STUDY OF STUMP FLEXION CONTRACTURE TOWARDS POSTURAL STABILITY FOR TRANSTIBIAL PROSTHESIS USERS

MOHD FAZLI BIN GHAZALI

FACULTY OF ENGINEERING
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MOHD FAZLI BIN GHAZALI

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ABSTRACT

Knee flexion contracture on the residual limb, which is called as stump flexion contracture, is a condition which refers to the inability of the knee to move in the normal range of motion (ROM). In simpler words, the knee cannot be fully extended. It is one of the common problems occurring among the below-knee amputees. The main cause of this condition is the failure of the soft tissue, which is commonly the flexor muscles, to lengthen in tandem with the bone. This happens as a result of muscles shortening and stiffness due to long periods of bending position or inactivity caused by illness and lack of exercise. Stump contracture could bring several adverse effects to the amputees when using prostheses, such as limitation of the motion required for regular activities and functions. To overcome the effects, a prosthetist will setup the prosthetic alignment according to the ROM of the stump. However, there is still no specific study regarding the effect of prosthetic alignment accommodating the ROM of stump contracture. The current study had been carried out by using Biodex Stability System (BSS) in order to investigate the effect of stump flexion contracture towards the postural stability among the below-knee prosthesis users with the intervention of alignment accommodation. The BSS provides the reading of anterior-posterior stability index (APSI), medial-lateral stability index (MLSI), and overall stability index (OSI). A higher reading of the index indicates lesser stability. Each of the subjects had been tested in three different sessions which were Visit 1 (before contracture improvement), Visit 2 (after contracture improvement without alignment readjustment), and Visit 3 (after contracture improvement with alignment readjustment). The APSI reading was significantly higher during Visit 2 with $p=0.007$ and $p<0.0001$ compared to Visit 1 and Visit 3 respectively. The OSI during Visit 2 was also found to be significantly higher compared to Visit 3 ($p<0.0001$). It was increased by 47.5% after Visit 1 but had been proven insignificant by one-way ANOVA statistical test ($p>0.05$). In Visit 2, the degree

of contracture was significantly improved ($p<0.0001$), which was 44.1% less than Visit 1. The stability index in anterior-posterior aspect (APSI) was proven to be lower as the prosthetic alignment was adjusted according to the ROM of the knee. This finding explains that the alignment set up based on the adaptation with the ROM of the stump can positively contribute in maintaining postural stability. With a significant number of subjects (n=10), the standard range of stability index also had been obtained for the amputee population who have similar characteristics.

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ABSTRAK

Pengecutan lutut pada bahagian amputasi yang juga dikenali sebagai pengecutan bagaian amputasi, adalah satu keadaan apabila bahagian amputasi tidak boleh bergerak dalam julat gerakan normal atau dengan kata lain, tidak boleh diluruskan sepenuhnya. Ini adalah salah satu masalah yang biasa berlaku dalam kalangan pesakit amputasi bawah lutut. Punca utama keadan ini adalah kegagalan tisu lembut yang lazimnya ialah otot flexor untuk memanjang seiring dengan tulang. Hal ini adalah hasil daripada pemendekan dan keketatan otot disebabkan posisi bengkok yang lama atau ketidakaktifan disebabkan sakit dan kurang bersenam. Pengecutan bahagian amputasi boleh membawa beberapa kesan buruk kepada bahagian amputasi apabila menggunakan prosthesis, seperti gerakan yang terhad untuk melakukan aktiviti harian biasa. Dalam usaha untuk mengatasi kesan-kesan buruk tersebut, pihak prostetis akan menjajarkan prostesis berpandukan julat gerakan bahagian prostesis. Walau bagaimanapun, masih tiada kajian khusus mengenai kesan penjajaran prostesis berdasarkan julat gerakan kekecutan bahagian amputasi. Kajian yang dilakukan ini telah dijalankan dengan menggunakan Biodex Stability System (BSS) untuk mengkaji kesan kekecutan bahagian amputasi ke arah kestabilan postur dalam kalangan pengguna prostesis dengan penglibatan penjajaran. BSS menyediakan bacaan indeks kestabilan hadapan-belakang (APSI), indeks kestabilan tengah-samping (MLSI), dan indeks kestabilan keseluruhan (OSI). Bacaan indeks yang lebih tinggi menunjukkan kestabilan yang lebih rendah. Setiap subjek telah diuji untuk tiga sesi yang berbeza iaitu Lawatan 1 (sebelum pembaikan kekecutan), Lawatan 2 (selepas pembaikan kekecutan tanpa penyesuaian semula jajaran), dan Lawatan 3 (selepas pembaikan kekecutan dengan penyesuaian semula jajaran). Bacaan APSI adalah jauh lebih tinggi semasa Lawatan 2 dengan $p=0.007$ dan $p<0.0001$ berbanding Lawatan 1 dan Lawatan 3. OSI semasa Lawatan 2 juga didapati lebih tinggi berbanding Lawatan 3 ($p<0.0001$). Ia telah meningkat

sebanyak 47.5% selepas Lawatan 1, tetapi didapati tidak signifikan berdasarkan analisis ANOVA satu arah ($p>0.05$). Dalam Lawatan 2, tahap kekecutan telah meningkat dengan ketara ($p<0.0001$), dengan 44.1% kurang daripada Lawatan 1. Indeks kestabilan dalam aspek hadapan-belakang (APSI) telah dibuktikan menjadi lebih rendah apabila penjajaran prostesis telah disesuaikan mengikut julat gerakan lutut. Penemuan ini menjelaskan bahawa penjajaran yang disesuaikan mengikut julat gerakan lutut bahagian amputasi boleh menyumbang dalam mengekalkan kestabilan postur. Dengan jumlah subjek yang signifikan (n=10), julat piawai indeks kestabilan telah diperoleh bagi populasi pesakit amputasi bawah lutut yang mempunyai ciri-ciri yang sama.

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LIST OF ABBREVIATIONS & NOTATIONS

AP	Anterior-posterior
APSI	Anterior-posterior Stability Index
BMI	Body Mass Index
BoS	Base of Support
BSS	Biodex Stability System
CoM	Centre of Mass
CoP	Centre of Pressure
CPO	Certified Prosthetist & Orthotist
GRF	Ground Reaction Force
LCL	Lateral Collateral Ligament
MCL	Medial Collateral Ligament
ML	Medial-lateral
MLSI	Medial-lateral Stability Index
n	Total Number of Subject
OSI	Overall Stability Index
PAPI	Prosthesis Alignment Perception Instrument
PTB	Patellar Tendon Bearing
ROM	Range of Motion
SACH	Solid Ankle Cushioning Heel
SD	Standard Deviation
SI	Stability Index

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CHAPTER 1: INTRODUCTION

This chapter provides a brief but complete overview of the reviewed literature regarding the stump flexion contracture and complications that could affect the daily life of below-knee amputees including the treatments and their effects when using prostheses. The aims and objectives of the current study, as well as the thesis outline, are also included as part of this chapter.

1.1 Introduction

Stump flexion contracture is one of the common problems occurring among below-knee amputees. It refers to the situation where the patient cannot fully straighten the knee or in other words, the range of motion (ROM) of the joint is limited from normal (LaRaia, 2010). It is a result of the shortening and stiffening of the muscles which might be associated with their structural changes due to the long period of the bending position or inactivity owing to illness and lack of exercise (Finger, 2008).

Figure 1.1: A stump with a few degrees of contracture. The picture was taken when the subject fully extended the knee (Abrahamson, 1985)

The significant characteristics of the flexion contracture consist of a limitation of joint mobility and an increasing resistance of the joint to passive ROM, which is the

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movement of joint applied by external power either by a being or an exercise machine (Katalinic, 2011). Based on the literature, the mobility of a joint is very important for a prosthetic candidate. This is because the limitation of joint motion, which refers to joint contracture, will significantly affect the fitting and functioning of the prosthesis (Bowker, 2004).

In overcoming the contracture, most of the efforts are focused on treating the contracture itself by decreasing the contracture angle or preventing it from becoming worse. For transtibial amputation cases, the amputees are advised to avoid placing any pillow under the knee. An extension board is commonly used to be placed across the back of the knee joint to secure the extension position (Pasquina, 2009). Besides that, stretching the soft tissues, which can be done actively or passively, is also very helpful to overcome the contracture. Active stretching means the amputees actively move the joint in full range of motion. Meanwhile, passive stretching refers to the use of a splint or an orthotic device to force the joint in the extended position (Knoope, 2011).

For an amputee who is going to proceed with using a prosthesis, the presence of stump flexion contracture could be a barrier for them to achieve a successful prosthesis usage. This is because the contracture will disrupt the prosthetic alignment and could lead to various kinds of adverse effects when using the prosthesis (Knoope, 2011). However, the alignment of the prosthesis still can be adjusted to accommodate the knee flexion contracture, if any, but if the angle exceeds 25º, the fitting might be difficult (Bowker, 2004). The prosthetic alignment can be defined as the positioning of the socket in relation to the other components of the prosthesis such as ankle joint and shank tube (Edelstein, 2011). Generally, a good prosthetic alignment will contribute to an energy-efficient and smooth gait pattern. (Lannon, 2003). For amputees with stump flexion contracture condition, the alignment that should be concerned is in the sagittal plane. It is the anterior-posterior (AP) positioning of the socket with regard to the foot.

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The socket flexion will be increased respectively with the contracture angle which means the alignment is deviating from the standard. Otherwise, the amputee will exhibit gait deviations during walking, such as rough rollover of the foot and inconsistent heel strike (Saleh, 1985). Prosthetic alignment is also vital in retaining postural balance either during walking or quiet standing (Chiari, 2002). Quiet standing can be defined as staying upright in a static condition without moving. The regulation of balance is a vital effort for the body in maintaining the stability in this position. Meanwhile, balance is the ability in regaining the Centre of Mass (CoM) within the base support to maintain body equilibrium. To preserve balance, the human body is believed to orientate the CoM which is a virtual point equivalent to total body mass (Hernandez, 2009);Alexandrov, 2005). This response will return the CoM to be within the base of support (BoS) which is the displacement region for the Center of Pressure (CoP). CoP, on the other hand, is the point of average distribution for total pressure towards the surface of the contact area (Gravante, 2003).

The balance of an individual can be assessed by measuring the displacement of the CoP, by calculating the Stability Index (SI). It is a standard deviation reading that assesses the path of sway around the zero point from the centre of the platform; the unit of measurement is in degree. It indicates the degree of foot displacement in sagittal and frontal plane motions (Ku, 2012). SI, which consists of Overall Stability Index (OSI), Anterior-Posterior Stability Index (APSI), and Medial-Lateral Stability Index (MLSI), are measured by Biodex Stability System (BSS). BSS was developed with the advantages and convenient technology to study postural stability. The system is available for a multi-range of people, easy to administer, and simple to interpret (Aydog, 2006;Salsabili, 2011).

A lot of research had been done to study the postural control during quiet standing among amputees. Ku et al. (2014) had done a systematic review regarding the

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factors that contribute to the balance instability in lower-limb amputees. In their reviews, it is found that the majority of the articles revealed an increase in postural sway among the amputees compared to normal population. One of the major factors that explained the instability was asymmetry in body weight distribution between the sound and the artificial legs. Meanwhile, Katch et al. (1988) and Salsabili et al. (2011) had proven that an increasing body-mass index (BMI) could bring significant impact on the postural control in terms of muscular torque, attentional cost, postural sway, energy cost, and motor reaction time. According to Colne et al. (2008), an increase in BMI could possibly reduce the ability of the muscles to generate sufficient force to control the CoM displacement. Another potential factor that is affecting postural balance is age. The elderly population had been found to exhibit greater postural sway, which means less stability (Ku, 2014).

1.2 Aims and Objective

In the rehabilitation process, stump flexion contracture is one of the major hindrances for an amputee to acquire a prosthesis. It has been found that 10º is the maximum amount of contracture for amputees to have great walking ability. Any degree higher than that could lead to the failure of the prosthesis usage for mobility. Even if it is usable, there will be a couple of factors to be reconsidered when making the prosthesis such as the alignment and components (Bowker, 2004; Knoope, 2011). Therefore, the aim of this study is to investigate the influence of prosthetic alignment intervention towards the stump contracture effect.

The objectives of this study are:

1. To evaluate the postural stability control among the below-knee prosthesis users, each with a different degree of stump contracture.
2. To determine the effect of prosthetic alignment accommodation with the degree of stump contracture towards postural stability control.

3. To determine the standard range of postural stability score for a certain range of stump contracture.

1.3 Thesis Outline

This thesis consists of five chapters. Chapter 1, the current chapter, gives an overview of the thesis by providing a brief explanation of the entire thesis in order to give the readers ideas and understanding about the research conducted in this study, especially the objectives and the variables used. Besides that, readers will also be informed on the main problems that lead to this research.

Chapter 2 is the Literature Review. In this chapter, more detailed information regarding the variables and the nature of the research are explained based on current literature as references. The references consist of books, articles from journals, other theses, and websites. To enhance readers' understanding, some figures are also included in this chapter.

The next chapter is Chapter 3, called Methodology. This chapter covers the design and workflow of this research, starting from subjects recruitment up until data analysis. Aside from explaining the steps and procedure of the research, the role of the researchers and the subjects themselves are also emphasized in this chapter.

Chapter 4, is on Result and Discussion. All the important findings and outcomes of this research are portrayed and elaborated here. In addition, the possible reasons that led to the results are also proposed and discussed. The discussions are mostly in reference to previous research and studies. Some results are compared and contrasted with previous findings, and the differences or similarities are discussed.

The last chapter, the Conclusion & Recommendation or Chapter 5, captures the overall findings from the research. In other words, this chapter is the closing chapter which concludes on what has been obtained from the research as a whole. As part of the

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closing content, the limitation of the study and the recommendations that could improve future studies and rehabilitation progress among below-knee amputee population are also included in this chapter.

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Chapter 2: Literature Review

Chapter 2 explores and elaborates the significant components and issues related to this study. The literature review presents knowledge gathered from previous studies and findings. The relevant information that is useful for this research is also included in this chapter. It helps the researchers and the readers to understand more about the issues and the previous findings that are related to this research.

2.1 Knee Flexion Contracture

Knee flexion contracture is one of the common problems that occur among the below-knee amputees especially on the amputated part. It refers to the condition where the patient cannot fully straighten the knee, or in other words, the ROM of the joint is limited as compared to normal. It could be permanent or temporary (LaRaia, 2010). The significant characteristics of contracture consist of limitation of joint mobility and an increasing resistance of the joint to passive ROM. Passive ROM indicates that the joint is moved by externally applied power, either by a person or by an exercise machine (Katalinic, 2011). Flexion contracture could probably happen not only at the amputated side but also on the sound side. The main cause of this condition is the failure of the soft tissue, which is commonly the flexor muscles, to lengthen in tandem with the bone. This failure is a result of the shortening and tightness of the muscles which might be associated with their structural changes due to the long period of bending position or inactivity due to the illness and lack of exercise. Surgeons believe that the flexion contracture at the knee joint is due to the tightness of collateral ligaments (Medial Collateral Ligament, MCL and Lateral Collateral Ligament, LCL) and biceps femoris (Finger, 2008).

