THE CONTROLLING OF DYNAMIC PARAMETERS OF KNEE JOINT IN TRANSFEMORAL AMPUTEE GAIT

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ABSTRAK

Manusia sentiasa berminat dalam menganalisis pergerakan manusia dan gaya berjalan. Tujuan menganalisis gaya berjalan orang cacat yang telah kehilangan sebahagian dari kaki atau anggota badan bawah adalah untuk meningkatkan gaya hidup mereka. Pada masa ini, terdapat lebih dari sepuluh juta orang cacat di dunia dan lebih daripada 250,000 orang kehilangan anggota badan mereka setiap tahun.

Untuk mereka bentuk kaki palsu pintar dengan tujuan memperbaiki kehidupan orang cacat, perkara pertama yang perlu diketahui adalah mengawal parameter mekanikal. Objektif bagi laporan penyelidikan ini adalah untuk mencari korelasi dan tafsiran korelasi tentang parameter kinetik dan kinematik sendi lutut dalam 4-rantaian bar transfemoral kaki palsu untuk rekabentuk kaki palsu pintar pada masa akan datang.

Untuk mengumpulkan data, penganalisa tiga dimensi bersama tujuh kamera inframerah dan dua plat berkuatkuasa telah digunakan. Kemudian, data yang dikumpul pula dianalisis oleh Matlab, SPSS dan Microsoft Excel.

Akhirnya, formula regresi bagi tiga parameter telah digunakan. Daripada analisis tugas eksperimen, hubungkait sederhana langsung momen lutut dan sudut lutut, serta korelasi utama songsangan tarakuasa lutut dan sudut lutut telah dapat diperolehi.

ABSTRACT

People have always been interested in analyzing human movement and gait. The aim of gait analysis of amputee who has lost a lower limb is to improve their lifestyle. Currently, there are over ten million amputees in the world and more than 250,000 people lose their limb every year.

For designing smart prosthetic legs to improve amputees' life, at first we should be able to control mechanical parameters. The intent of this research report is to find the correlations and interpretation of such correlations of kinetics and kinematics parameters of knee joint in 4-linkage bar transfemoral prosthetic leg for future design of smart prosthetic leg.

A three dimensional motion analyzer with seven infrared cameras and two force plates was used to collect data. Then, the collected data were analyzed by Matlab, SPSS, and Microsoft Excel.

Finally, the regression formula for three couple of parameters was extracted and the moderate direct association of knee moment and knee angle, moderate inverse correlation of knee power and knee moment, and major inverse correlation between knee power and knee angle were obtained from the analysis of the experimental tasks.

ACKNOWLEDGEMENTS

This research project would not have been possible without the support of many people.

Firstly, I would like to convey thanks and express the deepest gratitude to my beloved parents, Mohammad Kamal Soodmand, and Parisa Abrishamkar for their unimaginable support and enthusiastic encouragement to pursue my studying up to this level.

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Abbreviations

3D	Three dimensional
AKP	Active prosthetic knee
BC	Before Chris, Before the birth of Chris
BCE	Before common era, Before the birth of Chris
GRF	Ground reaction force
HS	Heel Strike
MS	Midstance
OHS	Opposite midstance
TF	Transfemoral
TO	Toe-off
UNICEF	United nations international children’s emergency fund

Definitions in Short

Amputee	The person who has had a limb removed due to an accident or a surgery.
Anthropometry	The scientific study of the measurement of the physical characteristics of human body such as size, weight and proportion.
Biomechanics	The field of science in which the concepts and knowledge of mechanics are applied to human body and movement system.
Force Plate	It is a measuring instrument to measure ground reaction forces generated by human body during walking or running due to his/her body weight.
Gait	Manner of walking or pattern of movement.
Kinematics	An area of mechanic which study of bodies in motion, and describing and quantifying of translational or rotational of bodies without regard to cause of the motion.
Kinetics	The area of mechanic that investigate about the causes of motion such as force, moment, and power.
Lower Limb	Lower part of human body, from Pelvic to the end.
Matlab Software	It is stand for “Matrix Laboratory” which is numerical software. It is using for technical computation.
Microsoft Excel	Microsoft Excel is spreadsheet software which provides an

environment for user to enter numerical values or data into the rows or columns of a spreadsheet, and to use these numerical entries for such things as calculations, graphs, and statistical analysis.

Midstance When the knee angle is zero and all the body weight is directly applied over the leg.

Motion Analysis It is an investigating and diagnostic technique to study of human movement.

Pearson Correlation A correlation coefficient between -1 and +1 that measure the degree of association between two different variables.

SPSS Software It is statistical software that is using to analyze the correlations of a series of data and result with tables and graphs.

Toe-Off The time when toe push off the ground and take off.

Transfemoral Amputee The person who losses leg between knee and hip. It’s also called above-knee amputee.

Traumatic Amputation Avulsion of a human limb due to an accident or injury.

Vascular Amputation A surgeon remove of a limb or a part of limb that no longer useful for body or because of extensive infection.

1. CHAPTER ONE: INTRODUCTION AND BACKGROUND

In the past, amputees had to use old versions of canes, wheelchairs, wooden peg leg, and crutches. However, nowadays, amputees can enjoy the benefits of numerous advances made in biomechanics and rehabilitation engineering by using many types of smart lower or upper limb prosthetics (L. L. Smith, 2006).In this thesis, the author presents the works that investigates the kinetics and kinematics behavior of a transfemoral prosthetic leg.

Legs and knees are extremely important in our body especially while walking or standing, consequently, our balance when standing is achieved with the help of the leg. Knee locomotion provides a connection between thigh and shank and also arranges the bending movement which allows us to walk (O'Rahilly & Müller, 1983).

This research is an attempt for a better understanding of transfemoral prosthetic leg behavior during normal walking in order to optimize the design of active prosthetic knee (AKP) for transfemoral amputee and improve the useful life of this kind of prosthetic leg.

1.1 Motivation

Currently, over ten million amputees exist in the world and according to the “limb for life organization report”, more than 250,000 people lose their limb every year, mainly due to diabetic diseases, cancers, gangrene, wars, and accidents (L. L. Smith, 2006). In addition, more that 85 percent of the people who have lost their limbs are injured in Afghanistan, Angola and Cambodia (Machel, Assembly, UNICEF., & Rights, 1996). There are many consequences apart from losing their limbs, such as losing their jobs, limitation of movements, and numerous difficulties in the daily activities. Therefore, the demand for the advanced prosthetic technologies is now increasing.

1.2 Research Justification

The concept of mobility is a task which is very easy for able-bodied. However, for lower limb amputee, a very simple task of walking on the ground is meticulously difficult. Therefore, equipped amputees with assistive prosthetics can help them to improve their lifestyle. Hence the significance of spending time and energy to investigate the rehabilitation issue is obvious.

The main hub of this research is the analysis of the Kinetics (Forces & Moment) and Kinematics (Joint Movement) of prosthetic knee in transfemoral amputees to find the relations among them and explain the causes of those relations which can help other researches to consider the output of this research project in their prosthetic knee design. Furthermore, most of the assistive devices which work appropriately in the initial stages may become inappropriate due to the environment change or the device fatigue. Therefore, they need to be reoptimized and reconfigured (Szeto, Enderle, & Bronzino, 2011).

1.3 Objective

The objective of this study is to evaluate of the transfemoral amputees gait with intention to find the correlations of kinetics and kinematics parameters of knee in transfemoral prosthetic leg. Moment and power as kinetics parameters and angle of rotation of knee as kinematics parameters were evaluated and the correlation of them were interpreted.

1.4 Significant of study

The output of this research will help to increase the understanding of interconnection of kinetics and kinematics parameters of knee in transfemoral amputee for future designing of smart prosthetic leg. This knowledge will help to determine the most suitable selection for a smart prosthetic knee and to determine the most efficient control parameters throughout the range of motion of knee during normal walking .

1.5 Background

This part aims at providing a brief background to help readers to get information about the works which have been done in this research report.

1.5.1 Anatomical and Terminological Terms

As you can see in Figure 1-1, orthogonal planes are generally used for describing a human body. The three planes employed here are described as Sagittal plane that divides the human body into the right, left parts, and corresponds with X-Y global axes. Secondly, it is the Transverse plane, which is a horizontal plane that divides the human body into cranial and caudal parts, and it also corresponds to X-Z global axes, and finally, the Frontal plane is a vertical plane that divides the body into anterior and posterior parts which corresponds to Y-Z global axes.

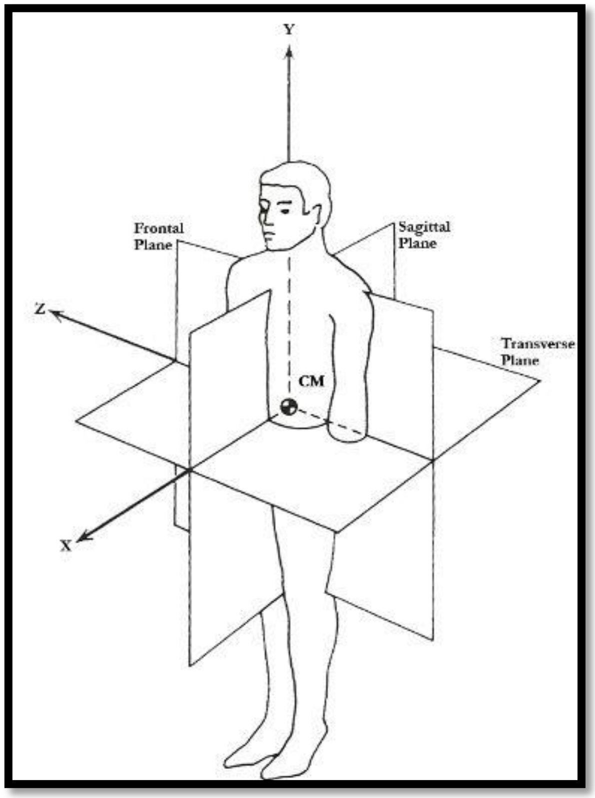

Figure 1-1 Three dimensional anatomical coordinate system (Winter, 2009)

In these planes, there are some directions to identify movements and parts of human body. In Sagittal plane, flexion/extension in frontal plane abduction/adduction, in transverse plane medical/lateral and some direction such as anterior/posterior or superior/inferior which are common between two planes (Hamill & Knutzen, 2006).

In Figure1-2 Directional terms of body (Hamill & Knutzen, 2006) Figure 1-3 you can find the directions of movement of hand and foot in human body. The description of these movement are specified in Table 1-1.

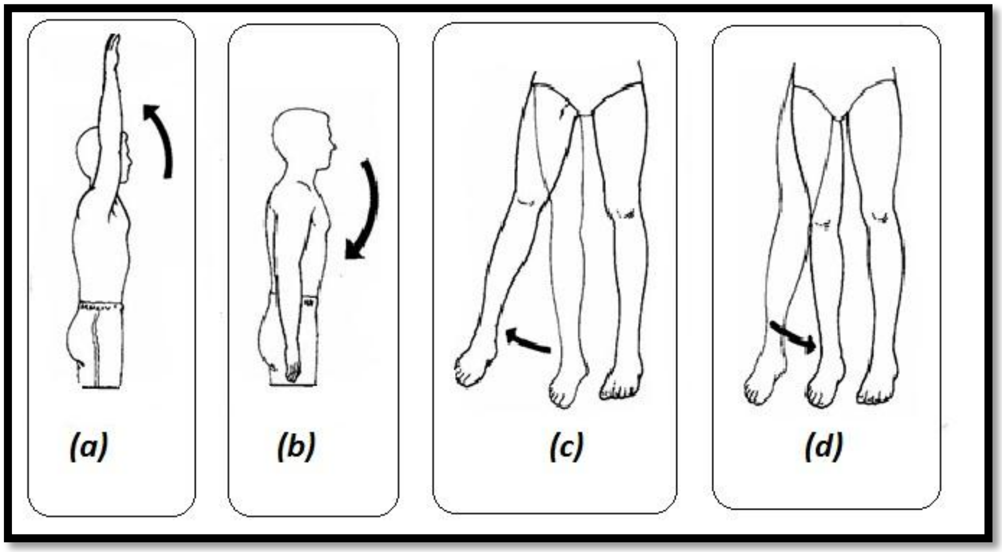

Figure1-2 Directional terms of body (Hamill & Knutzen, 2006)

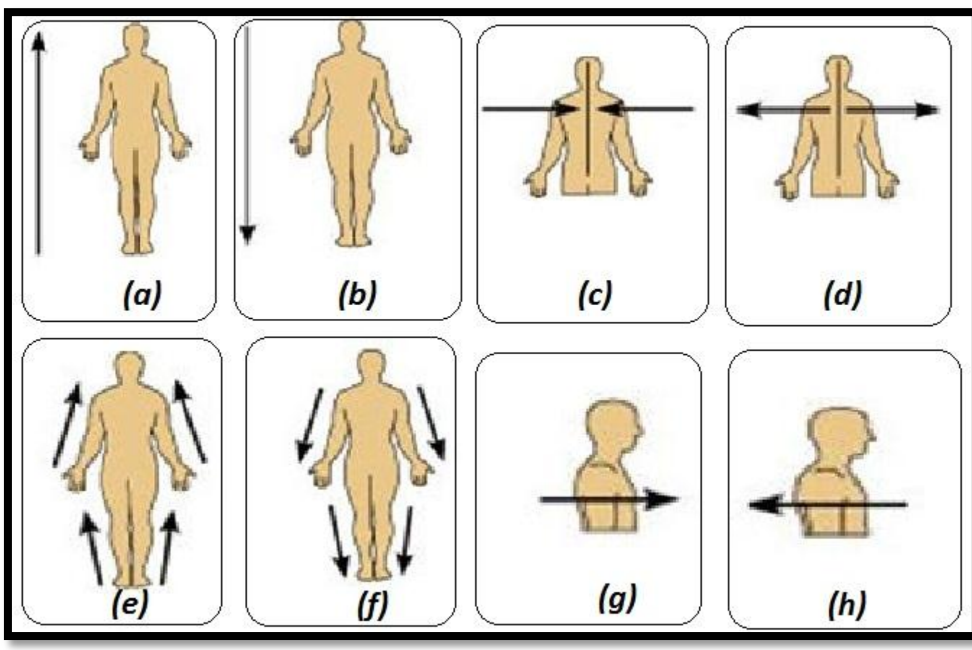

Figure 1-3 Directional terms of body

Table 1-1 Orientation and directional terms

Row No.	Term	Definition	Figure No.
1	Flexion	when angle between two segments are decrease	1-2a
2	Extension	when angle between two segments are increase	1-2b
3	Abduction	when segment moves away from midline of body	1-2c
4	Adduction	when segment moves toward midline of body	1-2d
5	Superior	Toward the upper part of body (Toward Above)	1-3a
6	Inferior	Toward the lower part of body (Toward Below)	1-3b
7	Medial	Toward or at midline of the body; to the inner side of body	1-3c
8	Lateral	Away from midline of body; to the outer part of body	1-3d
9	Proximal	toward to the origin or the point of attachment of the segment	1-3e
10	Distal	away from the origin or the point of attachment of the segment	1-3f
11	Anterior	Toward or at the front of the body (toward in front)	1-3g
12	Posterior	Toward or at the back of the body (toward behind)	1-3h

In the Figure 1-4 all the directions are shown simultaneously on a human body.

