Mechanics of Human Movement
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Lecture – 48
Design Considerations: Prosthesis and Orthosis

So, we have looked at the action of some of the prosthetic faith, some of the different designs.

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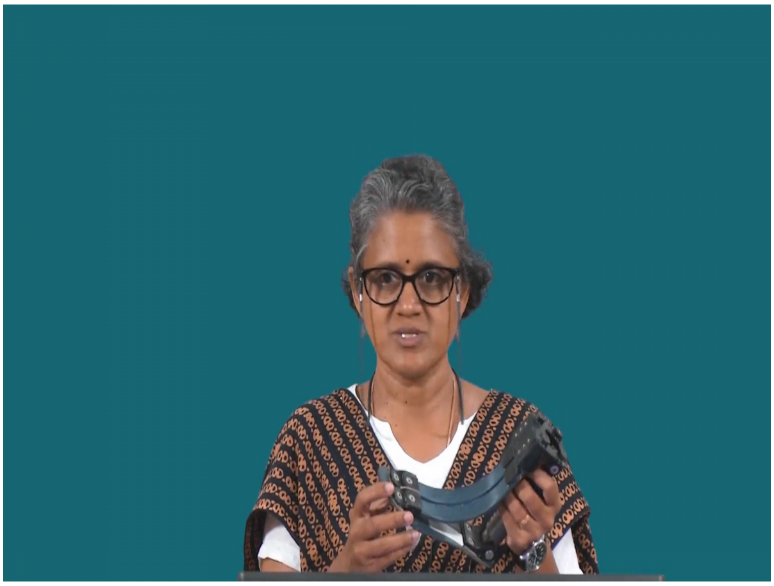

Today I brought some to show you a actual models. So, this is the pathfinder two foot that you see here, this is a foot that is used for users to perform, you know users with high activity levels. So, this is the shock absorber at the heel which is customizable you can see the valve here, but they can just put a pump in our they can either pump it up if they want to say go for a run or and then bring it back down the pressure if they want to just walk. So, depending on so, that way they can customize the resistance of the foot.

So, this is a low profile version so it does not have the adjustability. So, it is directly attached to the socket, so it does not have that alignment which you saw in the picture here ok. So, this does not have this ducktail alignment.

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So, this is and you can see these springs what happens is when the heel compresses these springs are deformed also right and so that is. So, the springs are always trying to come back to their original position and so and then as you move as we go over the toe they get compressed further. And the release helps in the forward propulsion of the foot. So, you can take a look at these models.

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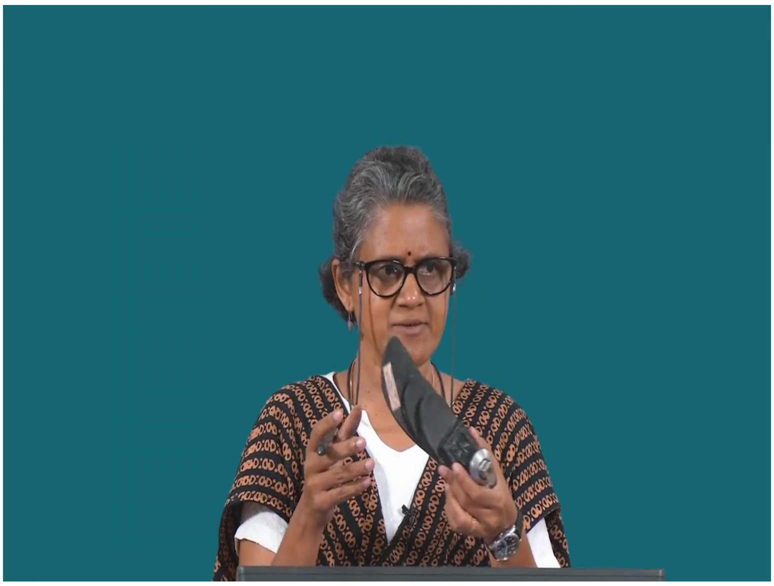

These are also for people who can who are moderately active. So, they have these you can see it has a keel which has the pyramid attachment and then you have these carbon epoxy plates composite, made of composite materials. So, these are because they very light weight. So, you will see a lot of composites used in prosthetic components because of their high strength to weight ratio as compared to metals even in metals you will see a lot of aluminium and titanium used; titanium is used in the high and prosthesis. Because it is; obviously, a lot more expensive, but you will see use of a lot of aluminium and composite materials in prosthetic components.