Stump flexion contracture condition among the amputees is less to be found in traumatic cases. Instead, neurological injury or vascular disease amputation cases are

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ones to frequently exhibit severe contracture complication (Pasquina, 2009). Neural problem is one of the contracture factors that lead to spasticity. The other factor is a nonneural problem, which could be due to the structural change of soft tissues as mentioned before (Katalinic, 2011).

The soft tissues contracture could even happen before the amputation surgery, a condition called preoperative contracture. It is common for it to remain even after the surgery. Meanwhile, the contracture that happens after the surgery is called postoperative contracture, which would be experienced by most of the amputees (Knoope, 2011).

2.1.1 Stump Flexion Contracture among Amputees

Stump flexion contracture becomes a common problem to the amputees because of several factors. The first being the long periods of muscle inactivity. For example, even before the surgery, most of the patients especially diabetic patients spend a lot of time lying on the hospital bed trying to salvage the limb from being amputated. A lot of medical problems also participate at this stage (LaRaia, 2010). Moreover, patients' activity normally becomes very limited during this period and thus will lead to the contracture not only at the knee joint but also the hip joint. Apart from that, according to Pasquina et al. (2009), another one of the factors is the domination of a muscle group which is encouraged by the limb length change/amputation. Inefficient, injured, or absent antagonist muscle groups are the facts that contribute to the agonist muscles domination. For example, the flexion contracture of a transtibial amputee might occur due to the excessive pull of the hamstrings muscles**.**

The lying position on the hospital bed either before or after surgery is also strongly related with flexion contracture. Most of the patients are likely to raise the head of the bed up to maintain the knees in a comfortable flexed position even during sitting as shown in Figure 2.1. Maintaining these positions for a prolonged period could

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contribute to both knees and hips contracture. Not only that, patients also normally sustain these improper positions even after they are discharged from the hospital. The lack of mobility training and delayed prosthetic fitting also contribute to contracture complication. It has also been found that the shorter the residual limb, the greater the risk of getting a contracture. Another potential factor that could lead to the contracture is the presence of injury proximal to the amputation level. For example, scarring quadriceps and flexion limitation could probably occur due to the injured knee or distal part of the femur. This complication would then, lead to the extension contracture of the residual knee, making the activities involving flexion movement become difficult such as sitting in a vehicle and limit the high level activities such as jogging (Pasquina, 2009).

Figure 2.1: A common position practiced by patients on the hospital bed. Maintaining this position for a prolonged period without doing the necessary exercises could contribute to hip and knee contractures (Doyle, 2015)

However, the flexion contracture problem normally occurs on the residual limb only. This is because most of the patients use the sound limb to transfer from one position to another by standing or hoping which are considered as an exercise. Thus, the risk of contracture to occur is less. Besides that, the amputees are likely to neglect the residual limb activity and exercise. This is the reason why the contracture normally occurs on the residual limb only. Since the joint contracture will affect the ROM, it also means that the residual limb won't be able to move in the required motion when being fitted with prosthesis. For lower limb cases, both below knee and above knee prostheses users could be affected (LaRaia, 2010).

2.1.2 Effect of Stump Flexion Contracture to the Prosthesis Usage

The mobility of joint is very important for a prosthetic candidate. This is because the limitation of joint motion which refers to joint contracture will significantly affect the fitting and function of the prosthesis. It has been found that 10º is the maximum amount of stump flexion contracture for the amputee to possess a great walking ability. With the greater degree of contracture, it could lead to the failure of the prosthesis usage for mobility. Even still can be used, there will be a lot of factors that need to be reconsidered during making the prosthesis such as alignment and components as shown in Figure 2.2 below (Bowker, 2004).

(a) **(b)**

Figure 2.2: (a) Standard tube adaptor (b) Angled tube adaptor with 10º slanting

For an amputee who is going to proceed with a prosthesis, the presence of flexion contracture could be a barrier for him/her to achieve a successful prosthesis usage. This is because the contracture will disrupt the prosthetic alignment that could lead to various kinds of adverse effects during using the prosthesis. The limitation of

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components also one of the problems that will emerge with the presence of joint contracture. As shown in Figure 2.3, different kind of socket adapter might be used for a prosthesis user with serious contracture problem (Knoope, 2011).

(a) (b)

Figure 2.3: (a) Standard socket plate adaptor (b) Flexion contracture socket plate adaptor (Slemker, 2011)

For a transtibial/below knee amputee, he or she can be considered as a good prosthesis candidate if the ideal residual limb range of motion can be achieved. It refers to the maximum flexion and extension of the residual knee. The normal flexion range is 0º to 145º. If the ideal range cannot be achieved, the amputee still might be able to use a prosthesis but some limitations could probably participate. In a normal gait, the knee range of motion is 0º to 70º as the 70º of flexion is during initial swing phase. However, for some other daily activities, more degree of flexion is required that is approximately 83º for climbing staircase, 93º during sitting, and 106º to tie shoelace. The alignment of the prosthesis still can be adjusted to accommodate with the knee flexion contracture if any but if the angle exceeding 25º, the fitting might be difficult (Bowker, 2004).

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Below knee prosthesis users will experience fatigue quicker than normal because standing and walking with a certain degree of knee bending will consume more energy and requires more muscle power. Meanwhile, for the above knee prosthesis users, standing with a straight spine could be impossible with the presence of hip contracture. Figure 2.4 shows such condition. In addition, the inability of the residual limb to fully extend will make the prostheses users become more fatigue as they try to walk and stand like a normal (LaRaia, 2010).

Figure 2.4: An above knee amputee with stump contracture walking with prosthesis (LaRaia, 2010)

The presence of contracture also will cause gait deviations which means difference in gait characteristics compared to normal pattern such as excessive knee flexion during heel strike or midstance. It will cause the amputee to feel like walking downhill (Knoope, 2011). The gait deviations normally happen when the amputee tries to compensate the gait pattern due to the stump flexion contracture. With the presence of the contracture, the swing phase of the prosthesis side will become limited and thus promote to the shortening of the step length. This will cause the gait become inefficient. In order to compensate with this unusual gait, most of the amputees will tilt their pelvic more forward so that the step length can be increased. This, however, will cause

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tiredness and promotes back pain. Opposite with the below knee prosthesis users, the presence of hip contracture will limit the above knee amputees to withdraw their prostheses backward as the sound leg start to swing. In other words, they won't be able to propel themselves forward as the residual limbs are limited to extend (LaRaia, 2010). Thus, the alignment of the prosthesis needs to be changed in response to the compensating movement in order to minimize the gait deviations. If the contracture brings so much limitation to the joint range of motion and non-treatable, the higher level of amputation would probably be done to ensure the patient is qualified as a prosthetic candidate (Bowker, 2004).

Significant stump flexion contracture also will affect the appearance of a prosthetic socket. This is to accommodate the deformity with the alignment of the prosthesis so that the efficiency can be maximized and the best walking gait pattern can be achieved. Besides the fact of the unattractive appearance, the prosthesis itself will be able to improve the contracture eventually, by stretching the contracted tissues during usage (Pasquina, 2009).

2.1.3 Stump Flexion Contracture Treatment

The treatment of flexion contracture should be started during the amputation surgery itself. Muscles lengthening and myodesis method in the middle of the surgical amputation could help to reduce the risk of contractures. The following efforts to prevent contracture after the surgery are the amputees positioning and stump dressing. For transtibial amputation cases, the amputees should be advised to avoid placing a pillow under the knee since majority of them would do that to obtain flexed resting posture. This habit is the common mistake done by the amputees that finally led to the flexion contracture (Bowker, 2004). Another effort of treating stump flexion contracture is by using the extension board when the amputees sit in the wheelchair. The board will

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be placed across the back of the knee joint to ensure the extended position as shown in Figure 2.5 (Pasquina, 2009).

Figure 2.5: A below knee amputee is using knee extension board while sitting on wheelchair (Huang, 2011)

In overcoming the flexion contracture, most of the efforts are focused on treating the contracture itself, decreasing the contracture angle or prevent it from becoming worse. Stretching the soft tissues is very helpful to overcome the contracture. Stretching means extending the joint. The stretching activities can be done actively or passively. Active stretching means the amputee actively move the joint in full range of motion. Meanwhile, passive stretching refers to the using of a splint or orthotic device to force the joint in extended position. However, this passive stretching could cause muscle cramp since the stretched tissues cannot be relieved by flexing the joint (Knoope, 2011).

However, stretching itself is not enough to maintain the ROM of the joint. Active exercise also should be included in the effort. The exercise should be in full

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ROM of the joint. It also should be instructed to the amputees so that they can practice the exercise every day until the full ROM is obtained (Pasquina, 2009).

A rigid splint or orthosis also have been widely used nowadays to overcome flexion contracture problem. Basically, the devices will help to maintain the soft tissues in a stretched position so that the contracture progression can be prevented (LaRaia, 2010). The application of extensor splint or orthosis device post to the surgery could prevent the knee flexion contracture or at least, reduce the contracture angle. Normally semi-rigid cast, which is also included in the splinting mechanism, will be applied to the stump. It is consist of a backslab placed posteriorly through the knee joint, extended from the proximal thigh and end up at the distal end of the stump. The backslab is wrapped snugly with a bandage, maintaining the knee in full extension position. Normally the semi-rigid cast will be removed and switched with the removable backslab after three to five days of application (Bowker, 2004).

Figure 2.6: Complete semi rigid-splint applied on a residual limb (Seymour, 2002)

Besides that, rigid and soft dressings are very effective mechanism in preventing stump flexion contracture as well. Rigid dressing is not only to maintain the knee in extended position but also an effective method in edema and pain management (Pasquina, 2009).

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Figure 2.7: Rigid dressing as one of the post-operative management (Bowker, 2004)

Dynamic splinting, which is more advanced splinting method is also very helpful in controlling flexion contracture. It is, however, will be effective for the stump with adequate tibial length so that the splint can be implemented appropriately (Pasquina, 2009). By using the dynamic splint, the connective tissues are not only able to be stretched, but the time of the joint to be in maximum extension position also can be prolonged (Finger, 2008). Finger et al. (2008) had proposed that dynamic splinting is an effective way to reduce the knee contracture as an adjunct to physical therapy. Thus, the regaining of knee full extension is possible.

Figure 2.8: Dynamic splint proposed by Finger et al. (Finger, 2008)

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However, they had mentioned that dynamic splinting is just a secondary intervention, after physical therapy. In their study, six to eight hours of wearing duration was already sufficient for the subject to regain full knee extension after experienced 20º of flexion contracture. Furthermore, the subject was also very compliant with the daily exercise schedule, making it even more possible.

Serial casting method is also one of the effective mechanisms to overcome the flexion contracture. As the name, the cast will be applied serially at the knee joint. The degree of extension will be increased gradually. The aim is to stretch the contracted joint. However, this method will consume longer period and cause discomfort to the amputees as the cast is bulky, heavy and cannot be opened anytime, unlike splint and orthotics devices (LaRaia, 2010). For serial casting, the residual limb will be dressed weekly for at least three weeks or until the surgical wound completely recover. The pressure sensitive areas such as tibial crest and patellar will be padded in order to prevent pressure necrosis. Between the periods of changing the cast, a full ROM exercise will be done. The amputee should avoid placing a pillow right underneath of the casted residual limb since it will promote hip flexion contracture (Bowker, 2004).

Knoope (2011) had carried out a project to design a new concept of brace that can prevent stump flexion contracture for transtibial amputees. The device is called The Flextension. Compared to the conventional brace, the Flextension able to keep the knee in extended position and at the same time allows the flexion movement of the residual limb. This concept significantly increased the compliance of the patients and comfort since the stretched tissues still can be relieved even the brace is on.

In term of efforts in preventing or reducing knee flexion contracture, manual and active stretching can be done just for few minutes with several sessions in one day while the positioning administration could be several hours or even for days (Katalinic, 2011). Katalinic et al. (2011) proposed that stretching doesn't bring significant improvement to

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the mobility of the joints. This conclusion was made based on the result obtained in their research towards subjects with neurological conditions who experienced contractures at distinctive joints. However, in their study, therapeutic exercises to improve the contracture were totally neglected. This could be the reason why the stretching effect can't be seen clearly throughout the research. Meanwhile, according to Finger et al. (2008), stretching intervention is the secondary mechanism to improve the contracture in adjunct to physical therapies, which is the primary intervention. In the research carried out by their team, they were very particular with the exercise programs scheduled for the subject. However, the effect of stretching alone to improve a flexion contracture for an extended period of time cannot be found yet since there is still no research has been done for more than six months period.

Another surgical amputation which is at the higher level will be considered for certain cases if all the contracture therapies have failed. However, it will be the last choice for both the physicians and the patients themselves since the higher level amputation will give a great impact to the functional activities in the future. It also depends on the degree of contracture. It will only be applied for the severe untreatable contracture cases (Pasquina, 2009).

The amputation cases due to burn injury are in a different category with distinct complications. When a skin graft is required, despite appropriate contracture management therapy and patient positioning, contracture will still develop slowly. The release of the scarred skin through plastic surgery procedure might bring some improvement to the contracture. However, the release of stiff muscle and tendon also might be necessary, depending on the cases (Katalinic, 2011).

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2.2 Prosthetic Alignment

In prosthetics, the most important biomechanical aspects are prosthetic alignment and socket design. The prosthetic alignment can be defined as the positioning of the socket in relation to the other components of the prosthesis such as ankle joint and shank tube (Edelstein, 2011). In general, good alignment of a prosthesis will contribute to an energy efficiency and smooth gait pattern. For example, smooth heel off prior to initial contact of the sound foot on the ground, controlled knee flexion after heel strike, and smooth rollover with limited hyperextension (Lannon, 2003). According to Edelstein et al. (2011), alignment is more vital compared to the type of foot used in improving the user's performance. The duration of pressure interface between the residual limb and prosthetic socket also highly influenced by the alignment set up. The ability of the user to walk on the sloped surfaces also markedly influenced by the alignment setup.

2.2.1 Alignment Adjustment Aspects

Basically, the alignment of the prosthesis will be adjusted according to the sagittal and frontal plane. Sagittal plane refers to the anterior and posterior positioning of the prosthetic components, especially the socket (Figure 2.9). There are two major purposes of adjusting the sagittal alignment properly. First, to minimize the tendency of the stump to slide down inside the socket. Second, to optimize the knee control (Lannon, 2003).