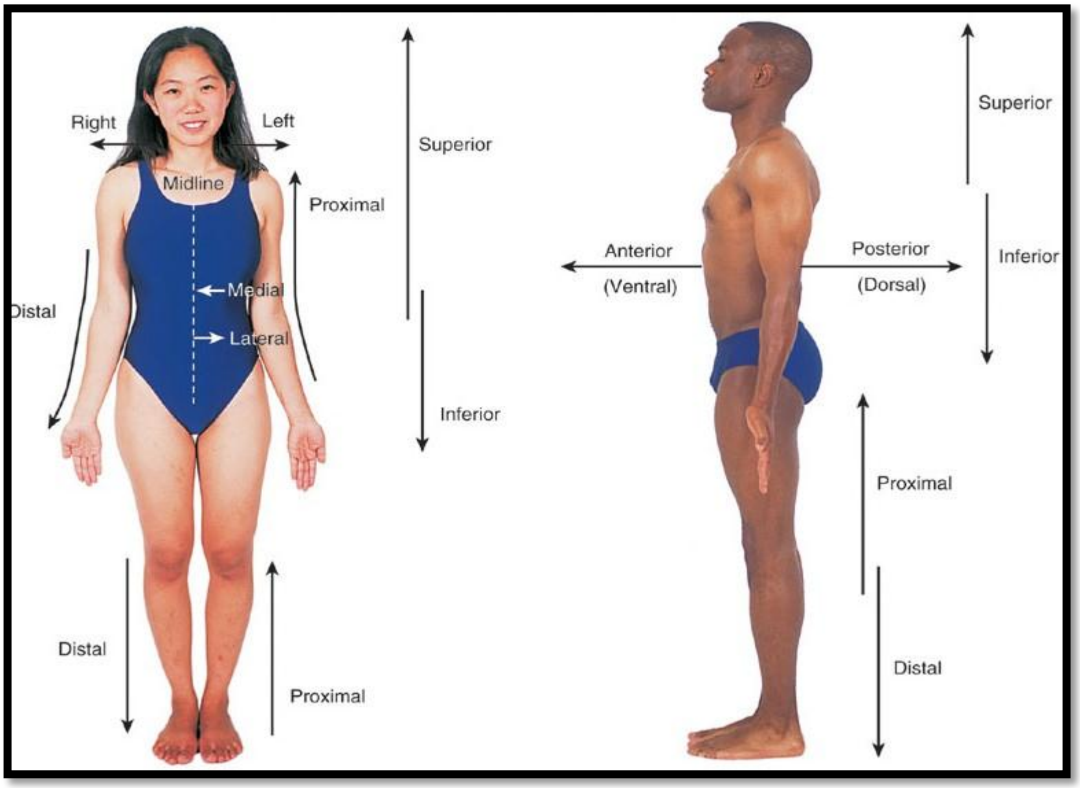

Figure 1-4 Directional terms (Thompson, 2011)

Specifically the directions of the movements of a leg are illustrated in Figure 1-5. Flexion and extension of the hip and knee in the sagittal plane are caused by leg muscles and abduction and adduction of hip has happened in frontal plane as it shown in Figure 1-5 (Higgs, 2004)

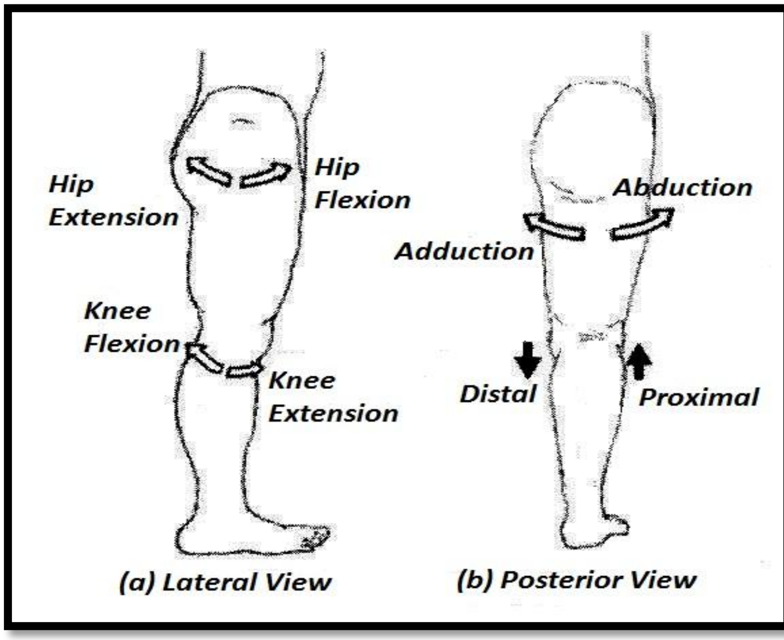

Figure 1-5 (a) Hip and Knee Movement in the Sagittal Plane. (b) Hip Movement in the frontal Plane (Higgs, 2004)

1.5.2 Prosthetic Terminology

Socket, knee, pylon, and foot are the components of a prosthesis transfemoral leg which can be connected in different steps as illustrated in Figure 1-6.

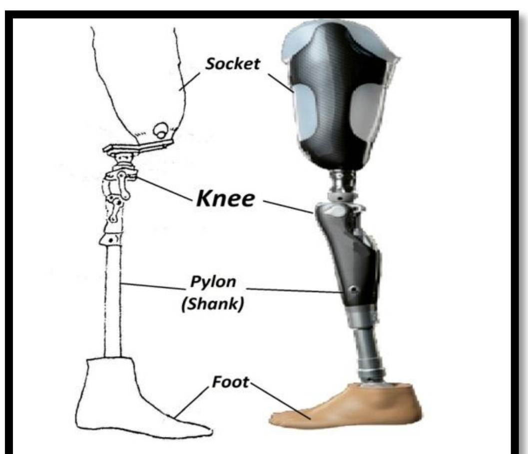

Figure 1-6 Component of modular lower limb prosthesis for TF (above-knee) amputee

The most critical part of prosthesis leg is the socket because it always is in contact with stump (amputee's residual limb). Sockets, which are too tight or too loose, can result in lots of discomfort on amputee's stump. Sockets are attached to the limb over a liner and their main duty is to transfer forces from prosthetic leg to the stump.

Knee is a very important part in human movement because it is located between two huge lever arms, thigh and shank. Therefore, it should sustains high forces (Guess & Maletsky, 2005). Simple prosthetic knee can be divided in two general categories, Single axis and polycentric knee (Higgs, 2004). Single axis knee has a very simple mechanism; it rotates at transverse axis like a pin joint. However, in polycentric, flexion of knee causes the movement of the axis of rotation.

Pylon is generally made of metal rods and it works as a support structure for prosthetic leg and works as a shank in human body.

Nowadays, pylons are made of carbon and fiber composite to make it lighter. Sometimes, manufacturers cover pylon with a foam or plastic to make it look more natural.

Foot is the lower part of prosthetic leg and it is designed to replace the physiologic foot system (Gitter, Czerniecki, & DeGroot, 1991). There are four classes of feet, single axis foot, SACH (solid ankle cushioned heel), Multi axis foot, and dynamic response foot.

1.5.3 Rehabilitation

Rehabilitation is a kind of treatment which intents to facilitate the proccess of recovery of injuries which may result in a human body due to illness, accedent, war and so on to help him/her to live as normal as possible (Cooper, Ohnabe, & Hobson, 2007). The main purpose of rehabilitation is to recover thr patient's physical or mental capabilities which might have been lost because of illness, injury or war.

1.5.4 Gait Assessment (Gait Analysis)

Gait Analysis is the methodical investigation of human walking or running in which body movement and body mechanics are measured , using an experienced observer's eye and brain enhanced by instrumentation (Ayyappa, 1997a).

Gait is defined as the manner of walking and **Gait Cycle** is defined as the repeating form of engagement of muscles and joints of the body when walking (Muscolino, 2010).

The term **Stride** is used to define a pattern of the gait cycle. A stride is composed of two **steps**: (1) left foot step and (2) right foot step.

A gait cycle has two main phases, (1) Stance phase which begins at heel strike and ends at toe off, (2) Swing phase which begins at toe off and ends at heel strike.

As you can see in Figure 1-1, stance phase itself has 5 different landmarks:

1- **Heel Strike** which is defined as the point of time that a person's heel makes contact with the ground.

2- **Foot Flat** which is defined as the point of time that foot is flat and whole plantar surface of it comes into contact with ground.

3- **Midstance** which is exactly the midpoint of stance phase. In this landmark the weight of the body is directly over the lower extremity. In other words, the angel between thigh and shank is 180 degree.

4- **Heel Off** is the point of time when heel leaves the ground

5- **Toe Off** is the last point of stance phase in which toe pushes off and leaves the ground.

In addition, swing phase is divided into three, approximately equal subdivisions: (1) Early Swing, (2) Midswing, and (3) Late Swing.

During gait analysis, at first it might be assumed that each phase account for fifty percent of the gait cycle; however, as it shown in Figure 1-7, stance phase accounts for sixty percent of the gait cycle and swing phase for forty percent. This ten percent difference is because of “Double Limb Support” in which both feet are in contact with ground (Figure 1-7 Phases and Landmarks of Gait Analysis (Muscolino, 2010)).

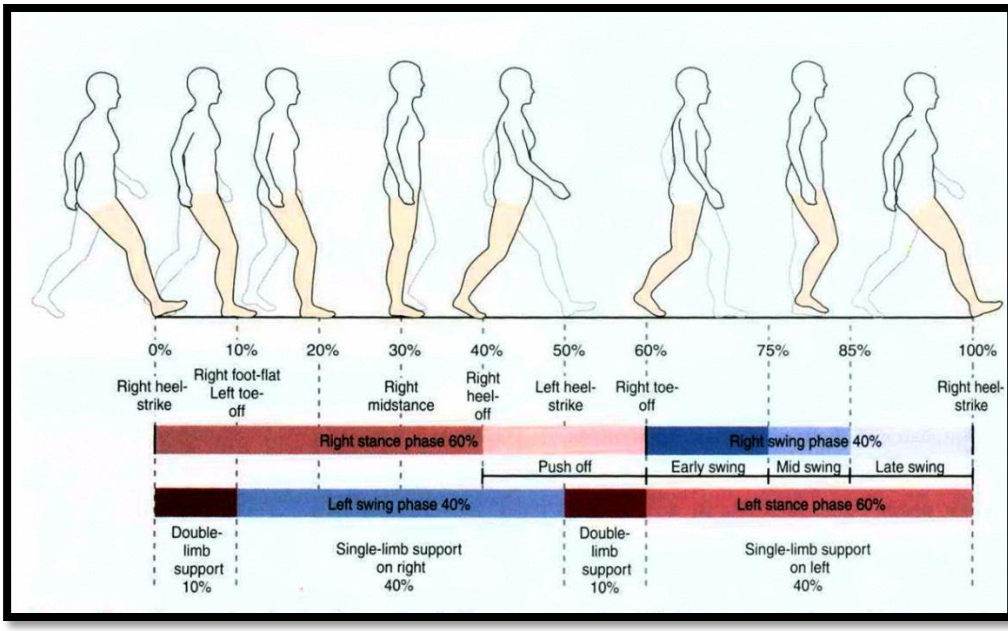

Figure 1-7 Phases and Landmarks of Gait Analysis (Muscolino, 2010)

1.5.4.1 Mechanical Parameters of Gait

Two types of parameters are important in gait analysis, Kinetics and Kinematics.

1.5.4.1.1 Kinematics

A branch of mechanics that deals merely with the depict the motion of body motion is known as kinematics (Koh & Tan, 2006). Kinematic analysis of human motion may be either qualitative or quantitative (Robertson, 2004). Position of the joints, velocity, angle between segments, acceleration, are the main kinematic parameters (Kreighbaum & Barthels, 1986). The main concern of kinematics is describing and quantifying positions and locations of bodies in both linear and angular way (Robertson, 2004).

1.5.4.1.2 Kinetics

A branch of mechanics that study of the cause of motion is called Kinetics. Force, moment and torque are kinetics parameters. Kinetics is concerned with the forces which are applied on the system (Hamill & Knutzen, 2006).

