Mechanics of Human Movement
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Lecture – 46
Introduction to Assistive Devices for Mobility

So, we have studied human walking in some detail and we also looked at some instances of pathological gait. So, from this point onwards, we will look at some of the Assistive Devices that are used for walking and also we will look at some of the criteria we need to use for design of these assistive devices. We will look at various types of assistive devices, how some of them accomplish the task and also you know if you want to design an assistive device, what are some of the criteria, we need to use for that.

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So, of course, the basic type of assistive devices are the crutches and walkers which are basically supportive external supportive devices that are used by people on a temporary or on a long term basis for walking. But today, we will start looking at things that are replacement or assistive devices for somebody to walk.

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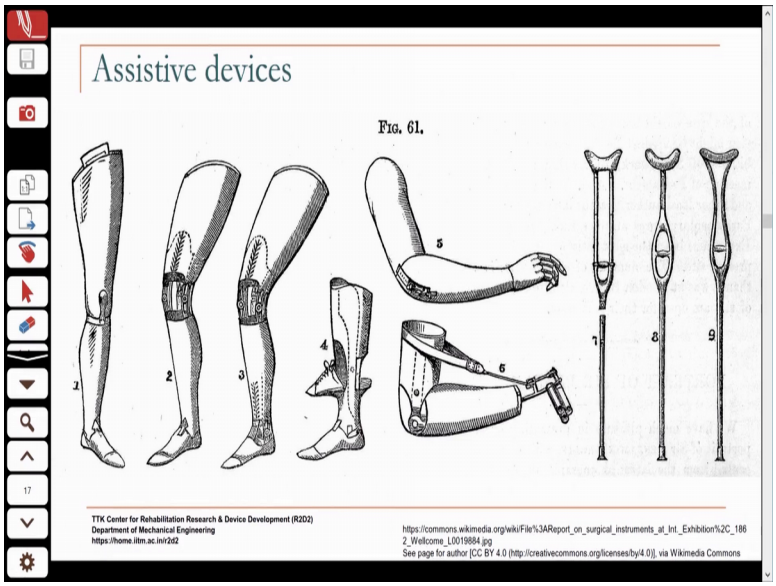

So, this is a picture of such assistive devices from the 19th century. So, assistive these sort of assistive devices for walking have been around for centuries. There from a very simple peg leg kind of thing that you see pirates for instance using now which is just a leg, a which is just a wooden stick with base to more sophisticated limbs that are that have been designed limbs and as there assistive devices.

This of course, you can see both artificial legs and artificial arms. So, for a missing limb, you have artificial legs and arms and also some designs of crutches that you see here. So, what are some of the types of assistive devices that we will be talking about?

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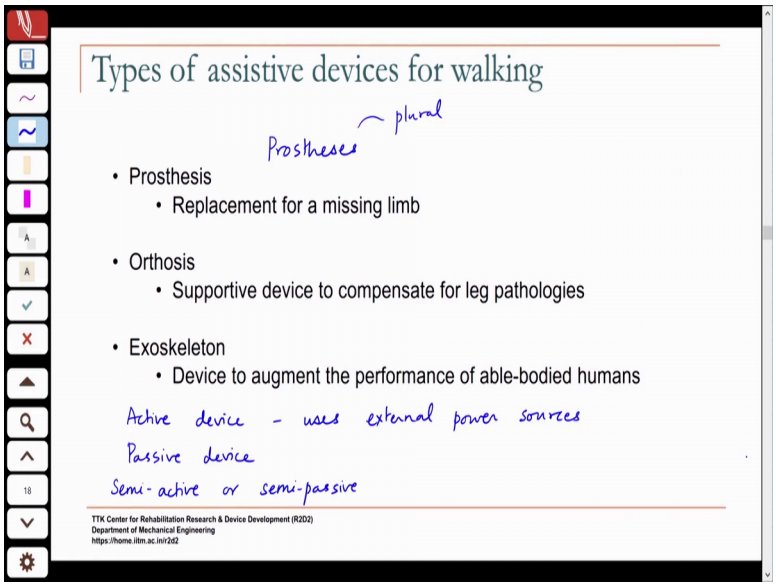

A prosthesis is the plural for this word is prosthesis; this is the plural for the word prosthesis. A prosthesis is essentially a replacement for a missing limb. On the other hand, an orthosis is a supportive device. So, you have the limb, but there are some impairments in the limb and so, you need to use some kind of a supportive device for the limb to compensate for the pathology in the limb. Recently you may have read a lot about exoskeletons. Exoskeletons are like devices that can be used to augment the performance of able bodied humans.

