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Dynamic Simulation and Analysis of Human Walking Mechanism

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Abstract. Behaviour such as gait or posture may affect a person with the physiological condition during daily activities. The characteristic of human gait cycle phase is one of the important parameter which used to described the human movement whether it is in normal gait or abnormal gait. This research investigates four types of crouch walking (upright, interpolated, crouched and severe) by simulation approach. The assessment are conducting by looking the parameters of hamstring muscle joint, knee joint and ankle joint. The analysis results show that based on gait analysis approach, the crouch walking have a weak pattern of walking and postures. Short hamstring and knee joint is the most influence factor contributing to the crouch walking due to excessive hip flexion that typically accompanies knee flexion.

1. Introduction

Human gait is one of the most important movement for develop of the human being activities in life. Human movement involves a complex movement of skeleton and muscles in various combination of bending, stretching, compressing and rotating actions [1]. During movements, the human body can move in a large number of degrees of freedom. In walking movement, it is required an appropriate coupling and coordinate movement of body segment to produce smooth motion, maintain balance and minimize energy expenditure [2].

Walking seems so simple that most of us do it daily since childhood. However, for those with an orthopaedic or neurological impairment, walking is no longer automatic nor simple [3]. For them, walking may have become struggle and pose a threat to one independence and quality of life.

Normal gait is a pattern of walking human normally adopted in undisturbed situation. Gait pattern are considered to be either abnormal or impaired if they do not satisfy certain key attributes of normal gait. It has previously been postulated that normal gait is more energy efficient than abnormal or impaired gait. Crouch gait pattern is characterized by increase knee flexion through stance phase. Individual with cerebral palsy who walk in a crouch gait often receive strength training as part of their therapy. The crouch gait will increase the energy costs of walking and can lead to joint pain and degeneration when during walking. It generally considered being a negative symptom of cerebral palsy [4].

Several factor have been linked with crouch gait, including muscle weakness, spasticity, skeletal deformities and tightness [4]. A link between crouched gait postures and the capacity of muscle to extend the hip or knee joints, individual may be required to exert more muscle force to maintain a crouched posture and to avoid injuries from falling and tripping.

Posture is the orientation of body segment that relative to the gravitational vector. It is an angular measure from the vertical. Balance is the dynamic of body posture to prevent falling or in another word is a process whereby the body's state of equilibrium is controlled for a given purpose. The difficulty which equilibrium can be disturbed is by encounter frequently in activities demanding static postures. Many skills and tasks involving the moving system. This concept also can be called as stability. It is related to the inertial forces acting on the body and the inertial characteristic of body segment [5].

The objective of this study is to know the posture of walking in a proper way and the parameter contributing in crouch walking will be identified. Besides, the method used to achieve of the study is conducted in simulation approach.

2. Methodology

In this research, the musculoskeletal modelling is all conducted in OpenSim [6]. The walking motion is assessed and analysed on some walking parameters. The investigation parameters involved in this work are hamstring, range of motion for right knee and ankle plantar flexion.

2.1 Human model

The main goal of this research was to evaluate between normal walking and crouch walking in a first stage by using a simplified version of a musculoskeletal model on which applied simple motion. In this study, the model is 3DGaitModel2392 [6]. This model consists of body, lower extremities and torso. It had developed by 23 degrees of freedom mechanical linkages, whereas the lower extremities and torso has 92 muscle-tendon actuators to represent 76 muscles.

The normal walking and four types of crouch walking (crouch 1 walking, crouch 2 walking, crouch 3 walking and crouch 4 walking) are simulated in this model. Crouch 1 is upright posture. This type of posture was defined from the average of gait data. Crouch 2 is interpolated posture. Crouch 3 is crouched posture, where this type of posture defined from the person with cerebral palsy and crouch gait. Lastly is crouch 4 is severe crouch posture or extrapolated posture. This type of posture had a huge abduction of tight.

2.2.1 Normal Walking Posture

Normal walking posture is walking in a proper way with a good posture shown in figure 1. A good body posture or structure is the bones and joints in the correct alignment. Thus, it can minimizes stress on muscles, bones and joints.

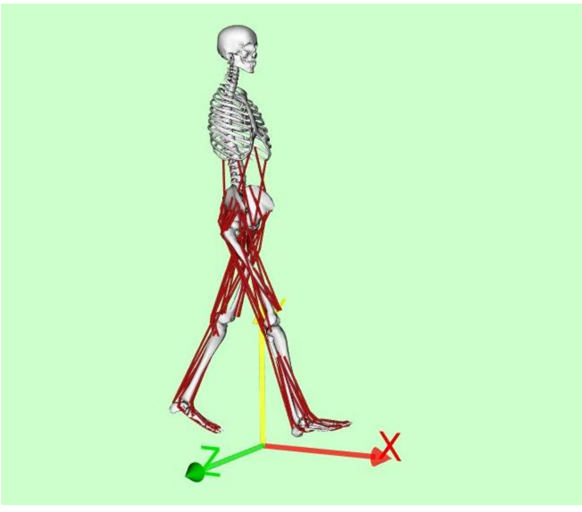

Figure 1: Normal Walking Posture

2.2.3 Comparison of Walking Posture

This stage is to compare the differentiation of walking and the parameter that contribute during this walking process. Normal walking as a reference to compared between the others walking. From there, it can be know what are the parameters that make someone cannot walk in the proper way. There were four type of comparison which is type 1 shown in figure 2, type 2 shown in figure 3, type 3 shown in figure 4 and lastly is type 4 shown in figure 5. During these walking activity, there will be flexion and extension of the legs. Flexion is the bending movement that result in decrease of the angle in a joints by bringing the bones together, while the extension is straightening movement that results in an increase of the angle in a joint by moving the bones apart. Hamstring muscle, knee and ankle is the parameter that interested to investigate which is the most factor in walking process.

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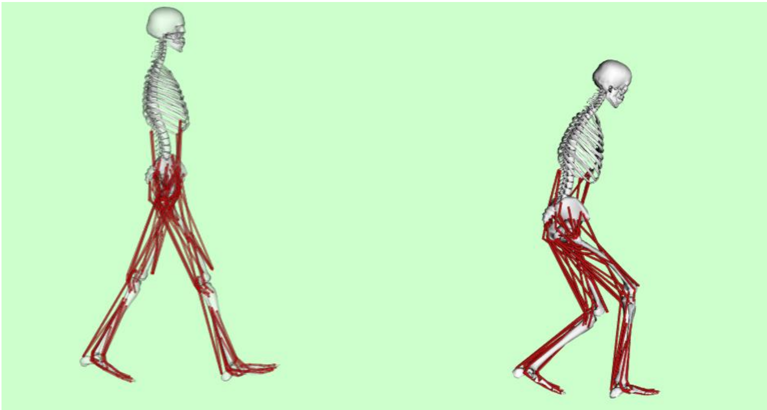

Figure 2: Normal Walking Posture and Crouch 1 Walking Posture (Type 1)

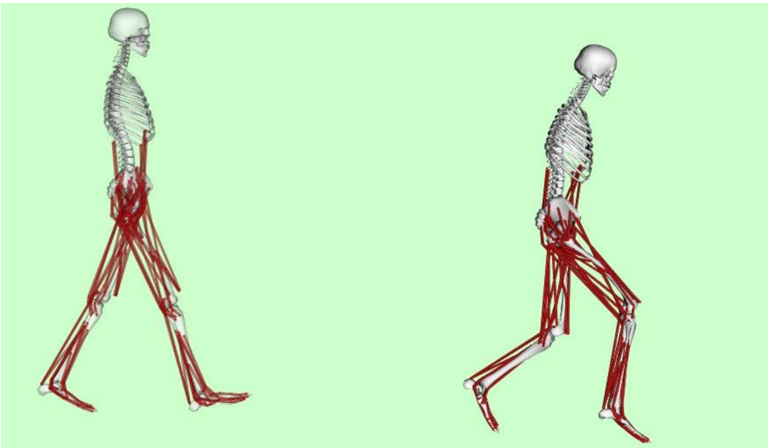

Figure 3: Normal Walking Posture and Crouch 2 Walking Posture (Type 2)

