3-5-Motions of the Pelvis during walking:

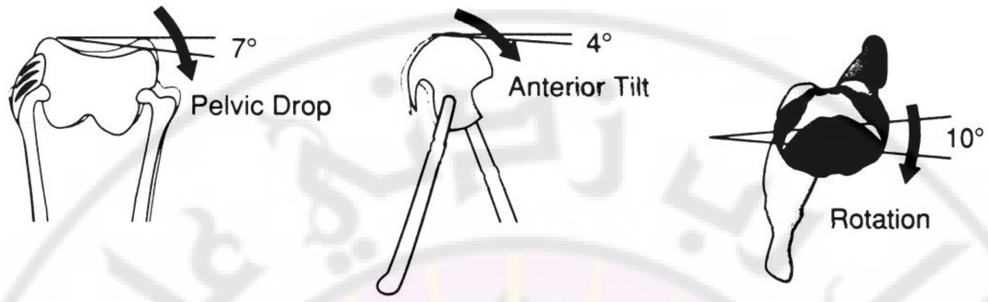


Figure 7.3 Motions of the pelvis during walking: Contralateral pelvic drop (7°), anterior tilt (4°), transverse rotation (10°).

Figure 3.1 Motion of the pelvis during walking

3-5-1-Pelvic movement in the sagittal plane:

Rotation of the pelvis about a M-L axis during walking occurs in the sagittal plane and is commonly known as anterior and posterior tilting (A-P tilting). The amplitude of this movement is about 4 degrees. A-P tilting of the pelvis displays a biphasic curve for one complete walking cycle (Fig. 3.2).

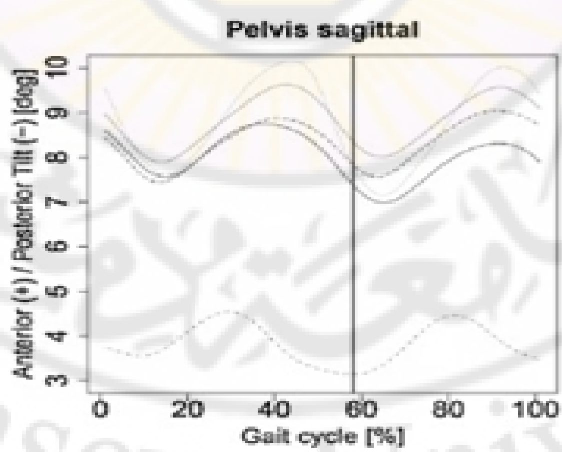


Figure 3.2 A-P Pelvic tilt

The mean pelvic A-P tilt angle during normal standing, which is essentially the point about which the A-P tilt movements of the pelvis oscillate, is approximately 11 degrees of anterior tilt. It was found that as the speed of walking increases, the mean pelvic A-P tilt angle becomes more anteriorly tilted.

The biphasic oscillation for one gait cycle can be described as follows. During the absorption period of stance phase, at the beginning of the stance phase, the pelvis posteriorly tilts slightly to reach a position of minimum anterior tilt. After mid-stance, the pelvis then anteriorly tilts, reaching a position of maximum anterior tilt around toe off. The pelvis then posteriorly tilts slightly during initial swing before anteriorly tilting again during terminal swing. This second posterior and anterior tilt during swing is produced by the stance phase forces of the contra-lateral lower limb. The pattern of A-P tilting of the pelvis is similar at all walking speeds. Likewise, the amplitude of A-P tilting appears to increase very little with faster walking speeds. It is thought that A-P tilting of the pelvis needs to be minimized to conserve energy and maintain efficiency in walking.

3-5-2- Pelvic movement in the coronal plane:

Rotation of the pelvis about an A-P axis during walking occurs in the coronal plane and is commonly known as pelvic obliquity or lateral pelvic tilt, The amplitude of this movement is about 7 degrees.

The pattern of pelvic rotation about an A-P axis during normal walking is shown in Fig. 3.3. At heel strike the pelvis is obliquely aligned, being slightly higher on the stance (ipsilateral) side and slightly lower on the swing (contralateral) side. Pelvic obliquity is thought to play a role in shock absorption and in controlling the smooth descent and ascent of the body's centre of gravity at this time. By mid-stance, the pelvis becomes horizontal. The pelvis then continues to elevate on the swing side, reaching a maximum downward obliquity on the stance side around toe off. During the swing phase, the pelvis then begins to rise on the initial swing side and lower on the terminal swing side as it approaches foot strike. During the remaining mid and terminal ipsilateral swing though, the pelvis then continues to rise on this side until maximum upward obliquity is reached during terminal swing. The elevation of the swing side pelvis during terminal swing maintains foot clearance as the swing side hip and knee are extending.

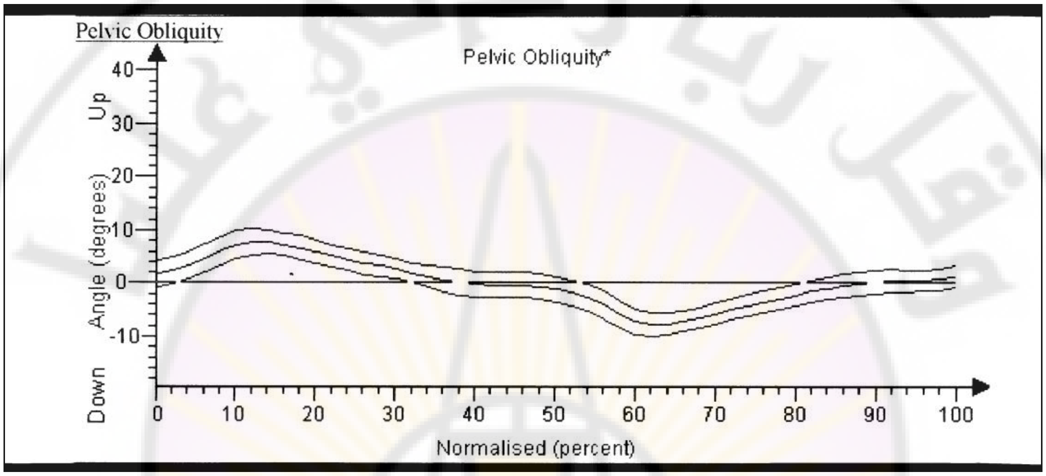


Figure 3.3 pelvic obliquity

3-5-1-Pelvic Rotation:

Rotation of the pelvis about a vertical axis during walking occurs in the transverse plane and is commonly known as axial rotation or internal and external rotation. Internal pelvic rotation is when the reference side of the pelvis is anterior and external pelvic rotation is when the reference side of the pelvis is posterior. At the customary cadence and stride of average persons, the magnitude of this rotation is approximately 4 degrees on either side of the central axis, or a total of some 8 degrees. The pattern of pelvic rotation about vertical axis during walking is illustrated in Figure 3.4.

The pelvis internally rotated during initial stance in walking, in order to increase stride length, which continues to increase until a maximal position of internal rotation is reached around midstance. During terminal stance the pelvis begins to externally rotate on the stance side and continues to increase until the beginning of swing phase. The pelvis then internally rotated and continues to rotate until the end of the swing phase.