1.5.5 Transfemoral Amputee (Lower Limb above knee amputee)

Foot, Leg, Arms, and hands or generally, Limbs, are parts of our body that give us special capability to manipulate objects around us. Our life will change if we lose one of these limbs forever and the way of touching, moving, working, and playing will be affected by this loss. A surgical procedure in which a part of a limb is removed to control the pain, disease or trauma in the affected area is called Amputation (D. G. Smith, 2004). In this report, author has tried to focus on the transfemoral amputees, or above knee amputations. The population of Transfemoral amputee is 31 percent of all amputations (Esquenazi, 2004). The most important factor for medical doctor to maintain during surgery is the length of the residual limb. The longer residual limb is easier to align prosthetic and also it has more ability to operate(Esquenazi, 2004). The following picture, Figure 1-8 illustrates the 4 types of transfemoral leg in terms of length of residual limb (Seymour, 2002).

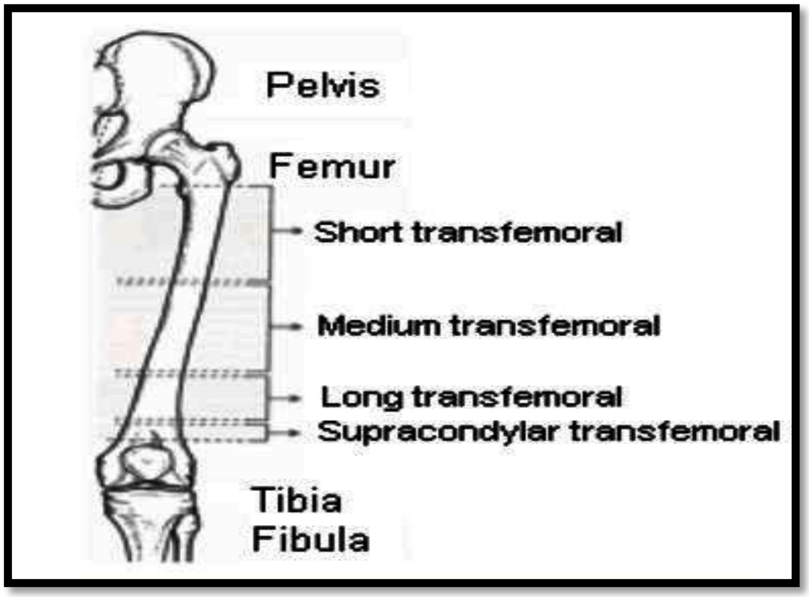

Figure 1-8 Level of Transfemoral Amputation (Seymour, 2002)

1.6 Thesis Organization

Investigation of mechanical behavior of knee joint in transfemoral amputee to find the relation and correlation of angle, moment, and power of knee in order to control them for future designing of a smart prosthetic leg.

Chapter 2 provided a review of literature about gait analysis, particularly for gait analysis of transfemoral amputee and also mechanical analysis of amputee gait especially for knee. This is followed by review of transfemoral prosthetic.

In Chapter 3, methodology, details of participants and instrumentation, process of gait analysis of TF amputee, data collection with a 3D motion analyzer system, and the way of data analysis with emphasize of how to normalize the data and analysis with particular software are presented.

Finally, Chapter 4 illustrates all the results of data analysis, with different types of figures and graphs, and discusses in brief what the correlations of the data are together.

2. CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Human Locomotion and Gait Analysis

Gait analysis of human is a concept that researchers are very interested in for many years. Since the earliest time people have been thinking about the way how they walking. These reasons of investigating on human locomotion have changed over the centuries (Andriacchi & Alexander, 2000). The caves drawings are present these changes. The first written document was made by Aristotle (384-322 BCE). In his paper he mentioned that if a man with a reed which immerse in ink attached to his head walking beside a wall on the ground the trace of ink would be zig-zag due to bending and standing upright habits during walking(Peck & Forrester, 1968). Human movement description and investigation was performed even by Greek philosophers (500-300 BC) (Lorini, 1991). First time, deductive reasoning and experimental observation are married together by Galileo Galieli (1564-1642) the most famous scientific of that period (O'Connor J & E., November 2002). In early nineteenth century, Weber brothers from Germany were made the initial academic and formal investigations of biomechanics (Whittle, 1996). Advances in four areas of science, kinematics, engineering mathematics, kinetics, and electromyography after that time have caused evolvement of "Gait Analysis". A review about earlier works in field of gait analysis was given by Garison (Garrison, 1960), Steindler (Steindler, 1953), and Frankel (Bresler & Frankel, 1950). Willhelm Eduard weber (1804-1891) was a physics professor at Leipzing University (Germany) started to work on mechanics of human walking apparatus and published some paper in 1836 (Weber, Weber, & Maquet, 1992). Then two of his bothers Renst Heinrich (1795-1878) and Eduard Friedrich Willhelm (1806-1871) closely continue Eduard consequences in practice. They used a stop watch, measuring tape and also a telescope for investigating of the position of limbs at 14 different frame of gait cycle they in their publication they published a picture which it was the first illustration for human gait (Figure 2-1)(Maquet, 1992).

2.2 Kinetics and Kinematics

The main concern of kinetics is on measurement of ground reaction forces which is the force between foot and ground. Ground reaction force (GRF) is measures by a kind of instrumentation which is assembled in the floor and is known as force platform. One of the most significant works in field of human movement was done by Jules Estienne Marey for measuring GRF (1830-1904). He started force and pressure measurement of human body. Therefore, he is known as the first modern gait analyst. Then Marey started to work with one of his students Gaston Carlet (1849-1892) who was invented a shoe with three pressure transducer to record the forces between the foot and ground.

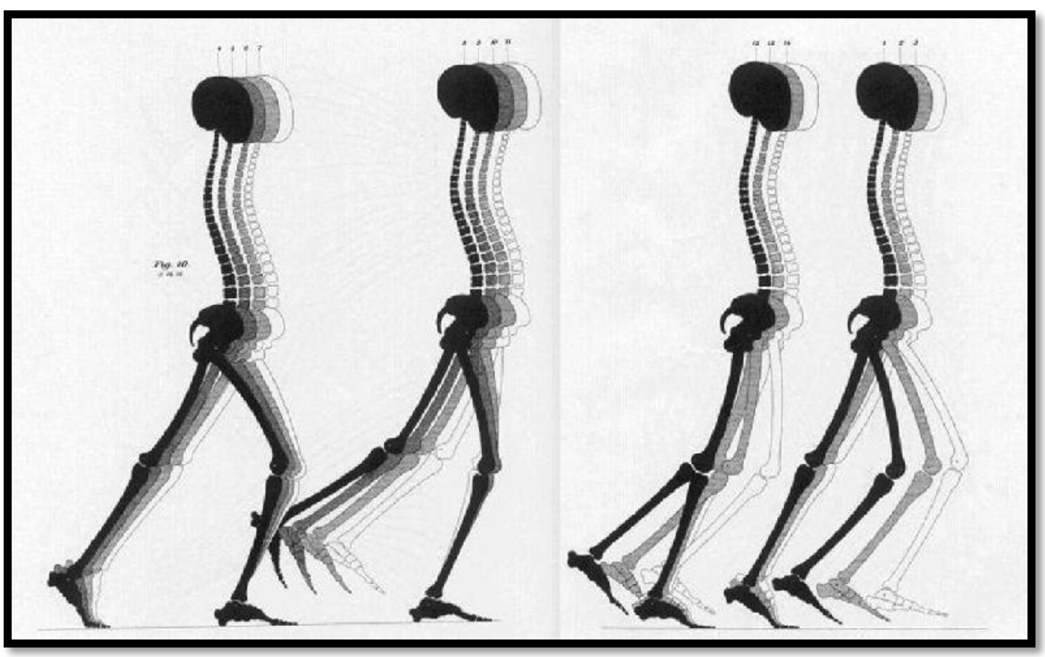

Figure 2-1 Fourteen instants of gait cycle (Maquet, 1992)

With the development of force plates the kinetics analysis of human movement was enabled to continue. A pneumatic system which measured in-shoe pressure were developed by Marey and Carlet (Rosenbaum & Becker, 1997). Kinematics is the human movement measurement. Coinciding with Carlet, Marey worked with Edweard Muybridge (1830-1904) to use his talent of photography to capture a specific instant, but Muybridge's technique was not useful for scientific measurement because the technique was not able to take pictures from proper angle. Muybridge used some cameras to take many pictures by triggered in succession. Coinciding with Marey & Muybridge, William Barune (1831-1892) and Otto Fischer (1861-1917) by using Newtonian equations and mechanics succeeded to report a calculation for estimation of joint forces and energy expenditure (Braune, Fischer, Maquet, & Furlong, 1988). Marey also started to collaborate with another student, Georges Demeny (1850-1918). The same technology as Marey & Carlet pneumatic system, had been used for a pneumatic force plate by Marey and Demeny (Rainone, 2008). However, their force plate abled to measured just vertical component. A three-component force plate was developed for the first time by Jules Amar (1879-1935) (Amar, 1920). As long as Amar was a rehabilitation specialist, he was always trying to measure amputees of the wars. Later on Herbert Elftman developed a full three-component mechanical force plate in 1938 (Elftman, 1938). Although most of the kinetics research of human gait has focused on GRF, Julian R. W. Morris has worked on acceleration of limbs (Morris, 1973). Nowadays, the output of modern gait analyzer systems has additional Kinetics data about joint forces and joint power based on complicated engineering mathematics and force platform data.

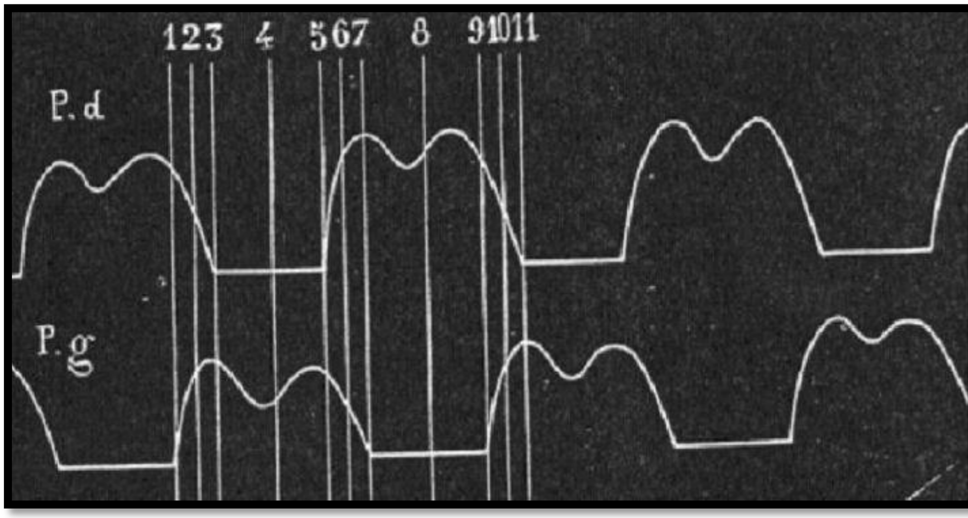

Figure 2-2 First recorded picture of ground reaction force by Carlet (Baker, 2007)

As the First World War injured people motivated Amar to work on his technique, the casualties of the Second World War drove the most significant advance in gait analysis in America by establish a Biomechanics Lab at the University of California at Berkeley. A team of 40 scientist headed by T.Inman (1905-1980) head of Orthopedic and Rehabilitation and D.Eberheart (1906-1993) head of Engineering to design and equip this lab. The output of their classical work at the lab made lots of resources of knowledge about mechanics of human movement. They measured the positions of segments and limbs with digitization of hundreds of pictures of cine film and a bunch of sophisticated calculations.

Ayyappa (Ayyappa, 1997b) mentioned that a gait cycle is the length of time between two particular events in walking cycle. Walking procedure can also account for the human gait cycle. The mechanism of gait including walking or running is stunningly complex. The seven components which collaborating of them determine of the way that we walk are mentioned in Vagughan book (C. L. Vaughan, Davis, & O'connor, 1992). These seven components are “the central nervous system, peripheral nervous system, muscles, synovial joint, rigid link system, movement (at ankle) and external forces” which are shown in

Figure 2-3. Saunders and his colleague (Saunders, Inman, & Eberhart, 1953) investigated on the six major determinations of normal gait. The sic major determinations are “pelvic rotation, pelvic tilt, knee and hip flexion, knee and ankle interaction, and lateral pelvic displacement”.

The most regularly method for measuring human locomotion is tracing movement of placed marker on the human body with 3D motion analyzer which is used in this research. This method developed by Benedetti and Capozzo.