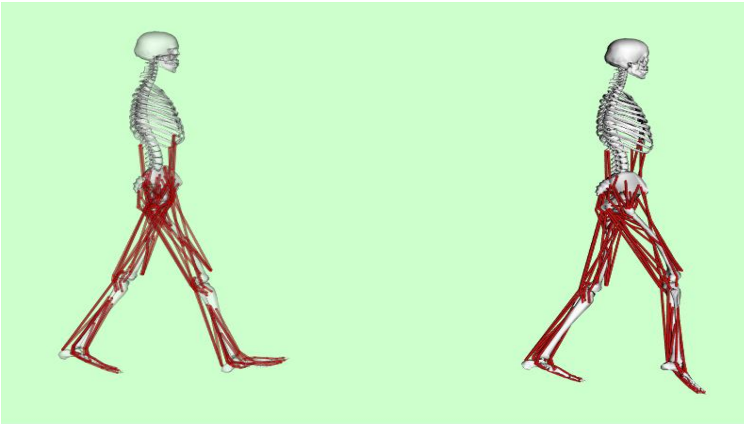

Figure 4: Normal Walking Posture and Crouch 3 Walking Posture (Type 3)

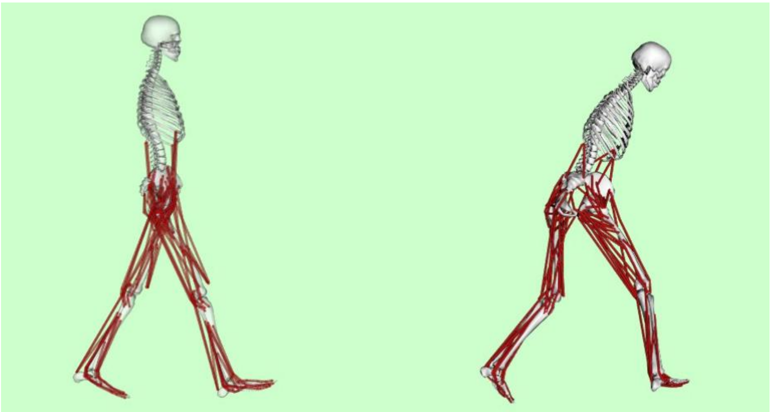

Figure 5: Normal Walking Posture and Crouch 4 Walking Posture (Type 4)

3. Results and Discussion

Investigation parameters are plot and presented to see the difference on each crouch posture.

3.1 Hamstring Muscle

In daily life activities, muscle strength is important. Force that provide from our muscle that allow us to walk, jump, climb stairs, run and perform athletic activities. Humans can increase their performance with training even for run faster, jump higher and lift more weight. The limitation performance of activities will be loss of muscle strength if it is disuse, aging and disease [7].

Walking may become impaired for human when muscle become excessively weak during daily life activities. The muscle strength is an important element for walking performance. The comparison of walking is to determine with joint rotation have the greatest influences on hamstring length during walking [8]. Data that gather from the simulation of hamstring is to see the different length of muscle. Muscle of hamstring type 1 shown in figure 6 and 7. The data shows that crouch 1 have small different hamstring length compared to normal. During initial to mid stance stage, there had some flexion of leg which is the foot is quickly change. Then, continue until initial swing which the leg had a huge of extension.

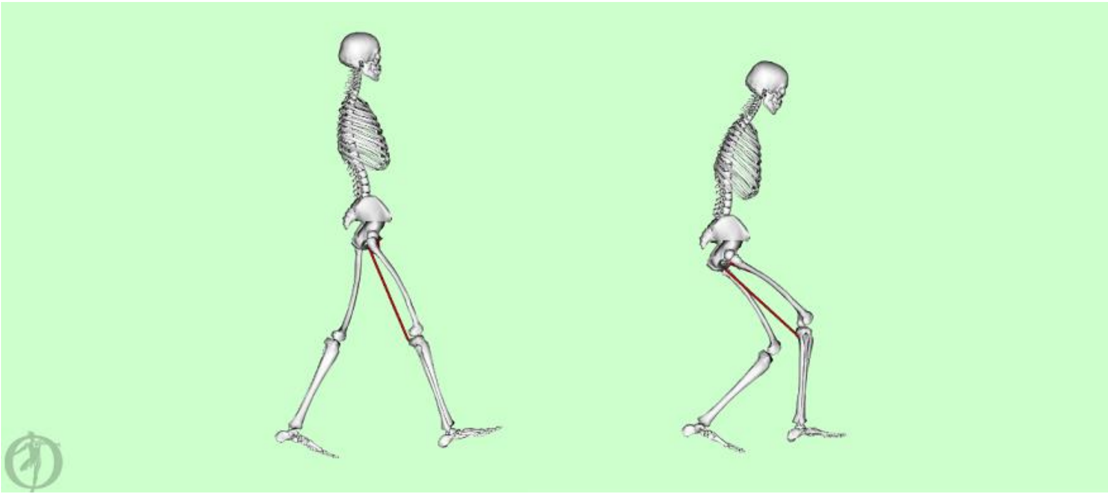

Figure 6: Muscle of hamstring in models type 1

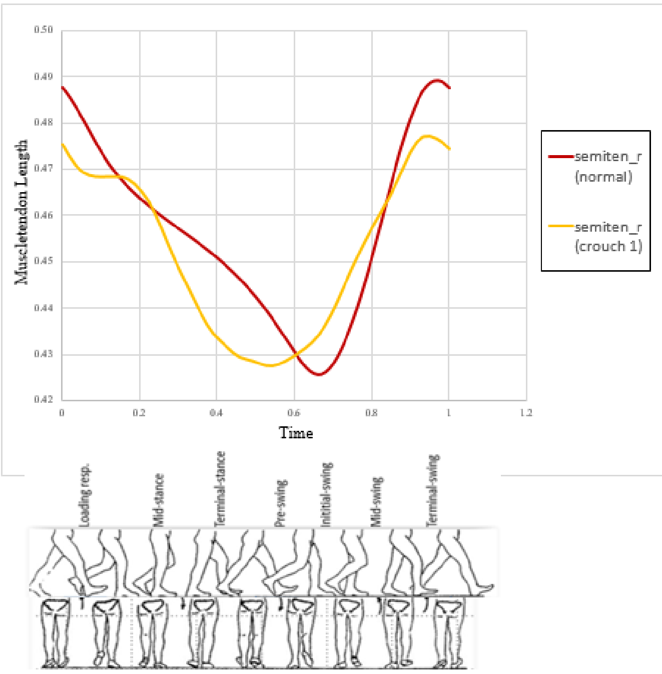

Figure 7: Graph of hamstring length for type 1

The data for type 2 that shown in figure 8 and 9. Its shows that the crouch 2 have a huge different of hamstring length. During initial contact, the crouch 2 walker need to use high of force to start the motion. Besides, during the terminal stance to swing phase, the changes of leg to fast and take a huge of flexion until the toe off. This because the length of hamstring are the one of factor that the leg stops early.