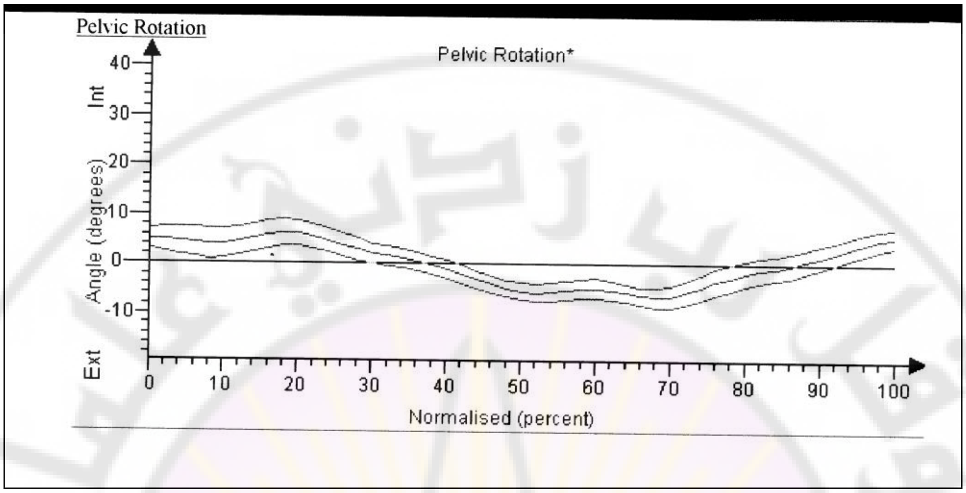
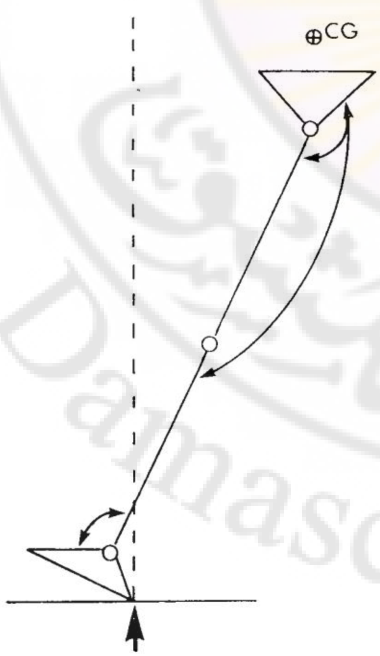


Fig. 3-4 Pelvic rotation

Chapter 5-Normal Human Locomotion

Normal human locomotion 7

Fig 5. Heel strike



Reaction:

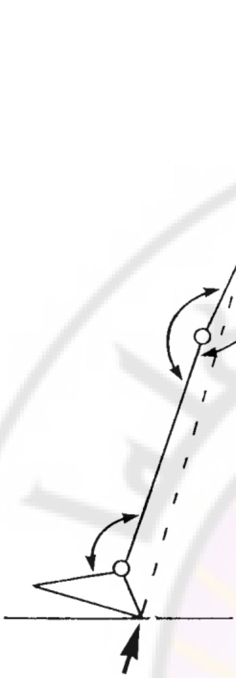
Anterior to hip causing flexion moment. Anterior to knee causing extension moment. Posterior to ankle causing plantarflexion moment.

Hip is flexed to 25°. The gluteus maximus and hamstrings are active in preventing further flexion.

Knee is in full extension at heel strike. The extension moment is overcome by action of the hamstrings which controls knee extension and initiates flexion.

Ankle is in neutral position then begins to plantarflex. This plantarflexion is controlled by action of the pretibial muscles.

Fig. 6. Shortly after heel strike



Reaction:

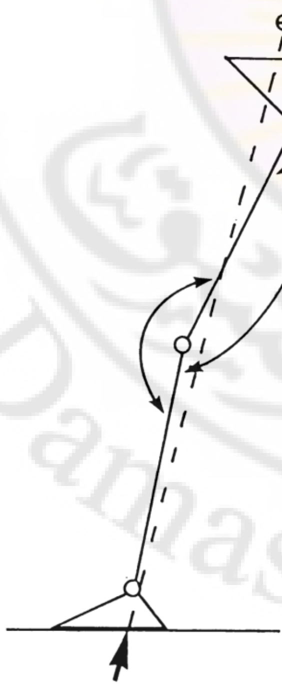
Anterior to hip causing flexion moment. Posterior to knee causing flexion moment. Posterior to ankle causing plantarflexion moment.

Hip is held in 25° of flexion by action of gluteus maximus and the hamstrings.

Knee is in 5° of flexion and continues to flex. The rate of flexion is controlled by action of the quadriceps.

Ankle is in 5° of plantarflexion and continues to plantarflex under the control of the pretibial muscles.

Fig. 7. Foot flat



Reaction:

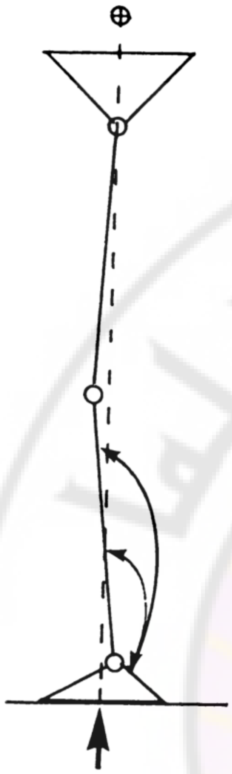
Anterior to hip causing flexion moment. Posterior to knee causing flexion moment. Posterior to ankle causing plantarflexion moment.

Hip is in 25° of flexion then begins to extend by action of gluteus maximus and the hamstrings.

Knee reaches 15° of flexion and continues to flex until it reaches 20° shortly after foot flat It then begins to extend. The quadriceps are active in controlling the angle of flexion.

Ankle is in 10° of plantarflexion. The plantarflexion moments reduce as the reaction moves along the foot and the pretibial muscle activity falls off. As the ground reaction passes anterior to the ankle joint the segments of the supporting limb begin to rotate over the fixed foot.

Fig 8. Mid stance



Reaction:

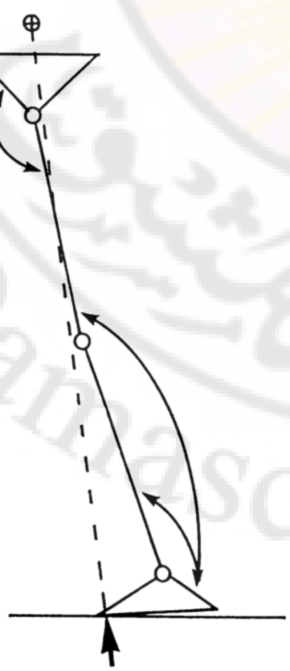
Passes through hip joint, no moment. Posterior to knee causing a flexion moment. Anterior to ankle causing dorsiflexion moment.

Hip is in 10° of flexion and continues to extend as the ground reaction moves posterior to the hip joint shortly after mid stance.

Knee reaches 10° of flexion and continues to extend. Quadriceps action has fallen off and it is suspected that the soleus is active in controlling knee flexion.

Ankle 5° of dorsiflexion and continues to dorsiflex due to ground reaction. The dorsiflexion is controlled by the calf group of muscles which begins to display activity.

Fig. 9. Heel off



Reaction:

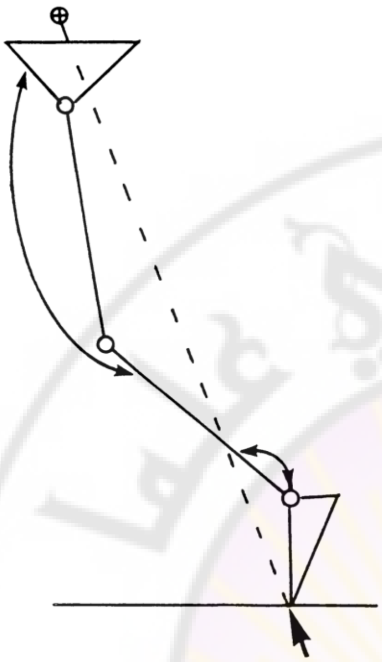
Posterior to hip causing extension moment. Anterior to knee causing extension moment. Anterior to ankle causing dorsiflexion moment.

Hip reaches about 13° of extension then begins to flex. The iliacus and psoas major are active in controlling extension and initiating flexion.

Knee is flexed to about 2°, which is the maximum extension reached at this point in the gait cycle. The gastrocnemius may be active in preventing further extension.

Ankle reaches 15° of dorsiflexion after which it plantarflexes due to a powerful contraction of the calf muscles which counteracts the dorsiflexion moment and assists in propelling the body forward.