So, these devices for instance in the military, the military in western countries as well as in India is spending a lot of money trying to develop this sort of devices because, the idea is to enable soldiers to do more. So, you know they walk on rough terrain, they walk carrying you know in huge loads, you know how can we design devices that will help them to do those things more efficiently. So, those are the exoskeletons.

If you look it prosthesis and orthosis they can be active or passive devices. So, an active device uses external power sources. So, you may have a battery connected to a motor to perform the movements. A passive device is basically you know actuated by the human body. You could also have things like springs in the body which when they are loaded you know they store and release energy, but those are all passive devices. They do not need a power source in order to operate. So, you have and you also have semi active

devices. So, devices which are a combination of semi active or semi passive devices, these are typically the sorts of device.

So, most exoskeletons used external power source because the idea is to augment what the human body can do right. So, in many cases they do use external power sources or at least they are semi active. You know in some joints they use an external actuator. In some they may just use the human power and they may use springs or springs to sort of store and release energy at appropriate points of the activity.

So, these are the three categories of devices. We will spend, we will probably spend more time talking about the prosthesis and the orthosis. Because a prosthesis is where you will see a lot of challenges because you are replacing something that is missing and that is where we will put our knowledge of what we have learnt so far right. Especially, with regard to walking, to see what would be the requirements for such a device and what are the challenges involved in designing a replacement a mechanical replacement device for the missing limb.

So, if you look at amputation, so, a prosthesis would have to be used by a person who is had a lower limb, a lower limb prosthesis or a prosthetic leg is something that a person who has had a lower limb amputation has to us. So, that means, their leg has been cut off at some level or the other and there could be various causes for a lower limb amputation.

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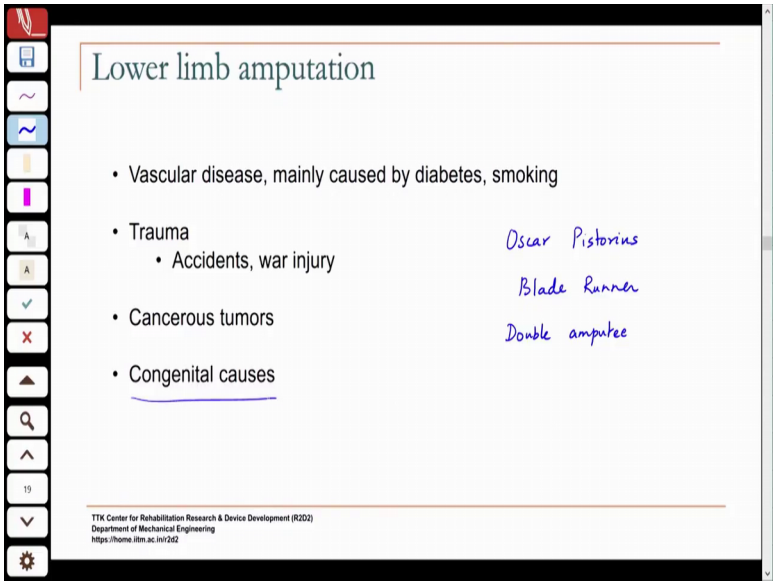

Vascular disease which affects the circulatory system is mainly caused by say diabetes or smoking, you know which is with sort of underlines why you should lead try to lead a healthy lifestyle is a major cause for lower limb amputation. So, it is one of the major causes for lower limb amputation, especially as a person ages. If they have diabetes for a long time then it is very likely that they may have to and if the diabetes is not controlled then it is very likely that they may develop this kind of secondary problems which could lead to an amputation in the lower limb.

Trauma due to accidents; so, motorcycle accidents are a very common cause for lower limb level amputations, very common cause for lower limb amputations. So, a war injuries; another reason why the defence is very interested in development of good prosthetic devices; because a lot of young people are injured or lose their limbs due to and in some places because of mind feels right, you have hidden minds you have people undergoing amputation having to undergo amputation.

Cancerous tumors are another reason. So, if they want to prevent the tumor from spreading, they may decide to amputate the limb at some point. And of and in some cases there are congenital causes which is by birth. The person may have some kind of a birth defect which prevents them from walking properly. So, have you heard about this guy called Oscar Pistorius? He was called the blade runner.

So, he is a double amputee, he is of course, he later on got into the news for the wrong reasons because he was accused of shooting his girlfriend. And, but he is he was initially a very inspiring double amputee because he participated in the paralympics, he tried out for the Olympics. He is a double amputee, he lost so, he was born without the fibula in both legs. So, his was a birth defect. So, his the cause for his amputation and because the fibula in at the ankle joint, you need the fibula also to form the for the ankle joint function effectively. Because his fibula was missing, the doctors actually decided to go ahead and amputate his tibia.