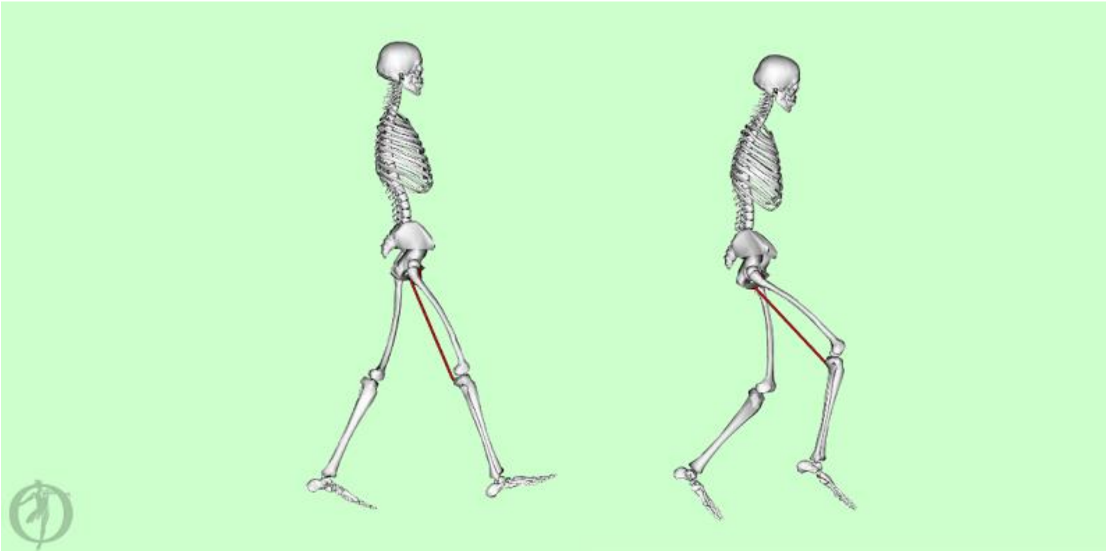

Figure 8: Muscle of hamstring in models type 2

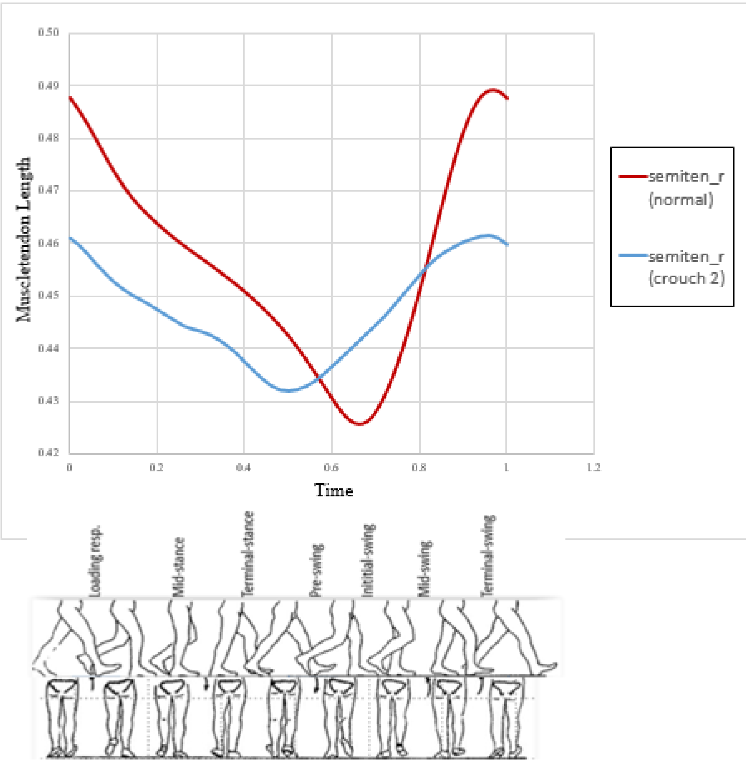

Figure 9: Graph of hamstring length for type 2

The data for type 3 shown in figure 10 and 11. It shows that the crouch 3 walker have similarity with the normal walker but it have a smaller different of hamstring length. During the initial contact the walking activity still in a right path, but when enter to mid stance stage the walking activity take quickly changes during flexion and extension. During the terminal swing which is the final stage to toe off, the crouch 3 had stop early due to smaller different of length.

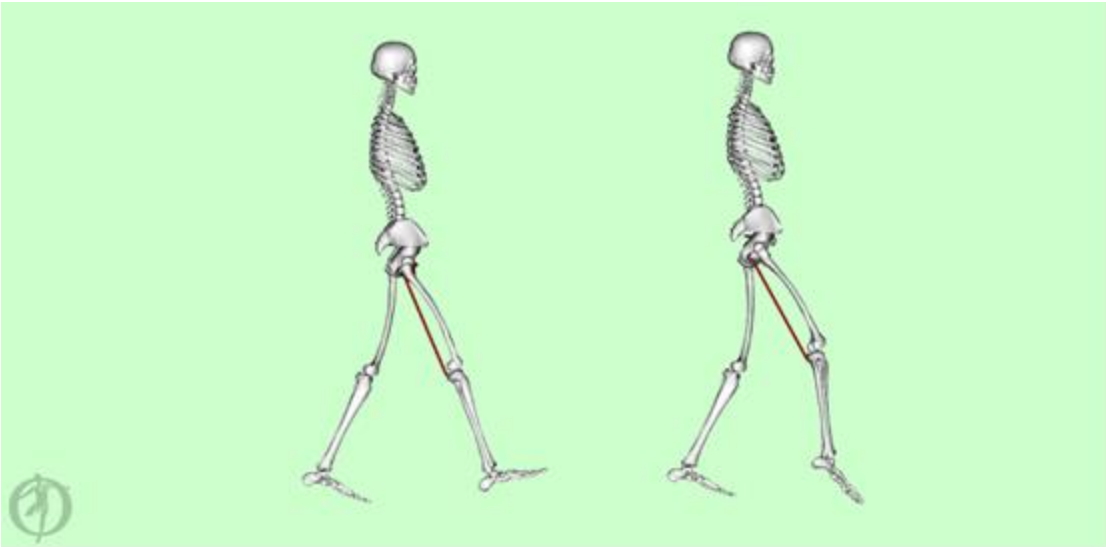

Figure 10: Muscle of hamstring in models type 3

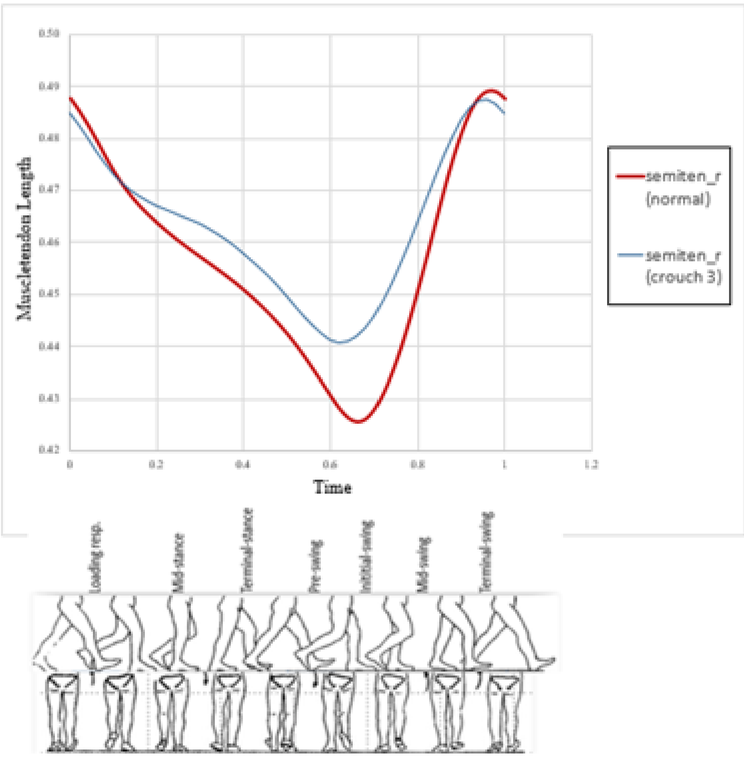

Figure 11: Graph of hamstring length for type 3

The data for type 4 shown in figure 12 and 13. It shows that the crouch 4 have a huge different of hamstring length compared to normal walking. This is because during the initial contact and process to swing phase, the changes of the leg is very quick.