So, again these they would depending on the so they will have these available in different stiffnesses depending on the activity level of the user. So, the prosthetist will prescribe certain and we will order a certain stiffness for the toe and the and the heel of course, would be like some kind of this does not have it here.

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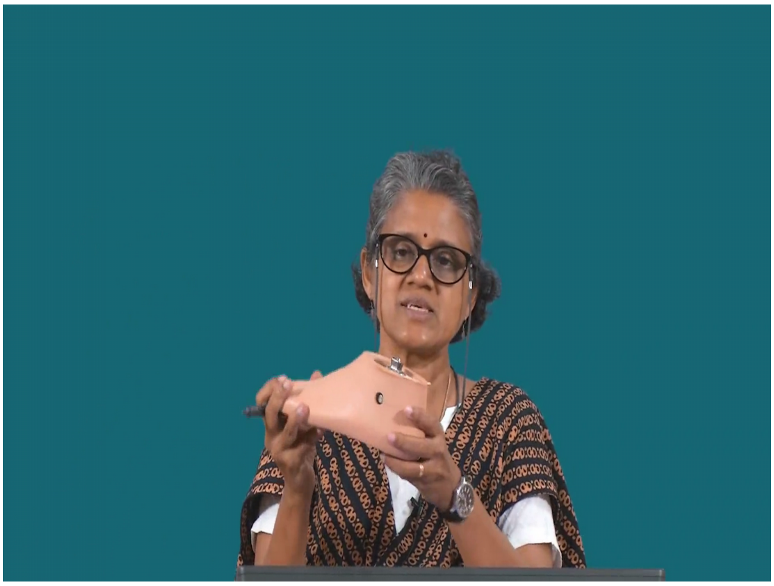

But of course, this is the single axis what I was telling you about this right here ok, this is this here is the ankle the bolt that functions as the ankle. And you have this part at the top which has the pyramid and you have two bumpus here like I said.

Which will control the; so, as it compresses the dorsiflexion and plantar flexion are controlled and again that is customizable. So, customization is a very important aspect of any assistive device design because you know just as even so called able body people are there are vast differences among us. Similarly when you have an impairment there could be significant differences in the say the level of the impairment you know the ability that is available after the impairment any other secondary problems that person may have etcetera.

So, the ability to customize and of course the weight and height, and you know those the basic parameters that differs among all of us. So, many of these designs you will see are very customizable; so, if one does not work you can there is bolt here, you can unscrew that bolt replace. So, they will the feet will usually come with maybe sets of bumpus. So, we can actually they may give it to you in three different stiffnesses. So, you can actually play around with and find the one that is most suitable for the user who is trying that foot.

So, this is the size 10 US size 10 25 centimeter. So, they mark that on the base of the foot and you can see here that if I place this flat there is a slight heel because it is meant to be worn in a shoe. So, when we wear it in the shoe then this is level ok. So, that these will go into again these will go into some kind of a foam cover like that, again you can see that this will be it will come with the foot shell or the foot casing will come with a heel height. So, that is I am, but yeah you are right if the base plate was flat then it is, there is no point in having this split springs ok. So, this one does not have that ability.

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So, this one the heel shock absorption is only by means of these spring itself. So, these are all different, this is a multi axial foot the MA stands for Multi Axial. So, you could have you know it has an ankle which provides motion in both planes possibly some rotation also about the longitudinal axis.

