefficient to X-ray energy. So, you have just distribution of mu in ultrasound we said we are just distribution of acoustic scatterers.

Here I am saying we are nothing but distribution of this magnetic moment vectors. So, we are just spinning charges all through the body. So, the good news is since each we have so many of you know what are we composed of water, so that means you have H 2 O. So, you have 2 hydrogen nucleus so you have plenty of hydrogen. So, for all practical purposes we will imagine that you have hydrogen nucleus is all spinning all over the body you have several localized places and each one has it is own tiny magnetic field.

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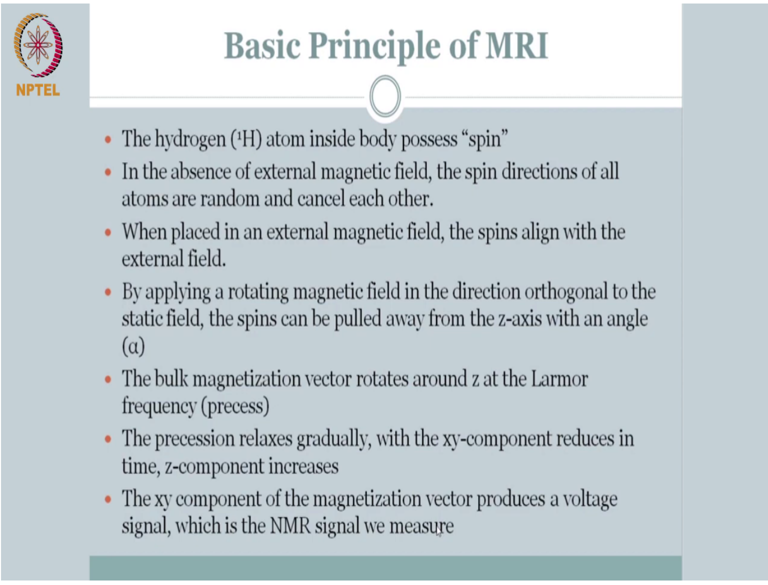

So, what does basic principle of MRI to basic principle that is captured is because of this magnetic field. What happens I am not really you know I am not really charged right. So, if you bring the bar if you bring a iron rod I am not attracting it. So, I am really having a net magnetic field, so if I take the bar magnet it may attract iron you know all your placeholders. But that is not happening right you and me I am saying we are all hydrogen we all tiny magnetic field, but you are not really attracting all the ferro magnetic objects.

Why is that? That is because here all the spins we have all the micro spins, but then it is all in each random directions and therefore, all the magnetic fields due to the individual spins cancel out. So, by itself you are not charged, but what will happen if I take this hydrogen it processes a spin, but it is all over the place and therefore it is getting cancels.

So, I do not have a net magnetization, but then if I start to put myself in. So, imagine that you have several different bar magnets I throw them in the table each one starts at different orientation. But then because of Earth's magnetic field everything will turn around and align itself to the Earth's magnetic field.

They would have started at different locations different orientation depending on how I threw it, but then it will align itself to the Earth's magnetic field. Similarly my hydrogen atoms are all in different locations having different magnetic moments in different directions. But the moment I subject it to a external magnetic field all the micro spins now will try to align each other ok.

So, that is what this exploited. So, we all have hydrogen atom there is a spin naturally therefore there is a microscopic magnetic moment vector. But by itself we are not there is no net magnetization, but when I put this patient in an external magnetic field all the small spin start to align itself in the direction of the external magnetic field. For the purposes of the you know discussion we say z axis is the direction of the magnetic field.

So, we will say at least in the physics part before we go to instrumentation the physics part we will say the z is actually going from floor to roof that is your z axis and therefore your x y plane is the floor plane right. So, what happens is you have rotating magnetic field. So, if you have a external magnetic field that is along the z direction, then all the microscopic spins all the moments will start to align itself in the same direction.

And therefore, you have a net magnetization or what we call this bulk magnetization vector that starts to rotate. Of course, we will get into the details of larmor frequency at which it is rotating all those things we will get. But you can actually imagine that there is a net magnetization that will is going to be having a direction in the z and that is also going to have some components on the floor ok.

Now the whole idea is we have this magnetization we apply a external magnetic field. So, the spin starts to align we apply another rotating magnetic field. So, that we make this net magnetization vector dance to our tunes that is essentially what it is. So, how it dance to our tunes each one will behave differently and therefore we can differentiate one material property based on its spinning spin properties and how it tunes to your dance you know how it dances to your tunes to the other location which does not.

So, the spin property right what are those we will look at it is what this changing from location to location and we are trying to characterize this spin property and trying to distinguish one location to the other location. That is what we to because here stop with the NMR which would be the physics part of it, how is this signal starting with the signal how do we take an image will be in the second part. I think this is a good time to stop too.