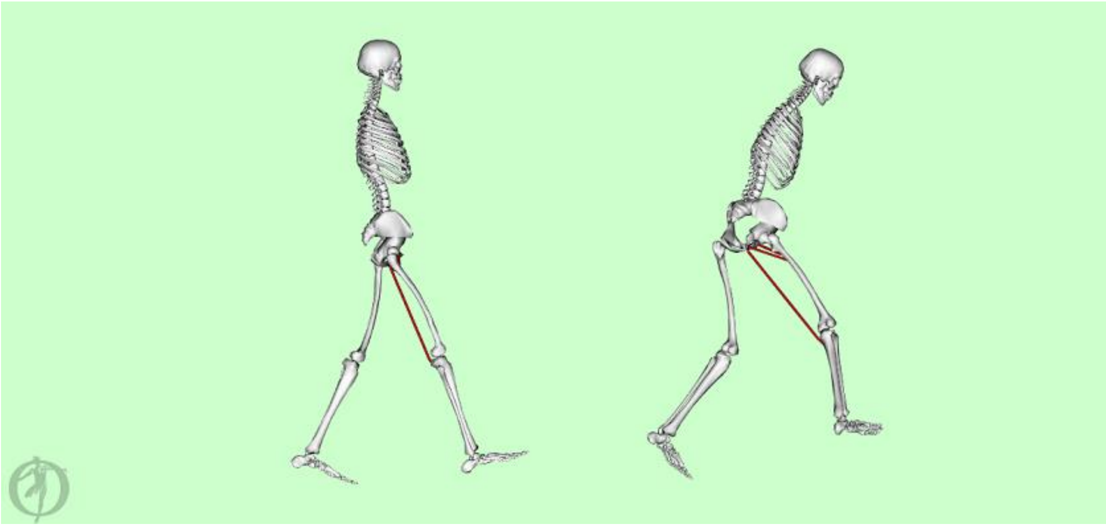

Figure 12: Muscle of hamstring in models type 4

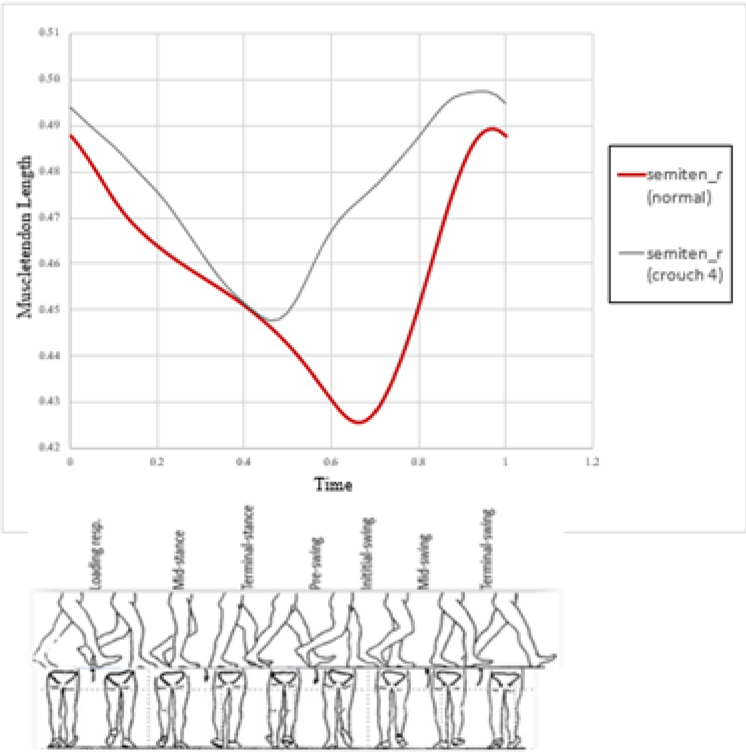

Figure 13: Graph of hamstring length for type 4

This is the overall of data hamstring length vs gait cycle for normal walking and all type of crouch walking as shown in figure 14. Hence, we can see that the most shorten hamstring length is crouch 4, next is crouch 2 continue to crouch 3.

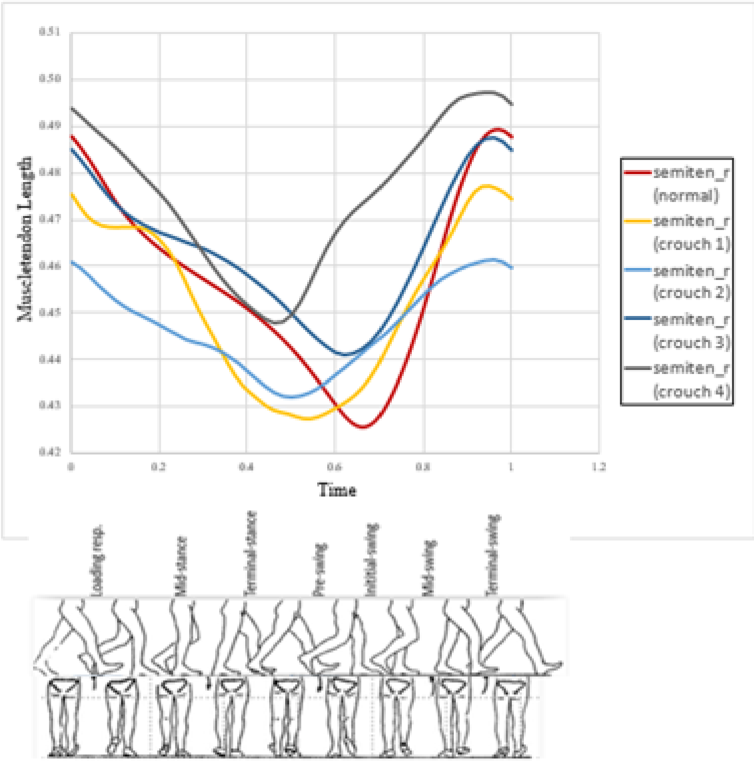

Figure 14: Graph overall of hamstring length for each model

3.2 Range Of Motion

Range of motion is the motion of the knee in vertical displacement during the walking activity. Joints and muscles are included in this motion. The data for type 1 shown in figure 15 and 16. It shows that the crouch 1 walking have a knee flexion angle. The knee angle for normal is -3.94 deg, while the crouch 1 walking is -59.26 deg. The motion for normal is smoother than crouch 1. This is because during the phase there have some extension of the hip joint then continue to knee joint and lastly to ankle joint. For crouch 1 walking have small changes that related to hip, knee and ankle joint. There is small flexion during the mid stance to terminal stance. The smaller extension occurring during mid swing stage.

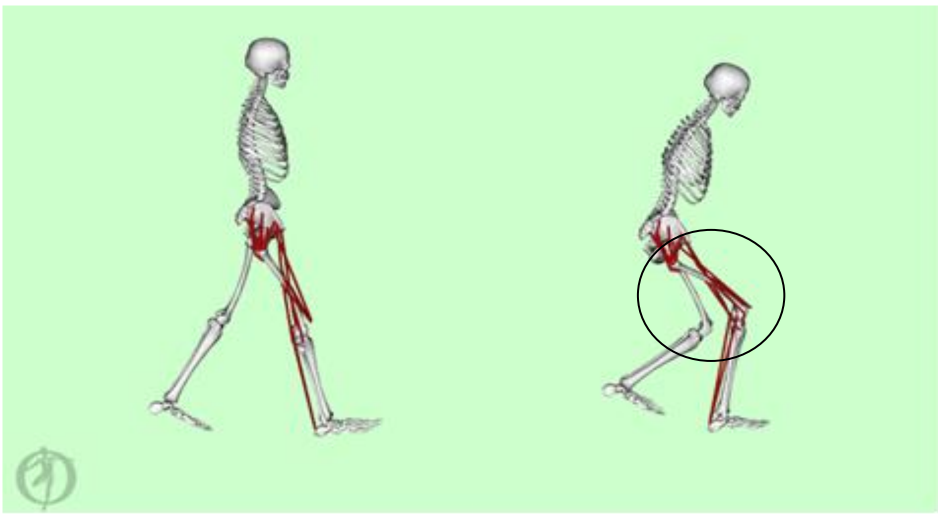

Figure 15: Knee flexion angles type 1

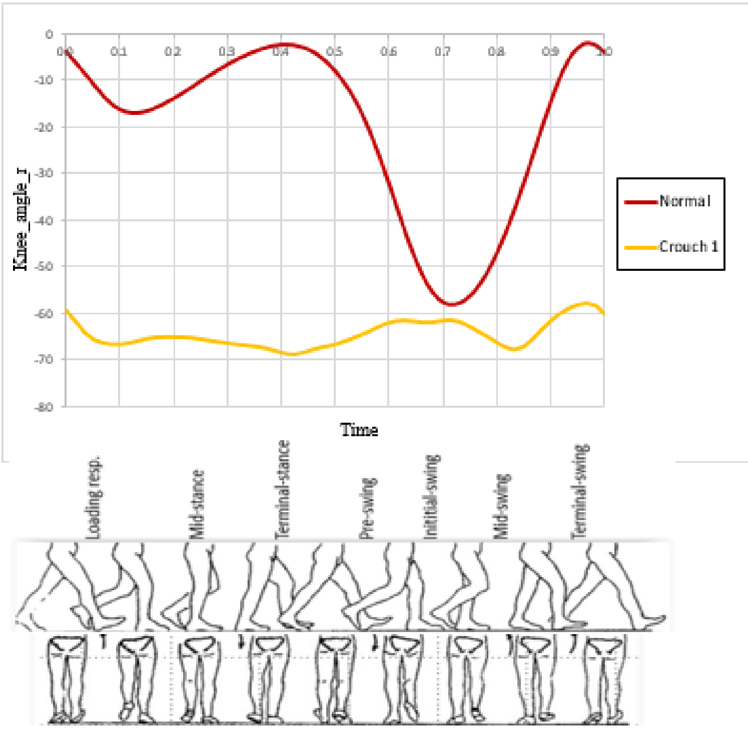

Figure 16: Graph knee flexion angles type 1

The data for type 2 is shown in figure 17 and 18. It shows that the crouch 2 walking have a knee flexion angle. The knee angle for crouch 2 walking is -54.94 deg. For type 2 the pattern of range of motion is same with type 1 but the crouch 2 pattern is smoother compared to crouch 1. During the stance phase and swing phase, the flexion and extension occur in small changes by hip joint, knee joint and ankle joint.