Fig. 10. Toe-off



Reaction:

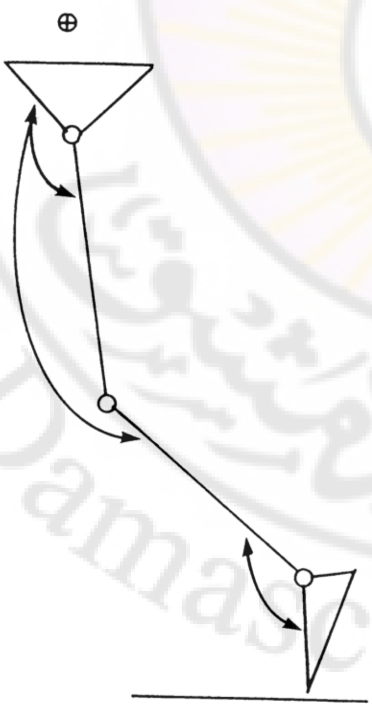
By toe-off the reaction has lost most of its significance as the majority of weight is borne by the other foot.

Hip is in 10° of extension and continues to flex due to the plantarflexion of the foot and activity of the rectus femoris.

Knee is flexed to about 40° and continues to flex under the small ground reaction moment and plantarflexion of the foot.

Ankle has reached 20° of plantarflexion due to contraction of the calf muscles. These muscles become inactive directly after toe off.

Fig. 11. Acceleration

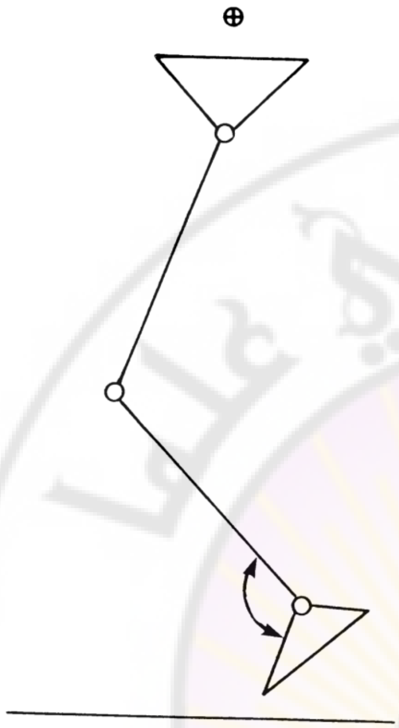


Hip is in 10° of extension and flexes as the hip flexors accelerate the limb forward.

Knee is in 40° of flexion and continues to flex under pendulum action as the limb accelerates.

Ankle is in 20° of plantarflexion directly after toe off. It then begins to dorsiflex under action of the pretibial group of muscles.

Fig. 12. Mid swing

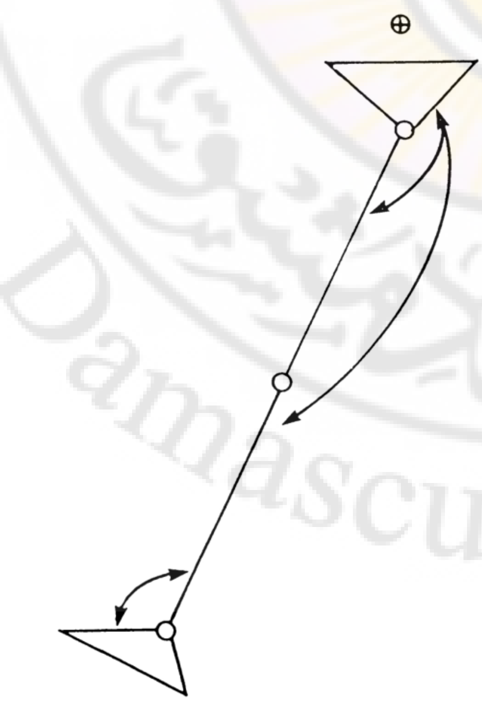


Hip is flexed to about 20° and continues to flex.

Knee reaches about 65° of flexion then begins to extend under pendulum action.

Ankle has reached its neutral position and is held there by slight activity of the pretibial muscles.

Fig. 13. Deceleration



Hip reaches 25° of flexion and is restrained by gluteus maximus and the hamstrings.

Knee is in full extension and restrained by the hamstrings.

Ankle is still held in the neutral position by action of the pretibial muscles.

The hip, knee and ankle are now positioned for the following heel strike. All the muscle groups that are necessary to counteract the ground reaction force are now active.

Chapter 6

Joint moments

6-1-Ankle joint moments in the sagittal plane (around Z axis):

Figure (6.1) shows the moment about Z axis of the shank at the ankle joint of 5 normal subjects during the gait cycle walking at normal walking speed.

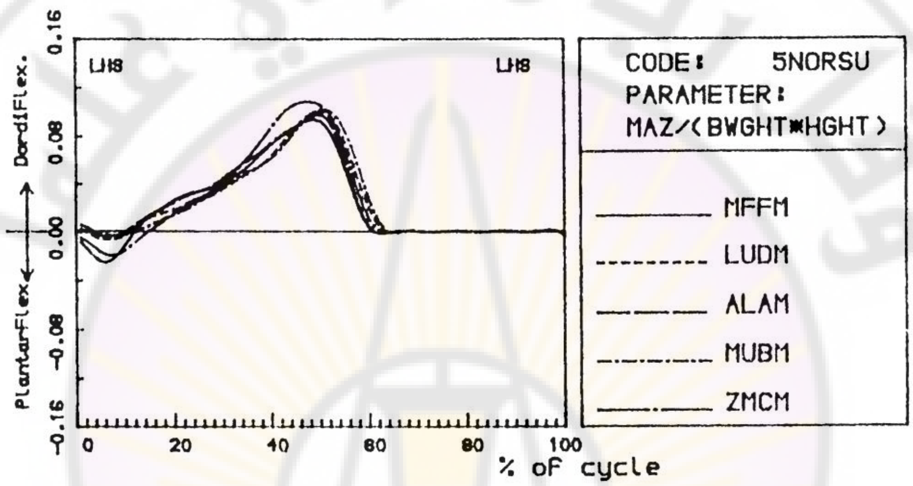


Figure 6.1 The ankle joint moment about Z axis of the shank of 5 normal subjects

At initial contact, floor contact by the heel places the body vector behind the ankle. This prepares the limb for the loading response action needed to preserve progression and provide shock absorption. After heel contact, with the body vector posterior to the ankle, rapid loading of the limb (60% BW by 2% of the gait cycle) immediately generates a plantar flexion moment that drives the foot toward the floor. This plantar flexion moment continue until about 12% of the gait cycle. The mean value of this moment is about 13 Nm (ranging from 0 to 43 Nm), this is influenced by the walking speed and the way the subject walks. The pretibial muscles decelerates the rate of ankle plantar flexion (passive foot drop) and active tibial advancement roll the body weight forward on the heel. After the forefoot contact the floor (foot flat) the motion changes from the foot to the leg (shank) causing changes of the moment from plantar to dorsi-flexion. Throughout mid stance the body vector advances across the foot in response to momentum from the swing limb and forward fall of body weight. This creates an increasing dorsiflexion moment that rolls the tibia forward from an initial 8^{o} plantar flexed position to 5^{o} dorsiflexion, while the heel and forefoot remain in contact with the floor. The soleus and gastrocnemius muscles (posterior tibialis muscles) reacts quickly to restrain the initial rapid rate of ankle dorsiflexion that follows forefoot floor contact. By the end of mid stance the heel rises as the tibia continues to advance and base of the body vector lies in the forefoot. With the body vector based in the area of the metatarsal heads the dorsiflexion lever (moment arm) is the full length of the forefoot. This combined with the maximal dorsiflexion moment at the ankle (about 113 Nm, range from 50 to 142 Nm). At the time of contralateral foot floor contact, rapid transfer of body weight begins. As a result the dorsiflexion moment decreased rapidly until it reach zero value at the time of toe off the ground (if the inertia forces are neglected).