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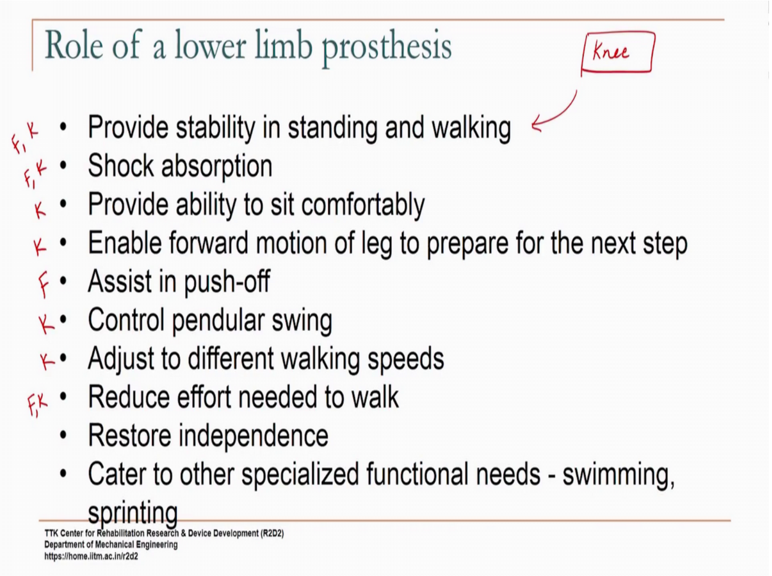

So, moving on just to recap role of a lower limb prosthesis because the feet is something that is common to all over limb prosthesis. So, now we had studied the prosthetic foot in some level of we have looked at the different designs and why do we need so many different designs, why is it why cannot we just have one foot that works for every; I mean, human foot there is only one design right it is not like each of us can get it customized.

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Is that the reason we, no my question is why do we have these different kinds of, different designs, why do we have so many different designs? Simple answer is different people approach a problem differently come up with different solutions, the other an the other reason is if you look at the variation in cost you can have feet that range from say a 1000 rupees to a few lakhs. Vast difference in cost and therefore, there could also be difference in functionality to some extent. Not necessarily a there is nothing that says that a you have to always choose something that is most appropriate for the user and the answer is not always the high end foot ok, but one of the reasons they exist is.

So, if you look at every company that makes these prosthetic feet they will have a variety of products to cater to different segments of the market; it could be (Refer Time: 08:56) So, if you if an old lady just wants to walk around the house after her amputation, she does not need a foot like the pathfinder it is not necessary. Whereas, a young girl who's lost her leg may be able to stay do more things with this kind of a foot, old lady may just need something to ambulate around the house and maintain her independence.

So, foot that still gives her the ability; so, she may not need to walk fast or you know. So, a SACH foot may be fine or a single access foot may be fine for such a person. So, they have to evaluate the cost versus the functional benefits that will be gained by the user and whether the foot itself is appropriate for the user because the most expensive need not always be the best solution for that particular person ok. But, companies like to have an array of options available.

Just as all cards get you from point a to point b right, but you have from the Nano you have Audi's and BMW's and Porsche's and what not right. So, it is a matter of you know the market segment that you are targeting and also what the user wants to get out of that. In terms of cars it is probably just a feeling of just state a symbol you know here fairly looking at a high and car you are still in the same traffic right you are not going to get there any faster. But we have probably slightly more comfortable inside while we are waiting for the traffic the do subside.

So, it is a personal choice and businesses like to offer their customers that choice they go from of course, with the devices that are you know functional which provide function like this that becomes even more important in order to accommodate the needs of different types of users. So, now as we move up the prosthesis so, we have looked at the foot we have looked at some types of ankle joints ok. So, we have the solid ankle and basically flexibility coming from before itself then of course, the single axis, multi axial etcetera which try to ambulate the human foot. Again reviewing so, providing stability during standing and walking, shock absorption so if you move up to a prosthetic knee ok.

So, a person with an above knee amputation now the knee also has to play a part in many of these functions ok. So, stability in yes you need a stable foot, but now you also need that knee also, that becomes another variable another since there is another degree of freedom at the knee that becomes critical. Shock absorption maybe you know if the foot provide some shock absorption, it may be enough in some cases it may be beneficial to provide some shock absorption at the knee also.

Ability to sit comfortably, this is very much the knee right enable forward motion of leg again you know, in the case of the foot the especially with the ones most of these do not have an active ankle. So, you really do not have the active dorsiflexion during swing to clear the ground. So, these passive feet cannot really provide that; yeah, in some cases they may have like a spring loaded thing that once there is no load on the foot. There may be a way to I have seen that more in orthosis than prosthesis, but so there maybe some compensation the person is using in their gait; in order to make sure that they clear the ground.