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Artificial?

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No, the I have not heard. See, again you need it is not just one component right. What about all the ligaments? What about everything else that needs to be part of the structure? So, it is not always easy to just replace a human body part by an artificial counterpart. With joints for instance, they try to do that. You know if it is the surface of the joint that worn out like you have knee replacements, hip replacements, where they going and basically cover the damaged joint with a mechanical device.

But again you have to have everything else, the structures around it intact in order to be able to control the joints; so, the muscles and the ligaments and all that. So, the fibula itself is missing probably more than the fibula is missing. The ligaments surrounding it may also not be around and it may be difficult to reconstruct everything around. So, it is not always easy to replace about.

So, in his case they actually went and amputated at below the knee, they performed an amputation and then fitted him with artificial limbs and he actually did ended up doing extremely well with the artificial limbs. He is to play football, he was a champion, sprinter, running, you know he did a lot of things before he became famous for the wrong reasons. So, but his is a case where it was a congenital cause.

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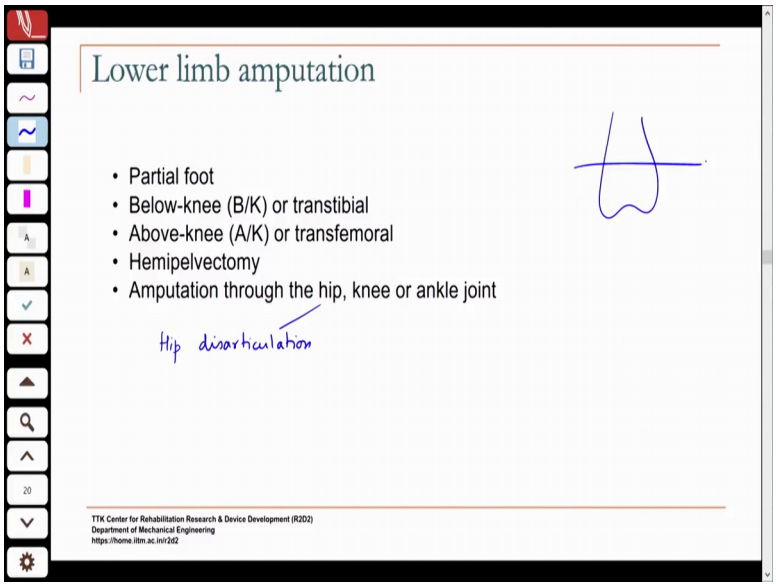

So, there are various levels at which a lower limb amputation can occur. You can have a partial foot amputation. So, many diabetics you know if they lose sensation or if they get a sore that does not heal then they may undergo some kind of a partial foot because that

is your load bearing surface, the foot right and if they have neglected and if a sore that has not healed then they may have to go and then actually amputate that part of the foot.

So, a the amputation can be at the level of a portion of the foot being removed. It could be a portion of the toes being removed some of the toes being removed or you could have an amputation at some level below the knee. So, the knee is preserved at some level on the tibia, you do a below it is called the below knee or a transtibial; trans is across the tibia cutting through the tibia.

So, you can have a below knee or a transtibial amputation. Moving higher up, in some cases if the knee cannot be saved, then you have to go and do and above knee or a transfemoral amputation ok, through the amputation through the femur is a transfemoral amputation. Even higher, you may have to do a hemipelvectomic. So, the pelvic itself is removed, a part of a portion of the pelvis is removed. In some cases, they will actually just basically separate if they can they will separate the bones that form the joint.

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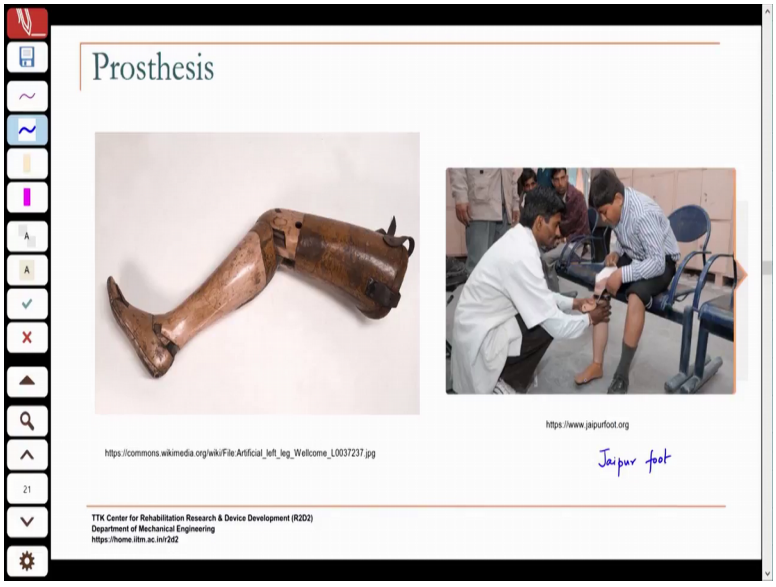