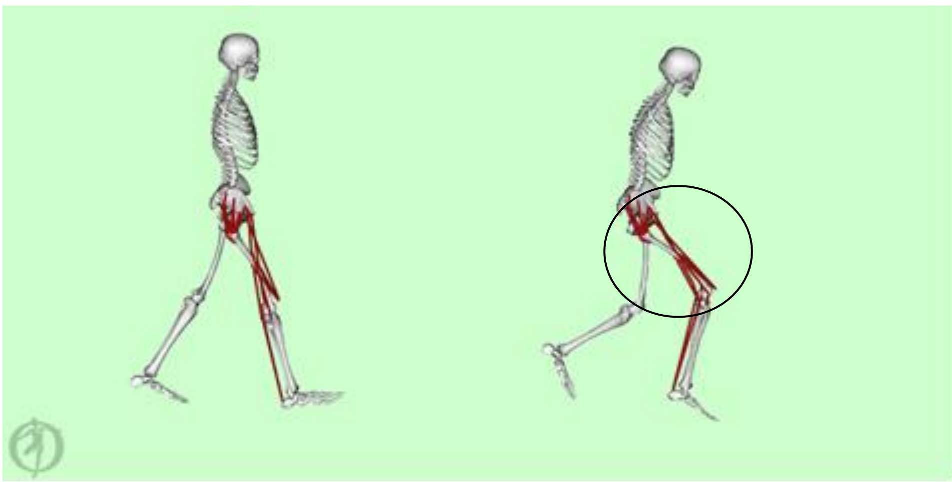

Figure 17: Knee flexion angles type 2

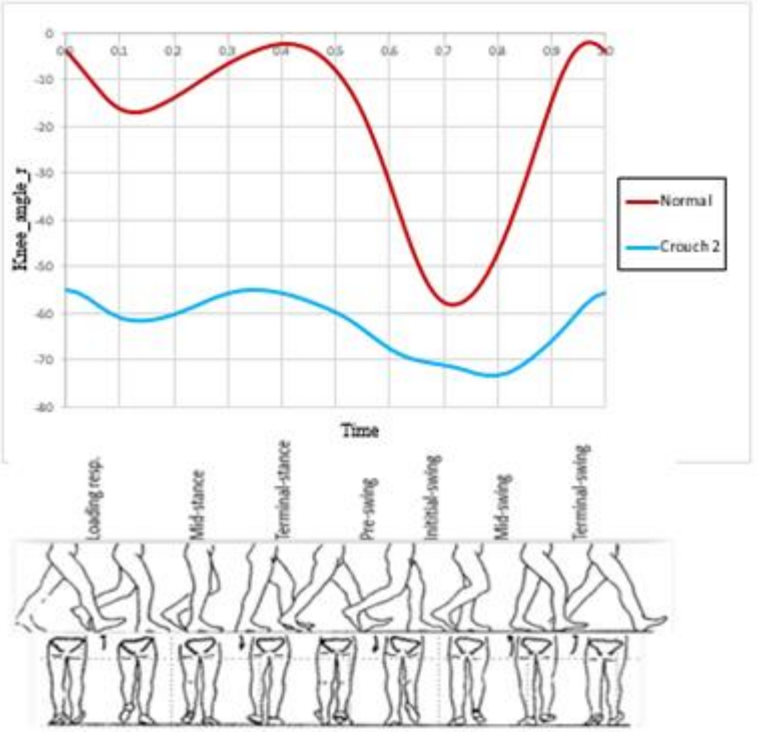

Figure 18: Graph knee flexion angles type 2

The data for type 3 shows in figure 19 and 20 It shows that the crouch 3 walking have a knee flexion angle. The knee angle for crouch 3 walking is -26.26 deg. During the initial contact, the pattern of the motion is same but the value is different with the normal walking. When enter the mild stance, there is small flexion occur. This pattern is continue until enter the initial swing. During this stage until terminal swing, there is small extension occur by hip joint, knee joint and ankle joint.

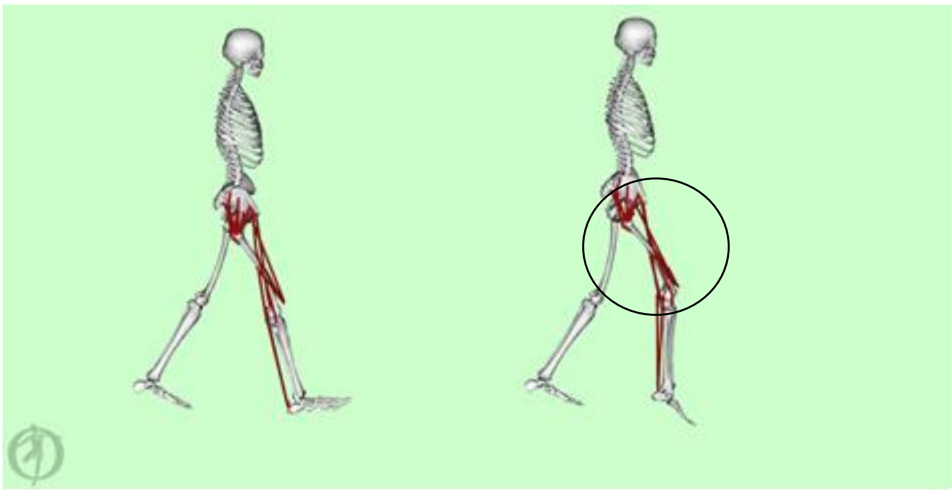

Figure 19: Knee flexion angles type 3

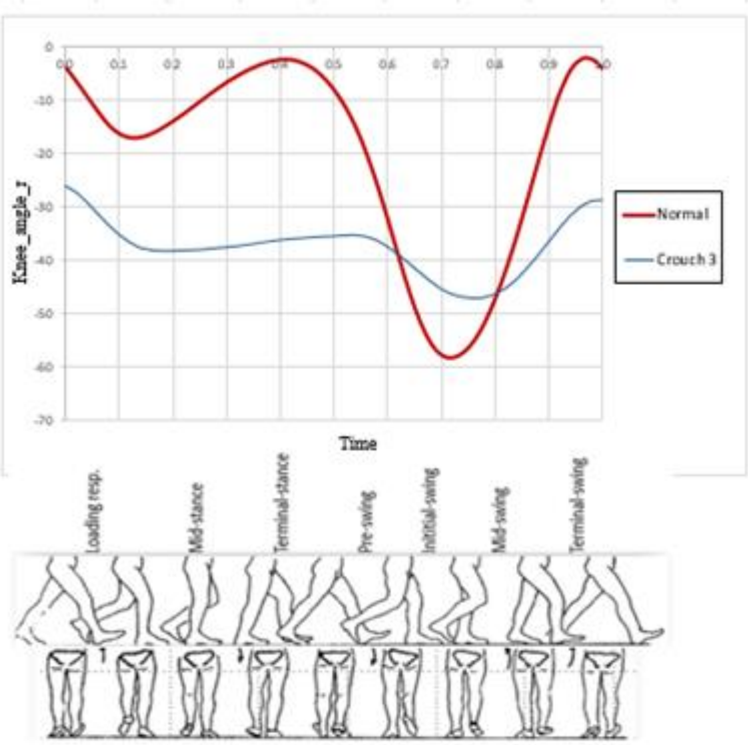

Figure 20: Graph knee flexion angles type 3

The data for type 4 shows in figure 21 and 22. It shows that the crouch 4 walking have a knee flexion angle. The knee angle for crouch 4 walking is -45.12 deg. The pattern of the graph motion for crouch 4 is same with normal walking but during the terminal stance to swing phase, the graph shows not smooth in changes because of the extension of the hip joint, knee joint and ankle joint is very quick.