So, they may flex the knee, hip and knee more for instance to clear the ground so, but in the case of the knee that becomes critical; assistant push of course, is more of the function of the foot, control pendular swing of the shank is a function of the knee. So, if you so, if you look at this is foot and knee stability in standing and walking, shock absorption may be foot and knee ability to sit comfortably, knee; forward motion, knee; assist in push off is more of the foot; pendular swing, knee; adjust to different walking speeds.

So, how the leg swings and whether it is ready for the next step; being able to control that swing is if you had the same swing, same resistance to the swing then you are not going to be able to change your walking speed because the foot will not be ready for the next step or it is there too early ok. So, that is again a function that the knee has to provide, reduce effort needed to walk both you know it depends on the function of the knee and of course, the function of the foot; the propulsion that it provides the energy storing and release feet do that.

And of course, these apply to both of all the components. Of course there are other ways also, in some you can have separate components you know because we have the endoskeletal prosthesis some prosthesis actually have a separate component for just shock absorption. So, they would put it you can have like a shock absorbing pylon, the pylon can actually be something that is like a telescopic pylon that offers resistance, which prevents the sharks from being transmitted like a suspension in a vehicle. So, the pylon can actually do that.

So, you may have, you may also have other you know for sitting comfortably. So, if you want to sit cross legged for instance you may have a component that helps to rotate the entire prosthesis, we can have a rotator that is attached to and that is the advantage of this kind of an endoskeletal prosthesis, you can build up with all these different components. So, we can have an separate rotator which you can use only when you want to sit cross legged because the advantage of kind of separating out some of these functions is it makes it easier to build the system, because if you have too many degrees of freedom in one then controlling it becomes difficult ok.

But for rotation for instance usually using a rotator like that is simple because you use it only when you need to and if somebody does not need that functionality, if they are not going that sit that way then it is something that they do not need in their prosthesis. Because maintenance is another key with all these parts put together, if somebody has to keep going back for maintenance of the prosthesis it can be very destructive to their normal life imagine if you have to keep going and you know lubricating your joints or having to get some maintenance is done on your body.

So, it is the same thing, this becomes the part of their everyday life and so you want to minimize the disruption. So, designing parts that are low maintenances key and one of the ways to do that is to kind of separate out some of these functions so that you only provide what is absolutely necessary. So, if you look at the gait of someone who has either lost part of the leg above the knee. So, has had a trans femoral amputation or if they have muscle weakness and they cannot control the knee ok, I showed you the KAFO the Knee Ankle Foot Orthosis which is used for people who have muscle weakness or some other kind of.

So, the KAFO is typically prescribed for somebody who has say a quadriceps they cannot control the knee ok. So, you have these braces which basically take the load and what we do there is have a locked knee. So, the KAFO with a locked knee essentially so the knee stays locked. So, then there is no worry about stability ok. The person cannot control the knee with their, and in many cases for prosthesis also they tend to use that kind of locked knee.

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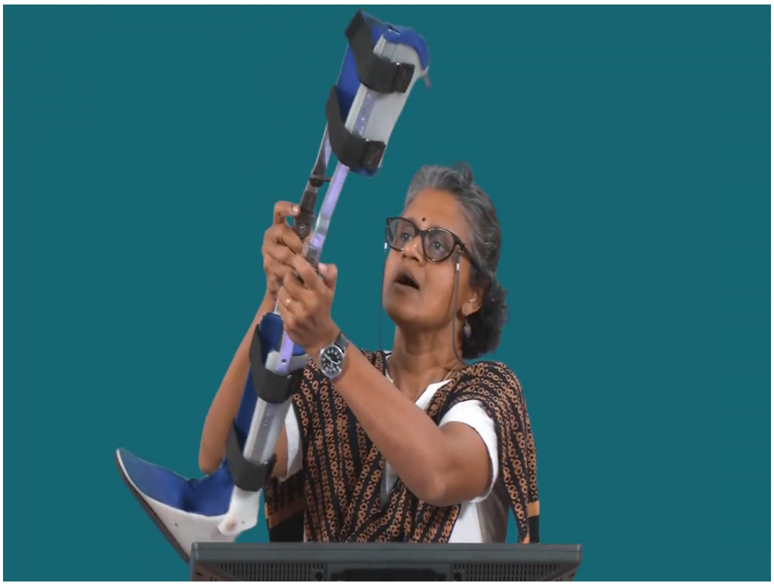

So, here is an example this is the most common type of locked knee that is used it is called a drop lock ok. So, if I do this then it unlocks and the user can unlock it only for sitting down. Once they straighten the leg ideally it should drop down like that and lock. So, that they are now ready to stand or walk with stability. So, this is a very simple solution, you can see that the knee is assembly just a hinge ok. So, this is an orthosis where you have these drop locks and the knee is essentially a hinge and it provides stability.