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So, those are the amputations through the hip, knee or the ankle joint. So, these are called; so, an amputation through the hip is called a hip disarticulation. So, it is basically separating the hip joint. You are removing the femur from the joint or at the knee ok. You can have, so, you can have an intact femur and basically the tibia everything below the tibia and everything below is removed ok. There are some advantages, there are some disadvantages to these sort of amputations. Amputations through the joints preserve you know most of the musculature and all that, but because of the structure of the human body they are much harder to manage with a prosthesis.

Because fitting the prosthesis; so, for instance if you look at the femur right, it is bulbous at the bottom ok. So, if you want to fit it through a socket, so, this is a an above knee prosthesis ok. So, this is what is called the socket of the prosthesis. So, here you see that if it is if it narrows down ok, then you can insert the femur into the socket. On the other hand, if a person has a disarticulation amputation ok, then they have a base that is larger than some of the proximal parts.

So, inserting it into something like this and then fitting it properly with that socket becomes a challenge. So, they may actually go and say ok, let us just do a above the knee amputation because it is easier to fit. But this has advantages because you have you preserve more of the body which is always a good thing.

So, most of your muscles etcetera, you can preserve you can you do not have to cut the muscles or you do not have to you can and also you will have better control of the prosthesis and the residual limb and you can have a better weight bearing surface also; when you are because if you insert the residual limb into the socket you have a better weight bearing surface if you do this disarticulation type of amputation.

But it is it is a very prosthetic management of disarticulation amputations are much more difficult. So, in many cases even if that would be the preferred route to take they may end up doing an amputation at a higher level for better prosthetic management. So, here is a very you know this is a very ancient type of prosthesis. They used to carve it out of wood ok. So, you see they have shaped it that is why you have the shank part, you have a foot that is also carved out and then you have the what is known as the socket, this part.

Again they have carved it out of wood ok. So, the entire prosthesis is made of wood and you have like a bolt that is joining the femoral part and the tibial part of the prosthesis to form the knee joint and then you have straps to attach it to the rest of the body. So, they would insert the residual limb into the socket and then maybe have additional straps to keep the prosthesis onto the body. So, this is a very crude very old type of prosthesis. Unfortunately, in many countries like many developing countries we still use prosthesis like this.

Now, there are many more sophisticated ways of making prosthesis. We will talk about the some of those. But some of these this is cost effective, this is study. So, if you are in a rural area and you know they may end up because of cost reasons or you know what is locally available they may end up getting prosthesis like this. Some of these are still used. You will still see prosthesis like this. On the right side, you see are you know indigenous Jaipur foot ok. So, this is one of the innovations from India that the is now world famous especially in developing countries.

Because of its durability and because of it is because of the use of appropriate technology for designing this kind of a. So, their artificial foot then you have. So, this is a person who has a below knee amputation. So, you can see that the prosthesis ends at the knee. So, this person also has you this socket and then the artificial foot.

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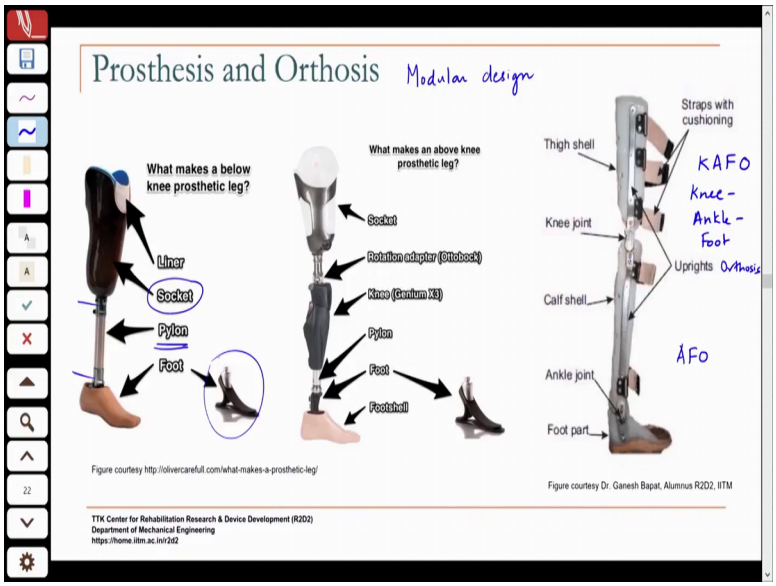

So, some of the more sophisticated prosthesis or more recent prosthesis actually use what is known as a modular design ok. So, you can see that in the previous case, the wooden prosthesis they would have to be shaped for each person. They would have to be custom made. So, now, recent prosthesis use what is known as a modular design, where they use some parts that can be sort of assembled together. So, there are still some parts that need to be custom made. For instance, the socket ok, because that is very dependent on the shape of the persons residual limb ok. So, the socket is something that still has to be custom made to for the user and then you would have some kind of a liner.