6-2-Ankle joint moments in the frontal plane (around X axis):

Figure (6.2) shows the moment about X axis of the shank at the ankle joint of 5 normal subjects during the gait cycle walking at normal walking speed. The inverting/everting (valgus/varus) moment at the ankle "MAX" tends to evert the ankle throughout the stance phase. This moment stabilizes the foot as weight is transferred over the support limb. This suggested that the centre of pressure was on the lateral side of the foot throughout stance phase. The average maximum value of this moment is about 30 Nm (about 2% of body weight and height).

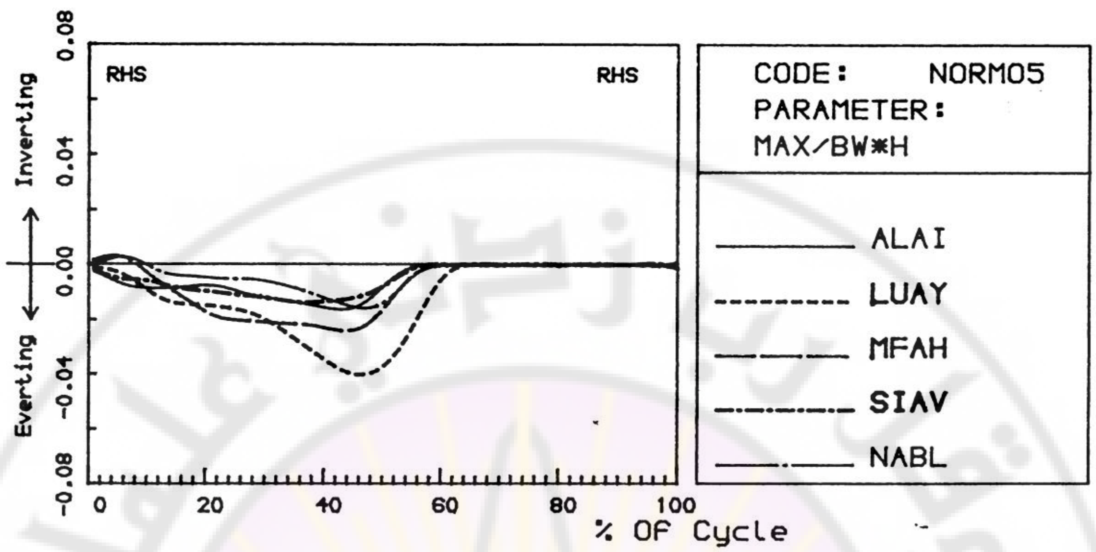


Figure 6.2 The ankle joint moment about X axis of the shank of 5 normal subjects

6-3-Ankle joint moments in the horizontal plane (around Y axis):

Figure (6.3) shows the moment about Y axis of the shank at the ankle joint of 5 normal subjects during the gait cycle walking at normal walking speed. The internal/external rotating moment of the ankle has a small external moment which started from heel contact to about 23% of the gait cycle. The average maximum value of this moment is about 6 Nm (0.5% BW*H). This is followed by a pronounced internal moment which reaches to a maximum value around the heel off. The average maximum value of the internal moment is about 15 Nm (1.3% of BW*H). The change of the rotation moment from external to internal is related to the changes of the ground reaction force FX.

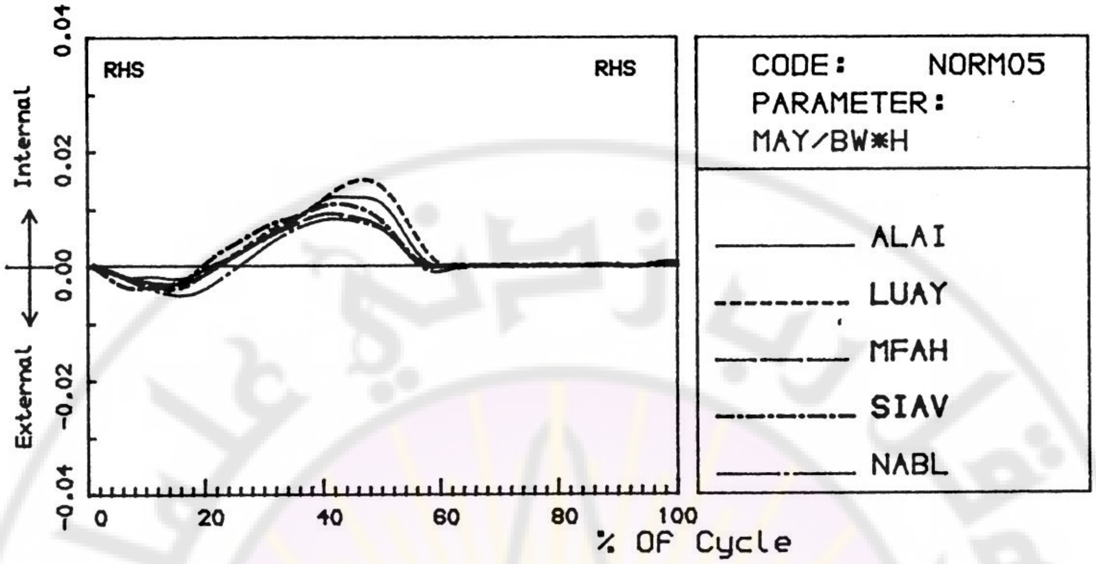


Figure 6.3 The ankle joint moment about Y axis of the shank of 5 normal subjects

6-4-Knee joint moment in the sagittal plane (around Z axis):

Figure (6.4) shows the moment about Z axis of the shank at the knee joint of 5 normal subjects during the gait cycle at normal walking speed.

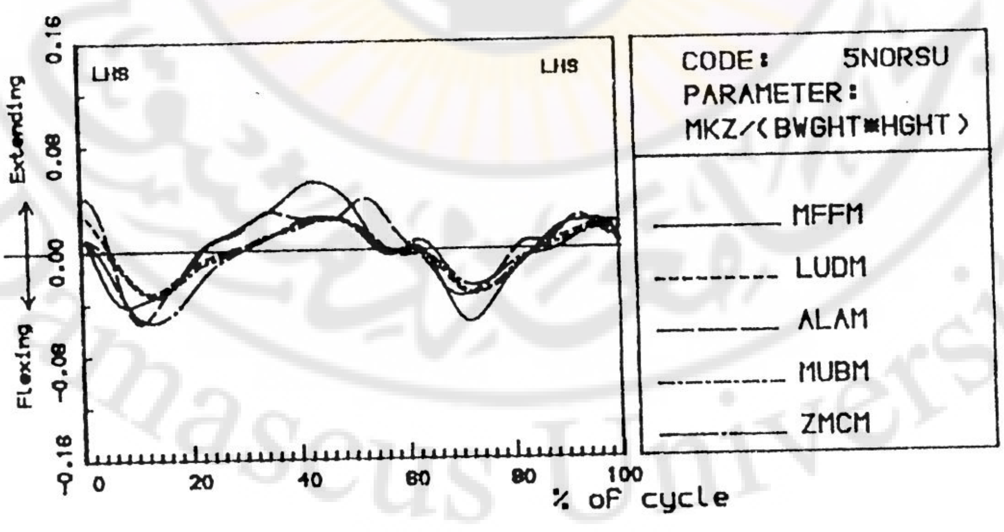


Figure (6.4) the knee joint moment about Z axis of the shank for 5 normal subjects

During stance phase the relationship of the body weight vector to the knee creates four moment patterns. The sequence is lock-unlock-lock-unlock or extension-flexion-extension-flexion as the limb moves through the gait phases.