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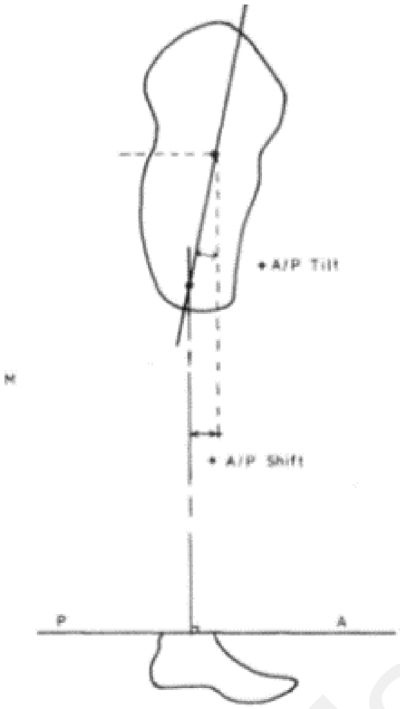

Figure 2.9: Socket tilting in sagittal plane (Zahedi, 1986)

Meanwhile, frontal plane refers to the medial and lateral positioning of the prosthetic components. The major roles of this plane set up are to provide comfort and narrow down the walking base so that it will be maintained in the normal range. According to the standard alignment setting, the socket should be positioned in 5º of abduction. This is to minimize the pressure on the fibular head.

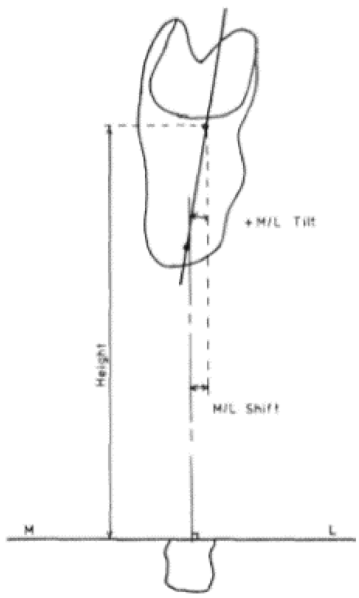

Figure 2.10: Socket abduction at 5^0 (Zahedi, 1986)

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This explains why for some cases the prosthetist place the socket slightly lateral to the foot (Figure 2.11). However, this alignment set up is only suitable for the users with great stability control (Edelstein, 2011).

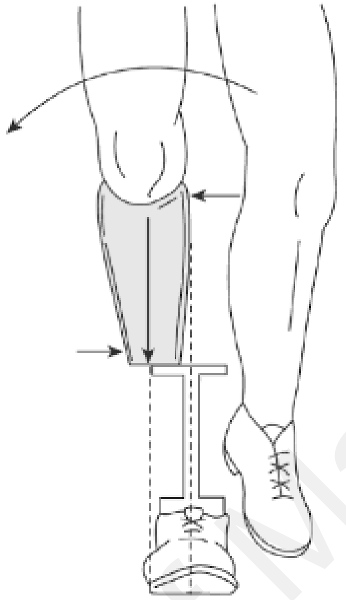

Figure 2.11: The placement of socket lateral to the foot (Edelstein, 2011)

However, for the users with poor stability control, the socket can be shifted medially to the foot line as shown in Figure 2.12 so that the walking base will be widened, providing more stability. The con of this alignment set up is it will cause more pressure on the fibular head (Edelstein, 2011).

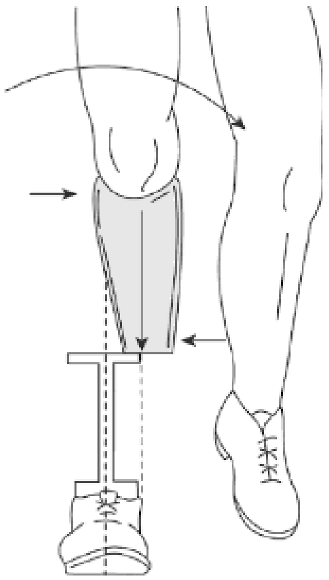

Figure 2.12: The placement of foot laterally, away from the body's midline (Edelstein, 2011)

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2.2.2 Alignment Adjustment Procedure

In general, the standard settings for prosthetic alignment consist of two phases. The first phase is bench alignment and the second phase is dynamic alignment. Bench alignment is the positioning of the socket with other prosthetic components according to the standard setup, without referring to the user. Meanwhile, dynamic alignment is more subjective. The prosthetist will set up the alignment when the user wears the prosthesis, based on the observation when the user is standing and walking. The alignment adjustment also will be made in response to the user's comments (Ali, 2013).

Proper dynamic alignment will be determined by the prosthetist based on the consideration of the anterior-posterior (AP) and medial-lateral (ML) positioning of socket and foot, height of the prosthesis, and foot rotation during ambulation. The AP aspect of socket alignment refers to the degree of the socket tilting or in other words, flexion of the socket. Adequate socket flexion will technically position the quadriceps muscle in fairly stretched condition, put them in advantage of controlling the prosthesis by preventing excessive recurvatum forces during late stance phase. Besides, the proper socket tilting also will promote the loading of pressure on the pressure tolerant areas (Bowker, 2004). According to the standard of bench alignment setup, the socket should be tilted approximately 5º of flexion so that the load will be focused more on the patellar tendon area which is one of the pressure tolerant areas. Meanwhile, the proper AP positioning of the prosthetic foot will promote even pressure distribution from heel to toe, hence the gait will become smooth and energy efficient. Technically, it will also provide controlled knee flexion moment during heel strike, as it progresses to loading response and midstance. This aspect of foot alignment also important in promoting heel off before contralateral heel contact and smooth rollover without knee hyperextension.

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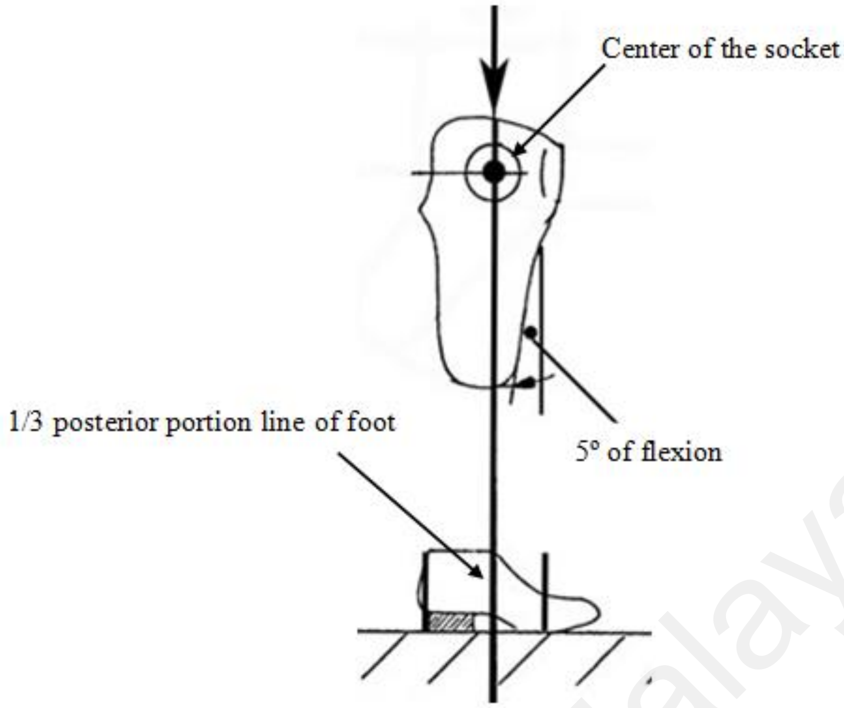

Figure 2.13: Socket flexion at $5^{0}$with response to shank tube (Lannon, 2003)

Dynamic alignment should be adjusted with the shoes on the prosthesis foot. This is because the heel height significantly influences the comfort and performance of the users. The presence of heel wedge will promote greater pressure at the distal tibia. Besides, it will also reduce pressure at the proximal part which refers to the patellar tendon area (Edelstein, 2011). During dynamic alignment setting, the center of the socket is commonly placed collinear with 1/3 posterior portion line of the foot. However, it might be shifted posteriorly if the user has poor knee control. It will promote more knee stability as the gravity line shifted anterior to the anatomic knee in response to the center of the socket placement. The same concept with opposite adjustment can be applied to the user who has good and strong knee control. The socket center will be placed slightly anterior to the standard so that the user will be able to flex the knee easier (Ali, 2013).

The most profound relationship between the prosthetic foot and socket is alignment. Besides that, it also has a very great influence to the user's comfort and prosthetic function. The proper foot alignment should be concerned in the sagittal and frontal plane. The foot position such as inversion/eversion, dorsi/plantar flexion, and foot rotation also important in order to gain its optimum function. For example, by increasing the plantarflexion of the foot, the resistance of the forefoot also will be increased during late stance phase. It is very useful for adjusting dynamic alignment (Boone, 2012). According to the research done by Ali et al. (2013), the interface pressure had increased on the proximal anterior region of the transtibial stump when the ankle was in neutral position, which refers to 0º. This was due to the limitation of the knee flexion. Meanwhile, when the knee flexion increased due to the dorsiflexion of the ankle joint, the interface pressure at the anterior distal region had been found increase as well. It was due to the ground reaction force effects that move far behind as the knee flexion increase.

The cushioning effect at the heel plays a significant role in providing knee flexion moment. Greater stiffness will increase the flexion moment and thus promoting greater knee flexion angle during loading response. The converse effect will happen for the softer cushioning heel. Apart from that, the shoe fitted to the prosthetic foot also has a high influence on its function, either improving it or make it less functional. Therefore, the selection of shoes also should be done properly. The heel height is the most important factor related to the prosthetic foot function. It should accommodate with the heel rise design of the foot so that the alignment of the socket in the sagittal plane will not change. Once the best alignment has been obtained, the amputee should not simply change the heel height of his/her shoe (Bowker, 2004).

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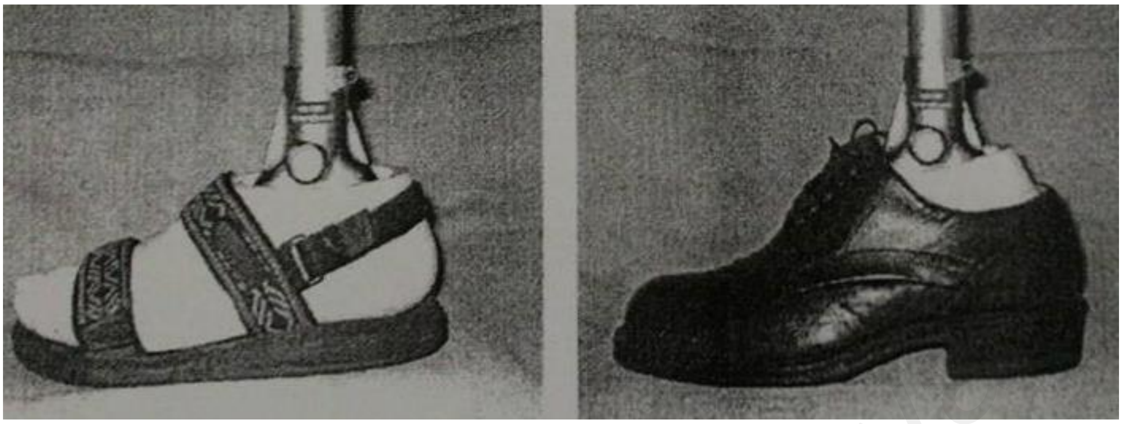

(a) (b)

Figure 2.14: The adjustable property of prosthetic foot allow it to accommodates with different heel height shoes (Bowker, 2004)

2.3 Biomechanics in Prosthetic

In prosthesis fitting process, there are two important considerations that are highly related with the biomechanics in prosthetics. First, the comfortability when using the prosthesis and second, the ease of walking.

2.3.1 Interface Pressure

The quality of the interface between the stump and the prosthesis is one of the critical aspects for any prosthesis (Boutwell, 2012). By minimizing the pressure distribution on the interface area between the stump and the socket, maximum comfortability can be achieved. The pressure can be minimized by increasing the total contact area of the stump with the socket which is highly influenced by the socket design. The other way to reduce the pressure is by minimizing the force applied to the stump. The prosthetic alignment plays a major role in this part (Hanak, 1990). These two ways of reducing the pressure are based on the formula (Boone, 2012):

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$$P = \frac{F}{A} \tag{2.1}$$

P: Pressure (Pascal, Pa)

F: Force (Newton, N)

A: Area of the contact surface (Square meter, m^2)

Generally, the stump will be exposed to two kinds of condition that should be taken into account when determining the comfortability of the prosthesis users. The first condition is pressure condition which will be bear by the stump as it fits inside the socket either statically which refers to static condition or dynamically which means in motion. Total contact surface of the stump and prosthetic alignment also play a significant role in the proper fitting of the stump inside the socket which later on will provide comfort to the user.

Meanwhile, the second condition is the rubbing and friction occur between the stump and the interior surface of the socket. Excessive heat will be generated and the skin abrasion most probably will occur if these rubbing and friction conditions are poorly controlled. The tissue ulcer might be developed due to the either sustained or intermittent (local) peak pressure between the stump and the socket (Eshraghi, 2013). According to Kang et al. (2006), approximately 30% of the lower limb prosthesis users having problems with their prosthesis that lead them not to wear it for a prolonged period. The problems could be the development of ulcers, infections, or pain.

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Figure 2.15: Tissue ulcer on a residual limb due to the excessive interface pressure between the residual limb and prosthetic socket (Goldberg, 2014)

2.3.2 Comfortability during Prosthesis Usage

The only way for the prosthetic users to describe comfort is solely by their subjective feedbacks. Boone et al. (2012) had carried out a research studying about the communication effectivity between the prosthetic users and the prosthetist as if they could perceive the alignment perturbations. The prosthetic alignments were adjusted angularly and translationally according to the sagittal and frontal plane. The evaluation had been done during static (standing) and dynamic (walking) condition. Based on their findings, verbal feedbacks and users' perception regarding the prosthetics function and satisfaction are normally used by the prosthetist to obtain the best alignment setup. However, there could be a barrier since not all the users are able to provide specific information regarding the comfort and performance of the prostheses. According to their study, even the best alignment setup could be obtained by the positive collaboration between the prosthetist and the users. However, there also could be disagreement between them. They also found that the socket fitting markedly influences the users' sensitivity to the alignment. It just took only a few steps for the users to detect the malalignment of the prosthesis. They also have found that the subjects' perception

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of the malalignment were very helpful in coronal/frontal plane and most of the subjects were able to communicate them effectively. However, the subjects had less sensitivity to detect the malalignment in sagittal plane.

A lot of studies had been carried out regarding the perception of the lower limb prosthetic users in response to the variation of the prosthetic feet, weight, prosthetic knee type, and pylon flexibility. The Prosthesis Evaluation Questionnaire is one of the valid tools that has been used in many studies to evaluate the lower limb prosthetic users' perception on its function. In a review article, its validity to clinically support the evaluation of different types of prosthetic foot had been proven (Boone, 2006).

