Mechanics of Human Movement
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Lecture – 42
Characteristics of Normal Gait Part III

So, last class we looked at the pattern of the ground reaction force vector during the stance phase.

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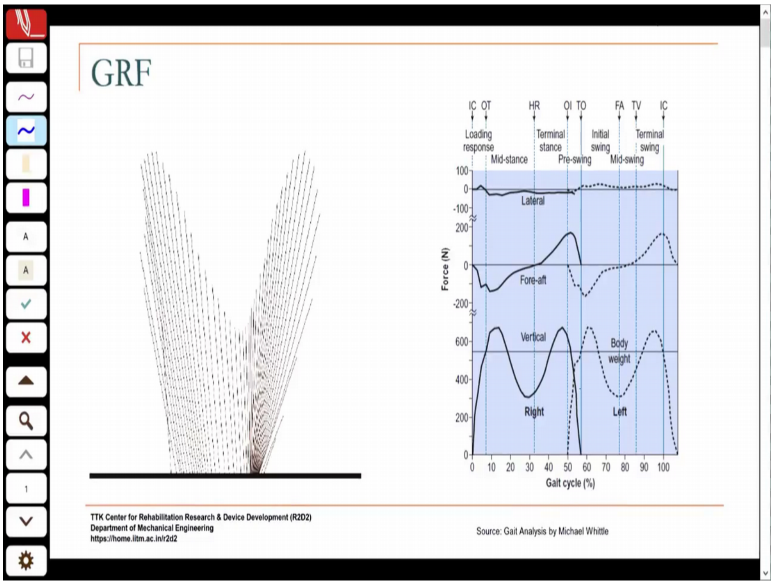

And you know this you can see here that the vertical ground reaction force has a characteristic M shape and that is the component that has the maximum magnitudes during gait. There are two horizontal components: one is the anterior posterior and then you have the medial lateral component. And the anterior posterior component as I mentioned is only about is significantly lower than the vertical GRF, and the medial lateral component is even lower than that, ok.

So, usually we only looked at the vertical component of the GRF, but the anterior posterior component shows you the effect of friction. So, you can see here that, in this case the friction is along the negative x direction initially, and then at push off its along the positive x direction. That is the direction of; if this is your direction of progression. So, friction opposes the motion in the initial weight bearing phase, because it has to stop the advancing foot from slipping. And then in the push off phase you have the foot is pushing off on the ground and then so the friction provides a force in the direction of progression ok.

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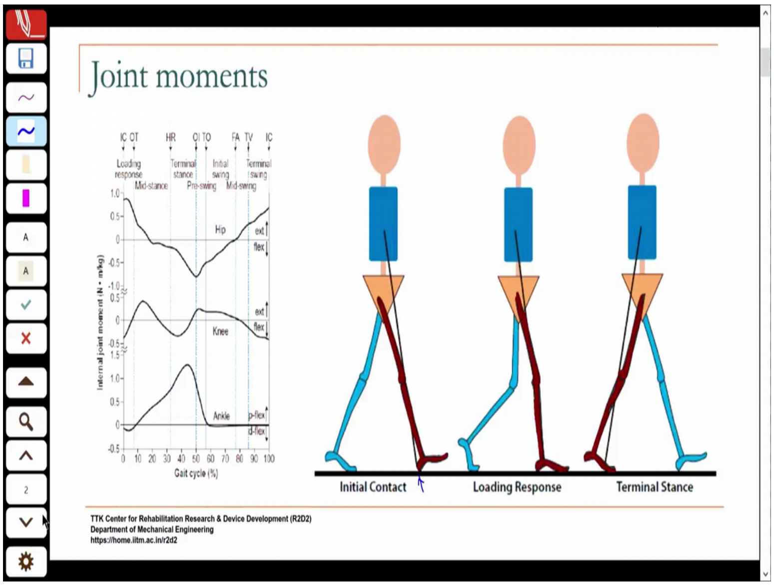

So, we also talked about the influence of you know how the joint moments; the net joint the internal joint moments act at the various stages of gait. And we looked at location of the ground reaction vector gives you a clue as to what the internal joint moment is going to be; the direction of the internal joint moment. But the actual joint moments are computed by inverse dynamics ok.

So, this is just to give you an intuitive feel for what its likely to be so that you have an idea; because the next thing we are going to do is look at muscle actions and knowing this you know we can kind of predict which muscles are going to be acting. So, its more like a its not the actual joint moment you cannot use it to actually compute the joint moments by this method. So, it is only to give you a feel for what are the moments that will be acting.

So for instance, at heel contact if the ground reaction force is trying to create plantar flexion then the resistive moment will be a dorsiflexion moment at the ankle. Similarly, you have here this is trying at the end of at initial contact you are actually trying to prevent hyperextension, because the shank is swinging forward due to the action of gravity and you want to prevent hyperextension of the knee, so you want to slow that down grab. So, you are counteracting the effect of gravity and so the internal joint moment is actually a resisting flexion moment; the external what is happening is its extending and eccentric action of the hamstrings will cause this flexion moment.