At initial contact the ground reaction force is anterior to the knee. This provides an extension moment during the initial 7% of the gait cycle. Its average maximum value is about 21 Nm (6.6 to 38 Nm). As body weight drops on the limb during the loading response, the vector rapidly aligns itself with the source of the ground reaction force. This moves the weight line back toward the body centre. By the 7% in the gait cycle the vector reaches the knee joint centre and then progressively becomes more posterior. A flexion moment of increasing magnitude is introduced. This results in a moment of about 50 Nm by the end of loading response. With the onset of single limb support (early mid stance), the relationship between body mass and the supporting limb begins to change. This reverses the direction of the vector. The effect is a progressive decline in the knee flexion moment. By the middle of mid stance (around 26% GC), zero moment is reached. Further advancement of the body mass over the supporting foot moves the vector anterior to the knee. An extensor moment is generated that progressively increases until the middle of terminal stance (42% GC). A mean peak extension moment of 30 Nm is generated. After that the body weight line moves closer to the knee, with zero moment occurring at the end of single limb support (around 55% GC). In pre-swing the vector again moves posterior to the knee, creating a flexion moment.

During swing phase, the knee is subjected to flexion moment during the first half of swing phase. The mean peak flexion moment is about 40 Nm.

During the second half of swing phase, the knee is subjected to extension moment. The mean peak extension moment is about 35 Nm. The value of knee moment during swing phase is influenced by walking speed and the mass of shank and foot.

6-5-Knee joint moments in the frontal plane (around X axis):

Figure (6.5) shows the moment about X axis of the shank at the knee joint of 5 normal subjects during the gait cycle at normal walking speed.

The adducting/abducting (valgus/varus) moment at the knee "MKX" tends to adduct (valgus) the knee throughout the stance phase. This moment stabilizes the knee as the external force vector lies medial to the knee joint (FZ is always directed to the medial side). The average maximum value of this moment is about 36 Nm (about 3% of body weight and height). It is noted that the pattern of this moment has two peaks and a valley. The first peak occurs at about 18% of gait cycle while the second peak occurs at about 54% GC, this coincide with the changes of the vertical ground reaction force.

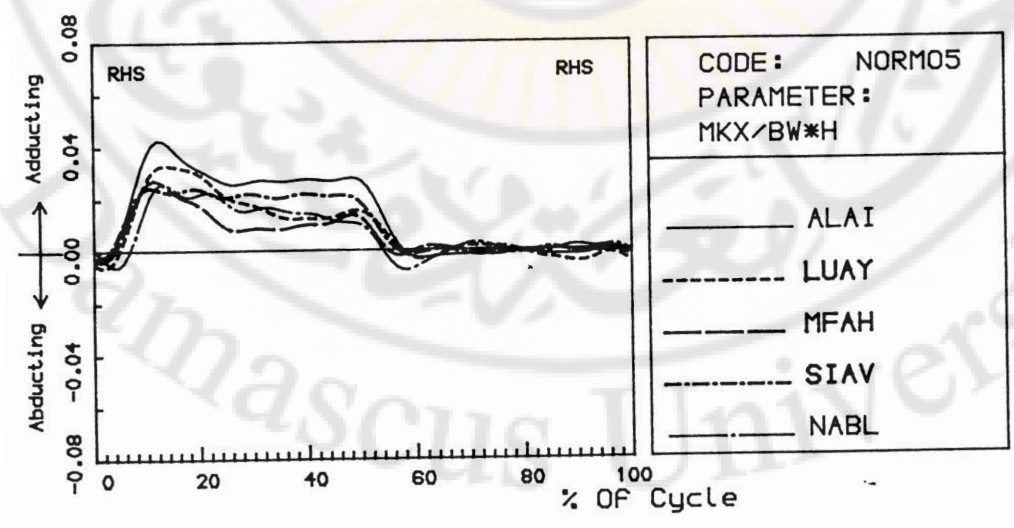


Figure 6.5 The knee joint moment about X axis of the shank of 5 normal subjects

6-6-Knee joint moments in the horizontal plane (around Y axis):

Figure (6.6) shows the moment about Y axis of the shank at the knee joint of 5 normal subjects during the gait cycle at normal walking speed.

The internal/external rotating moment of the knee has a small external moment which started from heel contact to about 23% of the gait cycle (35% of stance phase). The average maximum value of this moment is about 6 Nm (0.5% BW*H). This is followed by a pronounced internal moment which reaches to a maximum value around the heel off. The average maximum value of the internal moment is about 15 Nm (1.3% of BW*H). The change of the rotation moment from external to internal is related to the changes of the ground reaction force FX.

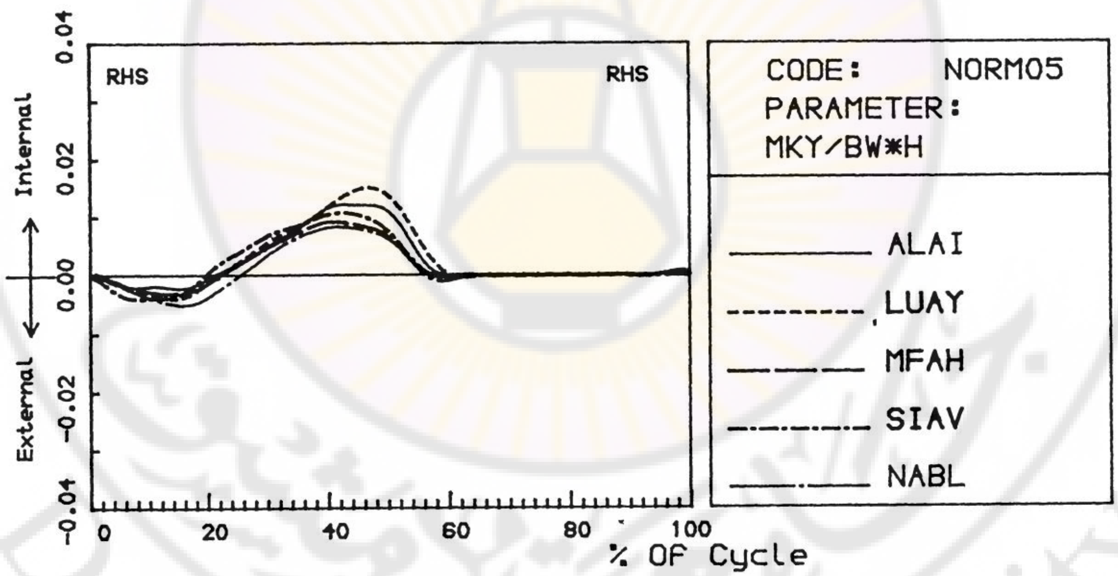


Figure 6.6 The knee joint moment about Y axis of the shank of 5 normal subjects

6-7-Hip joint moment in the sagittal plane (around Z axis):

Figure (6.7) shows the moment about Z axis of the thigh at the hip joint of 5 normal subjects during the gait cycle at normal walking speed.

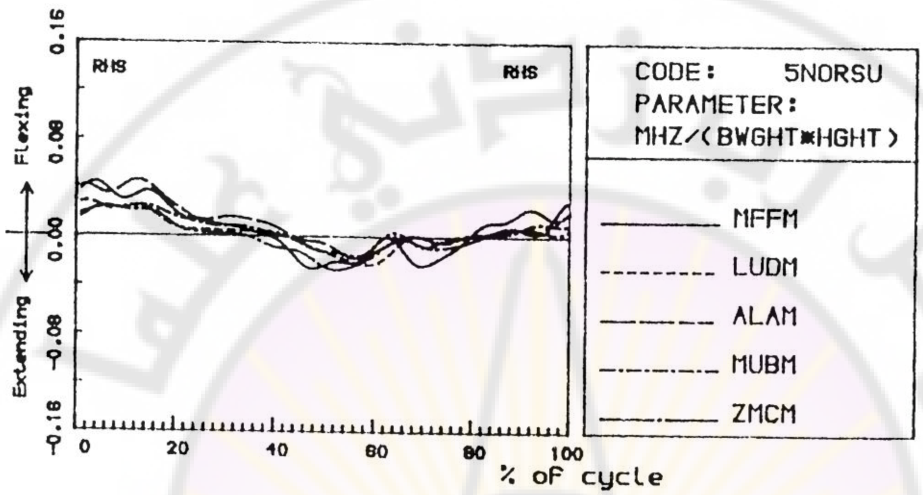


Figure (6.7) the hip joint moment about Z axis of the thigh for 5 normal subjects

The hip joint is subjected to a large flexion moment at initial contact, due to the body vector which is anterior to the hip joint. This flexion moment continues into mid-stance and begins to decrease as the centre of gravity moves over the supporting leg. The average maximum value of the flexion moment is about 40 Nm (ranging from 23 to 65 Nm) which occurs at about 12% of the gait cycle. The direction of the moment changes to extension at this point in time, increasing in magnitude from mid-stance to late stance to control the extension of the hip. The peak of hip extension moment (about 35 Nm) occurs as the foot leaves the ground (around 55% GC) and hip flexors actively initiate swing acceleration of the leg. During mid to late swing, a hip flexion moment is created by eccentric contraction of the hip extensors to decelerate the thigh. The average maximum value of this moment is about 21 Nm. The value of hip moment during swing phase is influenced by walking speed and the mass the lower limb (thigh, shank, and foot).