In order to obtain the best alignment that gives comfort to the subjects and get agreement for both subjects and the prosthetist, we had prepared a set of questionnaire that mimics with the Prosthesis Alignment Perception Instrument (PAPI) software. The questionnaire inside the PAPI software allows the subjects to describe their own perception of the prostheses in both sagittal and coronal plane. These are through their response towards the typical questions on how do the alignment make them feel when using the prostheses. The questionnaire from PAPI software is as Figure 2.16.

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Figure 2.16: PAPI software guide the subject to express their view and feeling toward prosthesis malalignment (Boone, 2012)

As shown in the figure, the questionnaire is provided with pictures and descriptions. Further verbal explanation will be given by the prosthetist to make sure the amputees really do understand with the questionnaire. The first three evaluations (early stance sagittal dynamic, late stance sagittal dynamic, and coronal dynamic) are regarding the perception during ambulation while the fourth and fifth evaluation (coronal and sagittal static) are during standing. From the scale 1 to 10, the subjects will mark the scale when they already satisfy with their perception towards the prosthesis alignments (Boone, 2012).

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2.3.3 Moment Effect

Based on the concept of moment, the reaction between the upward force from the ground and the downward force by the stump able to create a rotation of the socket about its geometric center. The tendency of the socket to rotate in turn creates forces on the stump (Lannon, 2003). These forces can be controlled by the socket design so that they will be majorly applied on the pressure tolerant parts rather than the pressure sensitive parts. It is expected that the change in alignment setup of a prosthesis will affect the pressure distribution (forces) on the stump since the direction of the upward and downward forces are also changing. Apart from that, the alignment between the socket and tube shank also has a great influence towards the reaction forces between the stump and the ground. Therefore, the proper alignment is very significant in providing optimum function of the prosthesis and users' comfort. The tendency of the socket to rotate about its center should be surmounted by the proper alignment setup in order to provide comfort during walking (Fernie, 1981).

2.4 Prosthetic Alignment with Stump Flexion Contracture

For the amputees with stump flexion contracture condition, the alignment aspect that should be focused is the sagittal plane which is the AP positioning of the socket with respect to the foot. For standard alignment setup, the center of the socket (from the side view) should lie in the same line with 1/3 of the foot portion from the back as shown in Figure 2.13 before (Lannon, 2003). Determining the socket flexion angle is a vital part of assembling a prosthesis. This is because it will bring significant effect to the prosthetic alignment. The angle of socket flexion can be defined as the angle between the longitudinal axis of the socket and the longitudinal axis of the shank. The standard angle used by the prosthetist is 5º. It has been found that the different angle of socket flexion setting will change the pressure distribution between the stump and socket interface (Kang, 2006). Besides that, for an amputee with stump flexion

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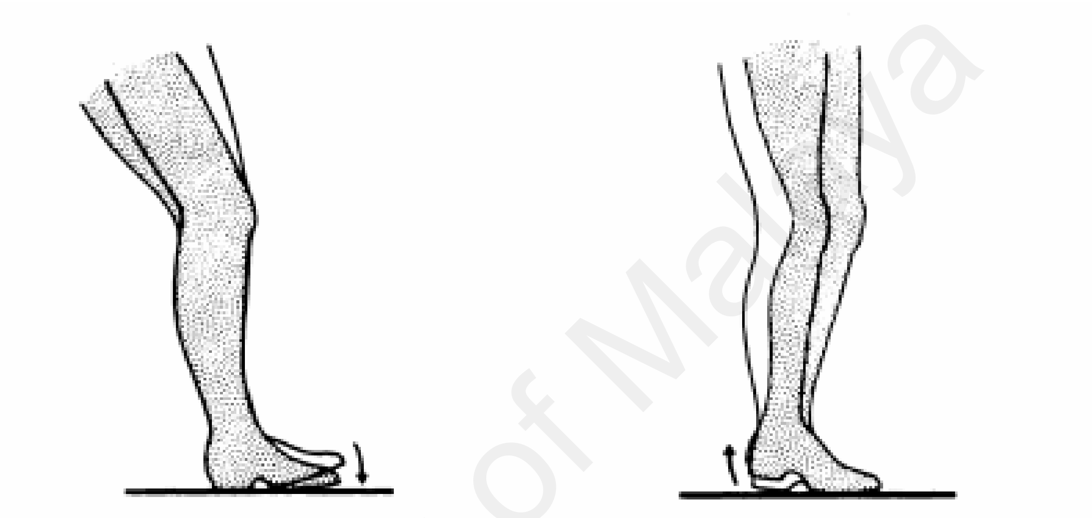
contracture, the socket flexion will be increased respectively with the contracture angle which means the alignment is deviating from the standard. Otherwise, the amputee will exhibit gait deviations during walking such as rough rollover of the foot and inconsistent heel strike (Saleh, 1985). It is due to the limited ROM of the stump compared to normal ROM.



(a) (b)

Figure 2.17: Possible gait deviations which may occur due to the improper socket adjustment. (a) The transition from heel strike to foot flat is quicker than normal. (b) Earlier heel rise in late rollover (Saleh, 1985)

Other than flexing the socket, gait deviations also could be minimized by dorsiflexing the foot which will promote smoother heel strike and rollover. However, according to Bowker et al. (2004), the prosthetic foot is supposed to be aligned in more plantarflexion position since this alignment will promote higher knee extension moment during toe off, thus most probably could improve the contracture eventually.

Kang et al. (2006) had done a research to study the effects of different flexion angle of the transtibial prosthetic socket to the interface pressure between stump and socket. This study was focused on the static and dynamic pressure by using the F-socket system. The experiment had been done in three different socket flexion angles which act

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as a manipulated variables. They were 0°, 5°, and 10°. Meanwhile, the ankle joint angle was set constant at 0º. It has been found that the pressure interface between the stump and socket during static standing can be reduced by increasing the angle of socket flexion. However, the suggested maximum flexion angle is just 10º. This is due to the adverse effect on knee joint stability that could happen if the socket flex excessively. During walking, the increase of socket flexion angle will result in decreasing pressure at the anterior proximal area but increasing pressure at the anterior distal area and vice versa.

Kang et al. (2006) had concluded that the change in anterior/posterior alignment of the socket, which refers to the socket flexion angle bring significant effect to the amount of pressure interface at certain areas on the stump. Thus, their study could be very helpful for the prosthetist in order to identify any possible problem due to the change in socket flexion angle including the complaint of pain from the amputees.

So far, there is still no specific study regarding the change in pressure on the stump with respect to the knee contracture after the alignment adjustment. There are two studies which had been done regarding the effect of flexing the socket to pressure distribution on the stump and socket interface (Kang, 2006). However, the gait deviations and range of motion with respect to the knee contracture of the residual limb had been neglected. These two factors are very important which could bring significant effect to the usage of the prosthesis in daily living.

For the below knee prosthesis alignment setup, the suggested maximum angle of socket flexion is 10^0. This is due to the adverse effect that it could bring towards the knee stability if the socket is flexed excessively (Kang, 2006). In fact, stability is one of the most vital components in human life since it is the main requirement for a human to carry out daily activities. Indeed, it is a necessary component to achieve body

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equilibrium and stability during ambulatory activities and even quiet standing (Ku, 2012).

2.5 Postural Balance among Amputees

Quiet standing can be defined as staying upright in a static condition without moving. The regulation of balance is a vital effort for the body in maintaining the stability in this position. Meanwhile, balance is the ability in regaining the Centre of Mass (CoM) within the base support in order to maintain body equilibrium. To preserve balance, CoM changes as the body is moving (Alexandrov, 2005). The amputation of lower extremities will cause the patients to change their locomotion pattern in order to preserve balance (Ku, 2014). It will involve the integration of sensory systems, joints, and multiple body segments. Literature has reported that in the United States in the year 2010, lack of balance control against perturbation is believed to be one of the biggest contributors to fatal falls incident (Adams, 2011).

2.5.1 Postural Stability Control

One of the components of the postural control is the ability of an individual to maintain balance during quiet standing (Ku, 2012). There are several psychological systems that involve in sustaining balance which are visual, vestibular, and proprioception systems (Karimi, 2008). According to Salsabili et al. (2011), individual's ability to maintain postural control and balance are affected by six conditions which are movement strategies, controls of dynamic, cognitive processing, orientation in space, sensory strategies and biomechanical task constraint. All these six conditions are proven to be responsible for controlling a body posture by (Hodges, 2002). Hodges et al. (2002) found that the postural control was affected by the response of the multiple body segments. For example, when an individual keep the balance against perturbation during quiet standing, ankle, hip and stepping strategies will trigger the response of regulating the CoM within the base of support in the sagittal plane. When it comes to the small

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perturbation which causes the line of the body to falls forward, the ankle joint will trigger foot plantar flexion response by activated gastrocnemius muscle. The hamstring muscles will keep the knee and hip maintain in balance position with the simultaneous response from the iliopsoas muscle which is to prevent the hip hyperextension. Meanwhile, the thoracic erector muscles group will trigger the movement of trunk against the perturbation direction, which is in this case, move in a backward direction (Horak and Neshner, 1986: Nashner, 1976: Shumway-Cook and Woollacott, 2007).

In response towards perturbation, human body is believed will orientates the CoM, which is a virtual point equivalent to total body mass (Hernandez, 2009). By regulating body's position, this response will return the CoM within the base of support (BoS) which is the displacement region for the Center of Pressure (CoP). CoP is the point of average distribution for total pressure towards the surface of the contact area (Gravante, 2003). It has been found that broad stance or in other words, wide base provide greater postural control during normal quiet standing (Bonnet, 2012). Another potential factor that is affecting postural balance is age. The elderly population had been found exhibit greater postural sway (Ku, 2014).

2.5.2 Factors Affecting Postural Stability Control

Dynamic control of a human body to gain static balance are divided into three essential aspects. They are body segment displacement, muscle activity, and movement pattern of CoP and CoM. Besides that, postural sway is used as an indicator of the dynamic control. It actually represents the displacement of CoP from the base support. Force plate with transducers was commonly used in the previous research to study CoP sway which is the most important parameter in studying human standing posture (Ku, 2014). Among the amputees, mean CoP position was generally veered towards the sound limb. Meanwhile, the normal population exhibits slight CoP deviation towards the dominant limb.

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Buckley et al. (2002), Hermodsson et al. (1994), Quai et al. (2005), Vanicek et al. (2009), Lenka et al. (2010), and Fernie et al. (1978) evaluate the postural balance represented by the CoP changes with different sensory perception. In their research, the trials were conducted with two visual conditions: 1) open eyes and 2) closed eyes. Generally, the closed eyes condition cause the increment of postural sway among the amputees. The sway was significant in the anterior-posterior plane of the sound leg while there was no significant postural sway at the medial-lateral plane. The subjects also exhibit greater balance achievement with the aid of visual and somatosensory inputs. The finding was in conjunction with the literature which stated that visual input and muscle vibration are able to influence the magnitude of proprioception input (Vanicek, 2009, Barnett, 2012 and Duclos, 2007). Thus, postural balance outcomes could be different as there is alteration in input information of the sensory system.

According to Horak et al. (2006), there are six components that should be taken into account for retaining postural balance. Those are biomechanical constraints, movement strategies, orientation in space, control of dynamic, sensory strategies, and cognitive processing. The study in sensory strategies came out with theories that the integration among visual, vestibular, and proprioception are significantly affecting balance control.

Meanwhile, Katch et al. (1988) and Salsabili et al. (2011) had proven the increasing BMI could bring significant impact on the postural control in terms of muscular torque, attentional cost, postural sway, energy cost, and motor reaction time. Ku et al. also found that the obese group exhibited significant greater sway of CoP compared to the underweight and normal weight groups. According to Colne et al. (2008), increase in BMI could possibly reduce the ability of the muscles to generate sufficient force in order to control the CoM displacement.

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There was a lot of research had been done in order to study about the postural control during quiet standing among amputees. Ku et al. (2014) had done a systematic review regarding the factors that contribute to the balance instability for lower limb amputees. In their review, they found that majority of the articles revealed the increase in postural sway among the amputees compared to normal population. One of the major factors that explained the instability is asymmetry in body weight distribution between the sound and the artificial legs. Duclos et al (2009), Nederhand et al. (2012), Hlavackova et al. (2011), and Nadollek et al. (2002) have found that the lower extremities amputees showed an asymmetrical reading of loading percentage between the prosthetic leg and sound leg. They tend to put on more load at the sound limb compared to the prosthesis. The asymmetrical loading percentage was also greater among the first time prosthesis users (Mayer, 2011). Meanwhile, the normal population generally exhibit equal load distribution between both legs.

Besides that, some other factors that contribute to the postural balance among the amputees are sensory inputs, stump length, confidence level, and center of pressure. According to Gaunard et al. (2011) and Lenka et. al. (2010), they have found that the subjects with shorter stump exhibit larger sway area compared to those with the medium and long stump length. Prosthetic alignment adjustment is also vital in retaining postural balance. Feet opening angle or in other words, out toing angle should be adjusted according to the standard so that the optimum stability could be achieved. This has been proven by the influence of biomechanical factors towards postural activity. The factors are consist of weight, height, maximum foot width and feet opening angle (Chiari, 2002).

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2.6 Biodex Stability System (BSS)

The balance of an individual can be assessed by measuring the displacement of CoP which means by getting the Stability Index (SI). The SI is divided into three categories. They are the Overall Stability Index (OSI), Anterior Posterior Stability Index (APSI), and Medial Lateral Stability Index (MLSI). These are the standard deviation readings that assess the path of sway around the zero point from the center of the platform in order to evaluate balance and measure balance performance. The units are in degree. In other words, these stability index indicates the degree of foot displacement in sagittal and frontal plane motions (Ku, 2012). It able to measures the foot displacement for up to 20^{0} of platform tilt in 360^{0} of range of motion.

In recent technology, the Biodex Stability System (BSS) is used to measure the displacement of the CoP. BSS has been developed with more advantages and convenient technology in studying postural stability. Besides of being convenient and portable, it also able to provide clinical data measurements related with the postural stability (Arifin, 2015). Previously, it had been utilized in the study of arthritis and ankle instability. The system is also available for multi-range of people, easy to administer, and simple to interpret (Aydog, 2006) (Salsabili, 2011). Arifin et al. (2015) had carried out a research to study the ability of BSS in quantifying postural steadiness among below knee amputees while standing with the prostheses on. In the research, they have found that the BSS could be handy and functional for the clinical assessment of postural stability for the purpose of prosthesis evaluation and even in rehabilitation progress.