So, a flexion moment does not necessarily mean the knee is flexing at that instant. Remember muscles can have concentric or eccentric action. So, they could be slowing down or causing the movement. So that is and here you see you can see that at initial contact, the ground reaction vector acts ahead of the hip joint. So, it would be trying to cause a flexion moment and so the internal moment that would be acting would be more of an extensor moment, ok. So, this is just to give you a clue into how this behaves.

Now, in most cases during gait you will find that the moments are kind of acting its eccentric action of the muscles that is producing the moments. Only in some cases you have concentric action, because if you look at, so let us look at say initial contact, ok.

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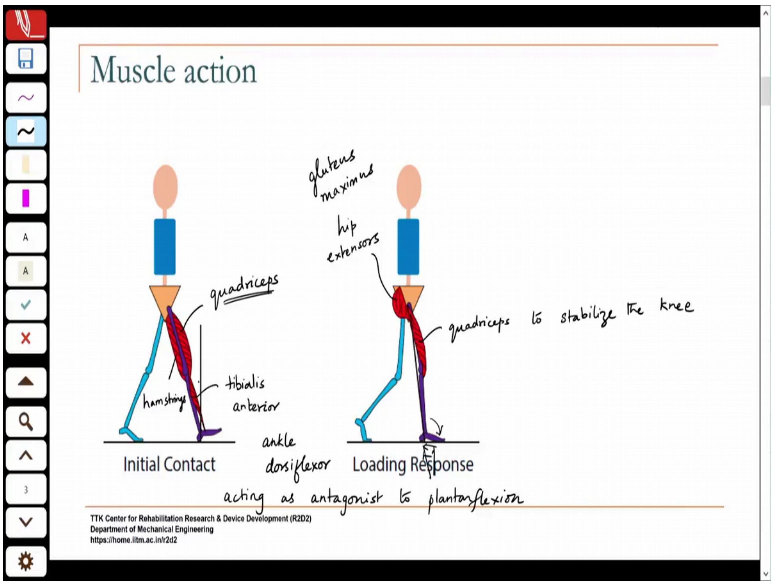

What is the function? So, when you have initial contact ok, you want to stabilize the knee, you want to the foot will be lowered to the ground. So, its this interaction between the ground reaction force and the muscles that is producing this. So, the ground reaction force is basically what is produced because of the weight and the movement of the body.

So if you look at it, if you look at this then you see that at initial contact initially you have the impact which is just vertical, but immediately it changes the ground reaction the direction of the ground reaction vector will change right. So, it will be like that. So, if you look at it then the pretibial muscles or the tibialis anterior. So, these are some of the important muscles that we will be looking at: tibialis anterior you have your quadriceps you have your hamstrings, ok.

So if you look at; why are the hamstrings likely to act at the end of swing? I just mentioned it a couple of minutes ago its swinging to slow down the swinging leg you have the hamstrings providing eccentric action; the hamstrings are stretching as the shank is swinging, and you have them acting to produce to slow down that extending knee and to prevent hyperextension. The quadriceps are acting to; so the action of the quadriceps is. So, some books say that there is some action in the quadriceps to cause extension of the knee others say that the extension mainly occurs in a passive manner because of gravity, yes.

Student: there is also the friction force (Refer Time: 08:20). So, that we (Refer Time: 08:22).

No, this is just initial contact and then immediately that is why the ground reaction force changes its. So, it becomes this plus this and becomes this ok. So, initially you remember if I showed you an initial contact it just sort of drops initially that impact is this. And then immediately friction also comes into play, because the foot is trying to slide with respect to the ground and friction opposes that and the ground reaction force changes direction.

So, if you look here, so the quadriceps also may be acting to aid the need flexion. And then the tibialis anterior prepares to act because, as soon as the foot is on the ground you have the heel rocker right. So, you have the foot that will plantar flex to achieve foot flat. And, that motion again has to be slowed down it has to be decelerated. And that happens with the act action of the tibialis anterior. The tibialis anterior is an ankle dorsiflexior right, but here it is acting as an antagonist to the plantar flexion ok; so ankle dorsiflexior acting as antagonist to plantar flexion of the foot.

Student: (Refer Time: 10:11).

Yes, plantar flexion is happening due to the ground reaction force, so the tibialis anterior slows that down. In some people if they have weakness in this muscle or if they have paralysis of this muscle the foot will just slap. So, that condition is called; so when they hit the heel it will just slap like that, because that muscle is not able to provide that eccentric action to slow down that motion; slow down the movement to foot flat. So, that is the action of.

Then you also have activity of the hip extensors which is the gluteus maximus and the quadriceps. Because now stabilizing the knee becomes important. So, during loading response there is controlled flexion. For controlled flexion to happen the quadriceps have to act, otherwise you are again going to have uncontrolled flexion and you will lose stability.

So, maintaining stability of the knee is paramount in the weight acceptance during weight acceptance or the loading response phase. So, the quadriceps act during that phase: stabilize the knee and also make the femur move forward. So, here the tibialis anterior is also acting to pull the tibia forward as you are moving, as the foot lands on the ground the tibia is also being pulled forward.