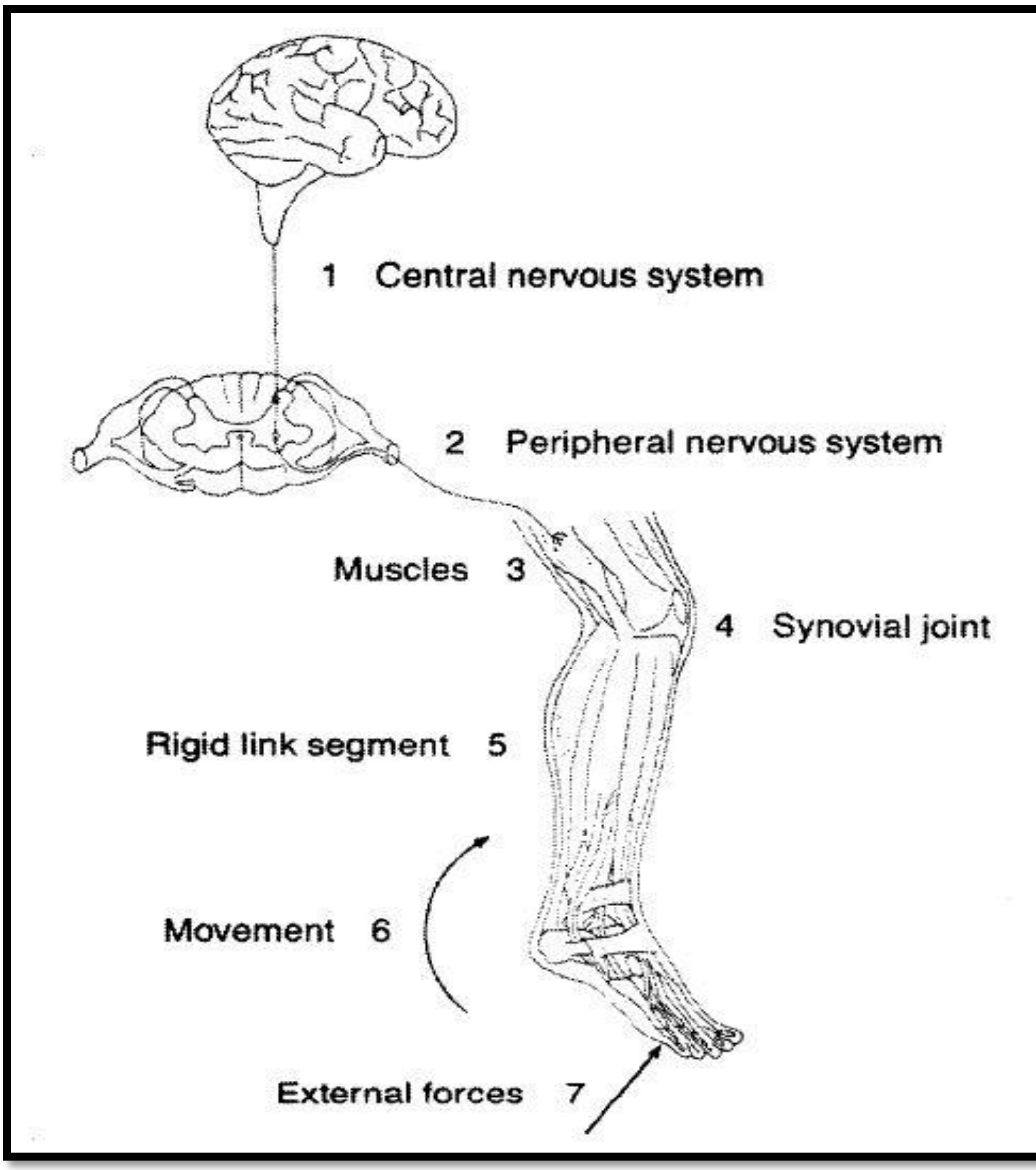

Figure 2-3 Component that have influence on gait (C. L. Vaughan et al., 1992)

Nowadays, human movement analysis has been examined in the field of Rehabilitations for designing optimized prosthetic limbs (Post, 2006). it is presently a popular and useful method for biomechanical investigation too (Benedetti, Catani, Leardini, Pignotti, & Giannini, 1998).

In this research the kinetics and kinematics data were analyzed for transfemoral gait. In 1992 Lasssel and his colleagues were did the analysis of kinematics data during a normal gait(Laassel, Loslever, & Angue, 1992). In 1994 Loslever with the help of Lassel did the statistical analysis of combination of kinetics and kinematics together for normal gait cycle(Loslever, Laassel, & Angue, 1994). The combination of these two latest papers but for transfemoral amputees is the main objectives of this research which is analyzing kinetics and kinematics parameters and statistical analysis of the combination of these parameters.

3. CHAPTER THREE: METHODOLOGY AND PROCEDURE

3.1 Introduction

The aim of this study to find correlation between the mechanical parameters, such as kinetics and kinematics in transfemoral amputee.

Firstly, we should find a proper transfemoral amputee with a good condition prosthetic leg (to avoid unforeseen errors). Then experimental task should perform in motion analysis laboratory. After experimental task, all the data should analyze with software of the 3D motion analysis system (Vicon MX System). Finally, the subjected parameters should extract from the output of 3D motion analysis system for data analysis and finding correlation and relation of them. In following figure (figure 3-1) the procedures of this research are shown.

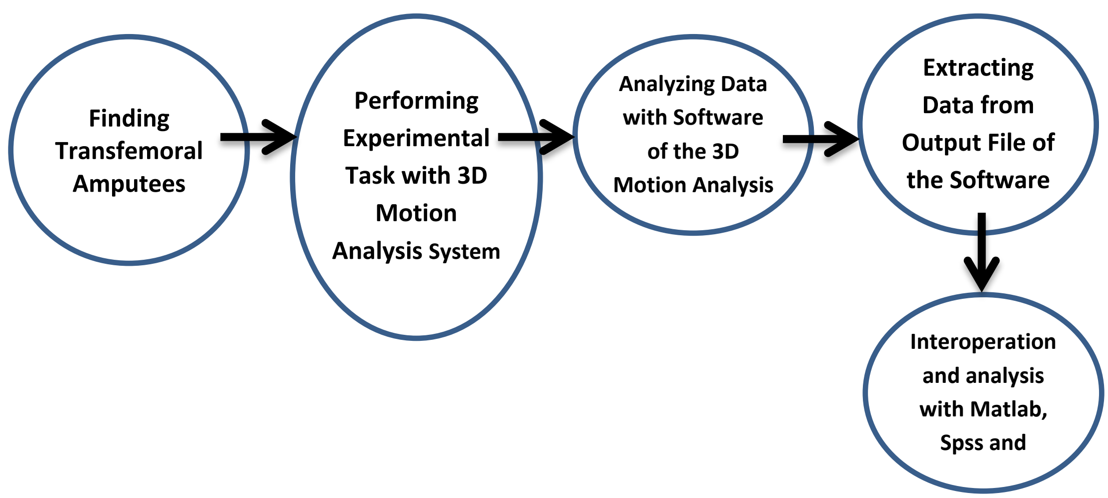

Figure 3-1 Structure of Methodology

3.2 Experimental Process

In this part the experimental task, subject of research and the instrumented which were used in this research were presented.

3.2.1 Participants

In this research the experimental data were collected from four transfemoral amputees with lower limb prosthetic were volunteers for data collection. All the amputees were participated in this gait analysis study had one long stump and they lost their limb because of trauma or vascular reason. The following table (Table 3-1) is showing the characteristics of amputees who are recruited for this study.

Table 3-1Characteristics of Amputee

Subject No.	Gender	Age (Year)	Height (mm)	Weight (Kg)	Amputation Etiology	Affected Leg
1	Male	32	168	61	Traumatic	Right
2	Male	34	172	72	Traumatic	Right
3	Male	48	160	101	Traumatic	Right
4	Female	28	153.5	55	Vascular	Right

3.2.2 Instruments

3.2.2.1 Meter

It is used for measuring the segments of body.

3.2.2.2 Anthropometer

Anthropometer (Figure 3-2) is an instrument for measuring the width of joints such as knee, wrist, elbow, ankle and etc.

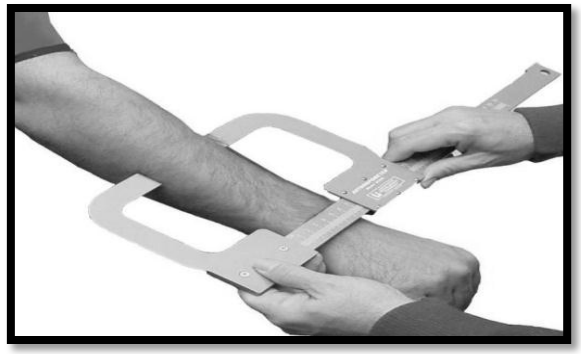

Figure 3-2 Anthropometer

3.2.2.3 Markers

Some reflective markers which detectable by infrared cameras to attach them on 39 points of participants' body.

3.2.2.4 Swimming Suits

All the subjects have to wear the swimming suite, because this kind of suit is very tight and suitable for this experiment, because we can attach all the reflective markers on the body and walking with least displacement of markers.

3.2.2.5 Force Plate

Two force plates (Kistler, Model: 9861-B) are used in this survey to record the ground reaction force (GRF) which they work with piezoelectric assistant (Osman, Ibrahim, & Abas, 2009).

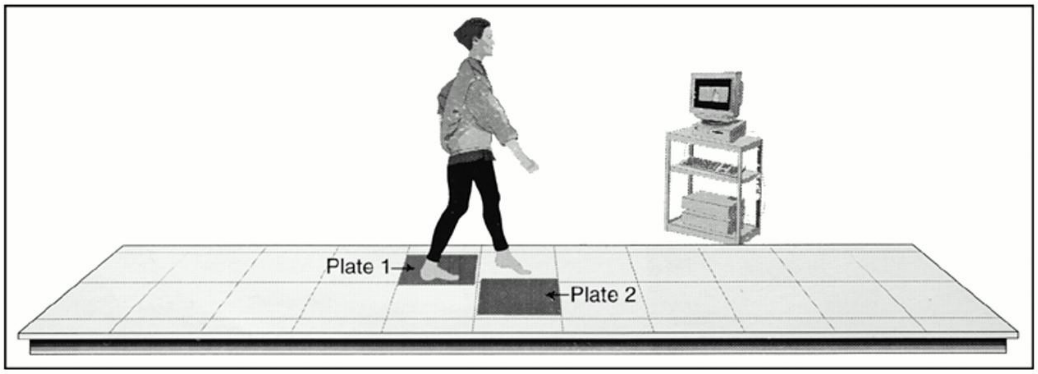

Figure 3-3 Schematic View of Walking in a Pathway with two Force plate (Bhave, Paley, & Herzenberg, 1999)

Table 3-2 Force Plate Output Signal

Output Signals	Channel	Description
F_{x12}	1	Force in X-direction measured by sensor 1 + sensor 2
F_{x34}	2	Force in X-direction measured by sensor 3 + sensor 4
F_{y14}	3	Force in Y-direction measured by sensor 1 + sensor 4
F_{y23}	4	Force in Y-direction measured by sensor 2 + sensor 3
$F_{z1} - F_{z4}$	5-8	Force in Z-direction measured by sensor 1- 4

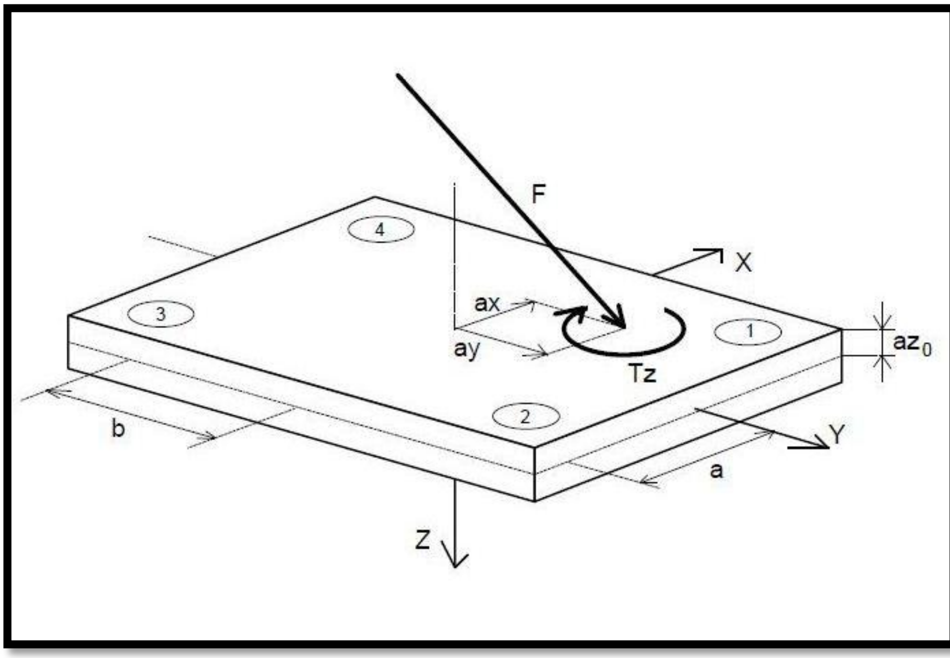

Figure 3-4 Force Plate and Related Parameters (K. Vaughan, 1999)

Table 3-3 Calculated Parameters (K. Vaughan, 1999)

Parameter	Calculation	Description
F_x	$= F_{x12} + F_{x34}$	Medio-lateral force
F_y	$= F_{x14} + F_{x23}$	Anterior-posterior force
F_z	$= F_{z1} + F_{z2} + F_{z3} + F_{z4}$	Vertical force
M_x	$= b \times (F_{z1} + F_{z2} - F_{z3} - F_{z4})$	Plate moment about X-axis
M_y	$= a \times (-F_{z1} + F_{z2} + F_{z3} - F_{z4})$	Plate moment about Y-axis
M_z	$= b \times (-F_{x12} + F_{x34}) + a \times (F_{y14} - F_{y23})$	Plate moment about Z-axis

3.2.2.6 MX Cameras and its System

Seven infrared cameras (Model: MX-F20) will be to detect the markers which are attached on the participants' body. They mounted strategically about 2.5 meters from the ground. Each camera approximately provides a capture volume of 4m × 4m × 2m and all of them cover all the 360° around the subjects (Osman et al., 2009). There is also a MX ultra-net to link between the MX cameras and the host Computer.

3.2.2.7 MX Cables

Proprietary MX cables connect the system components, providing a combination of power, Ethernet communication, synchronization signals, video signals, and data ("Vicon MX Hardware System Reference," 2006).

3.2.3 Data Collection

As it mentioned, for motion analysis of the participants in this research a three-dimensional motion analyzer system (VICON 370) with seven infrared cameras is used. Figure 3-5 Basic Architecture of 3D motion Analyzer Systemis shown the basic architecture of 3D motion analyzer system.