6-8-Hip joint moments in the frontal plane (around X axis):

Figure (6.8) shows the moment about X axis of the thigh at the hip joint of 5 normal subjects during the gait cycle at normal walking speed.

The adducting/abducting (valgus/varus) moment at the hip "MHX" tends to adduct the hip throughout the stance phase. This moment stabilizes the hip as the external force vector lies medial to the hip joint (FZ is always directed to the medial side). The average maximum value of this moment is about 65 Nm (about 5.5% of body weight and height). It is noted that the pattern of this moment has two peaks and a valley. The first peak occurs at about 18% of gait cycle while the second peak occurs at about 54% GC, this coincide with the changes of the vertical ground reaction force.

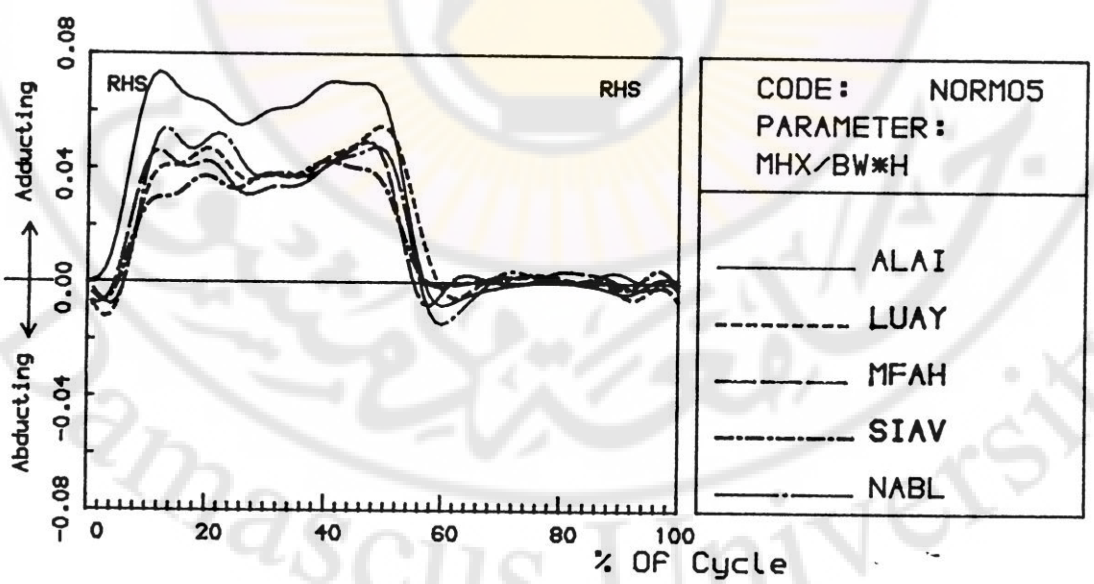


Figure 6.8 The hip joint moment about X axis of the thigh of 5 normal subjects

6-9-Hip joint moments in the horizontal plane (around Y axis):

Figure (6.9) shows the moment about Y axis of the thigh at the hip joint of 5 normal subjects during the gait cycle at normal walking speed.

The internal/external rotating moment of the hip has a large external moment which started from heel contact to about 30% of the gait cycle (43% of stance phase). The average maximum value of this moment is about 15 Nm (1.3% BW*H). This is followed by an internal moment which reaches to a maximum value around the heel off. The average maximum value of the internal moment is about 10 Nm (0.8% of BW*H). The change of the rotation moment from external to internal is related to the changes of the ground reaction force FX.

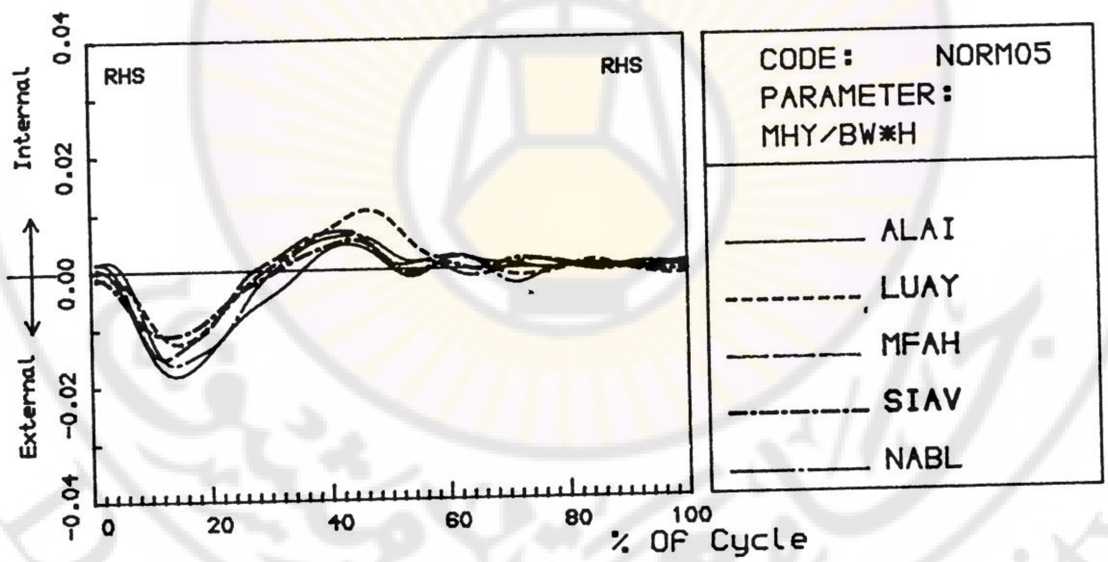


Figure 6.9 The hip joint moment about Y axis of the thigh of 5 normal subjects

Chapter 7

ENERGY EXPENDITURE

There are two ways to calculate the energy expenditure in the human body:

1-the metabolic energy

2-the mechanical energy

7-1-The metabolic energy:

The measurement of the oxygen consumption of the body provides a measure of the energy expenditure of the body. It is convenient to translate oxygen units into heat units such as the gram-calorie (cal.), which is the amount of heat necessary to raise the temperature of 1 g of water 1°C.

A conversion factor has been found:

1 ml oxygen/min $\xrightarrow{\text{gives}}$ 5 cal/min

1 l oxygen/min = 5 Kcal/min

Considering the body mass per kg and the speed of walking (v) in m/min, it has been found that the oxygen consumption in (ml/min) $\dot{V}O2$ is given as:

$$\dot{V}O2 /kg = 5.9 + 0.0011 V^2$$

By using the conversion factor we find:

$$E = 29.5 + 0.0055 V^2$$

Where: E is the energy expenditure in cal/min/kg.

From this equation we find that the energy expenditure is proportional to the body mass and the speed of walking.

7-2-The mechanical energy:

To discuss the mechanical energy of the human body, we will start with the definition of work.

7-2-1-Definition of work:

-If we apply a force F on a solid body, the body will move from point (1) to point (2) as shown in Figure (7.1).