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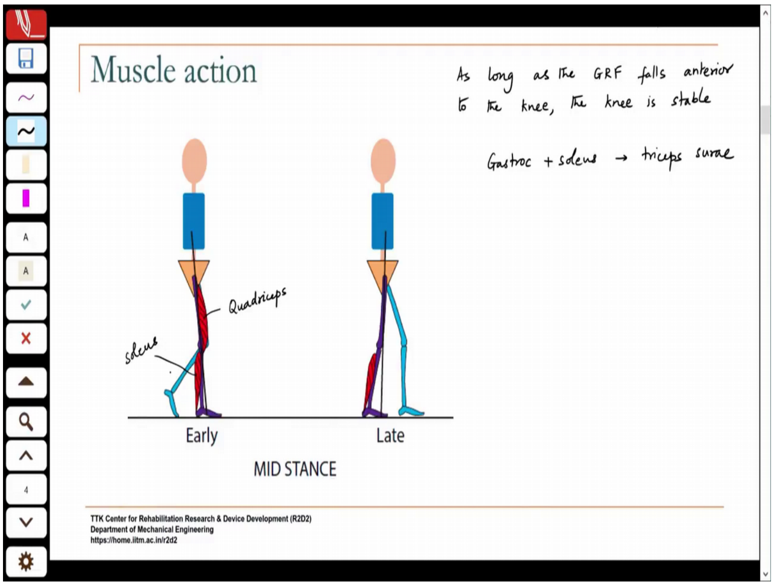

So, in early to late mid stance you have it with most of; you know if you look at the ground reaction force vector its close to most of the joints. So, there is not much destabilization happening, ok. So, things are now able to move over the ankle, but you know knees almost knee is extended and you can the destabilizing effect is now gone, because the knee is straightened and then the vector actually moves in front of the knee.

So, anytime the vector the ground reaction force is anterior to the knee its ok, because its creating an extension moment and the knee really cannot you know there is a mechanism built in to prevent the knee from hyperextending, because of the structure of the joint. So, the knee cannot move, of course if you have joint laxity looseness in the joint then some people end up hyper extending the knee, and they have those sort of problems. But, in most cases for normal walking because there is an inherent lock extension lock, beyond that you cannot extend the knee can only flex. So, if as long as the GRF is anterior to the knee the knee is stable.

So, you have some quadriceps activity to stabilize the knee and you have some soleus or you know this is part of the triceps surae. You have the gastrocnemius and the soleus together; you have gastroc plus soleus is called the triceps surae. So, in that initially you have some soleus muscle activity starts coming into play from early to late mid stance; to start lifting the foot the goal is to advance the advanced to the forefoot basically. From the flat foot to you want to advance the center of pressure to the forefoot as you are moving. And that is that action is accomplished by the soleus muscle.

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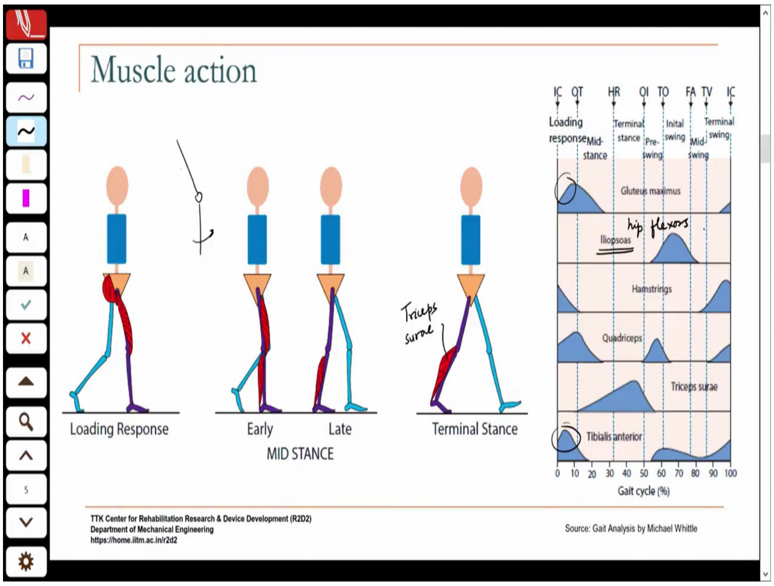

So if you look at this then you have the hip; the hip extension also helps to stabilize the knee, because you have this like this right ok. So, I have to move these two like that ok. So, I have to straighten this and pull that helps to stabilize the knee.

So, in early mid stance you have quads and the soleus muscle, then towards late mid stance its basically this is the soleus plus the gastroc muscle. So, if you look at EMG patterns during gait this is a typical pattern. So, you will see activity EMG does not tell you how much, what force the muscle is producing, but it tells you when the muscles are active. So, if you look at this then you see that initially you have, as you saw in the earlier hamstring activity at initial contact is high to decelerate then you also have high quadriceps activity during the loading response phase.