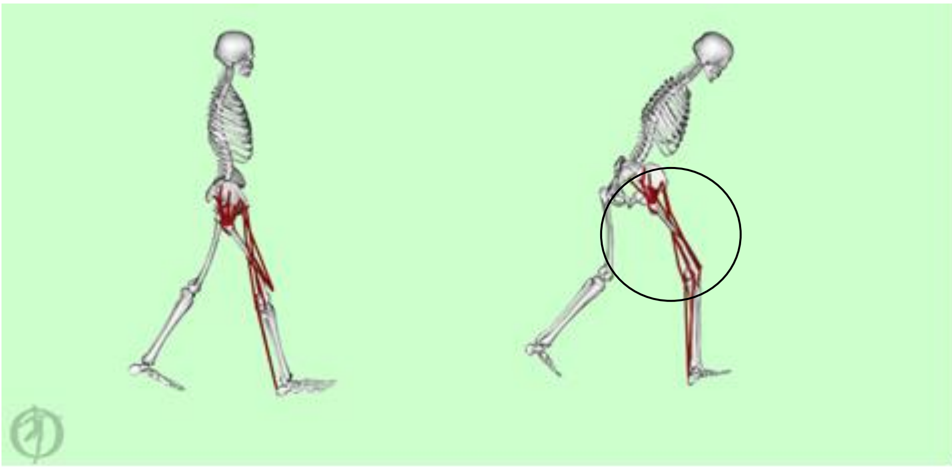

Figure 21: Knee flexion angles type 4

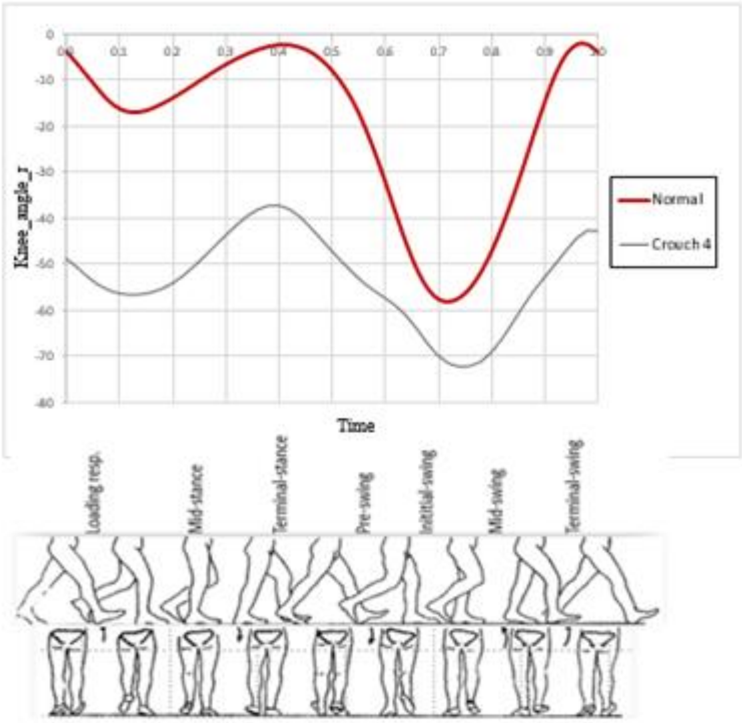

Figure 22: Graph knee flexion angles type 4

This is the overall of data right knee angle vs gait cycle for normal walking and all type of crouch walking as shown in figure 23. Hence, we can see the most bending angle for knee is crouch 1, next is crouch 3 continue to crouch 2 and lastly is crouch 4.

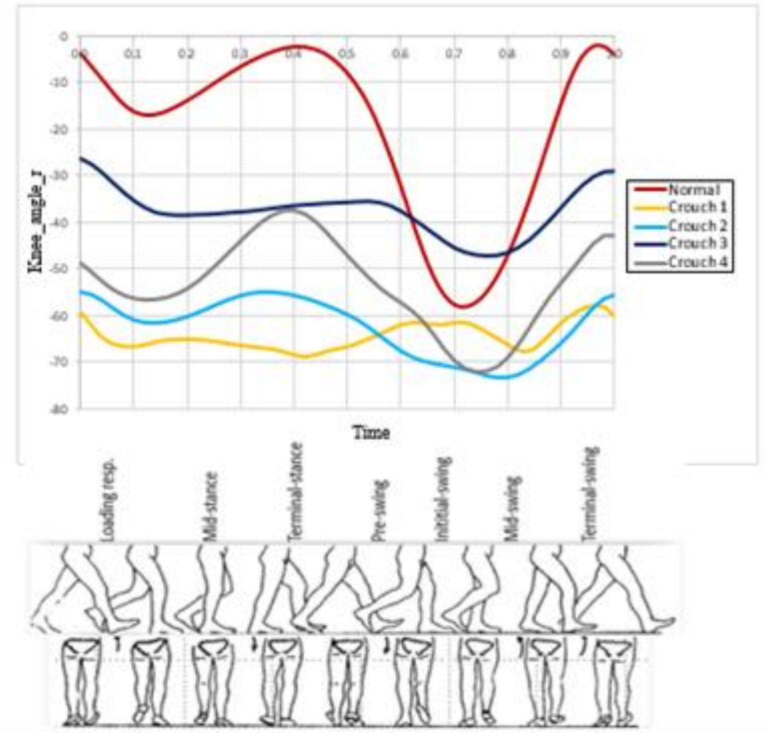

Figure 23: Graph overall of range of motion for each model

3.3 Ankle

Movement of ankle is the one of the factor to walking, running, jumping and others activity. The movement of ankle have two type which is when the foot of the top is called dorsiflexion while when the foot in the bottom is called plantar flexion. The data for type 1 shown in figure 24 and 25. It shows that, pattern of the graph for the ankle plantar flexion for crouch 1 walking is same with normal walking. The ankle take action at stance phase in loading response, mild stance and terminal stance. The ankle angle for normal is -1.7 deg while crouch 1 is 13.07 deg. It shows that the graph of crouch 1 is upper than normal walking. This is because the angle of the ankle. During initial contact, the crouch 1 had directly flexion while for normal there had some time to start flexion.

Figure 24: Ankle Plantar Flexion type 1

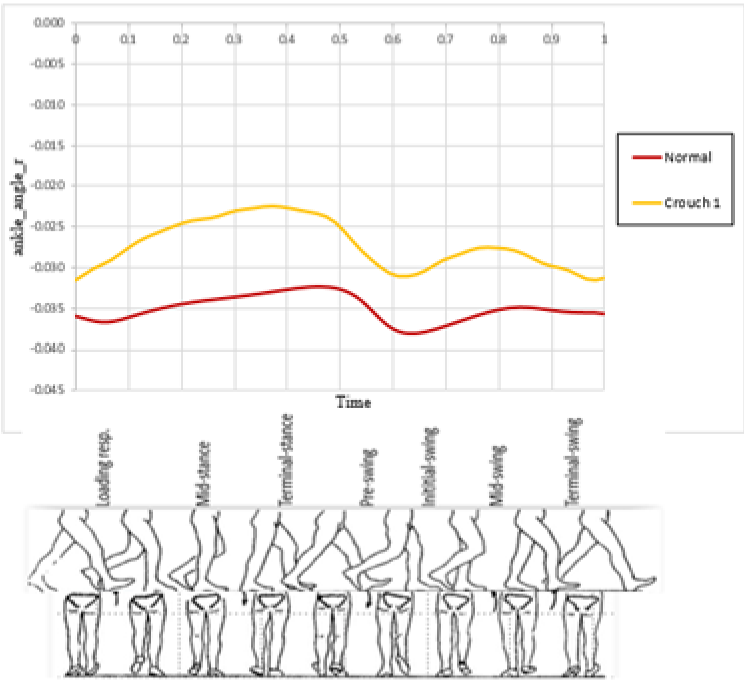

Figure 25: Graph Ankle Plantar Flexion type 1

The data for type 2 shown in figure 26 and 27. It shows that, crouch 2 walking pattern. The ankle take action at stance phase in loading response, mild stance and terminal stance. The ankle angle for crouch 2 walking is -16.17 deg. The graph shows the crouch 2 during the initial contact, the flexion is directly occur during the walking in small changes. Then, there is no extension occur There is small changes of ankle plantar flexion compared to normal walking.