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2.7 Summary

First and foremost, below-knee amputees with stump flexion contracture condition will have limited ROM of the stump. This is the result of the muscles and ligaments tightening due to the long period of bending or being inactive (Figure, 2008). The literature has identified several potential factors that could contribute to the stump flexion contracture condition such as maintaining the stump position when the amputees are lying on bed, limited activity of the affected lower limb prior to surgery, delayed prosthesis fitting, and neglection of doing exercise (Pasquina, 2009; LaRaia, 2010; Doyle 2015). Prosthesis fitting and functionality could be affected by the contracture condition. In addition, special components might be needed to accommodate the prosthesis with the contracture condition (Bowker, 2004). However, there are several ways to prevent or reduce the contracture condition such as stump splinting and stretching exercises. In order to overcome the adverse effects, the prosthetic alignment itself could help the amputees with stump flexion contracture condition in gaining the optimum stability and function (Huang, 2011; Knoope, 2011).

Meanwhile, where prosthetic is concerned, alignment is vital in determining the efficiency and function of a prosthesis (Lannon, 2003). The prosthetic alignment adjustment will involve two anatomical planes which are sagittal (anterior-posterior) and frontal (medial-lateral) plane. The adjustment methods consist of two phases, which are bench alignment setup and dynamic alignment setup (Ali, 2013). A proper footwear is also very important for alignment adjustment. The heel height is a prominent aspect of consideration when choosing a proper footwear. The height must be able to accommodate to the rise of the heel design of the prosthetic foot.

In term of biomechanics, there are two factors that could greatly influence the prosthetic fitting and amputees' comfortability which are interface pressure and moment effect. The pressure distribution between the interface area of the stump and the inner

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layer of prosthetic socket must be minimized to gain maximum comfortability. On the other hand, based on the moment concept, there will be a tendency for the socket to rotate when the amputees walk with the prosthesis which will create forces on the stump (Lannon, 2003). Therefore, a proper socket design will be able to control the forces so that they will be majorly applied on the pressure tolerant parts of the stump (Fernie, 1981).

Next, for the amputees with stump flexion contracture condition, the main focus of the prosthetic alignment is on the sagittal plane. The socket flexion will be increased according to the contracture angle (Salleh, 1985). However, according to Kang et al. (2006), different socket flexion angle could cause different amount of pressure on certain areas of a stump. Hence, to compensate with the contracture condition, foot dorsiflexion angle also need to be adjusted accordingly to ensure smooth rollover when walking (Bowker, 2004).

Apart from that, from the prospect of postural balance, lower-limb amputees tend to change their locomotion pattern in order to maintain their balance (Ku, 2014). The balance is attained from the response of multiple body segment (Hodges, 2002). Moreover, Bonnet et al. (2012) has found that wider base will provide greater postural balance during a normal quiet standing. Besides that, there are several factors that could influence the postural balance among lower-limb amputees such as BMI, stump length, confidence level, and prosthetic alignment (Chiari, 2002; Lenka, 2010; Gaunard, 2011)

Consecutively, to measure postural balance during quiet standing, BSS was widely used. It measures the displacement of the body's CoP by SI reading, which consist of APSI, MLSI, and OSI. Besides providing clinical data related with postural stability, it is also convenient and portable (Arifin, 2015).

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Chapter 3: Methodology

Chapter 3 provides the details of how the experiment had been carried out. It also highlights some issues and conditions that need to be achieved or avoided in order to complete the research successfully. This chapter is arranged and written based on the relevant literature and is inclusive of data annalysis method.

3.1 Introduction

This study was conducted in three phases. Figure 3.1 on page 41 shows the phases involved and some brief description on the workflow of this research.

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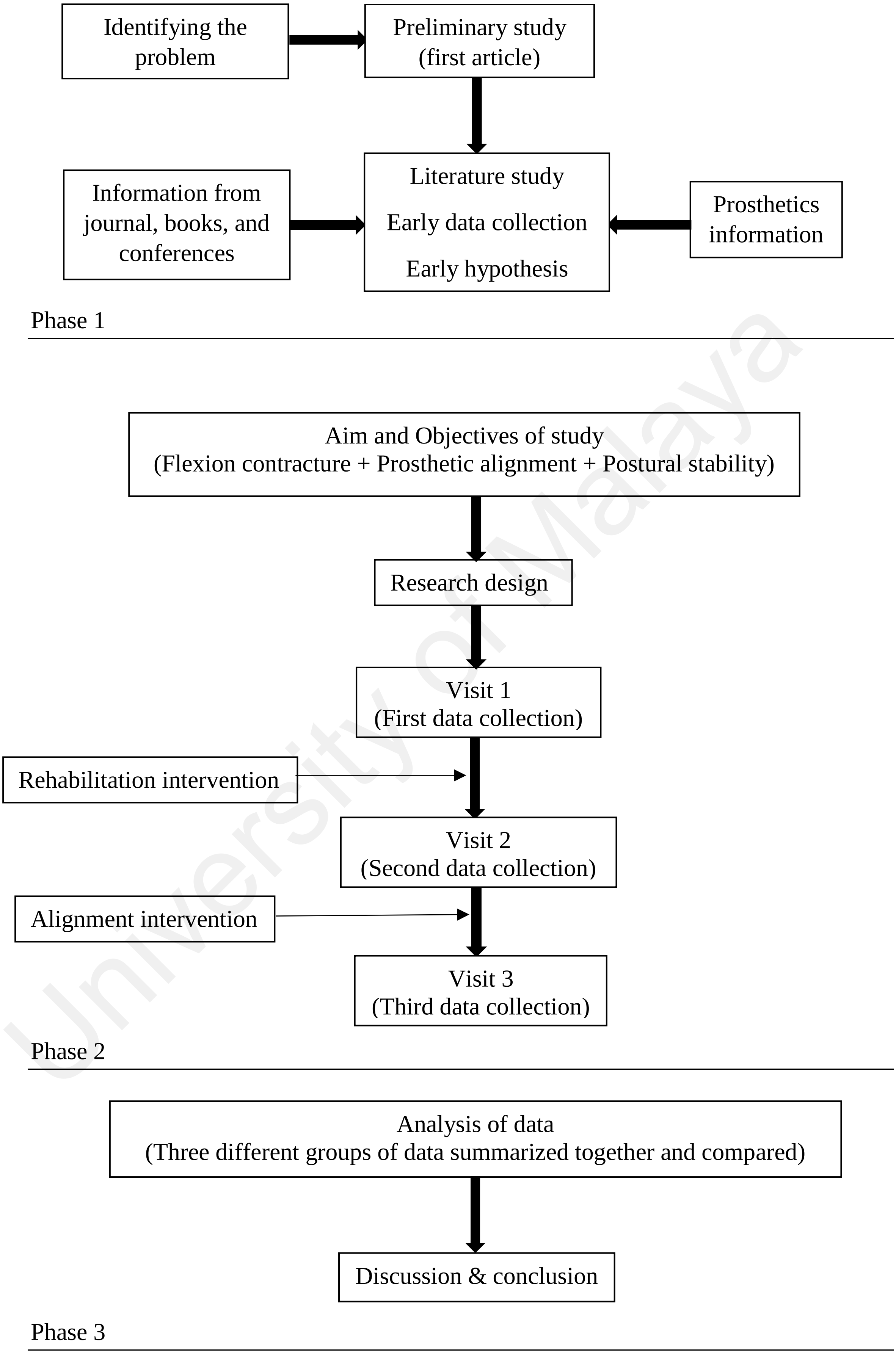

Figure 3.1: Methodology flowchart.

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3.2 Ethics Approval

The research protocol for this study was approved by the Medical Research Ethics Committee (MREC), Ministry of Health Malaysia with Approval ID: NMRR-16-2106-32880 (IIR). The ethics approval letter is as attached in **Appendix H**. The MREC approved it noting that the data collection for this study will only be involving Physical Evaluation. All participants were required to sign a written consent form prior to the tests.

3.3 Subjects Recruitment

The test was conducted on 14 subjects. However, only 10 of the subjects fulfilled all the inclusion criteria without any exclusion criteria throughout the experiment. The inclusion criteria were as follows:

1) Unilateral transtibial amputee.

2) An age limitation was set, starting from 50 to 75 years old in order to narrow down the optimum dynamic alignment. It was because Zahedi et al. (1986) have found that wide range of alignments could satisfy the amputees and those alignments can be considered as optimum alignments in clinical situation which means not only acceptable by the amputees, but also satisfy the prosthetist judgment. However, these ranges might not be applicable to the entire amputee population since they were studying the active subjects. Hence, middle-aged and elderly patients who are older than 50 years old are preferred to young and active patients.

3) Subject must have a stump flexion contracture of at least 10º with 25º as the acceptable maximum contracture. Based on Bowker et al. (2004), the alignment of a prosthesis can still be adjusted to accommodate the knee flexion contracture, unless the angle exceeds 25º then, the fitting might be difficult.

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4) Good compliance in the effort of reducing their knee contracture. The minimum amount of knee contracture that should be reduced is 5º. Thus, another SI reading at different contracture angle will be obtained in conjunction with the first objective, which is to study the postural stability control at different stump flexion contracture angle. The final SI data obtained can also be used to construct the standard range of the postural stability score at certain degree of the contracture, which is required in the third objective.

5) Able to communicate their individual perceptions towards the alignment since they can directly feel and respond to the changes of mechanical effects. The communication between the subjects and the experimenter/prosthetist is vital to ensure that optimum dynamic alignment could be achieved. The questionnaire should also be filled in efficiently (Boone, 2012).

6) The subjects are using the same endoskeletal prosthetic system, PTB socket with pelite liner, and SACH foot, regardless of the usage period of the prosthesis. The type of prosthetic foot, which also includes the ankle, must be the same since Ariffin et al. (2015) have found that the types of prosthetic foot influence the user's postural stability during quiet standing. Nederhand et al. (2012) also found that there was a significant correlation between the stiffness of the prosthetic ankle and the balance control.

7) Must fulfil all the requirements listed above. The failure of the subject to fulfill any of the requirement will be met with disqualification.

On the other hand, the exclusion criteria were as follows:

1) Reluctant to comply with contracture improvement efforts (contracture improvement does not reach at least 5^0).
2) Presence of wound or injury on the residual limb.
3) Unable to stand with prosthesis independently.

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4) Body weight change more than 3 kg throughout the experiment. This was because the change in body weight was proven to affect the stability control (Corbeil, 2001) (Teasdale, 2007).

3.4 Clinical and Laboratory Setting

Zahedi et al. (1986) have found that different prosthetists would possibly give different ranges of the prosthetic alignment and these ranges were accepted by the amputees. Interestingly, they also found that a prosthetist could not repeat the same alignment adjustment. This will significantly influence the research outcome as the dynamic alignment in response to the knee contracture was one of the most important variables for this study. Therefore, the alignment setup starting from bench until dynamic alignment was done under supervision of a single prosthetist. To achieve higher consistency, a checklist had been prepared as a guide for the prosthetist to supervise the dynamic alignment. In addition, a set of questionnaire for the subjects was also prepared to get their feedbacks towards the alignment setup.

The subjects' particulars are attached in **Appendix A** including height, body weight, leg length, and stump length that were recorded during every visit. The experiment was carried out at Motion Analysis Laboratory, Faculty of Engineering, University of Malaya. All the instruments setup, calibration, and measurement were done by the same experimenter.

A list of stretching and active exercise together with pictures in **Appendix B** were given to every subject after the first visit as a guide for them to improve their knee contracture. The experimenter also demonstrated and taught the subjects based on the list to ensure their understanding. The subjects were advised to do the exercises at least two sessions per day. Minimum period given for the subjects to achieve the minimum knee contracture improvement (5º) was 14 days.

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3.5 Experimental Setup

In this research, every subject was asked to visit to the laboratory for three times (Visit 1, Visit 2, Visit 3). For every visit, the subjects were given a briefing about the experimental procedure and purpose, so that they could give their cooperation with ease throughout the experiment. The subjects were also advised to wear short pants. Before the arrival of the subjects, the laboratory and equipment were well prepared and the Biodex Stability System (BSS) was tested to make sure that it is in a proper functioning state.

3.5.1 Visit 1

i. When the subjects had arrived, they were asked to fill up the Participant's Particular Form (**Appendix A**). Then, their personal information, as shown in Table 3.1, were measured and recorded. For the angle of knee contracture on the residual limb side, the reading was obtained as explained in **3.6 Measuring Stump Flexion Contracture Angle**.

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Table 3.1: Subject's personal information

Subject	1	2	3	4	5	6	7	8	9	10
Cause of amputation										
Age (years)										
Sex										
Body mass (kg)										
Height (cm)										
Time since amputated										
Amputation side										
Activity level (K-Level)										
Length of stump (cm)										

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ii. The prosthetic alignments were checked again according to **3.8 Prosthetic Alignment Setup** procedure even if the subjects were already satisfied with the previous alignment. This was to ensure the consistency of the experiment, by leaving the optimum alignment set-up task to a single person under the supervision of the same prosthetist, by using the same procedure and references. Besides that, the alignment setup was in accordance to the current stump flexion contracture condition. The SI data obtained later will be helpful to achieve the second objective as mentioned in page 4 and 5. When the optimum alignment had been obtained, the prosthesis was taken out and the alignment angles were measured and recorded as in **Appendix C**.

iii. After the subjects were done with the prosthetic alignment setup, they were allowed to walk around the lab with the prosthesis on in order to get used to the new alignment setup.

iv. Now that the subjects were ready; **3.9 Postural Stability Evaluation** experiment was started. The result and data obtained were recorded.

v. After the experiment was completely done, a stump contracture splint was given to every subject together with the exercise list (**Appendix B**). The subjects were advised to wear the contracture splint all the time as they were not wearing prosthesis. Meanwhile, the exercises in the list should be done in at least two sessions per day. The next visit was arranged in the next 14 days at least, based on the knee contracture improvement (5º minimum).