So, the hamstring activity once the foot makes contact it starts reducing. But you have high quadriceps activity to stabilize the knee, and then you also have high quadriceps anterior activity in the loading response phase too. And then you have the hip extension also happening. So, the hip is extending moving towards extension, because its in a flexed position we saw that it move and then you have hamstrings etcetera.

So, the gluteus maximus after that the hip extensors do not really do much for the rest of the gait cycle and then again come into play only during terminal swing. These muscles the iliopsoas are the hip flexors, ok. You can see that they are mainly active during swing phase.

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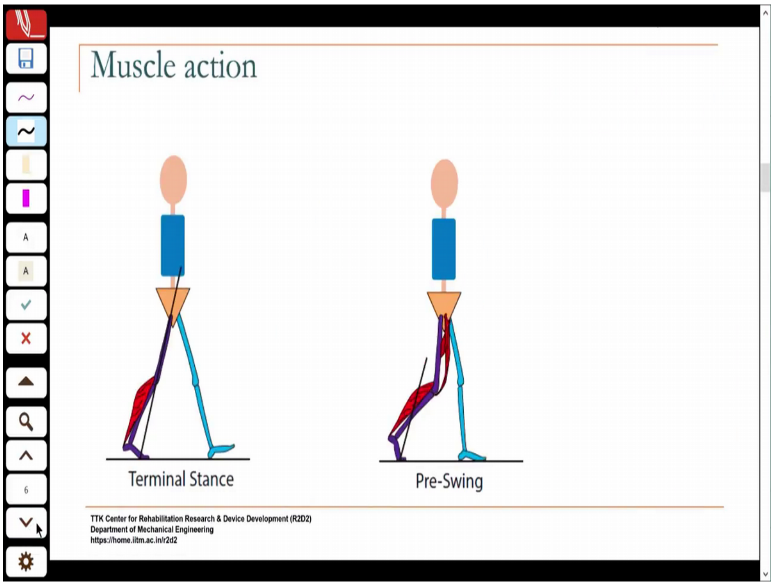

So if you see here, once it gets into the pre swing now you have to lift the leg of the ground. So, that is when the hip flexors start coming into play.

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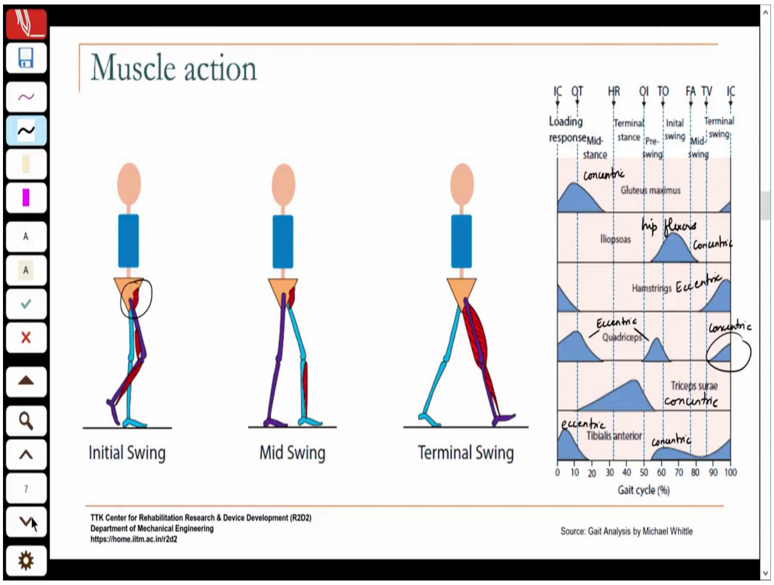

So, you see there that the hip flexors the iliopsoas are now acting during the swing. So, these are your hip flexors. And the quadriceps at initially to stabilize, then again in pre spring also there is some activity from the quadriceps, again to prevent sudden knee flexion. So, its more of an eccentric action.

And then you have towards the end.

Student: The knee flexion.

To prevent knee flexion; so the quadriceps here you see the ground reaction force in the pre swing acts to flex the knee, ok. And they are just resisting uncontrolled knee flexion, eccentric activity in the quadriceps.

So you see that, during loading response and during pre swing the quadriceps action is eccentric. So, it is resisting knee flexion; resisting knee flexion its eccentric. Only towards terminal swing there may be some activity for the quadriceps to make the leg swing along with gravity. So, that action may be concentric, but you cannot so the EMG does not tell you whether the action is concept; the signal just says this muscle is active and this is the strength of the signal. But it does not tell you whether its eccentric activity or concentric activity. You have to look at the picture or big picture to see what kind of activity is happening at that stage of the gait cycle.

So, this activity here where it is trying to flex the knee, help gravity flex the knee and this you will find is especially important when you have artificial limbs, because, many artificial limbs will be lighter than the not the limb that it replaces. And there is a reason for that, because you do not have the same level of muscular and neural control when a person has an artificial leg. So, you tend you make the prosthesis lighter, but that can actually affect the swing. Because, in the normal limb you know if you have a certain weight and it swings forward without muscle activity; in the case of the prosthetic limb it may not reach the end of swing because it does not have enough inertia to do that, ok. The gravity cannot alone make it swing forward like that.