It could be like a question liner, it could be like a gel liner or it could be stocks, it could be something that questions the interface between the residual limb and the socket. It can also draw out the sweating the perspiration. So, you need because if this is enclosed in that socket then you need to have a way to keep it dry and wick out the perspiration. So, they may also what happens is during the day, the volume of the limb actually changes the fluid accumulation causes the volume to change in the course of the day.

So, they may have to in order to maintain the fit they may have to use some kind of liners or socks and they may have to adjust the number that they use through the day in order to maintain a good fit. So, the socket is a very critical component of the prosthesis because this is the part that is custom made and so, if this is not properly fit ok. So, if the

person has pain, the person has pressure points in the in the socket fitting then it does not matter what kind of sophisticated components you put below the socket.

Because if they are uncomfortable, if they inter it is like wearing tight shoes ok. It does not matter how well you know how good you feel about yourself otherwise. Your tight shoes will keep reminding you right, how comfortable you are ok. They may look very good or they may, but if you are they are uncomfortable that is where your mind is going to be. So, that is the importance of having a good socket fit and it still is more of an art ok. There are now more sophisticated methods that use scanning and 3D printing and all that to design the socket, but a lot of it has to do with the you know knowing which parts of the limb can bare pressure.

You know like bony prominences for instance, if you load those you are going to have pain. If you have fleshy tissue those can take more pressure. So, there is a lot of skill involved in fabricating the socket and that plays a huge part in how well a person is able to function with a particular prosthesis. So, socket fit is very very critical. Then you have a load baring member called the pylon ok. So, the pylon is basically just a tube. It could be a metal tube, it could be a composite tube and that can just be cut to size.

So, depending on what components the person is going to use they will take a pylon and cut it to the right side. So, that it can you can have the right height for the person. So, these are all connectors ok. You have connectors, at the top and the bottom of the pylon which attach. So, all these components are sort of put together like this. So, many of these are off the shelf ok.

Similarly, even with the feet, the prosthetic foot, you have them in different sizes just like you have shoes. So, you can have them in different sizes, you can have them in different stiffnesses, we will talk about why we need them like that what the different stiffnesses and they can again be put together. So, you can have from the shelf you pick and choose which components you want and you can assemble the prosthesis, but the socket alone has to be custom made.

And these connectors also have certain adjustments that need to be done. So, alignment, alignment is basically how the various components go together in the in the prosthesis. And as you saw during walking, the alignment will have an influence on where the load liners with respect to the various joints.

So, they have to be arranged in certain specific manner in order to ensure stability and other requirements for walking. So, alignment of the prosthesis and these connectors typically provide that kind of alignment ok. They help adjust make adjustments to the alignment. Again this is an advantage of the modular kind of design versus the rigid, everything made together because there once it is made there is no change possible ok.

Here some changes are possible to ensure a more smooth walking action. So, when you have an amputation ok, the higher the level of the amputation the greater the challenge in getting the person to be able to function and do the activities of daily living, mainly, walking when you are talking about the lower level. But, you have a partial foot amputation. Yes, the walking is affected but the prosthesis that you would use would be far simpler than say somebody with the below the knee amputation or a transtibial amputation. You go up higher in the chain; you go to an above knee amputation.

Now, so, with the below knee amputation you have to somehow compensate for the ankle action because that is a joint that is now missing and it is a joint over which you do not in a most. So, this for instance is the passive prosthesis. There are no motors or no power sources actuating the joints. In the below knee prosthesis, the person still has control about the knee joint ok. They can still control the, they have some musculature around the knee joint which is still intact. So, they may still be able to flex and extend the knee at least to some extent. So, the challenge; so, here the ankle joint is what you have to sort of compensate for in the design. As you go up higher, the knee joint also comes into play.

So, now you have to compensate for the ankle and the knee in an above knee prosthesis and the fact that you do not have all the surrounding musculature, all the other control mechanisms are gone around those joints. So, in a passive prosthesis like this one, all the control of the prosthesis happens by means of the residual limb that is inserted into this socket ok.