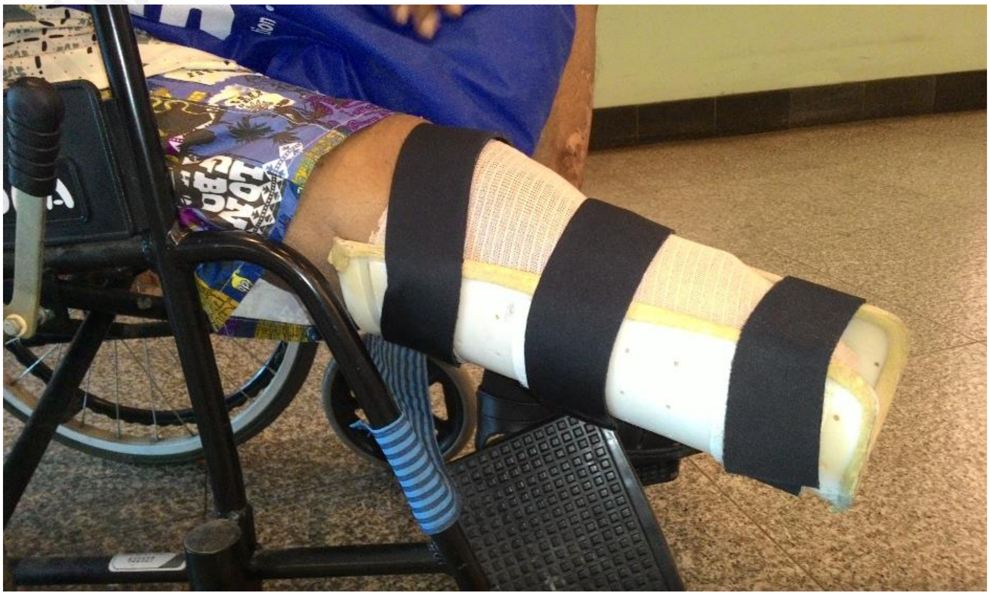

Figure 3.2: One of the subjects wearing the stump contracture splint provided

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3.5.2 Visit 2

i. The subjects' body weight was measured again to ensure that there was no significant difference with the 1st visit. The angle of the stump flexion contracture was also measured again according to **3.6 Measuring Stump Flexion Contracture Angle** to find the difference in the SI reading that will be obtained later, with different degree of contracture as required in the first and third objectives.

ii. Step iv as in **3.5.1 Visit 1** was repeated without changing the alignment even if the stump flexion contracture angle had improved. The purpose was to study the ability of the subjects to control postural balance with the previous alignment setup even when the range of motion (ROM) of the residual limb had improved. The SI readings obtained will be analysed and compared with the readings obtained during Visit 1 and Visit 3 later, where the prosthetic alignment was adjusted according to the contracture condition, as required in the second objective.

iii. When the **3.9 Postural Stability Evaluation** experiment was completed, the alignment setup was redone starting from the static to the dynamic alignment (**3.8 Prosthetic Alignment Setup**) according to the improved knee contracture angle. When the optimum alignment was obtained, the prosthesis was then taken out and the alignment angle was measured and recorded again, for the second time according to **Appendix C**.

iv. Subjects' postural stability with the new prosthetic alignment setup would be studiedin the next two weeks. The purpose was to allow them to accommodate with the new alignment setup and obtain maximum control toward the prosthesis (Koehler-McNicholas, 2017; Agrawal, 2013).

3.5.3 Visit 3

i. The subjects' body weight and knee contracture angle were measured again to ensure that there were no significant changes.

ii. Step iv as in 3.5.1 Visit 1 was repeated.

The summary of the whole experimental protocol is shown in Figure 3.3.

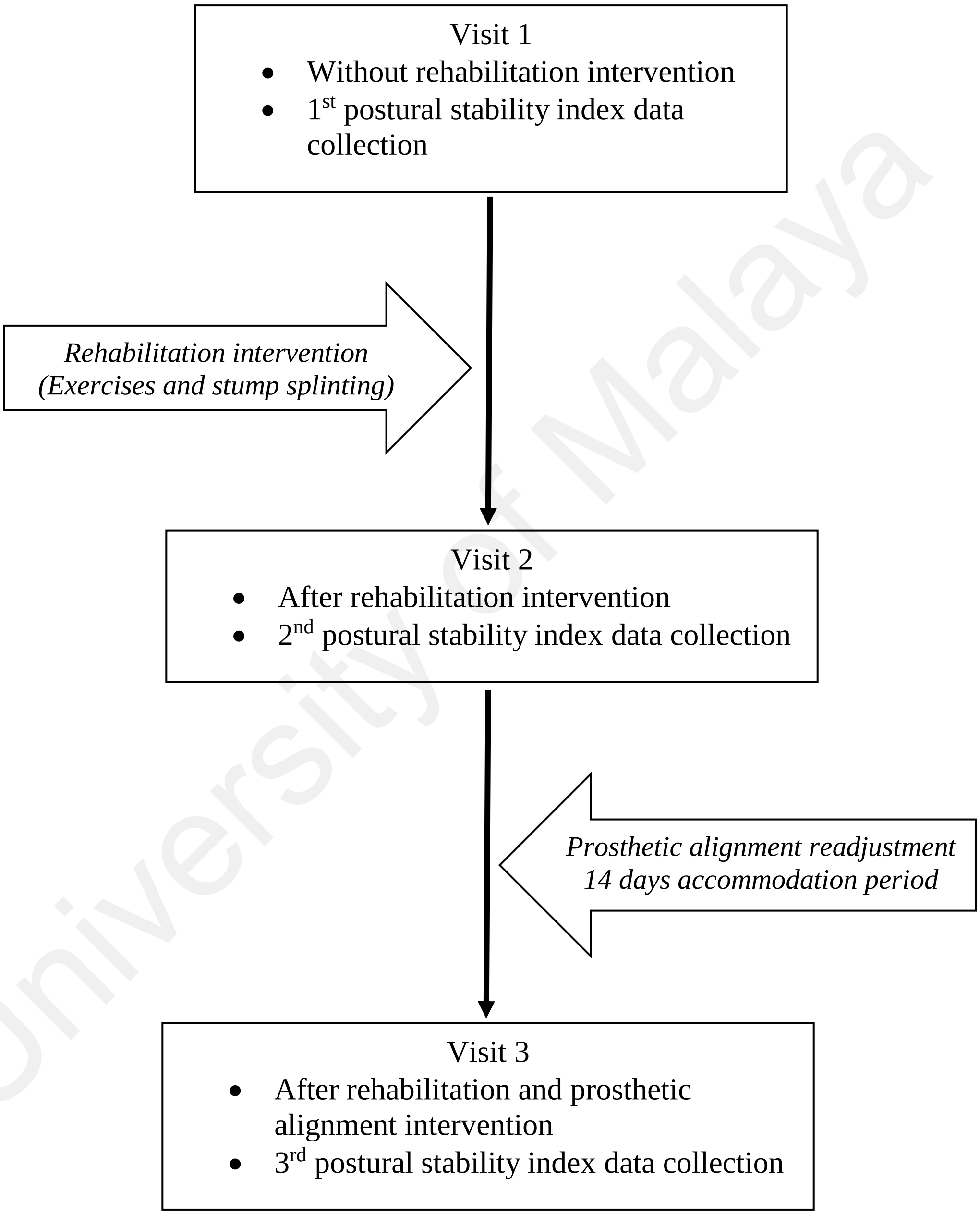

Figure 3.3: Experimental protocol flowchart

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3.6 Measuring Stump Flexion Contracture Angle

Subjects' stump flexion contracture angle was measured in every visit. Each subject was asked to extend the knee as much as possible. The goniometer was then placed at the mid patellar level laterally over the knee with the upper arm of the goniometer was pointing towards the greater trochanter while the lower arm was aligned parallel to the tibial bone (Figure 3.4).

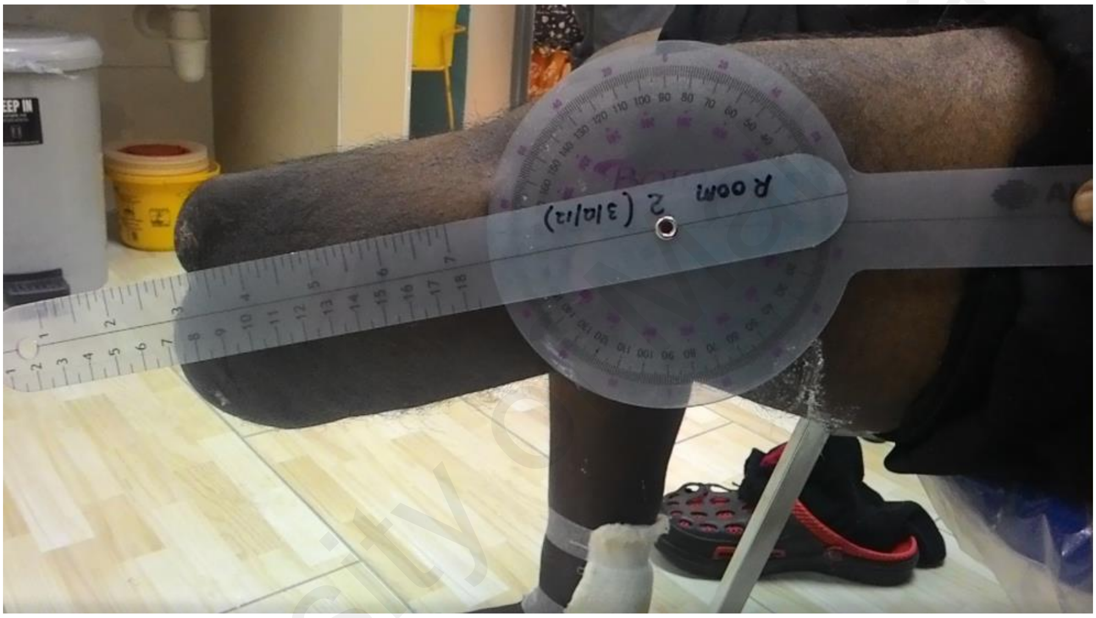

Figure 3.4: Positioning of goniometer

3.7 Alignment Adjustment

For the components used in this research to change the alignment, there were two locations of screws that could be adjusted:

1. Below socket
2. Ankle level

By adjusting only one of those, the socket or the foot would be tilted (Figure 3.5(b)). Whereas, by adjusting the screws at both locations, the foot or the socket would be shifted as the foot was always flat on the ground (Figure 3.5(c) and Figure 3.6). These adjustments were applied to both sagittal and frontal plane aspects.

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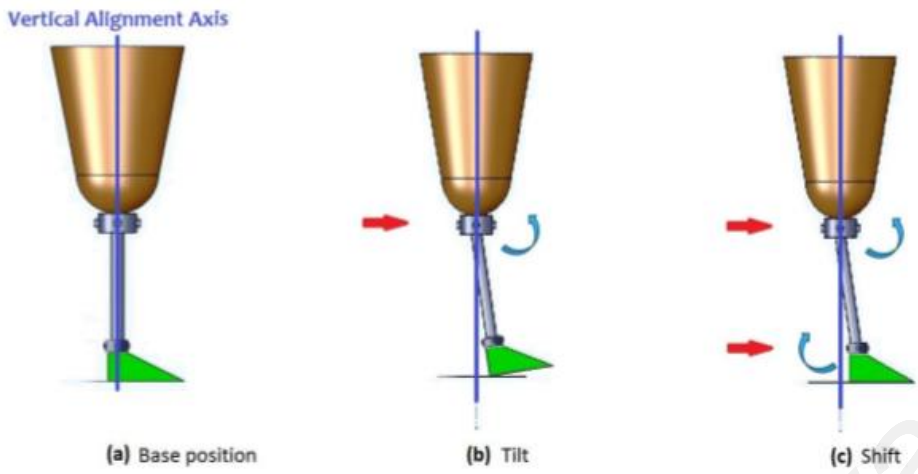

Figure 3.5: Alignment adjustment in sagittal aspect (Chen, 2012)

Figure 3.6: Foot and socket shifting in frontal aspect (Chen, 2012)

3.8 Prosthetic Alignment Setup

Biomechanics in prosthetics is generally referred to prosthetic alignment and socket design. These are the two components that are strongly related to biomechanics in prosthetics. The first one is the comfortability when using the prosthesis while the second one is the ease of walking. By minimizing the pressure distribution on the interface between the stump and the socket, comfortability can be achieved. One of the ways to reduce the pressure is by minimizing the force applied to the stump. The prosthetic alignment plays a major role in this part (Edelstein, 2011).

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Prosthetic alignment can be defined as the orientation and position of the major components of a prosthesis. The major components are the socket, joint (if any), and foot (Zahedi, 1986).

Basically, the alignment of the prosthesis will be adjusted according to the three orthogonal planes of Cartesian system which are sagittal, frontal, and transverse plane (Chen, 2012). Sagittal plane refers to the anterior and posterior positioning of the prosthetic components, especially the socket. There are two major purposes of adjusting the sagittal alignment properly which are to minimize the tendency of the stump to slide down inside the socket and to optimize the knee control (Edelstein, 2011).

Meanwhile, frontal plane refers to the medial and lateral positioning of the prosthetic components. The major roles of this plane setup are to provide comfort and narrow down the walking base so that it will be maintained in normal/standard range (Edelstein, 2011).

For all the subjects in this research, their prosthesis underwent three standard alignment setup (Figure 3.7).

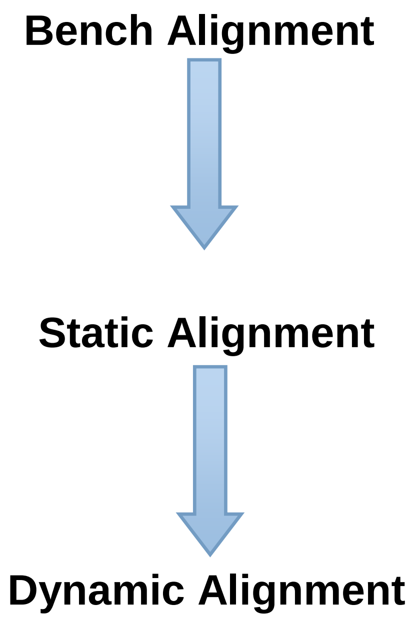

Figure 3.7: Alignment setup flow

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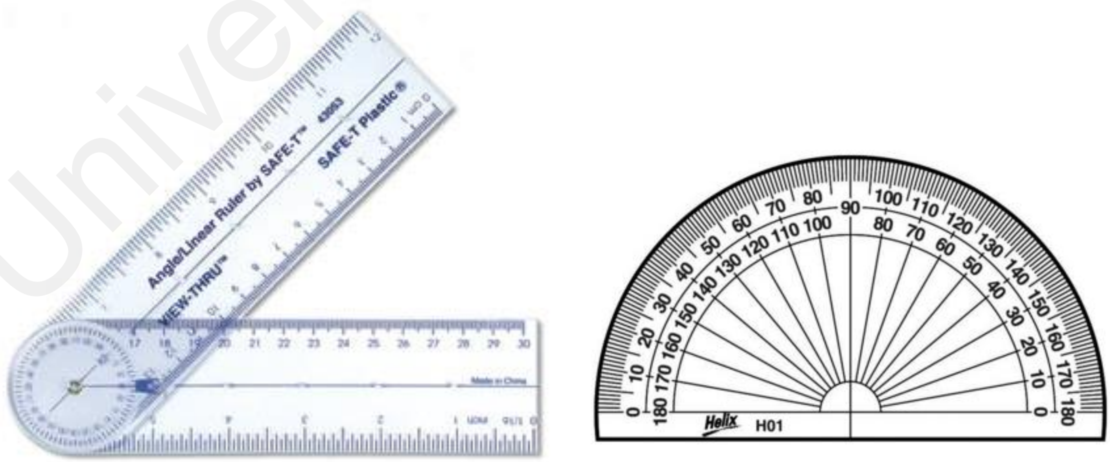
All these alignment setups were done by using Graticule laser (Bosch) as a plumb line (Figure 3.8), protractor, and goniometer to measure the angle (Figure 3.9).