So, it is the simplest solution to provide stability now a person who is using this and it sometimes used in prosthesis also. So, if a person in above knee prosthesis if the person has limited control over their residual lump or if they tend to walk on uneven terrain we are maintaining balance becomes difficult then they may be prescribed it is its also one of the least expensive, it is just a bolt right. The in this case for a prosthesis it would just be a bolt they would prescribe a knee like that which just locks and the only time, the only reason they provide unlocking is for sitting down. Because if we did not have the unlocking then you cannot sit down you have to have an extended leg all the time ok.

So, they provide the unlocking mechanism only for sitting down and otherwise the knee stays locked. So, yes it fulfills the purpose of providing stability while standing and walking, now how does the person have, how does how will the person have to walk with such a knee they will have to figure out some way to clear the ground.

So, now you do not have a separate swinging shank and you know you do not have any. So, the most common that you will see type of walking that you will see is circumduction. So, from the hip which is where they have control they will move the leg in this kind of along an arc, you have both abduction flexion extension at the hip to move the limben circumduction.

The problem with this kind of walking is that there is a research that has shown, not only is the gait noticeably abnormal ok, it is very noticeably abnormal when somebody walks like that it also leads to increased energy expenditure it is its difficult to walk like that and. So, in many cases the user will reject the prosthesis after awhile, because they just find it to see this is this is quite heavy. They already have either limited musculature or you know weak very weak musculature. So, operating a device like this with their own power becomes very tire some and so in many cases they would stop using a device like that, but it at least enables them to still walk ok. And there is also research that has shown that because of this abnormal gait it causes damage to other joints in the long run.

So, if you study, if you will look at the kinematics and the four split data and try to do the inverse dynamics for a person with this kind of a gait you will find like that the hip loading, knee loading on the other side everything is higher than what it is for a person with a so called normal gait ok. So, this is another disadvantage of this kind of a lock knee, but in many places because of economics and because of lack of accessible surroundings, environments or you know uneven terrain. In many places they end up getting like in India and other places, people who are economically disadvantaged end up getting a prosthesis like this.

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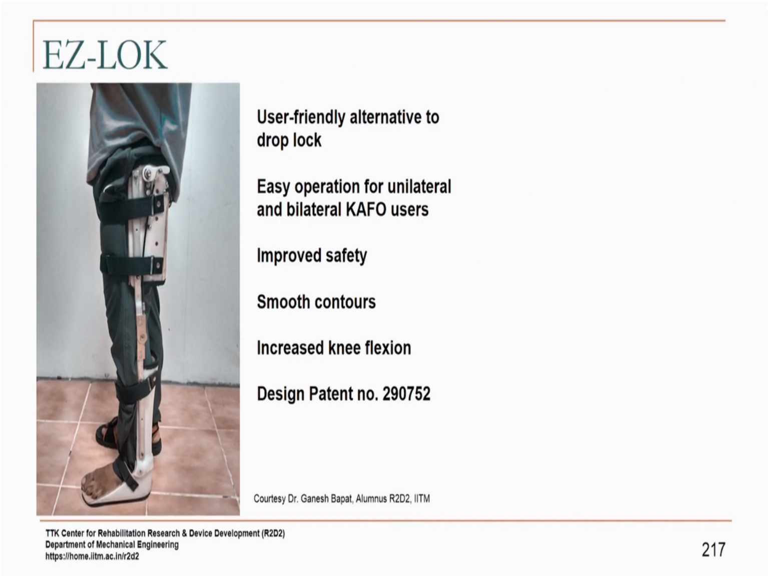

So, this is so some people may still need to use a locked knee in this kind of a an orthosis.