And so, you may need what is called an extension assist, you want something that will help because you do not have the quadriceps muscle you know if the amputation is above the knee joint. The knee here you have the quadriceps acting to help extend the swinging leg, which would be absent in the case of prosthetic leg. And so, you may have to have an additional extension assist in order to help and do that. But that is what so the quadriceps acts with gravity; here it is concentric action because it is actually actively extending the knee. In these two cases it is resisting the flexion of the knee ok.

So, these two are eccentric, this is concentric action in the quadriceps, ok. Hamstrings it is essentially eccentric action, because it is trying to prevent its resisting the extension of the knee providing resistance to that. Hip flexors this is concentric action, because you are actively flexing the hip. This again is concentric action here, because you are moving the hip towards extension.

In the case of the triceps surae midstance to terminal stance they are lifting putting the foot into plantar flexion. So, if you see here, here this pushing off you have significant activity in the triceps surae at the push off stage to propel you know you are pushing off on the ground ok. So that activity is concentric activity because you are causing active plantar flexion of the ankle to push against the ground and generate the forward propulsion, ok.

Tibialis anterior, if you see here in the loading response face what is happening remember its resisting the plantar flexion. So, this is eccentric action here. And during swing, remember I told you the tibialis anterior is the ankle dorsiflexor. During swing what is one of the functions you have to clear the ground, you need foot clearance. And so during swing this action is concentric; during initial to mid swing it is concentric action to keep the foot slightly dorsiflexed so that it can clear the ground more easily. And then towards the end it again becomes eccentric action, because its preparing for to resist that foot slap. So, its starting to prepare for that.

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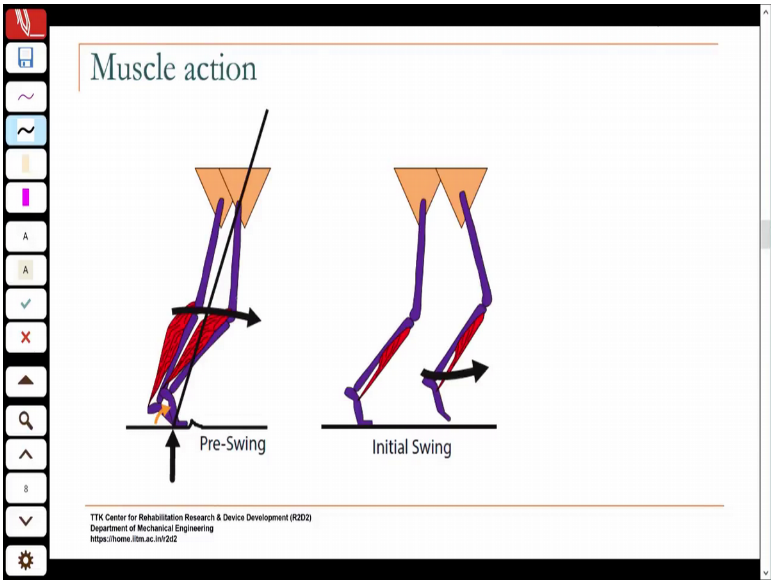

So you see here, in pre swing you have the triceps causing this active plantar flexion and then initial swing you see the tibialis anterior acting to lift the foot off the ground. Because, the foot is in a highly plantar flexed state where it lifts off the ground and then as its swings forward if you are still in that plantar flexed state you are going to stub your toe and fall ok.

So to enable that foot clearance now the tibialis anterior dorsiflex is the foot. This is another challenge in people with paralysis of the tibialis anterior. If they have paralysis of that muscle then this the foot will tend to hang like that. And that can lead to pathological gait, as we will see shortly when we look at gait other than what is considered normal, ok.

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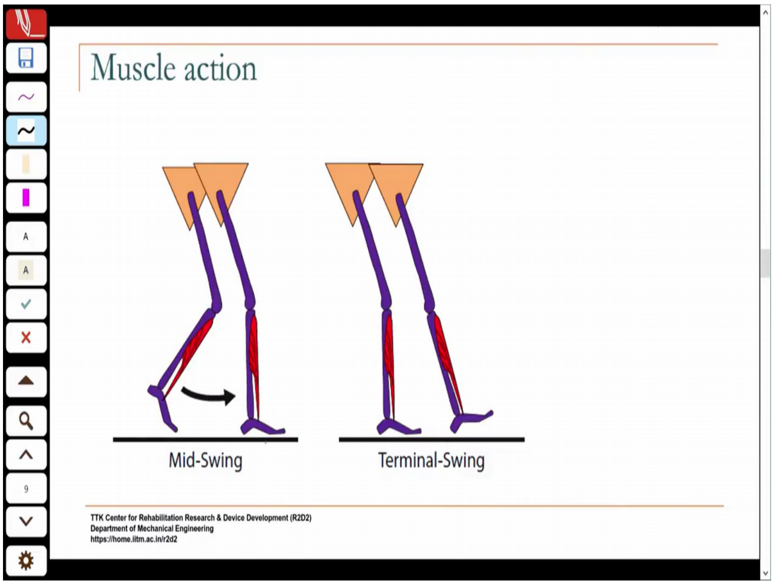

So, again mid swing you see though it brings the foot back to the neutral position and then you have terminal swing.