Figure 3.8: Graticule laser



Goniometer

Protractor

Figure 3.9: Goniometer and Protractor

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3.8.1 Bench Alignment

Bench alignment is the positioning of the socket with other prosthetic components according to the standard, without referring to the user. According to the standard of bench alignment setup, in sagittal aspect, the socket should be tilted approximately 5º of flexion so that the body load will be focused more on the patellar tendon area which is one of the pressure tolerant areas (Lannon, 2003). In this study, 5º of socket flexion was added to the degree of flexion contracture when the contracture was presence. The centre of the socket was placed collinear with 1/3 posterior portion line of the foot. A wooden block with suitable thickness to the approximate heel height was placed at the heel during this setup (Figure 3.10).

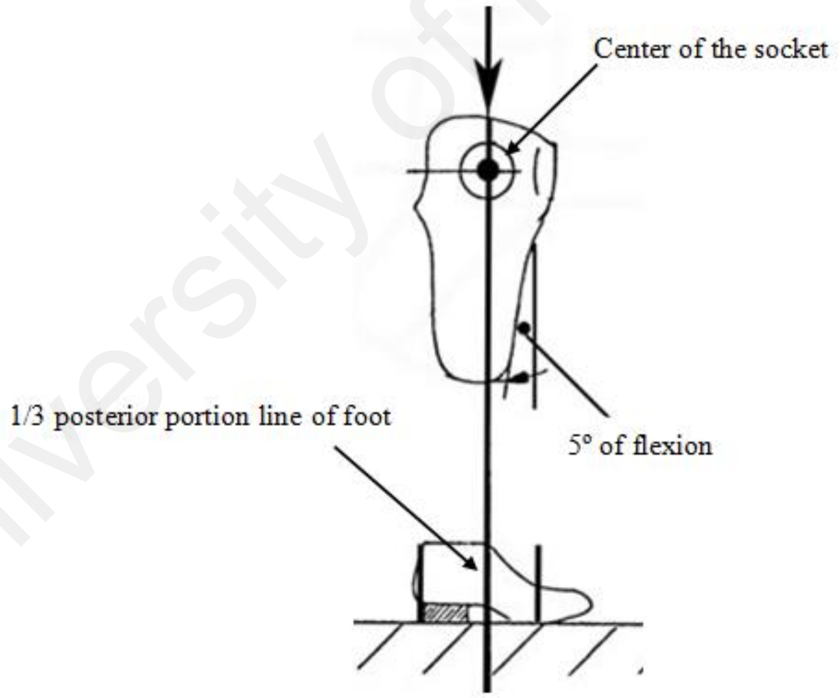

Figure 3.10: Bench alignment setup in sagittal plane (Lannon, 2003)

Meanwhile, based on the standard alignment in the frontal aspect, the socket was positioned in 5º of abduction (Figure 3.11). This setup would promote the distribution of load at the pressure tolerant areas in medial-lateral aspect, such as medial tibial flare and lateral shaft of fibula. This was due to the normal genu varum moment generated

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during stance phase. This would also help the subjects to experience narrow base gait which will reduce the energy expenditure (Edelstein, 2011;Bowker, 2004).

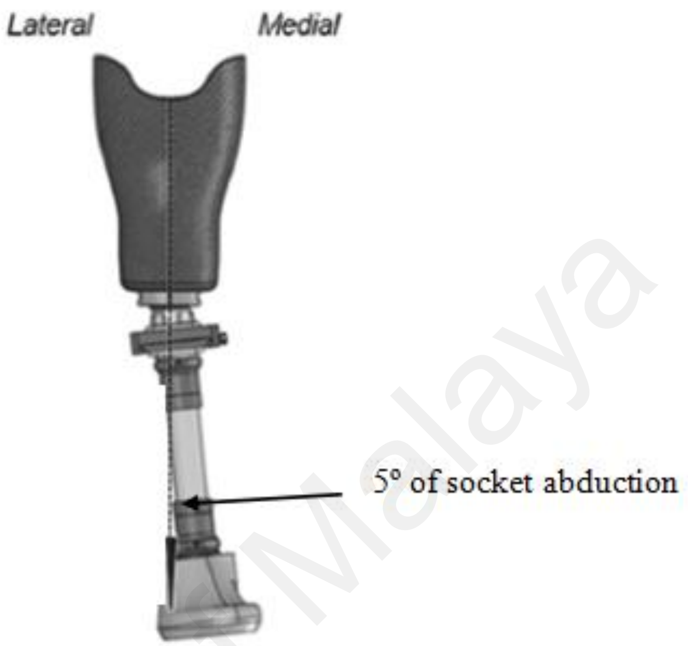

Figure 3.11: Bench alignment setup in frontal plane (Kobayashi, 2014)

Whereas, in transverse aspect, the value of the toe-out angle was based on the angle between the net forward gait progression and the medial borderline of the foot. For the bench alignment setup, the medial border line was positioned parallel with the progression line (Bowker, 2004). This results the subjects' prosthetic foot became 5º to 7º toe-out (varies according to the different manufacturers), just like the normal anatomic toe-out.

3.8.2 Static Alignment

Static alignment is the alignment setup of the prosthetic components when the subjects were standing steadily with the prosthesis on (Chen, 2012). At this point, it is possible to see the result of the section **3.8.1 Bench Alignment** done before whether the setup fits with the prosthetist's and subjects' requirement.

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The alignment adjustment was also made in response to the subjects' comments (Edelstein, 2011). Proper alignment was determined based on the consideration of the AP and ML positioning of the socket with respect to the foot, prosthetic height, and foot rotation (Bowker, 2004). A flowchart as shown in **Appendix D** regarding the four factors was prepared to fulfil the requirement of the experimenter, the prosthetist and the subjects (Zahedi, 1986; Bowker, 2004; Edelstein, 2011). The adjustments made were as shown in Figure 3.5 and Figure 3.6 previously.

3.8.3 Dynamic Alignment

Dynamic alignment was more subjective compared to the bench and static alignment. The experimenter set up the alignment when the subjects were wearing the prosthesis, based on the observation when they were standing and walking. The alignment adjustment was also made in response to the subjects' comments.

3.8.3.1 Prosthetist Judgment

Prosthetist's judgment is very important for a dynamic alignment setup. In this study, the judgment was made based on the knowledge about gait pattern and loading concept on stump, personal experience, and the most important factor, subjects' feedbacks. All these factors play a significant role in the validity of the judgment made by the experimenter and the prosthetist so that the optimum alignment which was acceptable by both the prosthetist and the subjects can be obtained (Zahedi, 1986). Therefore, based on the literature in dynamic alignment setup, an alignment flowchart (**Appendix E**) had been prepared as a reference for the experimenter in setting up dynamic alignment (Bowker, 2004; Edelstein, 2011; Boone, 2012; Chen, 2012). With this flowchart, the consistency of this research also can be amplified.

3.8.3.2 Subjects' Evaluation

The only way for the prosthetic users to describe comfort is solely by their subjective feedbacks. Verbal feedbacks and users' perception regarding the prosthetics function and satisfaction are normally used by the prosthetist to obtain the best alignment setup. According to Boone et al. (2012), the best alignment setup could be obtained by the positive collaboration between the prosthetist and the users. Based on their study, they have found that the subjects' perceptions of the malalignment were very helpful in coronal/frontal plane and they were able to communicate them effectively.

Questionnaire was one of the media for the amputees to deliver their feedback to the prosthetists. It was also one of the qualitative assessments which were able to improve the prosthetist's understanding and act as a reference for them to get the optimum alignment setup during walking (Condie, 2006). This measure is commonly used by the prosthetists worldwide since the reliability and validity are internationally accepted (Gauthier-Gagnon, 2006);Boone, 2009).

Therefore, in this study, a Subjects' Evaluation Form for the subjects had been prepared as a reference for the prosthetist and the experimenter in dynamic alignment setup (**Appendix F**). The form was similar with the questions in the Prosthesis Alignment Perception Instrument (PAPI) software, a software which is internationally used by the prosthetists to get the feedback from the amputees (Boone, 2012). The questionnaire inside the PAPI software allows the subjects to describe the perception of the prostheses in both sagittal and coronal plane based on the typical questions on how the alignment made them feel when using the prosthesis.

As shown in **Appendix F**, the form was provided with pictures and description. Further verbal explanation was given by the prosthetist to ensure the subjects understand the questions asked. The three evaluations (early stance sagittal dynamic, late stance sagittal dynamic, and coronal dynamic) were regarding the perception during ambulation. From the scale 1 to 10, the subjects mark the scale when they already felt satisfied with their perception towards the prosthetic alignments. The scales 4 to 7 were

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considered satisfying. If the subjects didn't feel any perturbation, they could give marks between 5 and 6.

3.8.3.3 Pain Checklist

According to Schmalz et al. (2002), the optimum alignment setup also important to minimize the energy expenditure and sensational discomfort during walking. The malalignment of the prosthesis will cause skin abrasion due to excessive shear force on the stump that leads to discomfort and pain (Zahedi, 1986). Theoretically, the amputees should be able to give valid perceptions to the alignment perturbations since they can directly feel and respond to the changing of the mechanical effects. This has been proven by Boone et al. (2012) and Kang et al. (2006), which reports the change in interface pressure between the socket and the stump in response to the variation of prosthetic alignment.

Consequently, in this study, a pain checklist had been prepared for the prosthetist and the experimenter as a reference when the subjects state any pain on the residual limb after the alignment setup (**Appendix G**). The checklist was based on the research carried out regarding the correlation between transtibial prosthetic alignment towards shear force on the residual limb (Boone, 2012;Edelstein, 2011;Kang, 2006). Since the pain caused by the malalignment of a prosthesis could lead to the rejection of the prosthesis by the wearer (Zahedi, 1986), the final alignment setup for this research was based on **Appendix G**, regardless of **Appendix E** and **Appendix F** if there was any pain presence.

3.9 Postural Stability Evaluation

Biodex Stability System (BSS; Biodex, Inc., Shirley, NY, USA) is a convenient and reliable system that is able to provide clinical data measurements for postural stability assessment (Testerman, 1999). It has been developed with more advantages and convenient technology in studying postural stability. Besides that, it also has been

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widely used in assessment of patients with ankle instability and arthritis. The system is available for multi-range of people, easy to administer, and simple to interpret (Aydog, 2006; Salsabili, 2011).

The movement pattern of Center of Pressure (CoP) and Center of Motion (CoM) are the essential aspects in dynamic control of a human body to gain static balance (Ku, 2012). CoP is the point of average distribution for total pressure towards the surface of the contact area. In response towards perturbation, the human body is believed will orientates the CoM, which is a virtual point equivalent to total body mass (Hernandez, 2009). By regulating body's position, this response will return the CoM within the base of support (BoS) which is the displacement region for the CoP (Gravante, 2003).

Besides that, postural sway is used as an indicator of the dynamic control. It actually represents the displacement of CoP from the base support. CoP sway is the important parameter in studying human standing posture. The balance of an individual can be assessed by measuring the displacement of CoP which means by getting the Stability Index (SI) (Ku, 2012). In this research, there are three types of Stability Index data collected from the BSS results. They are overall stability index (OSI), anterior-posterior stability index (APSI) and medial-lateral stability index (MLSI).

All subjects underwent bipedal stance test (BLS) for the experiment in order to evaluate the postural balance score under static level. This study implemented the crossover study design. Every subject underwent the same procedures throughout the experiment.

In the experiment, the subjects were standing on the platform with bare feet for both prosthetic and sound legs. The subjects were barefoot because the optimum prosthetic alignment for all of them was previously obtained and set when they were barefoot. Adding the footwear on the prosthesis will change the biomechanics of the

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prosthesis itself, resulting distortion from the optimum alignment setup obtained before.

On the platform, they were asked to stand still and comfortably with their arm crossed over their chest. Their visuals were maintained by looking straight at the monitor. The platform was then unlocked to allow the subjects to place their feet in a comfortable and stable position while simultaneously maintaining the position of a moving pointer at the centre point on the monitor. The platform was then locked, and the subjects were asked to maintain the foot position and the moving pointer at the centre point throughout the static balance test (Figure 3.12). Figure 3.13 shows one of the subjects during the experiment.

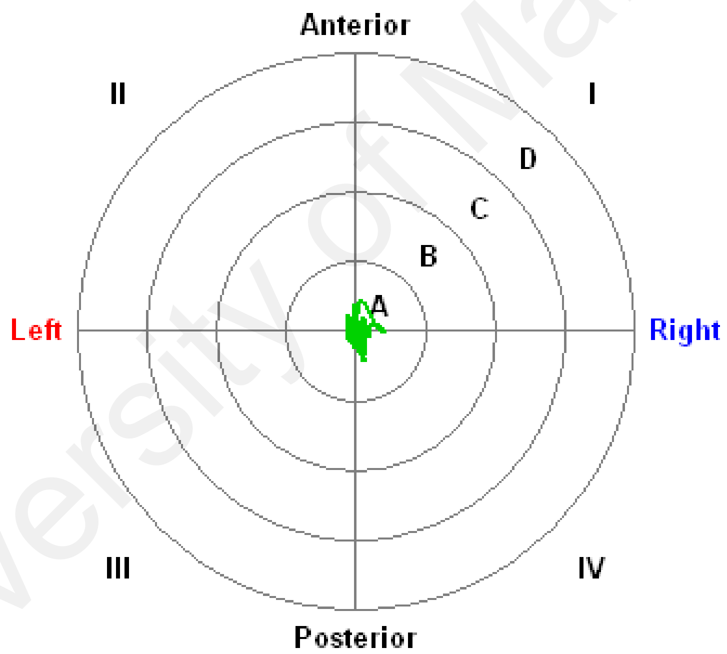

Figure 3.12: The trajectory of CoM displacement from platform's center belong to the subject number three in the third visit

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Figure 3.13: Subject number two in experiment during Visit 1

To ensure the consistency and precision of this study, the subjects were allowed to practice the balance training for one time only so that the learning effect could be minimized (Pincivero, 1995). Any differences between the trials were not related to learning effect. Five successful trials were conducted for each subject with 30 s duration each. The subjects were allowed to rest for 20 s in between the trials by sitting. However, they were instructed not to change their feet position on the platform. The data were then collected and averaged. The handrails attached to the BSS were used to prevent fall in case if the subject loss balance. For a successful trial, handrails should not be used at all.

The three aspects of stability indexes as mentioned before which were the OSI, APSI, and MLSI were measured for the purpose of upright postural stability assessment. The standard deviations (SD) of the CoM displacement from the zero point

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which was the centre of the platform were represented by these three indexes (Arnold, 1998). The units are in degree. In other words, these stability indexes indicate the degree of foot displacement in sagittal and frontal plane motions. For the unstable posture, the stability index reading would be higher in correspond to the greater body movement while lower stability index indicates greater posture stability. The software used to measure the stability indexes was Biodex software (version 3.1; Biodex® Medical System, Shirley, NY, USA). The sampling rate was 20 Hz. These formulas were used by the software to measure the OSI, APSI, and MLSI:

$$\text{OSI} = \frac{\sqrt{\sum(0-Y)^2 + \sum(0-X)^2}}{Number\ of\ samples} \quad (3.1)$$

$$\text{APSI} = \frac{\sqrt{\sum(0-Y)^2}}{Number\ of\ samples} \quad (3.2)$$

$$\text{MLSI} = \frac{\sqrt{\sum(0-X)^2}}{Number\ of\ samples} \quad (3.3)$$

X = total horizontal deviations along the mediolateral axes.