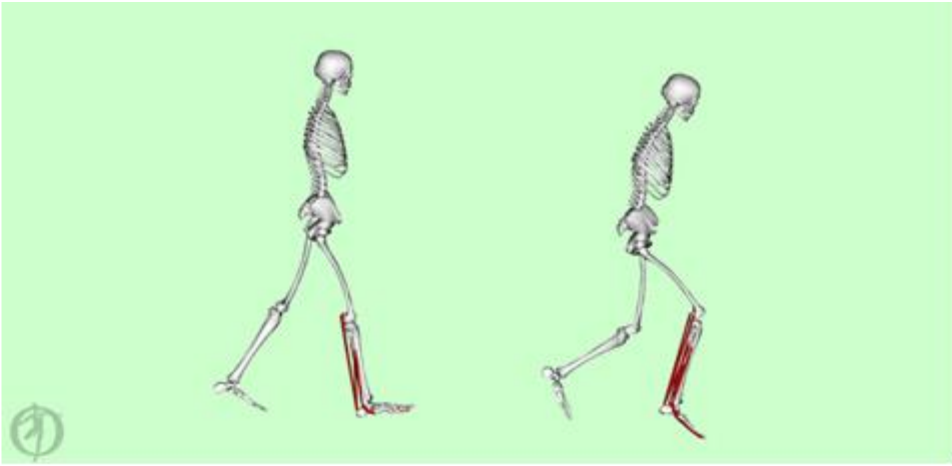

Figure 26: Ankle Plantar Flexion type 2

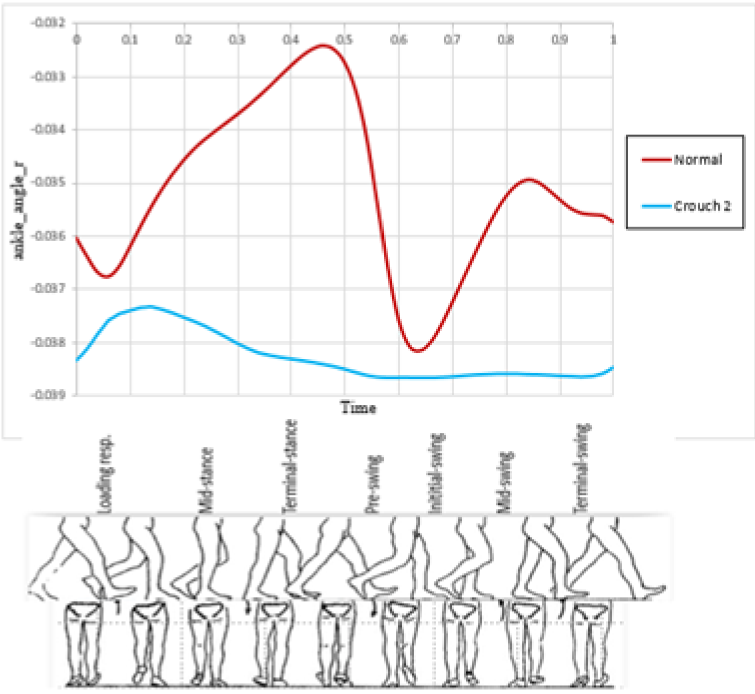

Figure 27: Graph Ankle Plantar Flexion type 2

The data for type 3 shown in figure 28 and 29. It shows that, the crouch 3 walking pattern. The ankle take action at stance phase in loading response, mild stance and terminal stance. The ankle angle for crouch 3 walking is -39.07 deg. The graph shows the crouch 3 during loading respond, there is no flexion. Then, during the extension process at pre swing until mid swing there is flexion occur with small changes during the walking and it continued until toe off.

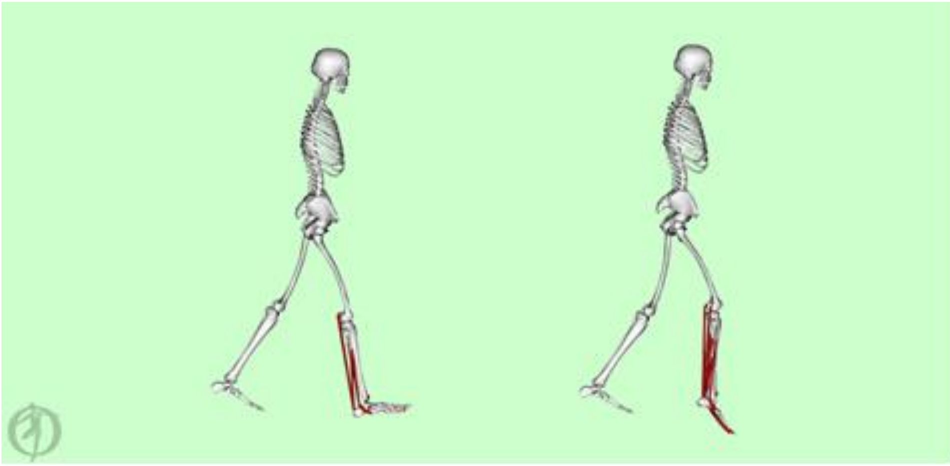

Figure 28: Ankle Plantar Flexion type 3

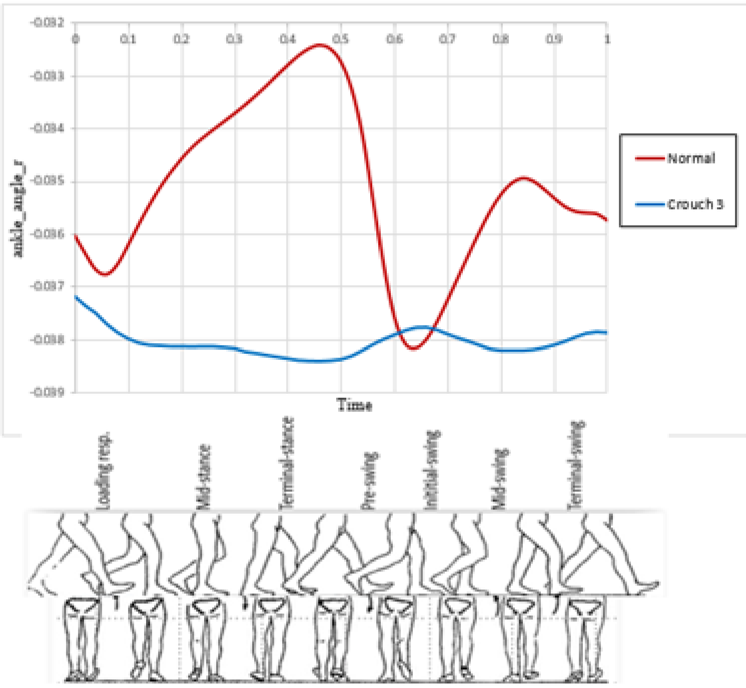

Figure 29: Graph Ankle Plantar Flexion type 3

The data for type 4 shown in figure 30 and 31. It shows that, pattern of the graph for the ankle plantar flexion for crouch 4 walking is same with normal walking. The ankle take action at stance phase in loading response, mild stance and terminal stance. The graph of crouch 4 is upper than normal walking. This is because the angle of the ankle. The ankle angle for crouch 4 walking is 20.45 deg. The graph pattern is not smooth and during extension occur, there had smaller changes. Besides, during initial contact to terminal stance the changes is very quick so that the extension take a quickly too.