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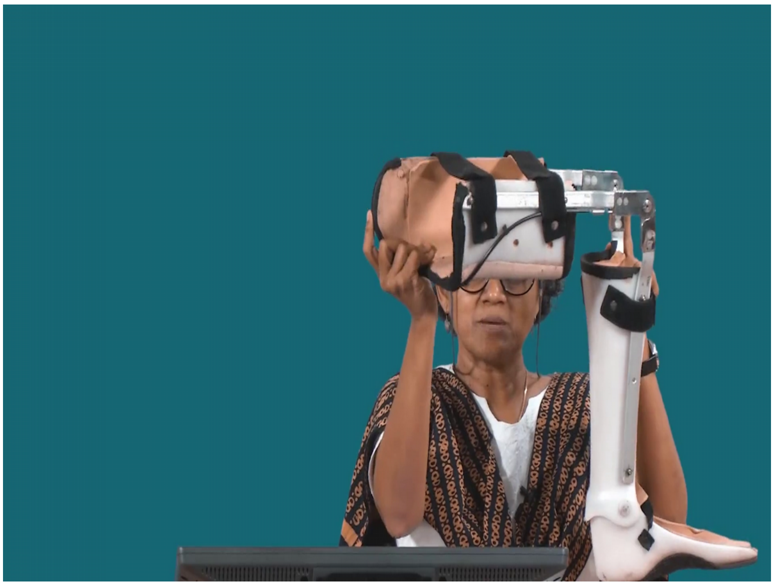

So, if you see this can sometimes be very cumbersome to operate this drop lock is very simple, but what happens is sometimes. So, they may wear they may be wearing the many people where this orthosis under their clothes. So, if they try to unlock this, you know then it may get stuck in their clothing which can also be a safety issue because when they stand up suppose it gets stuck and does not lock then they going to fall down.

And you can also say that the design has such sharp edges so, many of them experience staring of clothes and all that.

So, these are small things that can be fixed fairly easily. So, one of my students has come up with a design that is a lever operated it is a user friendly alternative to this drop lock and what it does is there is a lever here ok. So, the person can operate it and its spring loaded ok. So, the lock itself is spring loaded. So, the person can operate it discretely and they only need to operate one side of it ok. So, they do not have to bend down to lift that.

So, they operate it will bend they can sit down and you can see its made with nicer contours also it provides more flexion again the Maruti car scenario I was telling you. Because it is very difficult those things provide only maybe 90, 95 degrees of flexion, which makes it very difficult to sit in cramped spaces or like even in the desks that you are sitting they are they are pretty narrow so it is difficult to sit and cramped spaces. And so this provides increased knee flexion and you can see that it positively locks, because it is spring loaded. So, when it goes up to the extension possession you can hear that click ok. So, it positively locks then it goes to the extent position.

So, this is one of the designs that are that we are working on in our lab and we will be starting the user testing with this, I we have already started it in some places and hope to have this available on a largest scale. Because it especially for if you imagine if somebody had to wear an orthosis like this on both sides bilateral they are wearing a bilateral, then for them while sitting down they will bend down try to unlock one side. When they try to do the other side sometimes one of these will drop down, the drop lock will come down. So, it becomes a very difficult thing for them to do and also like when you are in public transport and all that we may not have that kind of space to bend down unlock and you know use these kind of devices.

So, the idea is to make the operation more user friendly and discrete, still by mechanically this is not the bests solution for walking, but some people may need it because they may not have the muscle strength for walking otherwise ok. So, there may be some candidates who still need only this kind of a solution. So, if you are look at a prosthetic knee overall we need to compensate for missing muscles and normal control mechanisms that are there in the body. So, if you look at, if you break it down to the walking cycle then in the stance face you need weight bearing stability and typically that is achieved by some kind of a braking mechanism in the knee. They will have some kind of a brake so that when there is load on the knee it is difficult to flex it ok. Geometric stability we will talk about that in a little bit more detail that is using some linkages that will provide stability; the advantage of geometric stability versus a braking mechanism is a braking mechanism bares with time ok.