So, I have to control the motion about the knee or the ankle at the interaction with the ground, everything has to be controlled with my residual length which is inside this socket that is my actuation mechanism. So, I push on the socket, I move the socket and that influences the motion of the entire prosthesis ok. That is again another reason why the fit has to be good to for you to have good control; good control, good sensory

feedback for the control of the prosthesis. So, in addition to, so, if you look at an above knee prosthesis again you may have again you will have a socket which will have to be custom made. You may have something like a rotation adaptor because you may want to be able to change the rotation of the leg, alignment of the leg in the transverse plane ok.

You may have or you know if you want to sit cross legged, some adaptors will allow you to basically change that angle so that you can sit cross legged ok. Then you may have some kind of a artificial knee and we will talk about the requirements, designed requirements for such a knee. You would have a pylon; you can have anything ranging from a very simple hinge joint for the knee to something much more sophisticated.

You have even microprocessor controlled knees which takes some input from load sensors and then and also the kinematic data and then control how the knee is going to function. Then you have the foot and you would have some kind of a foot shell. So, it could be like a solid foot which has the foam moulded around what is whatever is there at the inside or you could have again a modular kind of foot where you have this kind of hardware that goes into a foot shell ok. So, basically the foot shell is basically for the cosmetic appearance and to use shoes.

So, the actual foot may actually look quite different from the shape of. Now, in the case of an orthosis ok, so, you have; so, an orthosis as I mentioned is a supportive device. So, for a person say who has muscular weakness because of polio ok, they are not able to control the knee in order to walk. So, they may be prescribed something like this. This is called a knee ankle foot orthosis. So, this has a knee joint ok, this has a knee joint. So, it has like a thigh band which is again moulded to fit the person. Some of these you have which are prefabricated. So, they may have you know different sizes of these available.

Because if they are made of thermoplastics, they can be heated and then custom fit to the person, but of course, the correct fit would happen only if it is custom made for the person, but these are some shortcuts that are used either to you know to speed up the time in which a person can get an orthosis and also for reduced cost because it is like clothes right, readymade clothes are typically less expensive than tailored cloths; something that is tailored for you ok. The tailored clothes would be more expensive, probably would take longer for you to get them.

So, it is like that. So, you have, so, you can see it is basically just a simple hinge joint for the knee and then you have a calf band. So, you have a calf band and then you have a foot. In this case, this foot can only dorsiflex ok. You have an ankle joint, but it is an ankle joint that allows only dorsiflexion. So, this may be something that a person who has a drop foot may be prescribed because you want to prevent the foot from going into the plantar flexed state ok, but it still provides some dorsiflexion. So, the, so, this in many cases the ankle may just be a solid ankle, where edges maintains the ankle in the neutral position ok.

So, depending on the stabilization required for the person, depending on their condition the muscle weakness what support they require this kind of. So, a person who has fairly good control at the knee, but has like a drop foot or some other problem at the ankle joint may be prescribed what is known as an ankle foot orthosis. So, that is just; so, there your; so, this is called a KAFO. So, it is a Knee Ankle Foot Orthosis or you could have an AFO which would not have a knee. So, it would be somewhere you know somewhere there ok.

So, and then you have the calf. So, you have a calf shell of foot part and this sort of components and you also have this straps which attached to the limb and they will have some kind of cushioning again because to so, that you distribute the pressure at the contact areas a better. In many cases especially, so, you saw with the wooden leg, the wood itself for shaped to look the normal leg. In many cases when you use this endoskeletal components. When we use all this hardware, people do not want to walk with you know look like a mechanical man right, a mechanical man or women.

So, they wanted to be covered by. So, what they would do is they would assemble all the mechanical components and then they would put a foam cover over that and shape that foam cover to match the other leg of the person and that foam colour cover can also be sort of painted with different skin tones. So, that it looks like their other leg. Prosthesis initially may look like this and then you can have a foam cover. So, you could put it into a shoe like this and then you may have some kind of a suspension sleeve that is basically to hold. So, instead of straps they may use like a tight elastic sleeve to attach the prosthesis to the rest of the leg.

So, this goes up over the thigh this part it stretches and goes up over the thigh. So, the prosthesis ends here at the knee ok, but the sleeve will go up over the thigh. So, that you are able to hold it. It would not fall off when you are swinging the leg ok. So, there are various ways of a; so, you may have a prosthesis that looks like a normal leg that is made to look like a normal leg or in some cases a person may you know if functionality is what they are looking for functionality for a specific reason is what they are looking for, the prosthesis may not look anything like a normal leg.