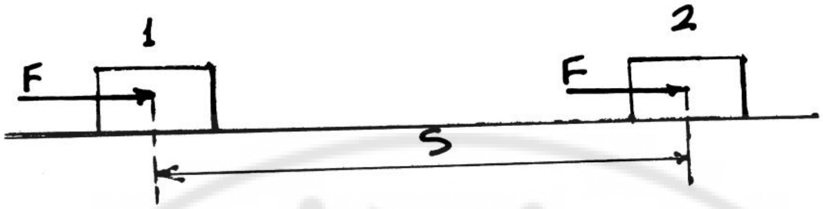


Figure (7.1)

Suppose that the distance between point (1) and (2) is S, we can find the work which has been done to move the body from point (1) to (2). This work is:

$$W = F.S$$

Where: W: work done (Nm) or (J)

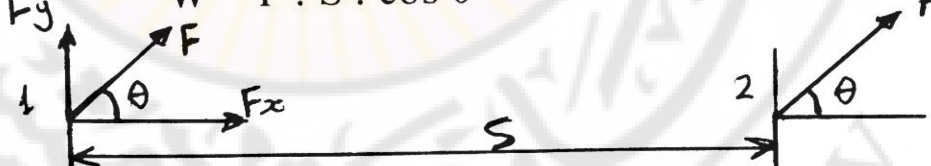
F : constant force (N)

S : displacement during the motion along the straight line (m)

-If the force is constant in magnitude but at a constant angle with a straight line displacement (see Figure 7.2) the work is:

$$W = F_x . S + F_y . 0$$

$$W = F . S . \cos \theta$$



الشكل (2-7)

Figure (7.2)

-In the case of three dimension of displacement (Figure 7.3):

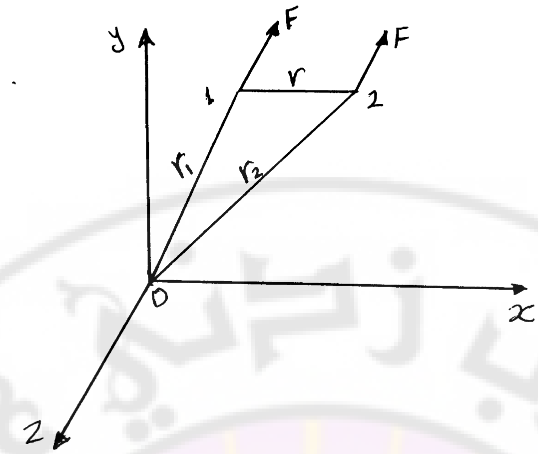


Figure (7.3)

The work is:

$$W = \vec{F} \cdot \vec{r}$$

or

$$W = \vec{F} \cdot (\vec{r}_2 - \vec{r}_1)$$

Since

$$\vec{F} = Fx\, i + Fy\, j + Fz\, k$$

$$\vec{r}_2 = x_2\, i + y_2\, j + z_2\, k$$

$$\vec{r}_1 = x_1\, i + y_1\, j + z_1\, k$$

We can write

$$W = Fx\,(x_2 - x_1) + Fy\,(y_2 - y_1) + Fz\,(z_2 - z_1)$$

7-2-2-The relationship between the work and the energy:

Let us consider a particle moving freely in the space under the action of applied force F and the gravity (Figure 7.4):

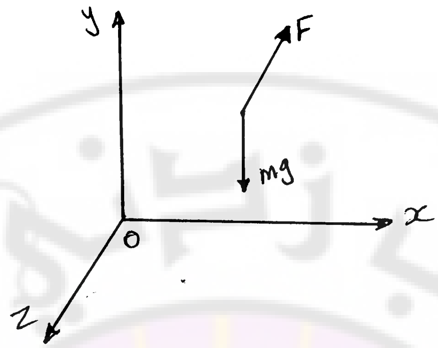


Figure (7.4)

According to the Newton's second law:

$$\sum \vec{F} = m\,\vec{a}$$

$$\vec{F} - m\vec{g} = m\,\vec{a} = m\,\frac{d\vec{V}}{dt}$$

$$\vec{F} = m\vec{g} + m\,\frac{d\vec{V}}{dt}$$

The power

$$P = \vec{F}\,.\,\vec{V}$$

Hence

$$P = m\vec{g}\,.\,\vec{V} + m\,\frac{d\vec{V}}{dt}\,.\,\vec{V}$$

$$P = mg\,V_y + \tfrac{1}{2}\,m\,\frac{d}{dt}(\vec{V}\,.\,\vec{V})$$

$$P = mg\,V_y + \tfrac{1}{2}\,m\,\frac{d}{dt}(V^2)$$

The work

$$W = \int_{t_1}^{t_2} P\,dt$$

$$W = \int_{t_1}^{t_2} \left(mg\,V_y + \tfrac{1}{2}\,m\,\frac{d(V^2)}{dt}\right) dt$$

$$W = mg\,(y_2 - y_1) + \tfrac{1}{2}\,m\,(V_2^2 - V_1^2)$$

The potential energy: $\Delta E_p = mg\,(y_2 - y_1)$

The kinetic energy: $\Delta E_k = \frac{1}{2} m\,(V_2^2 - V_1^2)$

Hence: $W = \Delta E_k + \Delta E_p$

In the case of human body segment, the kinetic energy has two parts:

$$\Delta E_k = \Delta E_k^T + \Delta E_k^R$$

Where:

ΔE_k^T : is the translational energy

ΔE_k^R : is the rotational energy

Hence the work is:

$$W = \Delta E_k^T + \Delta E_k^R + \Delta E_p$$

$$\Delta E_k^T = \frac{1}{2} m\,(V^2_x + V^2_y + V^2_z)$$

$$\Delta E_k^R = \frac{1}{2}\,(I_x\,\omega^2_x + I_y\,\omega^2_y + I_z\,\omega^2_z)$$

$$\Delta E_p = m\,g\,y$$

Hence:

$$P_1 = \vec{M}_1 \cdot \vec{\omega}_1 + \vec{F}_1 \cdot \vec{V}_1$$

$$P_2 = \vec{M}_2 \cdot \vec{\omega}_2 + \vec{F}_2 \cdot \vec{V}_2$$

Where:

ω is the angular velocity

M is the moment (Figure 7.5)

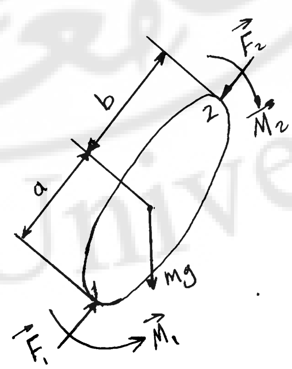


Figure (7.5)

7-3-Muscle Mechanical Power:

At a given joint, muscle power is the product of the net muscle moment and angular velocity:

$$P = M\,\omega \quad (W)$$

Where: P = muscle power, watts

M = joint moment of force, N.m

ω = joint angular velocity, rad/s

The convention of M and ω is such that P is positive if M and ω have the same polarity (concentric contraction). Conversely, when M and ω have opposite polarities we have an eccentric contraction and P is negative.

7-4-Positive work of muscles:

Positive work is work done during a concentric contraction, when the muscle moment acts in the same direction as the angular velocity of the joint. If a flexor muscle is causing a shortening, we can consider the flexor moment to be positive and the angular velocity to be positive. The product of muscle moment and angular velocity is positive; thus power is positive, as shown in Figure 7.6a. Conversely, if an extensor muscle moment is negative and an extensor angular velocity is negative, the product is still positive, as shown in Figure 7.6b. The integral of the power over the time of the contraction is the work done by the muscle and represents generated energy transferred from the muscle to the limbs.

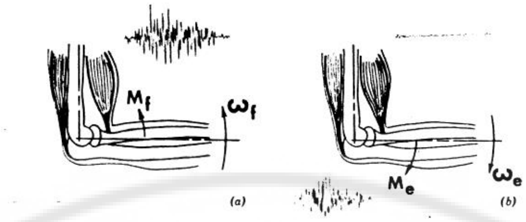


Figure 5.1 Positive work as defined by the net muscle moment and angular velocity.
a When a flexion moment acts while the forearm is flexing.
b When an extension moment acts during an extensor angular velocity. (By permission of *Physiotherapy Canada*.)