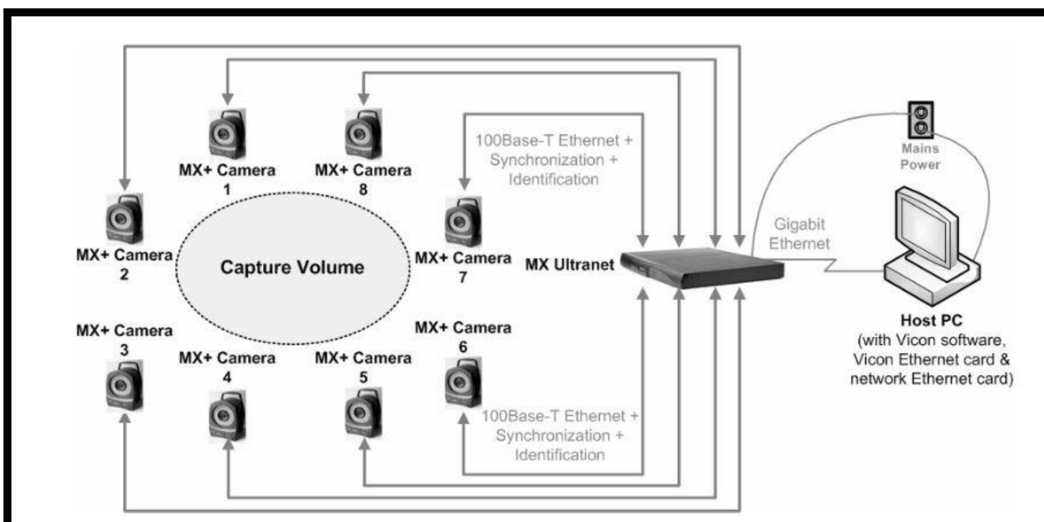

Figure 3-5 Basic Architecture of 3D motion Analyzer System ("Vicon MX Hardware System Reference," 2006)

3.2.3.1 Calibration

First of all the instrumentation such as cameras and force plates were calibrated. For cameras a wand was used to define point (0,0,0) for motion analyzer system. The aim of calibration process is for linking cameras to each other to the real environment. It means we tell each camera its position relative to the others and also from zero point which we specify for the system. In the specific software of the system from the right hand camera tab, and from the wand menu we should select the type of the wand and then click on the start calibration then start waving the wand in free space of the room until system collected more than 1000 points of wand for each camera.

Figure 3-6 Transfemoral amputee walking in the pathway

There is a light on each camera that with start calibration the light flashing yellow when the light on camera stop flashing and change to green it means the calibration of this camera is finish. In this case the direction of (Z) is toward vertical, (Y) is fore-and-aft, and (X) is toward lateral.

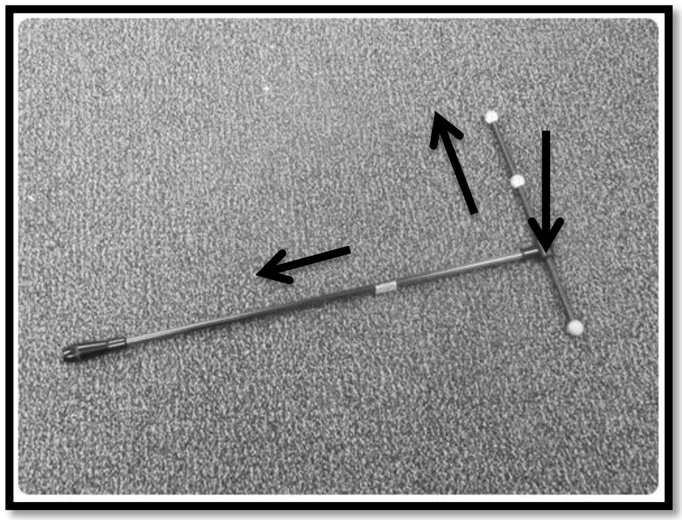

Figure 3-7 The Wand for Calibration

For Calibration of force plates, we should define the zero weight point for them. From the Software, when there isn’t any load on the force palates we should click on the calibrate bottom then the calibration for force plates will done.

All the calibration processes are done in the Vicon 3D motion analyzer software.

3.2.3.2 Description of Doing Experimental Tasks

For modeling 3D movement of human body the 3D location of markers which are located on the body of subjects (Figure 3-8) must recorded. To increase accuracy of the data, subjects must wear the swimming clothes to prevent changing the position of the markers during walking. For amputees, the markers are attached to their body based on the location of the markers on of the intact limb it means prosthetic leg assumed as normal leg and markers were put on the specific point of normal leg which is shown in Figure 3-8 The Marker Placement Map (Pitkin, 2009). Positioning of the markers has been made through approximation (Hansen, Meier, Sessoms, & Childress, 2006; Underwood, Tokuno, & Eng, 2004). In this research because data of lower limb is target of our research markers are attached only to the lower limb. When amputee walk in the pathway, the next step is definition of the location and connection of body segments in the software. Each marker in the software should specify for a specific joint, segment, or a location (Figure 3-9 and Figure 3-9).

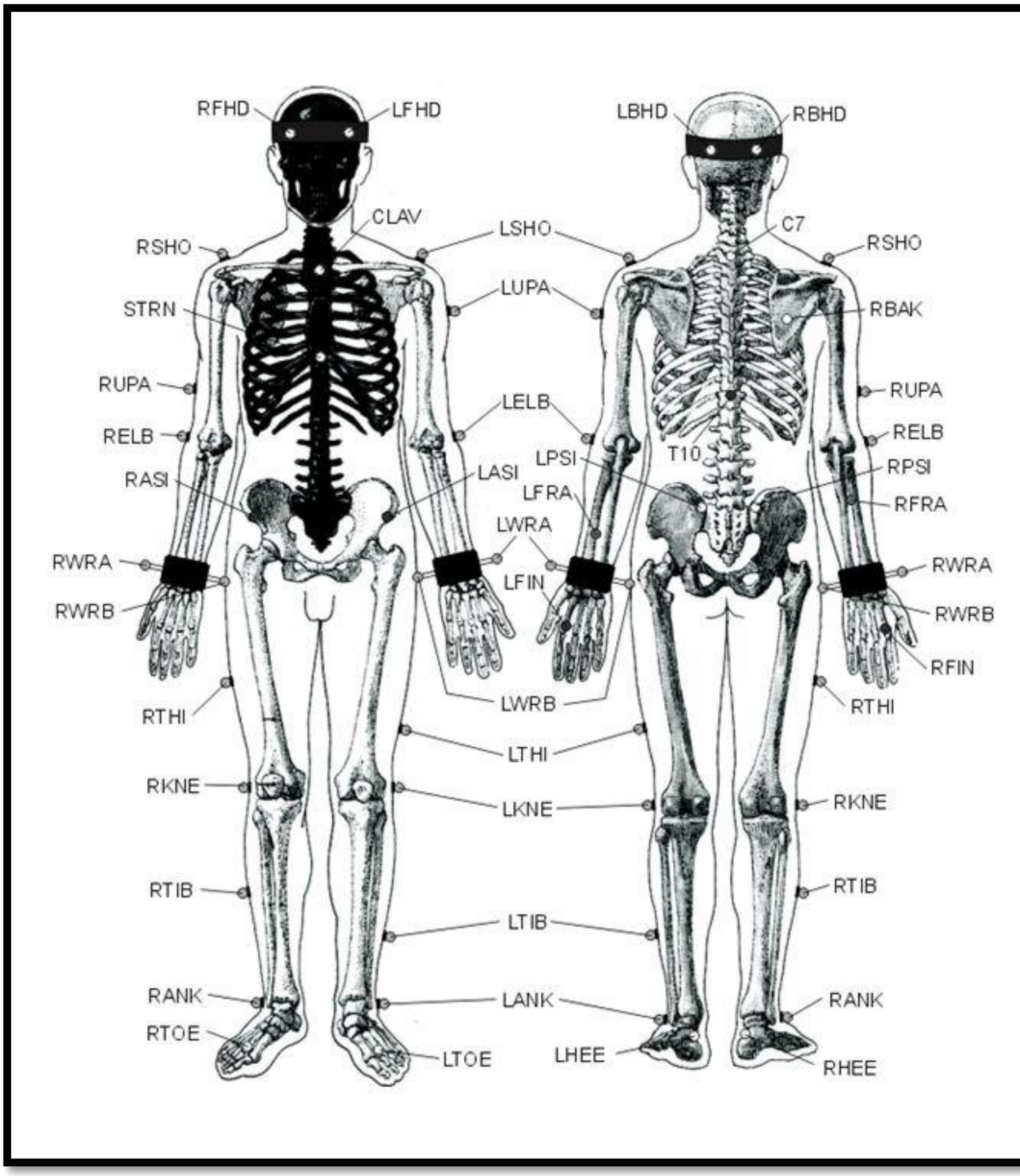

Figure 3-8 The Marker Placement Map (Pitkin, 2009)

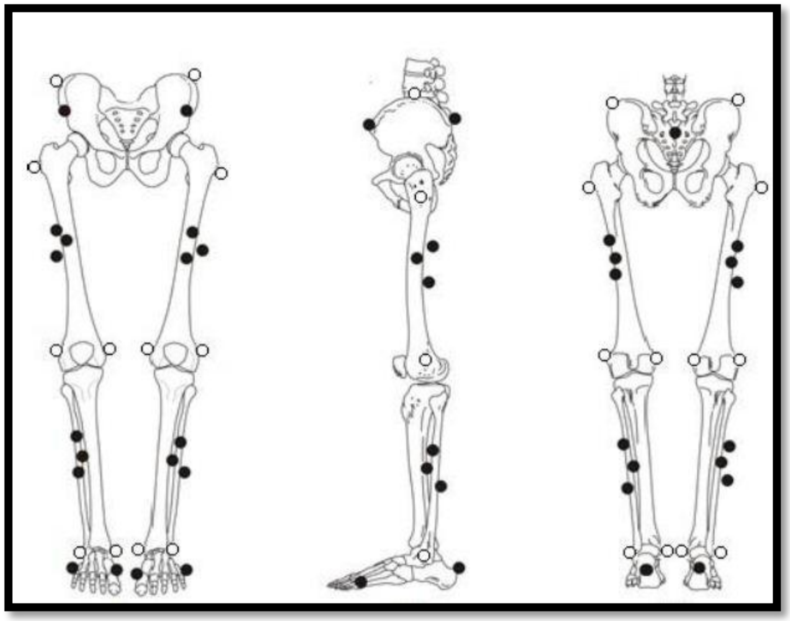

Figure 3-9 Placement for Defining. White markers are located in specific joint and segments Black markers are located for tracking of s segments movement (Cappozzo, Catani, Della Croce, & Leardini, 1995)

Before doing experiments, anthropometric data of lower extremity were collected for all subjects. Then prior to the main experiment, all the subjects walked along the specific pathway in the lab for three times to accustom to the task and also the pathway. All the amputees walked with their own shoes. The subjects were free to walk at self-selected speed on a ten meter specified pathway which was equipped with two force plates (Kistler, Model: 9861-B) for measuring ground reaction forces and seven cameras to detect the path movement of the markers and estimate the kinematics data. After walking in the pathway the recorded data should calibrate (Figure 3-11 Calibration of Data with the Software) and analyze with the software of system. The output of the 3D motion analyzer system is a Microsoft Excel file which include all the Kinetics data such as forces and moments and also kinematics data such as angle of joints. In this research power, moment and angle of knee (Figure 3-10 The Direction of Knee Angle) were subjected.

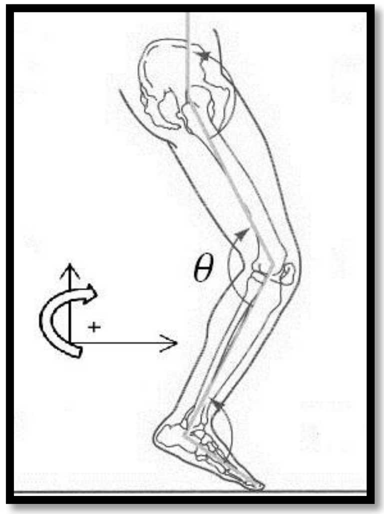

Figure 3-10 The Direction of Knee Angle

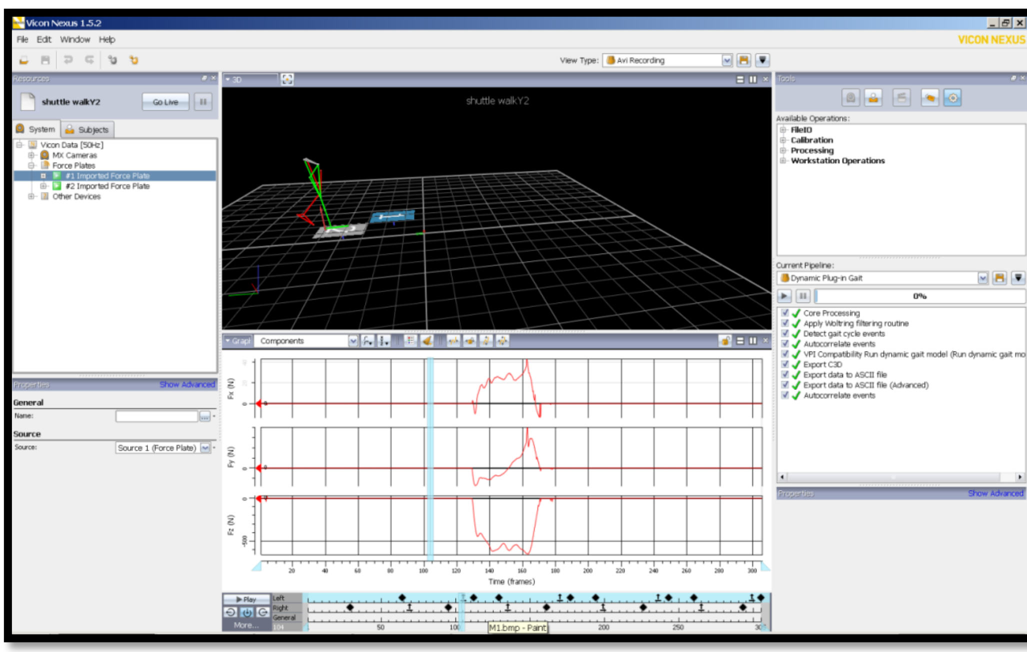

Figure 3-11 Calibration of Data with the Software

3.3 Data Analysis

When capturing of movement data is complete, significant data must extract from the raw data of the software's output. Then the data which are obtained from 3D motion analysis system must analyze and categorized for finding results. The unit of moment of force that obtained from the 3D motion system is “N.m”. However, the body weights of our patients are different, so we should divide the data of each person with their own body weight to convert them to “N.m/Kg”, then the resulted data are comparable together for different patients. For each parameters 12 set of data were available (4 patients each has 3 trials). To compare two different parameters the average of all data for each parameter was calculated. Furthermore, obviously there are some errors in the experimental tasks and some of the data caused inconvenient in our results. Therefore, for eliminating these data and make them smooth with help of Matlab software, in its “Curve Fitting” tools we can fit and smooth the data and make the data normalized (Figure 3-12).