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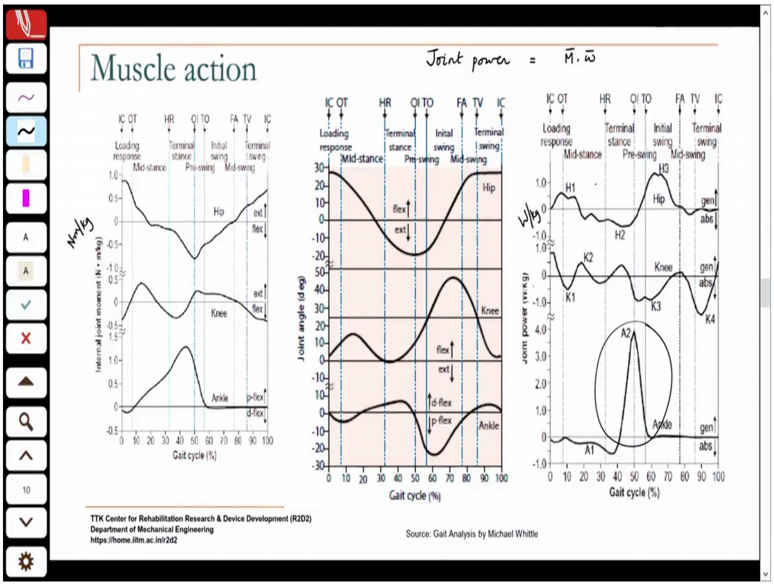

So if you look at, you have the joint motions here. So, what is your power? Joint power is M dot omega; internal joint moment dot product of that with the angular velocity vector. That is your definition of joint power.

So, if you look at this then when your internal joint moment is in the same direction as the angular velocity of the joint then you have power generation. That means it is the muscle is undergoing concentric action you have power generation. Then when you have, when the muscle is resisting or when its slowing it down right then you have power absorption. And you can see here like at the knee for instance there is more power absorption than generation. At the hip, the primary power generation is initially when you are extending the hip and then when you are flexing in swing ok.

So, we will not go into this in a lot of detail, but just you should be able to, because this can be you know whole series of understanding the power transfer between the various limbs is for; it can be pretty complicated for a first time introduction to gait so we will. But you can in general if this if the moment is in the same direction as the angular velocity then you have power generation otherwise you have power absorption. And in the knee if you look at it the primary function is power absorption. So, in most cases that is where you have eccentric action at the knee; the majority of the action knee is eccentric resisting the movement.

And if you look at the three joints the maximum power generation occurs at the anchor in the push off phase. Terminal stance to pre swing the push off phase you can see that maximum power is generated. So, usually these joint moments and powers are all normalized by the body mass. So, you have here the unit here is Newton meter per kg for the joint moment. And this is watt per kg for the joint power ok, so that gives you an idea of.

So knowing this is necessary, because when you are trying to design to compensate you know if you. So, understanding this mechanism of human walking is necessary because if you want to design devices that can enable a person to walk in the absence of their at anatomical joints and muscles and all that. Then, you have to understand the functions that are performed at various stages of the gait cycle. So for instance, you know how do you provide power generation at the ankle for efficient walking, how do you provide power absorption at the knee for efficient walking you know.

The hip in most cases is because most people will have. So, if you are talking about a person with an amputation they will still have some of their hip muscles intact, not how much of their hip muscles is intact will depend on the length of the residual limb, how much you know where it was cut off. But, they will have some control over the hip joint. So, if you have an artificial knee and an artificial ankle what should they be able to do and even in the hip you may not have the same level of power generation and absorption ok. So, when we talk about assistive devices we will discuss that.

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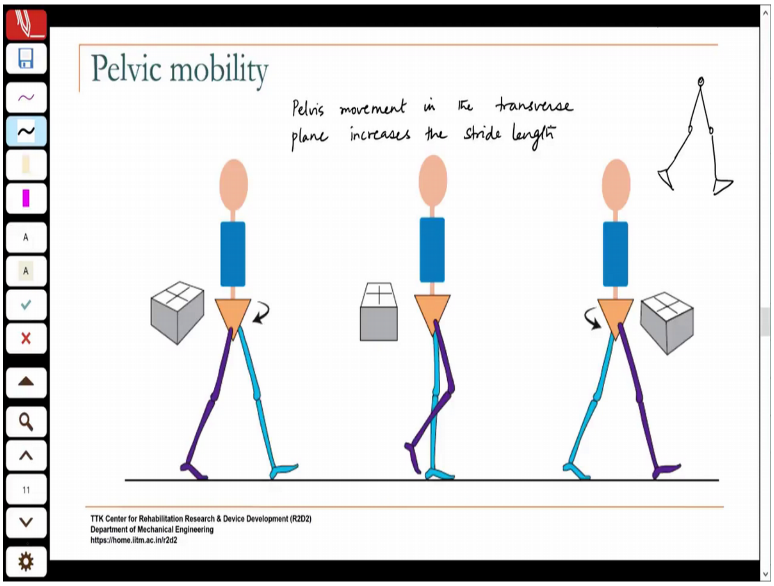

So, if you look at the pelvis, we have mainly looked at the motions in the sagittal plane, because that is where the predominant motions at the hip knee and ankle occur. But the frontal plane motions also have some influence on the gait. And one of the main influences is one is of course balanced, but the other one is if you look at the pelvis from the transverse plane if you look at it. So this is, if you look at it from the transverse plane there is the pelvis moves back and forth, and that actually helps to increase your step length ok.