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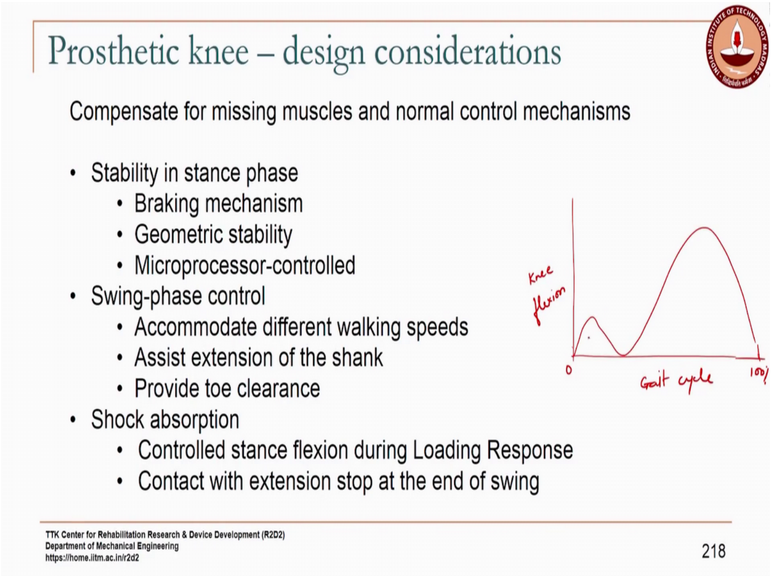

So, a person may actually become dependent on the braking mechanism and then suddenly one day it may it may have worn off to the point where it is not able to brake any more ok. So, where it is a geometric stability it arises out of the geometry of the linkage itself and so it is not subject to wear, with it does not change with time so it is more consistent.

Then the most sophisticated designs have some kind of microprocessor control that is built into the knee which will sense what is the load on the leg and then accordingly make sure whether you know, whether the knee can bend or not you know whether the knee has to be kept stable or it will it will look at. So, it will have some kind of a control system to determine that.

So, stability in the stance face which is very critical for walking is provided by some of these different mechanisms, in the case of swing phase control one of the requirements is to accommodate different walking speeds and basically assess the extension of the shank.

So, if gravity you know with the human leg, human shank you have a certain mass and moment of inertia ok.

Most of these prosthetic legs are lighter because to improve the overall efficiency of walking the masses reduced and because of the lack of the other control mechanisms. But that can also hinder the extension of the shank it may not be enough; so, you may actually need something to pull it you know, pull it forward gravity alone may not be enough to assess the extension of the shank.

The other aspect of swing phase control is to provide toe clearance in some way ensure that toe clearance is provided, in addition to that if you look at shock absorption what you have in the foot may be enough. But if not, if you look at normal walking if you want normal gait you remember it at the knee you have two instances of flexion. You have so if you look at the knee flexion versus percentage of gait cycle the knee pattern looks like this right over the gait cycle. So, this is the knee flexion 0 to hundred 100 of gait cycle you have some flexion in the stance face and that contributes to the shock absorption.

Now, in many cases this knee flexion is difficult to provide in a prosthetic knee because again it is the this happens during stance when there is loading on the knee. So, if a person has loaded the leg and they start feeling you know they find the knee is bending it gives them a feeling of insecurity ok. So, they may not be able to handle that, they may preferred to feel that my knee is locked I can bare weight on it rather than slight stance flexion also controlling that stance flexion is important. Even if you provide so say you provide a new amputee with a knee that allows some kind of. So, they are not used to I will completely locked knee during stance.

So, they may be more open to be trained with knee that provides stance flexion controlling the stance flexion is also an important aspect in the design because if its if you have free flexion then again stability becomes an issue the other instance where you need some kind of dampening or shock absorption is when the leg swings forward and then contexts the extension stop ok.

Because you do not have any eccentric muscle action decelerating that helping to; so, when it contacts that stop otherwise you will have an impact ok. So, that is another instance where they are needs to be some kind of dampening in the knee. So, there are various types again as with the prophetic feet the kinds of knees that are available many many, you can have single axis, knees and these can have different types of single you know swing control ok.

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So, swing control can be, you can have friction you can have swing control using hydraulic or pneumatic units or now you also have knees that use MR fluid to control the swing face. Then of these some of them can be just mechanical hydraulic or pneumatic or they could be also microprocessor controlled they could be some level of microprocessor control in built into the knee to handle different situations.