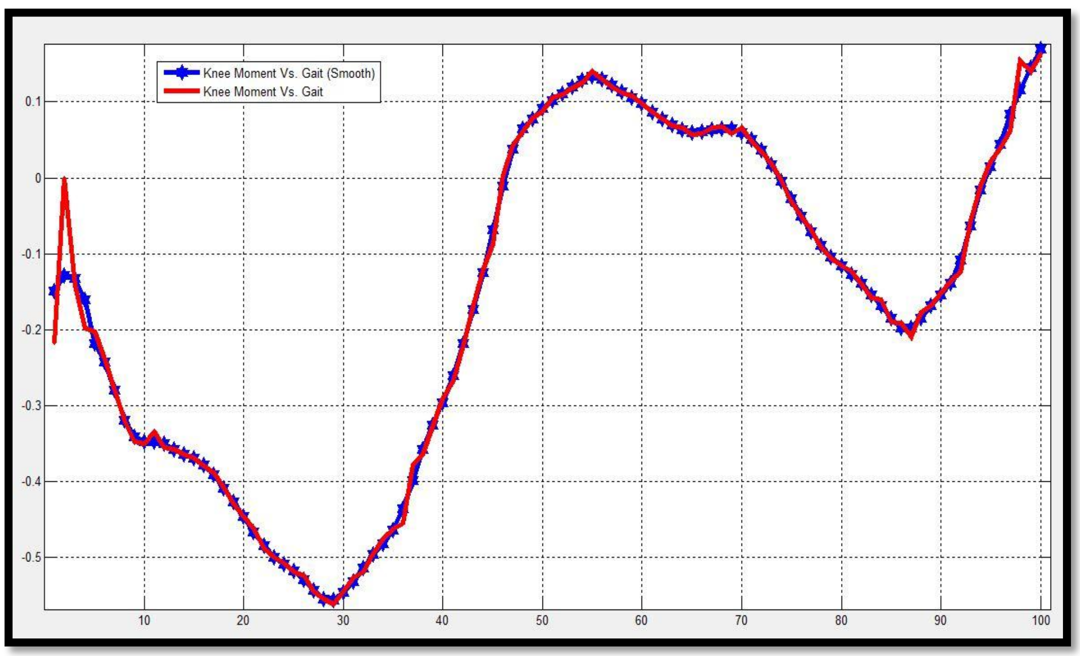

Figure 3-12 Curve fitting with Matlab for knee Moment data. Red Curve is normal date and Blue curve is smoothed data.

When final normalized data are obtained for knee moment and angle then from the following equations, power data for knee was calculated.

$$Power = Torque\ \times Angular\ velocity$$

Equation 3-1 Power (Meriam & Kraige, 2006)

Where units are:

For power is "$\frac{W}{Kg}$", Torque is "$\frac{N.m}{Kg}$", and Angular velocity is "$\frac{Rad}{S}$"

However, we have torque and angle. Therefore, for calculating angular velocity the following formula was used.

$$\omega = \frac{\Delta\theta}{\Delta t}$$

Equation 3-2 Angular Velocity (Meriam & Kraige, 2006)

$$\omega = \frac{\theta_2 - \theta_1}{\frac{1}{Frequency}} = \theta_2 - \theta_1 \times frequency$$

Equation 3-3

The unit of θ which obtain from 3D motion analyzer is "degree", so from the Equation 3-4 all the angles change to "Radian" in order to use for Equation 3-3 .

$$Radian = Degree\ \times \frac{\pi}{180}$$

Equation 3-4 transformation of Angle Unit

Finally, after calculating power data, they were normalized with curve fitting tool of Matlab (Figure 3-13).

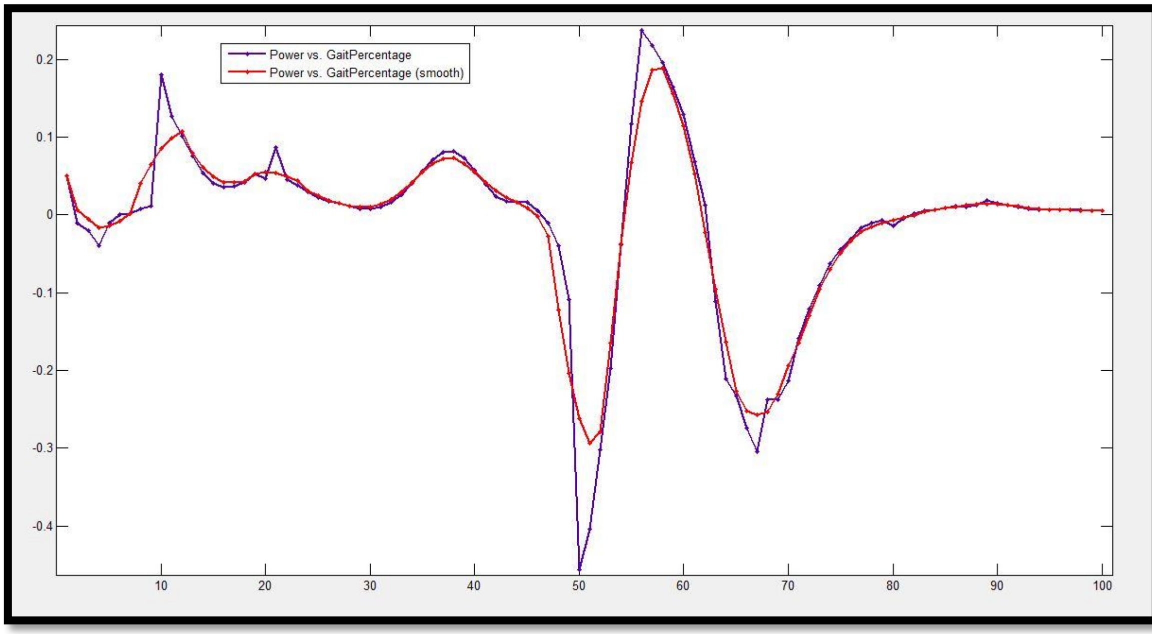

Figure 3-13 Curve fitting of Matlab for Knee power Data- Red line is smooth data and blue one is raw data

After the mentioned procedures, all the normalized data are ready for statistical analysis. The first analysis of data was done in Microsoft Excel software and graph of angle, moment, and power of knee in sagittal plane were drawn in this software as well. Then for finding correlation of these three important parameters of knee Spss software as a well-known and powerful statistical software was used. Spss is a software which is developed for analyzing numbers and drawing graphs (Morrow, Jackson, Disch, & Mood, 2010). Linear regression analysis was performed to compare two parameters together and also for finding the nature of relation which is available between two parameters. Beside output of regression linear which is interpreted in next chapter (Chapter 4), a scatter plot also obtained for data analysis to help the interoperation of the correlations.

The aim of data analysis is to find relation and correlation between the parameters of knee which are very important to control in amputation walking.

4. CHAPTER FOUR: RESULTS AND DISCUSSION

In this chapter, the obtained result from 3D motion analyzer system of transfemoral amputees with prosthetic leg during self-selected speed of level walking will be evaluated and explained.

Three parameters of gait are subjected in this research, one kinematics (Angle) and two kinetics (moment and power). All of the data which were obtained from the motion analyzer system were normalized as explained in previous chapter.

4.1 Normal vs. Transfemoral Gait

The following graphs present the kinetics and kinematics data of the normal and transfemoral gait cycle.

The vertical line in Figure 4-1, Figure 4-2, and Figure 4-3 is divided the stance and swing phase which is at approximately 60% of the gait.

4.1.1 Normal Gait Data

Kinetics and kinematics gait analysis data were acquired with Vicon Motion analysis system in a healthy self-selected speed gait of a male subject (Pitkin, 2009).

As predicted and shown in the Figure 4-1 the range of knee angle during stance phase is lower than swing phase. For moment, at Toe-off the moment which is applied to knee is almost zero and at OHS (Opposite heel strike, when the opposite leg is at heel-strike position) the moment of knee is at its maximum amount. For power of knee as you can see in Figure 4-3, the value of power at Toe-off is almost zero. It is very clear because moment and power have a direct relation together as it can be proved in Equation 3-1, and also at OHS the power is at its maximum value.

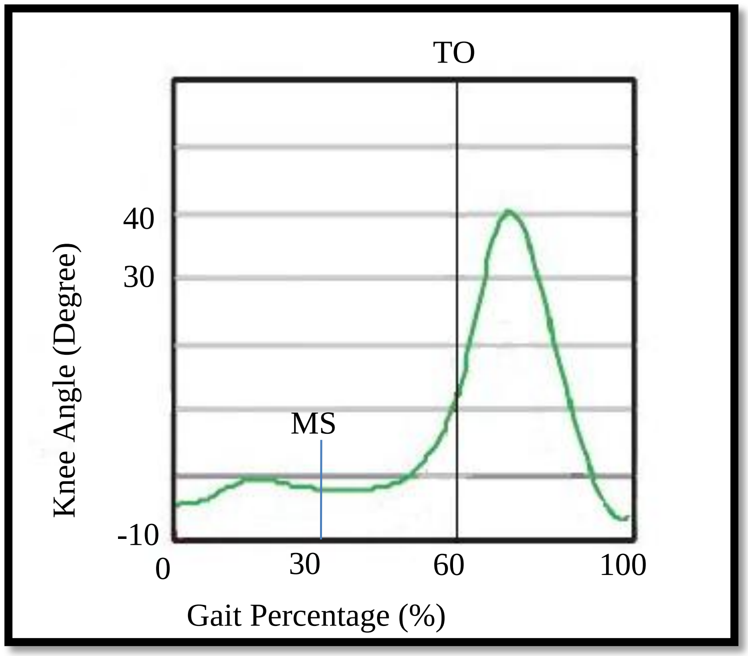

Figure 4-1 Normal Gait - Knee Angle

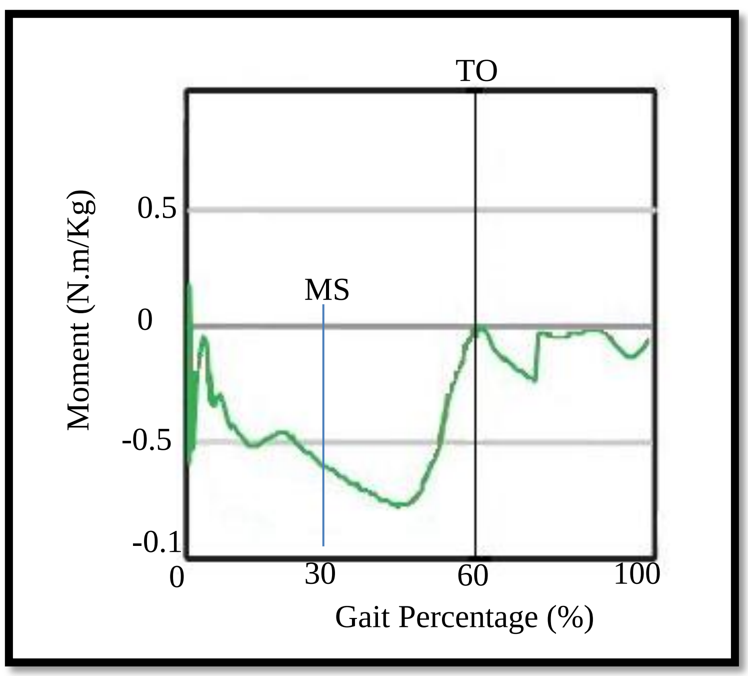

Figure 4-2 Normal Gait – Knee Moment

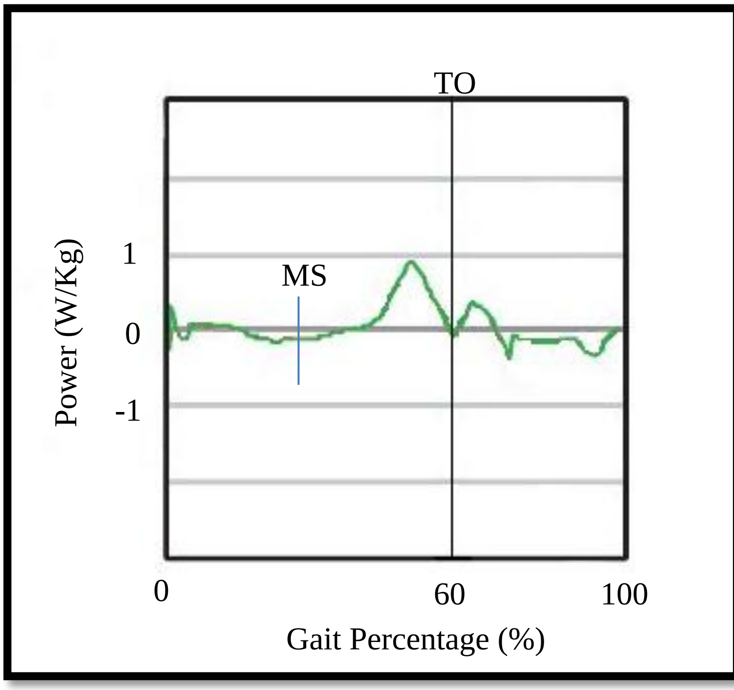

Figure 4-3 Normal Gait - Knee Power

4.1.1 Transfemoral Amputee Gait

The following graphs (Figure 4-4, Figure 4-5, and Figure 4-6) are present the same parameters as normal gait but for transfemoral amputee gait.