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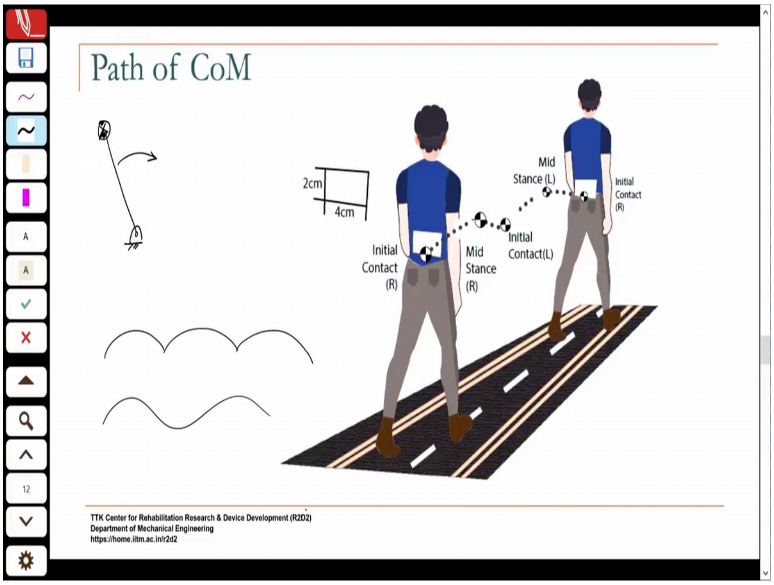

So, if you did not move your pelvis at all, you would have you know in the transverse plane you would have a particular step length. Say if you just have like a stick right and the pelvis did not move then you know this point is; but, because the pelvis also has this movement in the transverse plane you are able to get increased stride lengths. So, that again improves the metabolic cost, because you are able to cover greater distances with the same set of motions.

So, the pelvis movement in the frontal plane sorry in the transverse plane increases the stride length. If you look at the center of mass of the body then; so its not just our goal with walking is to move it forward ok. If you are walking you are moving it you are moving the. But in addition to the moving forward the center of mass actually has an up and down trajectory ok; sort of a sinusoidal trajectory. So, it moves in this kind of a rectangle. So, it also moves in the lateral direction.

So, you have the center of mass moving up and down if you look at it from the sagittal plane and then its also moving if you look at it from the transverse plane you will see that its also moving sideways, because every time you shift you are shifting your weight from one leg to the other. And as that is happening the center of mass is also having a trajectory in the you can see that its moving in that fashion in the transverse field.

So, it sort of reaches its highest point during mid stance because, at mid stance you will remember that the knee is now fully extended and you are pivoting about the ankle; you have the ankle rocker right. So, if you think of it as. And many models of walking, there are many simplified models of walking which basically model walking is an inverted pendulum. So, if you have the center of mass, so the stance can be modeled as an inverted pendulum ok. So, in the mid stance face is when you have the highest location of the center of mass and then it falls down and then you know now it shifts to the other leg and then the sort of the same thing happens. So, its actually like this ok.

But, because of the flexion at knee movements at the other joints this movement gets smoothened out to something like that. The movement of the center of mass instead of it being a series of sharp arcs like that as you would predict from the inverted pendulum model you actually have a smooth trajectory because of the. So, knee flexion during loading response; for instance contributes to lowering the trajectory of the center of mass; it is to smoothing the trajectory of the center of mass.

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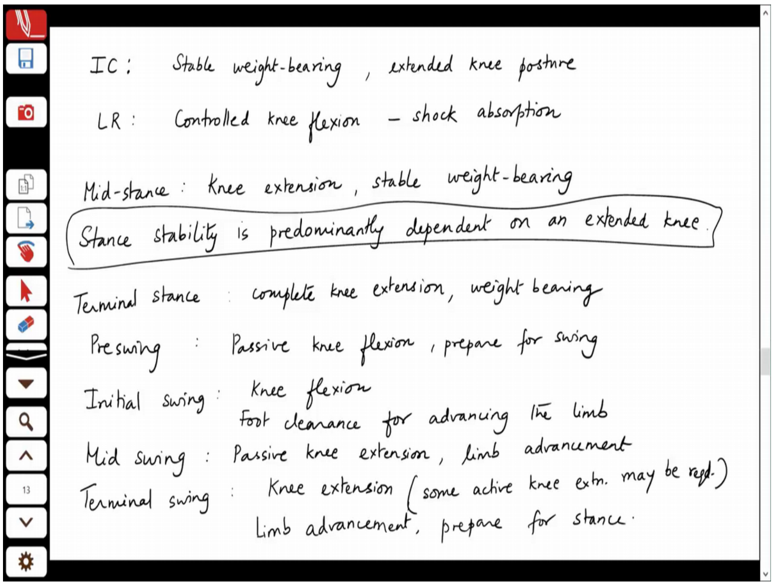