So, you can see here. This is the sort of blade that Oscar Pistorius also uses for running. So, this is a guy who is running with this kind of a prosthesis. So, putting this kind of a foam cover and all that for this would not really severe purpose. So, some of them may just wish to show off their high tech leg and they would be with the not covering a hit up with the foam cover ok. So, and the prosthesis may actually not look like anything like the anatomical leg ok.

So, there are prosthesis like that as well. Of course, these are very specialised functional you know a prosthesis that are for a specific function. A person may not be able to walk very comfortably with this kind of a with just a C shaped spring because then you would be constantly walking on your toes. Even if you are standing you would be it like standing you know leaning forward right because you do not have a base. So, depending on the function the types of prosthesis that are used may be quite different.

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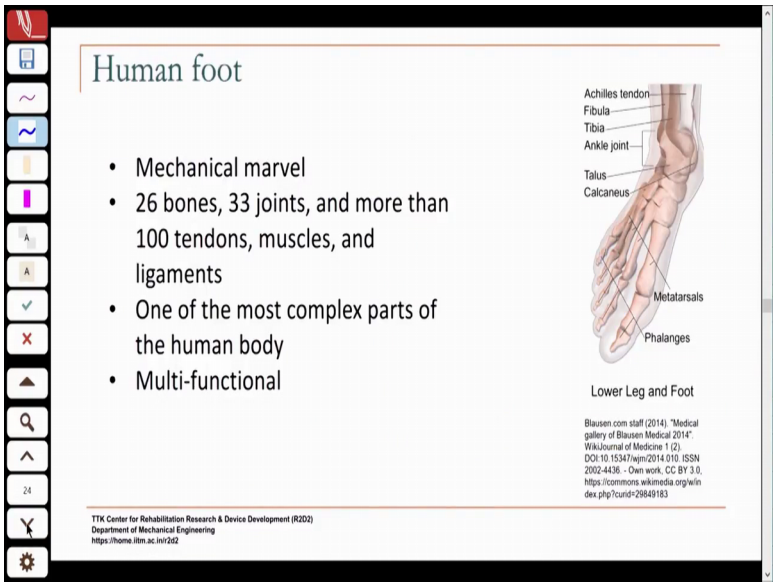

So, let us now start with the foot ok, the foot. So, any prosthesis you have to have a foot, whether it is above knee below knee whatever you have to have a foot because that is your interface with the ground ok, so, for walking. So, if you look at the human foot, the human foot has so many parts. It is you know you try to replicate it mechanically, it is a huge challenge; it is a huge. You have so many different moving parts and they are all controlled by so, many muscles and tendons and ligaments in the foot.

And so, replicating that in a mechanical system will be a nightmare because, you do not only controlling it but even maintaining it. Even if you managed to design something; you know you have all such a paths moving against to one another. You are going to have huge noise issues huge maintenance issues. So, it is one of the most complex parts of the human body and the others aspect of it is you know if it is you look it all the things that you do with your foot all the things that your able to do with your foot ok.

Even though we say that you know the foot is simpler than the hand right, the hand has many more degrees of freedom and that is why creating a mechanical substitute for the hand is very difficult because of all the degrees of freedom that you have. But, the foot is also if you if you think about it, you can walk on different types of terrain.

You walk uphill, downhill, over steps, all sort of things. You look at a ballet dancer. The foot is so rigid, they are able to you know all these parts together, they are able to make it is so rigid has to be able to stand on tiptoe ok. You have so many moving parts in here and yet, they are all held rigid in order to be able to stand on tiptoe ok. Or a when you are walking on uneven terrain or if you look at somebody climbing a tree and the grip the you know those people who harvest the coconuts or you know from the palm tree, you will see that they actually grip the tree with their foot. The foot confirms to the tree. So, you have that much flexibility in the foot to actually grip.

Most of us because we are not used to using our feet leg like that would not be able to do it. We are not able to confirm it, but the foot is capable of doing that. So, the foot is very multi functional and that is an aspect of the foot that is very difficult to replicate in a mechanical system. So, in many cases what will happen is if a person wants to do multiple activities they may end up having different prosthesis different prosthetic feet for those activities. So, it is very difficult to design a foot, so that it can do all of these things ok. So, that is one of the big challenges of trying to design a prosthetic foot.