For angle of TF amputee, the range of movement is lower than normal gait but for value of angle at TO is almost equal to normal gait.

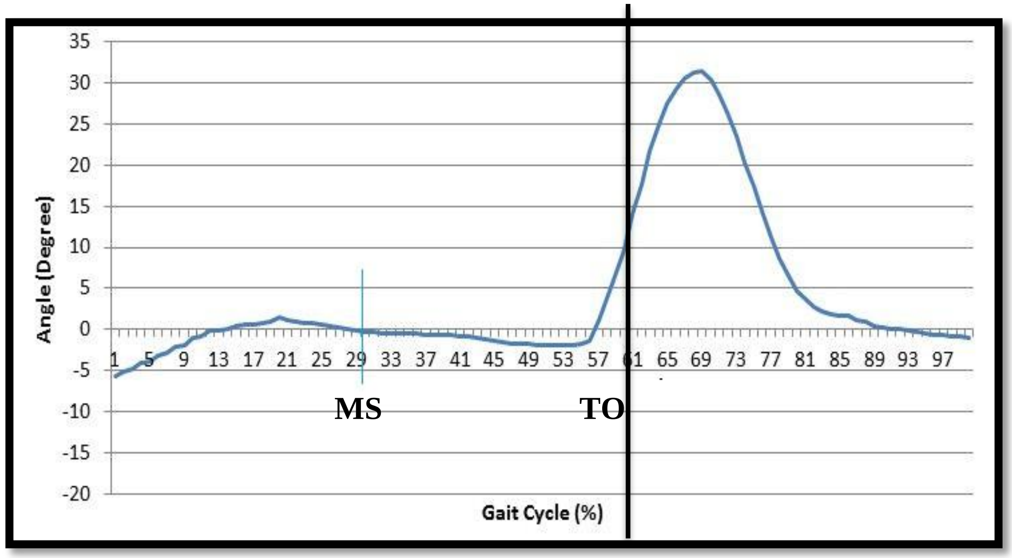

Figure 4-4 TF Gait - Knee Angle

Moment of knee for TF amputee gait is almost lower than normal gait. However, in the most critical point of gait, TO the value of moment was supposed to be almost zero which is not.

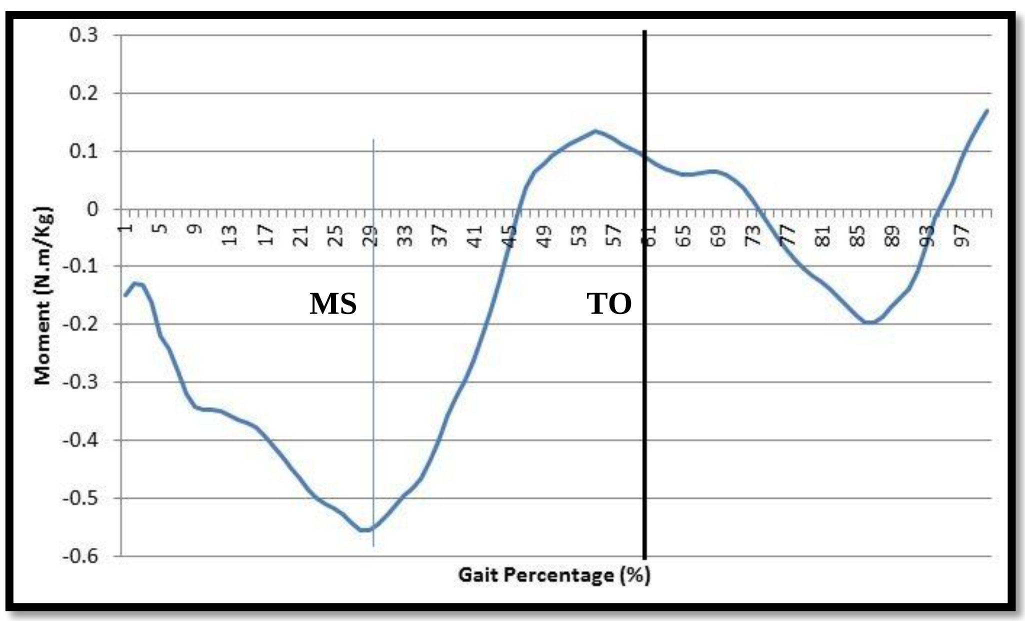

Figure 4-5 TF Gait - Knee Moment

The power which amputee should spend to walk with his/her artificial leg is more or less higher than normal gait. At Toe-off as the same as normal gait, the spent power of artificial leg is almost zero.

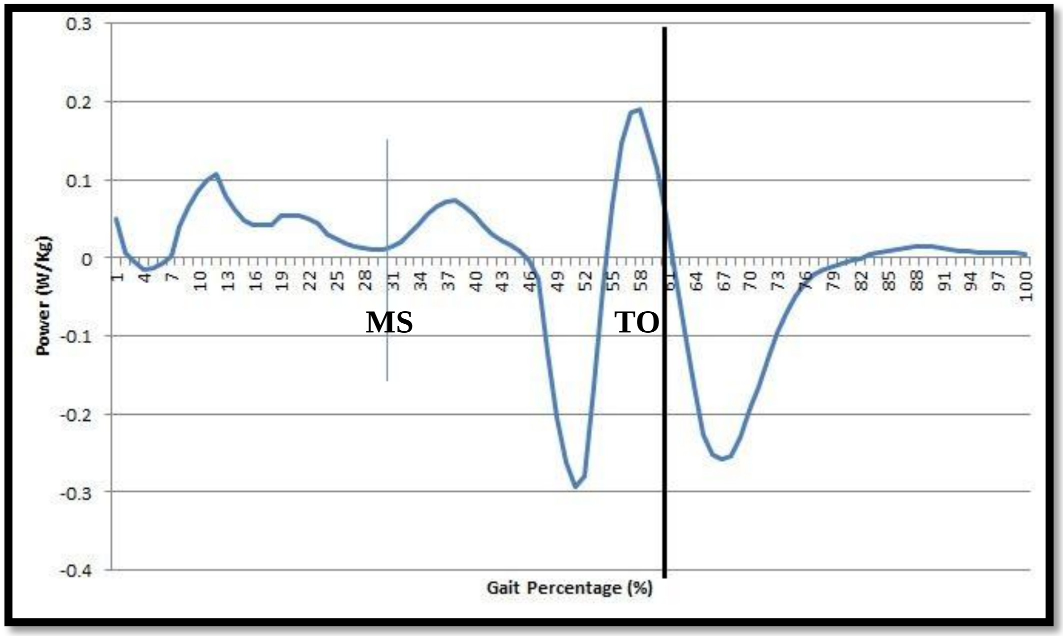

Figure 4-6 TF Gait - Knee Power

4.2 Statistical analysis of Transfemoral Amputee Gait

In this part all the parameters of gait are compared to each other and the correlation of them were extracted and mentioned here.

4.2.1 Angle versus Moment

The result obtained from statistical analysis with Spss for these two parameters are shown below.

The first table, Table 4-1 is descriptive statistics data of these two parameters. The mean, standard deviation and number of them are shown in this table.

Table 4-1 Descriptive statistics of moment and angle of knee for TF amputee gait

Descriptive Statistics

	Mean	Std. Deviation	N
Moment	-0.1621	0.22263	100
Angle	3.9541	9.60811	100

Second table of regression output is correlations data of these two parameters. Pearson correlation coefficient is number in range of -1 and +1. This value is measures the degree of association between two variables (for instance here, moment and angle). A positive value of Pearson correlation coefficient means a direct association between parameters. In the other word, it implies large values of moment tend to be associated with large values of angle and small values of moment tend to be associated with small values of angle). However, negative value of pearson correlation coefficient demonstrate the inverse association of the parameters (Gravetter & Wallnau, 2008).

Table 4-2 Correlations of knee moment and angle data for TF amputee gait

Correlations

		Moment	Angle
Moment	Pearson Correlation	1	0.395**
	Sig. (2-tailed)		0.000
Angle	Pearson Correlation	0.395**	1
	Sig. (2-tailed)	0.000	

**Correlation is significant at the 0.01 level (2-tailed)

So, from Table 4-2 we can found that moment and angle of the artificial leg has direct association.

The significant coefficient of this correlation is almost zero and for $P<0.05$ the correlation is significant. Besides, its value is positive thus, increases of moment significantly relate to increases of angle. However the Pearson correlation coefficient is 0.395 it means the power of significant correlation of these two parameters are medium (for pearson correlation coefficient between 0.3 and 0.49 is consider as moderate to substantial linear correlation (De Vaus, 2002)(Figure 4-7)) and illustrate that these two parameters are follow each other in increasing and decreasing but not in a very strong way.

In Table 4-3 there is a parameter "R", which indicate how strongly moment and angle are related together. So for this correlation R is equal to 0.395 which is not very high. Standard error of estimate is associated with regression analysis in term of prediction a particular value base on the regression equation. In the other words, standard error of the estimates measures the dispersion of angle estimate around its average and as long as this value is lower than 10 (10%) the amount of error is negligible.

Table 4-3 Model summary of regression of knee moment and angle of TF amputee gait

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.395[a]	0.156	0.147	8.87358

a. Predictors: (Constant), Moment

In Table 4-4 at the cross of column B and row of moment there is a value, 17.028 that named unstandardized coefficient which is means that the increase value of moment for one unit is caused unaveraged 17.028 increases in angle of knee. Furthermore there is another constant, named intercept which is in cross of B column and constant row, 6.715 which shows the value of angle when the value of moment is equal to zero.

Therefore, with the help of the mentioned constant we can extract regression equation (Equation 4-1) which is takes the form:

Predicted Variable (dependent) = (Slope× Independent Variable) + intercept

Equation 4-1 Regression equation(Johnson & Christensen, 2007)

The slope is shows how steep the regression line is. A horizontal line demonstrates 0 slope, slope of 1 is a diagonal line from the left bottom to the right upper part, and slope infinity is a vertical line. Intercept line is where the regression line crosses the angle axis (dependent variable) when the moment (independent variable) has value of zero.

Therefore for our regression we have:

$$\textbf{Angle} = (\textbf{17.028} \times \textbf{Moment}) + \textbf{6.715}$$

Equation 4-2 Regression equation of knee moment and angle of TF amputee gait

Table 4-4 Coefficient of regression of knee moment and angle of TF amputee gait

Coefficients [a]

Model	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	Std. Error	Beta	
(Constant)	6.715	1.100		.000
Moment	17.028	4.006	0.395	.000

a. Dependent Variable: Angle

Figure 4-8 illustrate linear scatterplot which can help for better understanding of relation between knee moment and angle of TF amputee gait in which you can find the positive slightly slope of the relation between knee moment and angle of TF amputee gait.

Interpreting strength of relationship coefficients		
Coefficient	**Strength**	**Alternate descriptors**
0.00	No (linear) association	
0.01–0.09	Trivial (linear) relationship	Very small, insubstantial, tiny, practically zero
0.10–0.29	Low to moderate (linear) relationship	Small, low, minor
0.30–0.49	Moderate to substantial (linear) relationship	Medium
0.50–0.69	Substantial to very strong (linear) relationship	Large, high, major
0.70–0.89	Very strong (linear) relationship	Very large, very high, huge
0.90+	Near perfect	

These interpretations apply equally to positive and negative relationships.

Figure 4-7 Interpreting strength of relationship coefficients (De Vaus, 2002)

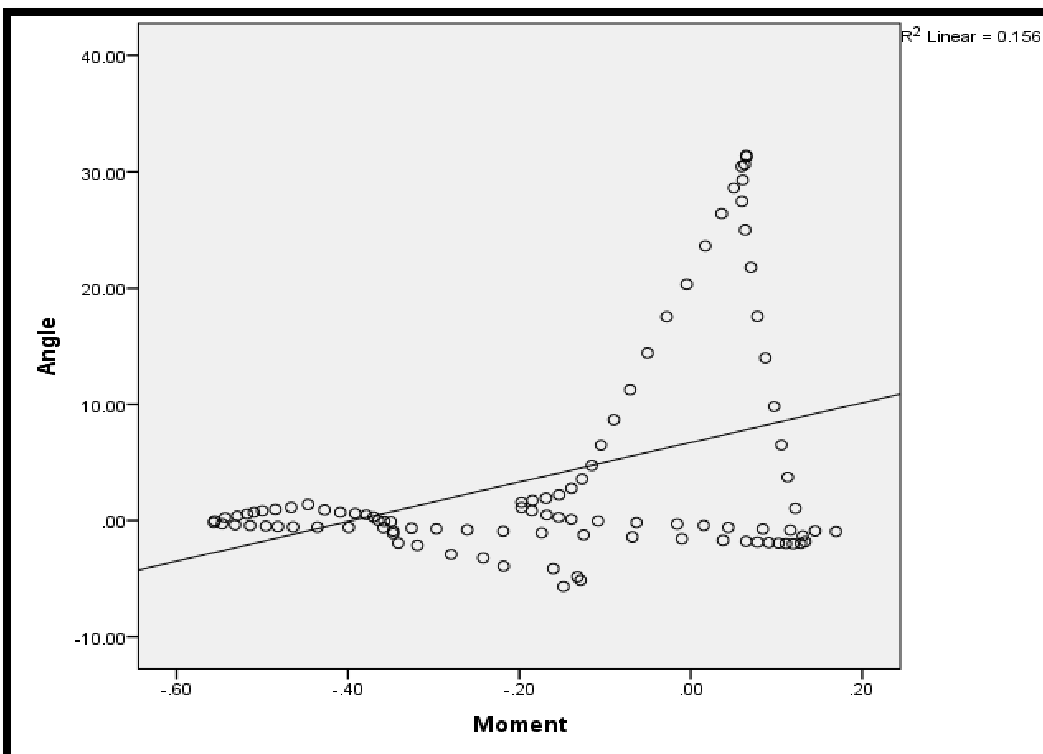

Figure 4-8 Linear scatterplot for knee moment and angle of TF amputee gait

4.2.2 Power versus Moment

In Table 4-5,

Table 4-6, Table 4-7, Table 4-8, and Figure 4-9 are illustrate the same analysis for power and moment of knee in TF amputee gait.