So, if you look at these functions that they have to perform at initial contact, if you look at this. So, stabilizing the knee is a key component of walking. So, at initial contact basically stable weight bearing is the key; so transferring the weight while maintaining stability of the knee. And so you have an extended knee posture. So, when it at initial contact the posture that you require for the knee you want the knee in extension full extension, because you want the stable weight bearing. In the loading response phase you have some knee flexion; you have controlled knee flexion and this serves the purpose of shock absorption.

Again if you look at the knee, knee extension is the key it stays extended and need because you need to have stable weight bearing. So, stand stability at any time is optimal when the knee is extended ok, it does not matter so much what the other two joints are doing. But, because the knee is the joint in between those two limbs stance stability is predominantly dependent on an extended knee. So, this is something that is very important, this function of the knee is extremely important. Maintaining the knee in extension at the right stages of the gait cycle is key to ensuring stability.

Then terminal stance you are basically looking to the knee can now starts to flex and you want to have as much flexion as possible in order to have a good stride length; because, if you do not move the weight to the forefoot sufficiently then your stride length is automatically going to be shorter right; so the more. So, if you if you take when you when you take longer steps, if you look at the knee you are going to flex it more right. So, you need sufficient knee flexion ok, end of extension then you need to have sufficient knee flexion in order to have a good step length or stride length right; assuming symmetric steps stride length is.

So, you are trying to maximize, because in walking you are trying to maximize the distance traveled. And so if you can take longer steps then you are for the same you know; of course you start walking then it becomes again we have to go back to these self selected the body is optimizing the energy consumption. That is why you have a certain self selected walking speed. But for that particular walking speed if you do not have sufficient knee flexion, so the knee flexion has to be sufficient in order to ensure the a good stride length. To achieve that you know 1.3 to 1.4 meter per second; that that is the average self selected walking speed optimal walking speed. So, you need to have.

So, you can see here this you need to have sufficient flexion in order to be able to swing through for a good step length. So, the objective is to complete knee extension, terminal stance you are still weight bearing, but you are starting to prepare for swing ok. So, you have in the pre spring phase when the other leg has now taken over the; is taking over the weight bearing function you want to flex the knee. So, you have passive knee flexion to prepare for swing. In the initial swing phase you need knee flexion and foot clearance is important for advancing the limb. And that is where the dorsi flexors come into play; active ankle dorsi flexion is responsible for providing the foot clearance.

Mid swing: now you have passive knee extension predominantly gravity is responsible, but there may be some activity from the quadriceps as well. And again the function is to advance the limb. And in terminal swing you have knee extension and now you may actually need active knee extension. Some active knee extension may be required why? because if you want to prepare the limb for the next stance phase, then the knee has to be in fully extended position when you hit the ground. If you hit the ground on a flexed knee your stability is compromised ok.

So, some active knee extension may be required, because you want to not only advance the limb but you want to prepare for the next stance phase. So, that is important. So, terminal swing is also very important because, you need to be ready for the next weight bearing phase. So, maintaining the stability of the knee again becomes important; which means if the stability of the knee has to be maintained, it means it has to be fully extended by the end of swing. So, you have to do what it takes to extend the knee fully to prepare for the next stance phase.

So, we have looked at if you remember the functions of the knee at the various stages of gait then you will have a good idea about what are the muscles that are needed to make that happen. Two broad functions you have weight bearing you have limb bond advancement. These are the two broad functions while forward progression is happening; that is the function of gait. Walking is to move the center of mass forward by ensuring stability when there is weight bearing and the limb advancement during swing.

So, if you can if you can keep that picture you know the reason I keep coming back to that gait cycle, if you can keep that picture in mind then the rest of it actually becomes intuitive. So, you can get a good idea of ok; if this needs to move from this to this where does the control need to happen, where does you know activity have to happen to make this successful ok.

So, that will help you know which are the key muscles that are necessary for gait. So, we saw hip extensors flexors, knee extensors flexors, flexors not so much at the knee its mostly passive knee flexion that is happening, but knee extensors the quadriceps are very very critical for gait. Similarly ankle its the dorsi flexors and the plantar flexes. The plantar flexes four push off the dorsi flexors for foot clearance. Knee muscles predominantly stability; extend the knee for stability keep the knee extended for stability ok. So, that is the function of the knee.

The advancement happens because of the hip flexion and the then the action of gravity hip. Flexion causes the limb to lifts from the ground you need that to lift the limb unload the limb and lift it off the ground and then with the aid of gravity the limb advancement happens ok.

So, we will continue and we will start looking at pathological gait from the next class.