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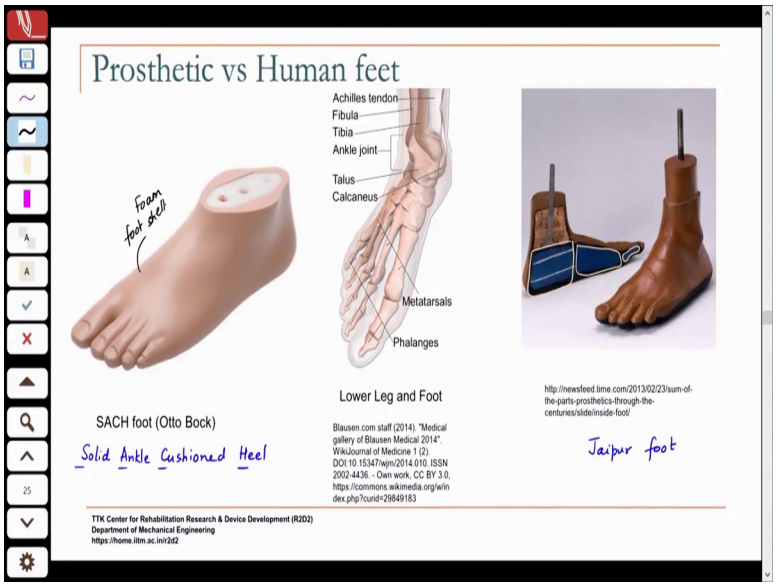

So, the simplest type of prosthetic foot is what is known as a SACH foot. So, SACH; stands for Solid Ankle Cushioned Heel, solid ankle cushioned heel is your SACH foot. And here you see on this side you see the Jaipur foot and you also see a cross section of the Jaipur foot. So, it has like a wooden block and some different types of rubber ok. So, you can see here.

So, you have some kind of rubber in this portion then you have another piece of type of rubber here and then at the toes you actually have different pieces of rubber to simulate. In this case, in the SACH foot, the inside is fairly simple ok. You have a wood block and I will show you in the next, but you can see very nicely how you know the detail in the external foot, the foam foot shell. So, this is usually made up of some kind of foam ok. So, it enclosed in a foam foot. So, you can see they are quite different. So, you look at the actual anatomical foot and replacement foot they are quite different.

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Some more designs of prosthetic feet; completely different from anything that you see in the human foot ok. These use some kind of springs you have, so much hardware ok. This is some kind of an ankle joint, this is actually a hydraulic unit that acts as an ankle joint. Then here you have a series of springs with foam in between ok. Here you have only one spring, but it is covered with some kind of material which is then in enclosed in this foam and many of these can be fit into these are some different colours of foot shells that are available.

So they you can order, you can say I want this size, I want this colour and some of them also have different heel heights. So, you could use them with shoes of different heel height because see when you your leg confirms again, so, you know when you wear shoes with different heels, you could wear your Hawai chappals or you could wear a shoe you know formal shoe that has heel height and your foot confirms to that. You know you do not start standing like this because you are wearing different shoes because, your ankle and foot have enough flexibility to adapt to the different heel heights.

If you have a foot which has a solid ankle then that can be a problem. So, they would actually have they would what is a shoe height you are likely to use and they would design and they will give you a foot that fits that heel height and if you use some other shoes with the different heel height, then your alignment will be off ok. Some of them have designs where you can actually adjust the heel height and the foot.

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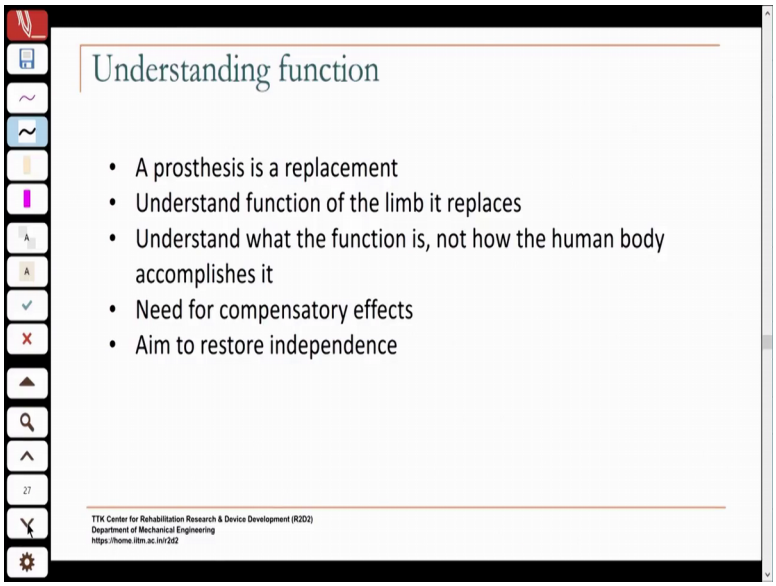

So, in the next class we will start looking at you know how do, we what is it? So, the prosthetic feet that are out there, a different from the human foot. Why have they evolved like that and what is you know how do we go about designing something like this? And the key to that is really understanding the function that the foot performs. So, the understanding the function is key to designing an assistive device and we will look at that in the next class.