So, you could have, here is an example of so, the simplest single axis knee is basically just a bolt and it will have like a sleeve bearing around it and if you tighten that the sleeve of that bearing. So, it could have like a slot this spin will be in casing which has like a slot just similar to this tube adopter that I showed you.

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And if you tighten this kind of you know if you have a slot and you tighten a bolt then it is going to increase the friction against that pin, against the knee bolt ok. So, the simplest type of single axis knee free moving single axis knee has frictional spring control. So, this is simplest simple, it is an expensive. The downside of frictional swing control is you can adjust the friction for a particular walking speed. If you change your walking speed you have to go back and adjust the friction it only works for that particular, it does not adapt on the fly it does not because the friction is not velocity dependent right. On the other hand if you have a hydraulic or a pneumatic unit the behavior of the, you know it will push the fluids so you will have a piston cylinder arrangement you could have it with the single axis knee.

And as the knee bends or extends you have this piston moving inside the cylinder attached in those cases because that movement is velocity dependent the hydraulic unit can easily adapt to different walking speeds. So, even if you set it for one walking speed there is a range around that walking speed for which it will be able to still function appropriately. Again added weight, added cost, added sophistication, added maintenance requirements because you could have leakage, you could have other issues with that ok. So, the simplest was the lock then you have the single axis with friction control, then you have single axis with more sophisticated swing control.

This is knee that is a slightly different version of a single axis knee it is called destabilized knee and if you see this is the knee bolt and it has this casing which has a slot unit around the so, you can adjust the friction. So, there will be a bolt that goes connects these two across this slot so that you can tighten that and squeeze the knee bolt accordingly to change the friction response of that bolt.

In addition what this also does is there is another pivot here and to which this is this and when you load the knee that further squeezes that slot. And the idea is that when its load bearing it will lock the knee, it uses only friction, it uses only friction. But it tries to do it in this manner it tries to. So, it used to be called the very first design that was similar to this used to be called the safety knee, they said you know if you walk with this you are not going to fall because it will lock. But again the problem is with a mechanical braking system like this, this is the essentially when it is loaded it acts like a brake system things wear.

And so, you know people started showing them saying you know you said it is the safety knee and you still I still fell walking with it. So, that is one of the stories behind this knee. So, they change the name to a stabilized knee rather than a safety knee. So, here you see what you see here is. So, you have this collar which will go on the pylon and then you have a spring ok. And then you have another movable collar at the bottom and these two are attached to the two sides of this knee. So, as you bend the knee this moves up, this slides up the pylon and compresses this spring ok. So, the view of this the spring so, the knee should actually be facing me like this; here I am looking at a sagittal view of the knee but an frontal view of the extension assist ok.

So, it is a bit confusing, imagine that the knee is turned around. So, it is facing you and these loops go around this on that side and on the backside the other loop goes around that then as the knee flexes. So, imagine there is a spring that ok. So, imagine there is a spring on this part which compresses as the knee bends because it is attached to that string right. So, it compresses and then so as the knee extends it is going to provide an extension assist. So, this is a simple design for a mechanical extension assist for the knee.

So, to help the knee in because it stores the spring energy and then releases it when there is no load or as the knee is straightening it will help the knee straighten. This geometrically this is a knee that provides the geometric clocking that I was talking about and we will explore that more in the coming classes ok. So, you have a braking type of a knee and then this is a knee that has hydraulic controller ok. So, this is a knee that has.

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Again so this is the piston cylinder arrangement I told you still have a single axis knee, but as the knee bends the piston gets compressed and there may also be a springers something to help it extend. So, you can control both the flexion and the extension resistance on this knee, they see like is a sophisticated microprocessor control knee.

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And we will you can see again they come in a variety of colors and geometries and different price ranges. Knees can cost anywhere up to you know 100,000 dollars. So, that that C leg that not this one, the C leg can run you know 50 30000 to 100000 dollars is microprocessor control knees, it can be pretty expensive.

So, it is out of range for most people, even in western countries that is one of the sad parts of some of these developments is that scientifically yes it is very sophisticated. But, unless you can bring the cost down your ability to make an impact in the lives of the people who need these kind of devices is limited.