In this case as you can see in Table 4-6 the significant 2-taied is also zero it means power and moment also has a significant correlation but because of the Pearson correlation coefficient which is -0.439 their correlation is inverse it means at the percentage of gait which moment tends to increase power tends to decrease. It's also obvious if you compare Figure 4-5 and Figure 4-6 for TF amputee gait, and also Figure 4-2, and Figure 4-3 for normal gait.

Table 4-5 Descriptive statistics of moment and power of knee for TF amputee gait

Descriptive Statistics

	Mean	Std. Deviation	N
Power	-0.0089	0.09989	100
Moment	-0.1621	0.22263	100

Table 4-6 Correlations of knee moment and power data for TF amputee gait

Correlations

		Power	Moment
Power	Pearson Correlation	1	-0.439**
	Sig. (2-tailed)		.000
Moment	Pearson Correlation	-0.439**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4-7 Model summary of regression of knee moment and power of TF amputee gait

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.439[a]	0.193	0.184	0.09021

a. Predictors: (Constant), Moment

For the regression formula of knee moment and power we can extract an equation as following:

$$\textbf{Power} = (-0.197 \times \textbf{Moment}) + (-0.041)$$

Equation 4-3 Regression equation for knee moment and power of TF amputee gait

Table 4-8 Coefficient of regression of knee moment and power of TF amputee gait

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	Std. Error	Beta	
(Constant)	-0.041	0.011		.000
Moment	-0.197	0.041	-0.439	.000

a. Dependent Variable: Power

Figure 4-9 is illustration the inverse correlation of the knee moment and power of TF amputee gait.

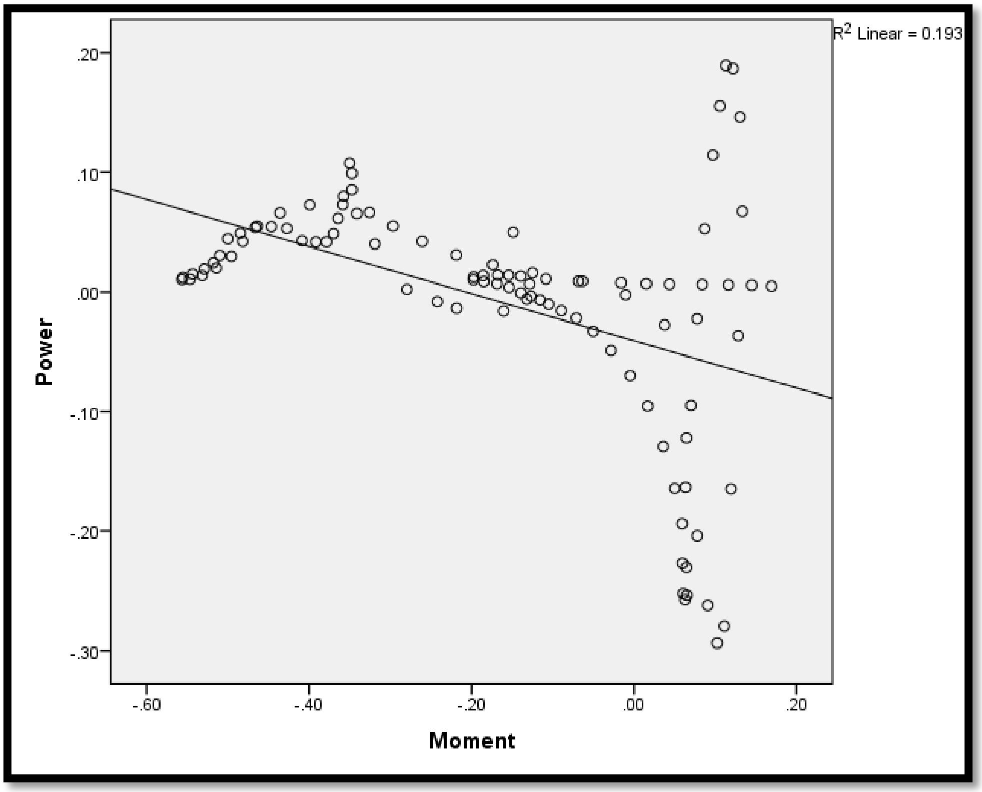

Figure 4-9 Linear scatterplot for knee moment and power of TF amputee gait

4.2.3 Power versus Angle

Finally, Table 4-9, Table 4-10, Table 4-11,

Table 4-12, and Figure 4-10 are demonstrated the statistical analysis for angle and power which interpreted for moment and angle in 4.2.1.

Table 4-9 Descriptive statistics of angle and power of knee for TF amputee gait

Descriptive Statistics

	Mean	Std. Deviation	N
Power	-0.0089	0.09989	100
Angle	3.9541	9.60811	100

For interpreting of the Table 4-10, as you can see the significant 2-tailed is zero. Therefore, there is a significant correlation between power and angle of knee for TF amputee gait. However, the pearson correlation coefficient which is -0.564 (Pearson correlation coefficient between 0.5 and 0.69 is showing a very strong linear relationship(De Vaus, 2002)) shows that the relation of the knee angle and knee moment are major but inverse and it is also more stronger than inverse relation of moment and power.

Table 4-10 Correlations of knee angle and power data for TF amputee gait

Correlations

		Power	Angle
Power	Pearson Correlation	1	-0.564**
	Sig. (2-tailed)		.000
Angle	Pearson Correlation	-0.564**	1
	Sig. (2-tailed)	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4-11 Model summary of regression of knee angle and power of TF amputee gait

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.564[a]	0.318	0.311	0.08289

a. Predictors: (Constant), Angle

From the data of

Table 4-12 the regression equation of linear correlation of knee angle and power of TF amputee gait can be written as below:

$$\textbf{Power} = (-0.006 \times \textbf{Angle}) + (0.014)$$

Equation 4-4 Regression equation of knee angle and power of TF amputee gait

Table 4-12 Coefficient of regression of knee angle and power of TF amputee gait

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	Std. Error	Beta	
(Constant)	0.014	0.009		0.114
Angle	-0.006	0.001	-0.564	0.000

a. Dependent Variable: Power

Figure 4-10 is demonstrated the negative slope of the relation between angle and power as the Pearson correlation mentioned before.

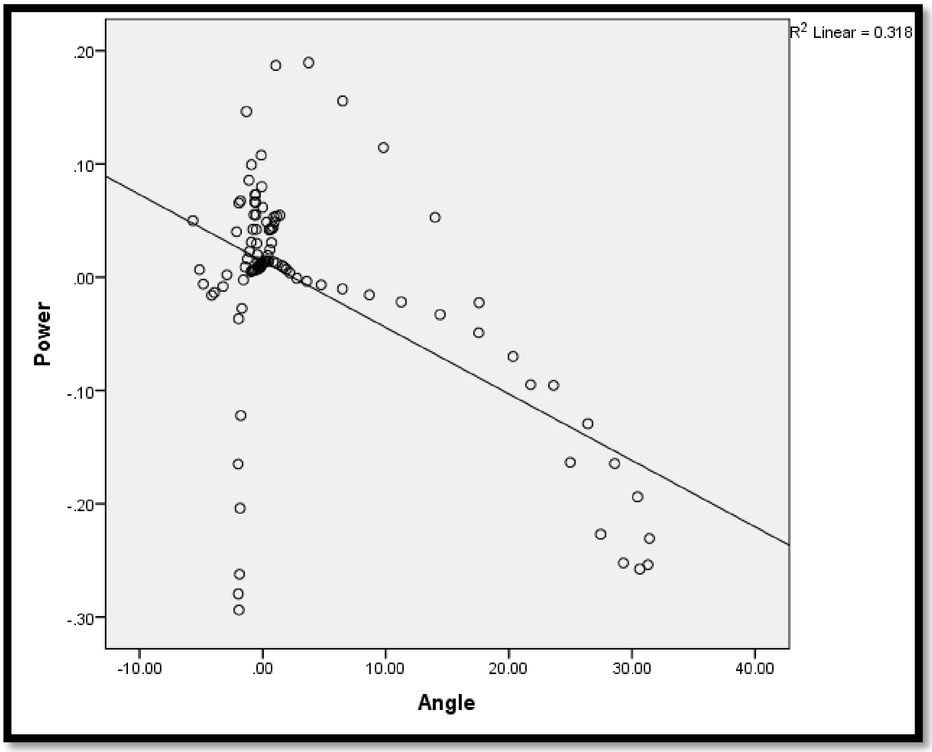

Figure 4-10 Linear scatterplot for knee angle and power of TF amputee gait

4.3 Discussion

Three kinetics and kinematics parameters were utilized to identify a characteristic pattern of human gait. Moment, angle, and power are the most effective parameters which can have a magnificent influence on the human gait.

Moment of the knee is the effect of ground reaction forces on the human body, As resulted in this research, for TF amputees in midstance position of the knee is in its highest level. This phenomena is quiet reasonable because at this position whole body weight is applied to the leg. At toe-off is quiet low because the contact area of the foot with ground is very tiny and also the angle of applied resultant force at that position is higher than midstance. Overall, the amount of moment which is applied in swing phase is less than stance face because at that period the foot doesn't have any contact with the ground.

Angle is another effective parameter which can control the limitation of amputees' movement. For prosthetic leg the range of knee angle motion is very important. The larger the range of knee angle can give more freedom to the patients to do more activities. As you can see in Figure 4-4 during stance phase as predicted the range of knee angle is less than swing phase because during stance phase knee doesn't have lots of flexion.

Power was the only single variable which revealed the energy expenditure of muscles. As resulted in this research, moment and knee has moderate inverse correlation together. It means in the whole gait, the knee moment and power did not tend to follow each other. So the influence of increasing knee moment on the knee power is tending to decrease knee power.

Changing of knee and moment and angle are agreed to each other. However, in midstance when the knee moment is at the highest point the angle is almost zero. Also after toe-off as you can compare in Figure 4-4 and Figure 4-5 angle is increasing but moment is decreasing first. This is just because at that level the direction of moment is going to change. Therefore the moment decrease but it is increased at the other direction.

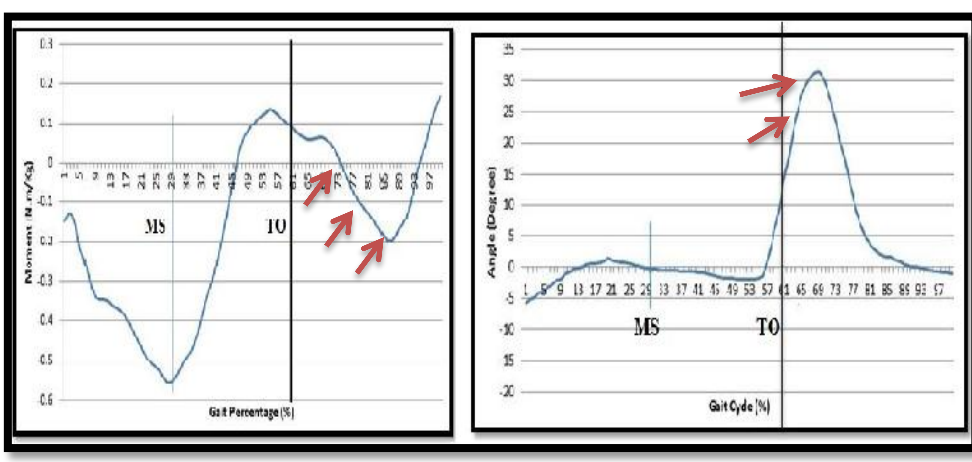

Figure 4-11 Comparison of knee moment and angle parameters figures

Knee angle and moment are abundantly having inverse relation. With comparison of the Figure 4-4 and Figure 4-6 we can easily find that especially after toe-off the knee angle and power changing in different way.

For designing a smart prosthetic knee especially for choosing a motor to generate power for movement of knee all these above correlation are used. The knowledge of each parameter alone in specific stage also will help designer to choose a perfect motor for a smart prosthetic knee.

4.4 Conclusion

The fundamental objective of this research is to find the correlation of the kinetics and kinematics parameters in transfemoral amputee gait. Throughout this research, four transfemoral amputees' gaits were evaluated with 3D motion analyzer system and the primary output data of this system were normalized with Matlab software. Then statistical analysis of these normalized data was performed by SPSS and Microsoft Excel software. Finally, in the last chapter the results were compared together and the correlation of three kinetics and kinematics were founded.

The above discussion has mentioned the proved correlation between knee joint moment-angle, moment-power, and angle power. For a whole gait of transfemoral amputee for self-selected speed normal walking, moment and angle have a medium direct correlation with each other, moment and power also have a medium correlation but inverse, and angle and power have a major inverse correlation with each other.

4.5 Future works and recommendations

Author has suggested two main ideas for the future of this research. The first one is to evaluate gait analysis of level walking for transfemoral amputee in different specific of walking such as toe-off, midstance, heel strike to find the critical point of walking in order to kinetics and kinematics and interpretation of their correlation. The second suggested future work is using the obtained correlations for designing a smart prosthetic knee to expand the TF amputee’s capabilities with choosing perfect sensors and motors for controlling knee.

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