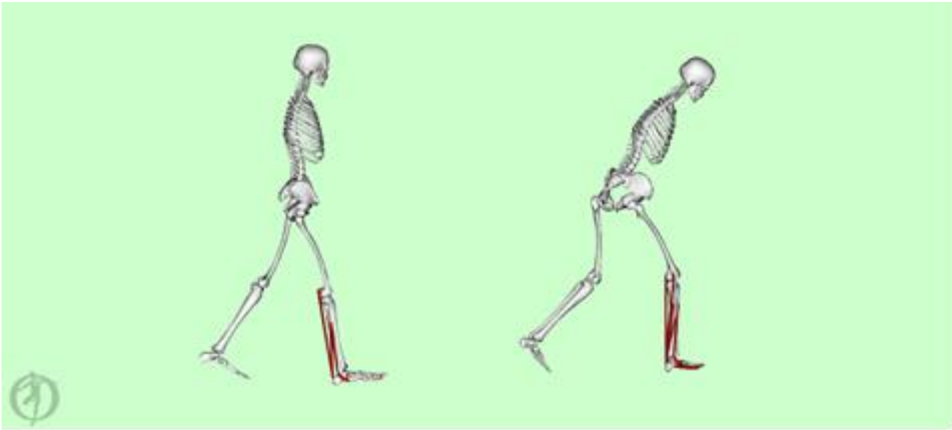

Figure 30: Ankle Plantar Flexion type 4

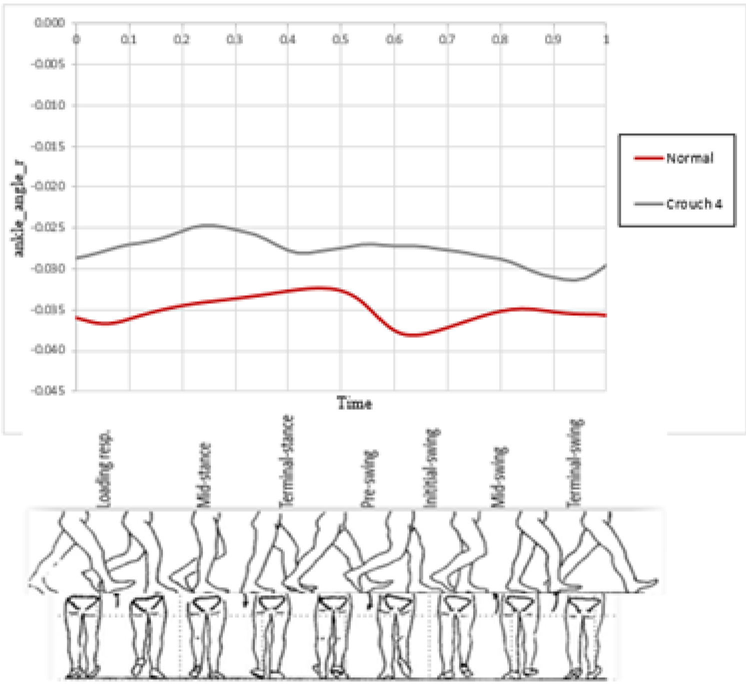

Figure 31: Graph Ankle Plantar Flexion type 4

This is the overall of data ankle plantar flexion vs gait cycle for normal walking and all type of crouch walking as shown in figure 32. Hence, we can see that, the most bending ankle angle is crouch 3, next is crouch 2 continue to normal, crouch 1 and lastly is crouch 4.

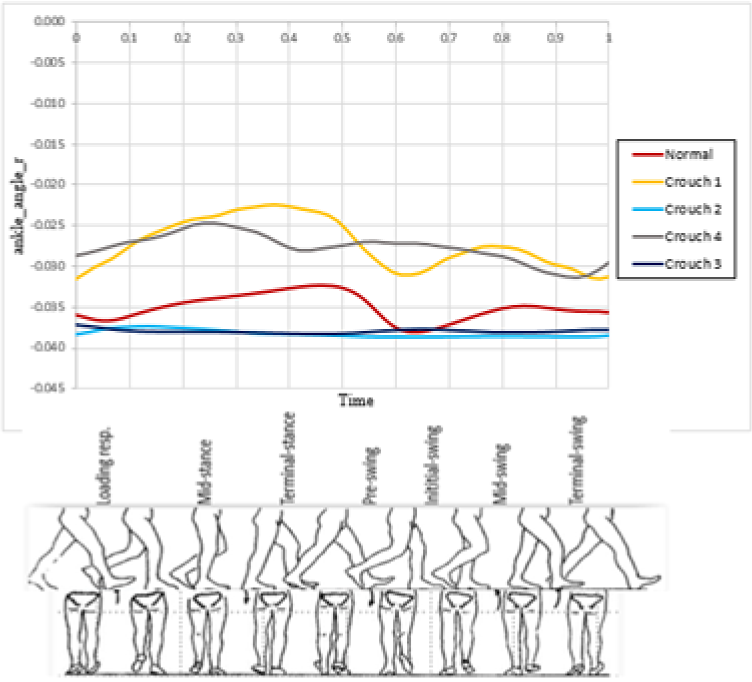

Figure 32: Graph overall of ankle plantar flexion for each models

3.4 Gait Analysis

The result indicate to investigate the posture of walking in a proper way and the parameter contributing in crouch walking. Analysis of this were performed in one type of normal walking and four type of crouch walking. Besides, by using a simulation platform to evaluate the human motion and its disorder. Other than that, the effect of human movement.

Individual who walk in crouched posture during single support may increase activation of the hamstring to accelerate the hip and knee toward extension since the capacity of the muscle group. Besides, usually the person received strength training as part of their therapy. Generally, crouch gait is considered to be disadvantages but however some an athlete adopts the crouched posture to rise their ability to move in any chosen direction [9].

During stance phase, the joint and muscle activity in heel strike stage at the beginning the hip joint is partially flexed with gluteus maximus and the hamstring. This contract immediately to initiate the hip extension. The knee joint in condition full extension or flexed about 5 degree and the quadriceps working eccentrically to control the knee flexion which follow immediately after heel strike. The ankle joint on heel strike usually to neutral position which up to 10 degree of dorsiflexion or plantar flexion. Next, in foot flat stage the hip joint is started to move into extension by concentric action of the hip. The knee has flexed further in order the effect of heel strike. This also is to reduce the vertical displacement of the center gravity that occur the body passes over the stance limb. At the ankle joint, the controlled plantar flexion to lower the foot to the ground which is undertaken by eccentric work of dorsiflexors. There is small amount of eversion to transfer body weight when the foot achieve good foot-ground contact. Then to mid stance stage, the hip extension continue and being produce by momentum and the muscle. Lastly, heel off which is the leading to push off. At the beginning of the phase, the center of gravity in stance foot, the force of gravity will increase the range of hip extension and dorsiflexion. The heel will rise off the ground and the plantar flexors will contact concentrically when full range of dorsiflexion to provide the propulsive component of push off. The walking speed from slow to moderate this contraction not usually very large as momentum as the major factor in moving the body forward. For normal walking, the hip extensor not active in this stage, but actually the hip and knee joints are usually starting to flex to prepare for swing phase.

During the swing phase, the joint and muscle activity have three stages which is acceleration, mid-swing and deceleration. In acceleration stages, the minor force is generated to push off the hip flexors and plantar flexors to accelerate the limb forwards. It is assisted by momentum and gravity. The both flexing which is hip and knee joint and the rapid movement towards dorsiflexion is to ensure that the toes do not catch on the ground. In mid swing stages, the flexion of knee and hip joint continues to keep the foot raised and avoid from toes catching the ground. This stage, the foot is lowered into slight plantar flexion. Lastly, deceleration process is the hip continues to flexion. The movement mainly produce by momentum and the hamstring act eccentrically to slow down the movement at the hip joint. The flexion to extension by the knee in the movement. The knee joint extension make the whole of the lower limb being moved forward by flexion of the hip and the resulting momentum. Towards the end of deceleration stage, extension of knee joint may have to be slow down and this is achieved by eccentric action of hamstrings. During the toe off or heel strike, the dorsiflexion contract strongly to ensure that the foot in optimum position condition.

The ground reaction force in gait is the foot contact with the ground, there will be vertical, anterior-posterior and medio-lateral force acting between the feet. At the beginning and end of stance phase, about 25% greater than body weight from the vertical ground reaction force and it is also same for anterior posterior ground reaction force [10]. The relatively small forces involved and the design of the human body that facilitates shock absorption. The cushioning effect of the knee flexion on initial foot and ground contact mean that repetitive strain injuries caused by ground reaction force are rare in walking.

The amount of energy required to walk at a comfortable pace is very small compared to other activities. Normal structure of human body or in normal pattern of walking are mostly to increase the energy expenditure significantly. Energy is conserved through the utilization of momentum, kinetic and potential. From the rhythmical, the center of gravity that produce vertical fluctuations in normal gait is similar fluctuations in kinetic energy and gravitational potential energy. In mid stance stage, when the center of gravity is highest, the gravitational potential also highest but the kinetic energy is lowest. Normal walking have a smoothness rhythmic walking compared to the crouch walking based on their posture, muscle pattern and regular stepping [11].

4. Conclusion

In conclusion, the human walking pattern is based on the human body structure or gait. For normal walking, the rhythmic of walking is very smooth based of their good body posture or structures. For the crouch walking that have problem in lower limb, they required high energy to make their body forward. Usually these crouch walker, have unstable during stance phase. The capacity of the muscle to generate extension accelerations at the knee. It also depends on the muscle activation level and physiological ability to generate force like hamstring, the bending of the knee and the ankle. The muscle must work harder to maintain their walking pattern. The moment of the hip, knee joint and ankle are related to ground reaction force. For further research, this simulation platform can be used to investigate other types of gait pattern such as running to improve the performance of athletes. The dynamic analysis of this study could also be implemented to analyze the gait kinematics and bone geometry.

5. References

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