Figure 7.6 positive power by the muscle moment and angular velocity

7-5-Negative work of muscles:

Negative work is work done during an eccentric contraction when the muscle moment acts in the opposite direction to the movement of the joint. This usually happens when an external force acts on the segment and is such that it creates a joint moment greater than the muscle moment. The external force could include gravitational or ground reaction forces. Using the polarity convention as described, we can see in Figure 7.7a that we have a flexor moment (positive) with an extensor angular velocity (negative). The product yields a negative power, so that the work done during this angular change is negative. Similarly, when there is an extensor moment (negative) during a flexor angular change (positive), the product is negative (Figure 7.7b). Here the net work is being done by the external force on the muscle and represents a flow of energy from the limbs into the muscles (absorption).

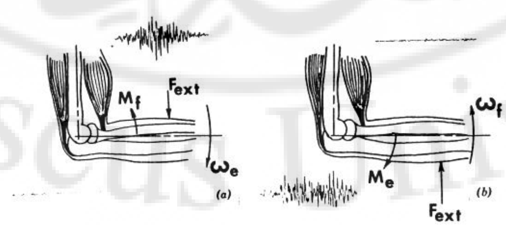


Figure 5.2 Negative work, as defined by net muscle moment and angular velocity.
a When an external force causes extension when the flexors are active.
b When an external force causes flexion in the presence of an extensor muscle moment.
(By permission of *Physiotherapy Canada*.)

Figure 7.7 negative power by the muscle moment and angular velocity

7-6-Mechanical Energy Transfer Between Segments:

Each body segment exerts forces on its neighboring segments, and if there is a translational movement of the joints, there is a mechanical energy transfer between segments. In other words, one segment can do work on an adjacent segment by a force displacement through the joint centre. This work is in addition to the muscular work can be used to calculate the rate of energy transfer (power) across the joint centre. Consider the situation in Figure 7.8 at the joint between two adjacent segments. F_{j1}, the reaction force of segment 2 on segment 1, acts at an angle θ_1 from the velocity vector V_j. The product of $F_{j1}V_j\cos\theta_1$ is positive, indicating that energy is being transferred into segment 1. Conversely, $F_{j2}V_j\cos\theta_2$ is negative, denoting a rate of energy outflow from segment 2. Since $P_{j1} = - P_{j2}$, the outflow from segment 2 equals the inflow to segment 1. This mechanism of energy transfer between adjacent segments is quite important in the conservation of energy of any movement because it is a passive process and does not require muscle activity.

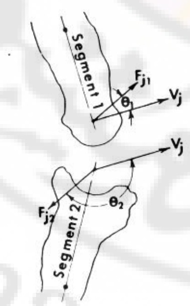


Figure 5.5 Reaction forces and velocities at a joint center during dynamic activity. The dot product of the force and velocity vectors is the mechanical power (rate of mechanical energy transfer) across the joint.

Figure 7.8 Mechanical energy transfer between segments

7-7-Lower limb joints power during walking for normal subjects:

7-7-1-Ankle power:

Figure (7-9) shows the ankle power changes for normal subject during gait cycle walking at normal speed (power generation +ve and power absorption –ve).

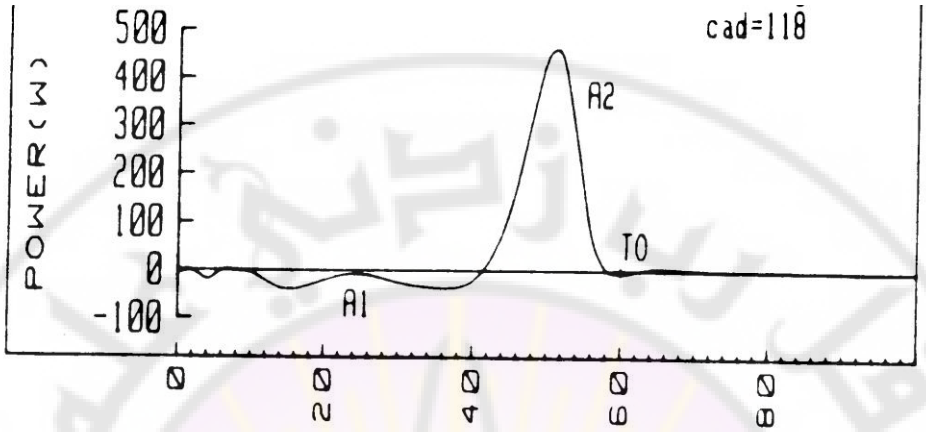


Figure (7-9) shows the ankle power

As it can be seen from Figure (7-9), from heel contact to around 5% of gait cycle, the absorption power was very small and not significant. During this period the foot plantarflexes under the control of pre-tibial muscles. From 5% to 40% of gait cycle, the leg rotates over the foot (ankle dorsi-flexes) under the control of calf muscles (extensor muscles of the ankle). This results in energy absorption of about -25 watt. Then at 35% of GC, the dorsiflexion moment has increased sufficiently to cause heel off and the by 40% of GC to cause active and rapid plantarflexion of the ankle. The product of Ma and ωa is quite high and the generation power is about 450 watt. At 60% of GC, toe off occurs and the strong dorsiflexion moment ends. A very small plantarflexion moment then causes rapid dorsiflexion of the foot until 75% of GC when it is sufficiently dorsiflexed to clear the ground in midswing. However, the power generation associated with this low mass movement is extremely small.

7-7-2-Knee Power:

Figure (7-10) shows the knee power changes for normal subject during gait cycle walking at normal speed (power generation +ve and power absorption –ve).

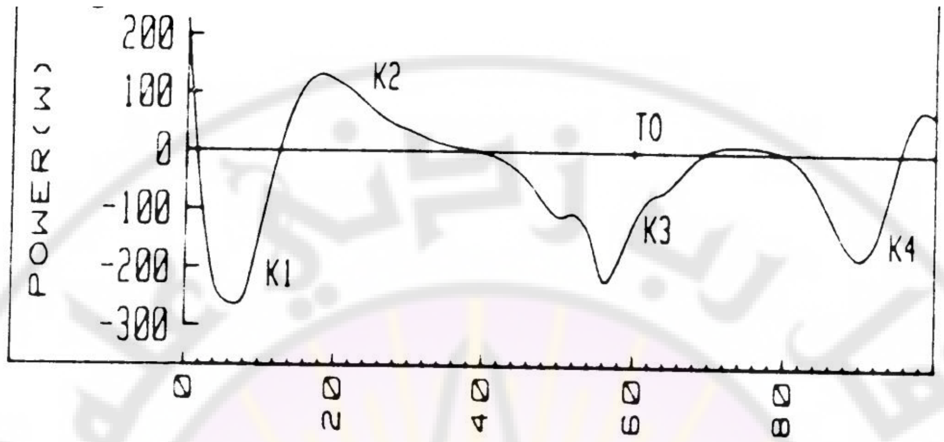


Figure (7-10) shows the knee power

The knee power curve shows four distinct phases of absorption and generation. From about 7% of gait cycle to 15% of GC, the knee flexes under the control of knee extensors and results in K1, the first major absorption power which is equal to about -250 watt. From 15% to 40% GC, the knee extends under the control of quadriceps. This results in K2, positive power equal to about 150 watt. At 40% of GC, the knee starts to flex and continues to do so into early swing (70% GC). The power at this period is absorption (K3) equal to about -200 watt.   Prior to toe off, the quadriceps absorb energy and provide some control to the flexed knee. After toe off, these same muscles continue to absorb energy by decelerating the backward swinging leg and preparing it for extension during most of swing phase. Finally, in the latter half of swing, the knee flexors (hamstrings) start working which absorb most of the energy (K4) from the swinging leg and foot. The value of this absorption power is about -150 watt.