Y = total horizontal deviation along anteroposterior axes.

In this study, x-direction indicated the displacement from horizontal along medial-lateral axes and evaluated as MLSI, while the vertical along anterior-posterior axes was indicated as y-direction and evaluated as APSI. As the Biodex system recorded the foot displacement in both direction, the OSI, APSI, and MLSI were automatically generated based on the equations. The combination of the tilt degree for both anterior-posterior and medial-lateral axes established the OSI score. According to Arnold et al. (1998), OSI is the best balance indicator in measuring overall platform balance.

3.10 Statistical Analysis

The stability indexes were presented as mean and standard deviation (mean±SD). Shapiro-Wilk's test was used to investigate the normality of the data. Based on the test, the collected data in this study was proven to be normally distributed. To determine the occurrence of significant difference in the SI readings between the three visits, the repeated measures analysis of variance (ANOVA) was performed. Meanwhile, Tukey's Honestly Significant Differences test had been used in the post-hoc analysis to determine where the differences occurred. For the degree of stump contracture between the three visits, one-way ANOVA was performed to determine whether the contracture readings were significantly different with each other. The significance level was accepted at $p \leq 0.05$ for both repeated measures ANOVA and one-way ANOVA tests. The statistical analysis was done by using statistical software Minitab Express 1.5.0 (Version 1.5.0, Minitab Inc, Pennsylvania, USA).

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CHAPTER 4: RESULT AND DISCUSSION

Chapter 4 presents the findings and outcomes of this research. It also provides clarification and justification for the results obtained which were made based on the literature and the new findings. In addition, the effectiveness of the research methods and the interventions involved in the research are also discussed.

4.1 Data Analysis

The experiments had been successfully done on 10 out of 14 below knee amputee subjects. It took around two months to finish all the three sessions. The range of activity level among the subjects started from K1 until K3. The mean age among them was 57.2 years old with a standard deviation of 6.25. The selected subjects had fulfilled all the inclusion criteria without any exclusion criteria throughout the experiment as mentioned in the methodology chapter. The demographic data for all the subjects in this experiment are as shown in Table 4.1.

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Table 4.1: Subjects' demographic information

Subject	1	2	3	4	5	6	7	8	9	10	Mean	SD[c]
Sex	Male	Male	Male	Female	Female	Male	Male	Male	Male	Male	n/a	n/a
Age (years)	55	53	50	58	64	51	51	63	68	59	57.2	6.25
Body mass (kg)	64	89	88	82	67	87	58	70	64	77	74.6	11.45
Height (m)	1.71	1.79	1.68	1.62	1.54	1.63	1.69	1.75	1.66	1.60	1.67	0.074
Cause of amputation[a]	D	D	D	D	D	D	D	D	D	D	n/a	n/a
Time (Years)[b]	2	2	2	1	2	3	2	1	4	3	2.2	0.92
Amputation side	Right	Right	Right	Left	Right	Right	Left	Left	Left	Right	n/a	n/a
Activity level (K-Level)	K1	K3	K1	K2	K2	K2	K2	K1	K3	K3	n/a	n/a
Length of stump (m)	0.15	0.18	0.13	0.15	0.20	0.13	0.19	0.19	0.15	0.14	0.16	0.026

[a]D=Diabetes, [b]Years since amputation, [c]Standard deviation

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4.2 Stump Flexion Contracture Analysis

Table 4.2: The degree of stump flexion contracture for all subjects during every visit (n=10).

Subject	1	2	3	4	5	6	7	8	9	10	Mean	SD
Contracture during Visit 1 (^{0})	12	16	15	11	12	21	17	16	11	14	14.5	3.171
Contracture during Visit 2 (^{0})	6	9	10	6	7	14	11	7	5	6	8.1	2.846
Contracture during Visit 3 (^{0})	6	11	10	4	5	13	11	5	5	5	7.5	3.342

***note that the contracture reading during Visit 1 was significantly lower than Visit 2 and Visit 3 ($p \leq 0.05$) while no significant difference between Visit 2 and Visit 3 ($p>0.05$).**

As mentioned in the required criteria list in Chapter 3, the minimum requirement of flexion contracture possession was 10^0, while the maximum was 25^0 for the first session. Based on the Table 4.2, the maximum reading was exhibited by Subject 6 in Visit 1 which was 21^0 while the minimum reading was 11^0, exhibited by Subject 4 and Subject 9. The greatest contracture improvement was achieved by Subject 8. He was able to reduce the flexion contracture by 9^0 which was 40.6% greater than the mean contracture improvement (6.4^0). The mean contracture reading during Visit 2 was significantly lower than Visit 1 ($p<0.0001$) which indicated the good compliance of the subjects throughout this experiment. Besides that, the mean reading of contracture was insignificantly improved by 7.41 % during Visit 3 ($p=0.0839$). Among all the subjects, there was a subject who exhibited a greater reading of flexion contracture during Visit 3 compared to Visit 2. Since the reading was still acceptable based on the required criteria (5^0 less than the reading during Visit 1), the experiment was still valid to proceed.

In this study, stump flexion contracture improvement was necessary for every subject before proceeding to Visit 2. In order to gain the improvement, the interventions of stump splint and stretching exercises had been practiced on the subjects. However, the positive results were only applied for those who complied with the interventions. 10 out of 14 subjects exhibited the contracture improvement according to the required

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criteria which was 5^0 minimum while the rest had failed to do so. The limitation of time was one of the possible causes. The subjects in this study were given two weeks times to achieve the minimal contracture improvement. In fact, several previous researchers who were studying the subjects with knee contracture required more than three months before they could see the significant improvement results, depend on the severity of the cases and subjects' compliance (Finger, 2008;Knoope, 2011).

4.3 Postural Stability Analysis

In an effort to study the biomechanical factors that bring significant influence towards postural stability among amputees, numerous studies had been carried out by the researchers with various conditions which act as manipulated variables while postural stability scores or stability index (SI) as responding variables (Ariffin 2015; Mayer, 2011;Buckley, 2002; Ku, 2012). However, there is still no study related to the correlation between the stump flexion contracture with postural stability among the amputees. Since the stump flexion contracture is one of the most common issues among the transtibial amputees, this study had been conducted to determine whether the limited ROM of stump could possibly affect the postural stability control during quiet standing. The influence of the prosthetic alignment could also be identified as whether it can compensate the limited ROM of the stump by bringing back the standard postural stability as for the standard ROM.

In the current study, Biodex Stability System (BSS) had been used to measure the displacement of foot CoP for both sound and prosthesis legs with different ROM of the stump during quiet standing. The data acquired in this study was postural balance score under static level or in other words, Stability Index (SI). SI represents the Standard Deviation (SD) that assessed the path of CoP sway around zero point from the center of the platform. It consists of Anterior-Posterior Stability Index (APSI), Medial-Lateral Stability Index (MLSI), and Overall Stability Index (OSI), which is the tilt degree combination for both medial-lateral (ML) and anterior-posterior (AP) axes. The postural balance assessment with different ROM of the stump in this study could contribute a vital information in rehabilitation field since stump flexion contracture is one of the biggest issues frequently emerging among the amputees (Knoope, 2011; Boone, 2012; Bowker, 2004). Based on the collected SI data, a standard range of postural stability score for the amputees who have similar characteristics as the subjects in this research also has been obtained, fulfilling the third research objective.

The mean and SD for all three stability indexes (MLSI, APSI, and OSI) and stump flexion contracture during Visit 1, Visit 2, and Visit 3 are as shown in the Table 4.3.

Table 4.3: Mean and standard deviation of stump flexion contracture reading and all stability index (MLSI, APSI, and OSI) for every visit (n=10).

	Visit 1 (Before Contracture Improvement)	**Visit 2 (After Contracture Improvement)**	**Visit 3 (After Contracture Improvement & Alignment Intervention)**
	Mean±SD	**Mean±SD**	**Mean±SD**
Stump Flexion Contracture (^{0})	14.5±3.171	8.1±2.846	7.5±3.136
MLSI (^{0})	0.99±0.67	0.85±0.29	0.73±0.23
APSI (^{0})	0.42[1]±0.27	1.26±0.54	0.57[2]±0.34
OSI (^{0})	1.20±0.71	1.77[3]±0.66	1.09±0.39

***Significant differences between APSI were indicated as [1](Visit 1 vs Visit 2) and [2](Visit 2 vs Visit 3) while between OSI was indicated as [3](Visit 2 vs Visit 3).**

As the data shown in the Table 4.3, during Visit 2, the stability index for anterior-posterior aspect (APSI) was significantly different from the score obtained during Visit 1 and Visit 3 in which $p=0.007$ and $p<0.0001$ respectively. During Visit 2, the ROM of the stumps improved while the prosthetic alignments remain unadjusted. The improvement of ROM in this study was in sagittal plane which refers to the

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improving degree of extension. During quiet standing, both subjects' knees will be in full extending position as they are capable of. With more degree of extension during Visit 2, the previous alignment setup promotes the body's CoM to sway more in sagittal plane compared to the frontal plane. This was because the alignment setup only matched the previous ROM which was before the contracture improvement. The socket flexion and foot dorsiflexion were more than the required angle which led to the excessive shifting of GRF vector posteriorly, promoting knee instability in sagittal plane (Kang, 2006) (Lannon, 2003). Even when the ROM of the stumps during Visit 3 were not much different compared to Visit 2, the alignment setup was adjusted accordingly. Therefore, the socket flexion and ankle dorsiflexion angle were as per required, avoiding the issue of shifting GRF vector from normal. Besides explaining the significant difference in the reading of APSI between Visit 2 with both Visit 1 and Visit 3, this also could be the reason of the higher APSI reading compared to MLSI in Visit 2 itself.

Meanwhile, the OSI readings in Visit 2 was significantly higher than Visit 3 ($p<0.0001$). It was also found that the OSI reading increased by 47.5% in Visit 2 compared to Visit 1. However, the increasing percentage was proven insignificant ($p=0.0643$). This finding may suggest the importance of prosthetic alignment with respect to the ROM of the knee joint. The improvement of knee ROM has been proven less effective for the amputees to gain more postural balance if the prosthetic alignment was not readjusted accordingly. This assumption is supported by the low OSI reading during Visit 3. Meanwhile, even the stump flexion contracture reading was significantly different between Visit 1 and Visit 3, the insignificant difference of OSI between both Visit ($p=0.344$) may also suggest that the adaptation of prosthetic alignment with the knee ROM is vital for an amputee to maximize the postural balance even there is a limitation in ROM.

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For the medial-lateral aspect of postural stability index (MLSI), the reading obtained in Visit 1 was 16.5% and 35.6% higher compared to Visit 2 and Visit 3 respectively. However, the differences were not significant with p=0.3022 between Visit 1 and Visit 2 and p=0.1573 between Visit 1 and Visit 3. This finding is related with the first objective, which is to evaluate the postural stability control among the below knee prosthesis users at certain degree of stump flexion contracture. It shows that at the range from $7.5^{o} \pm 3.34^{o}$ to $14.5^{o} \pm 3.17^{o}$ flexion contracture, the medial-lateral postural stability of the amputees during quiet standing was not affected by the contracture itself. Despite of the improper alignment adjustment in Visit 2, the MLSI reading in other visits was still insignificantly different with each other. This is related with the second objective, which is to determine the effect of the prosthetic alignment accommodation towards postural stability control. Within the contracture reading as mentioned, the postural stability control in medial-lateral aspect was not affected by the alignment setup, whether it was adjusted accordingly or not according to the contracture condition.

However, the readings of MLSI exhibited by the subjects was significantly and insignificantly higher than APSI during Visit 1 (p=0.0073) and Visit 3 (p=0.0582) respectively. These findings were in agreement with Blaszczyk et al. (2007), who claimed that the postural instability is usually associated with the body sway in lateral aspect. Trunk and hip are the segments responsible for controlling balance in medial-lateral direction while the medial-lateral motion towards lateral direction is generated by pelvis segment (Shumway-Cook, 2007). In addition, based on Mayer et al. (2011) findings, the CoP sway was more prominent on ML axes compared to AP axes among the lower limb amputees. It was due to the reaction of both sides of hip joints to stabilize the body CoM as a compensation response to the loss of an ankle joint (Horak, 2006; Buckley, 2002). This is in conjunction with the lack of active ankle control of the

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prosthetic limb (Curtze, 2012). In addition, the lower limb amputees also commonly have a problem with weight shifting in effort to maintain the postural stability in medial-lateral aspect (Isakov, 1992). Therefore, the higher reading of MLSI compared to APSI for both Visit 1 and Visit 3 result was expected. However, it may not be applicable in Visit 2 since there was a significant GRF vector shifting in anterior-posterior aspect due to the improper alignment set up.

All the findings that relates the postural stability score (SI) with the stump flexion contracture condition and prosthetic alignment have provided clarification and justification for the first and second objectives of this study.

Meanwhile, previous research has found that the orientation of body plays a significant role in regaining postural balance (Horak, 2006). It could be more crucial as the orientation involved is at the lower segment of the body which refers to the prosthetic alignment with respect to ROM of the stump for this study. Thus, it is expected that the change in stump ROM or the alignment setup will bring a difference in postural stability index during quiet standing. This is because the extension angle of the stump and the prosthetic alignment during quiet standing will determine the position of Ground Reaction Force (GRF) vector. As the line vector falls more forward, the knee will be more stable in extended condition (Edelstein, 2011;Bowker, 2004). This will significantly influence the CoP sway in AP axis.

As per required in the third objective of the study, with the significant number of subjects involved (n=10) and narrow criteria regarding age, activity level, type of prosthesis, and degree of stump flexion contracture, the SI obtained in this study can be referred as a standard value for the amputee population who have similar criteria. However, the index reading from Visit 2 was not included in the suggested standard range value since the prosthetic alignment deviated from the condition of the stumps. Only Visit 1 and Visit 3 were referred. Figure 4.1, 4.2, and 4.3 represent the suggested

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standard range of MLSI, APSI, and OSI respectively for the amputee population with the same criteria in this study. As shown in the Table 4.3, these standard range of the SI cover the amputees with the range of the stump flexion contracture at $7.5^0 \pm 3.34^0$ and $14.5^0 \pm 3.17^0$. The maximum value of the suggested range in every graph is based on the highest product of addition between the mean and the standard deviation while the lowest line of the range was the lowest subtraction product of the standard deviation from the mean. The suggested ranges of the stability indexes are as the shaded region in the figures.

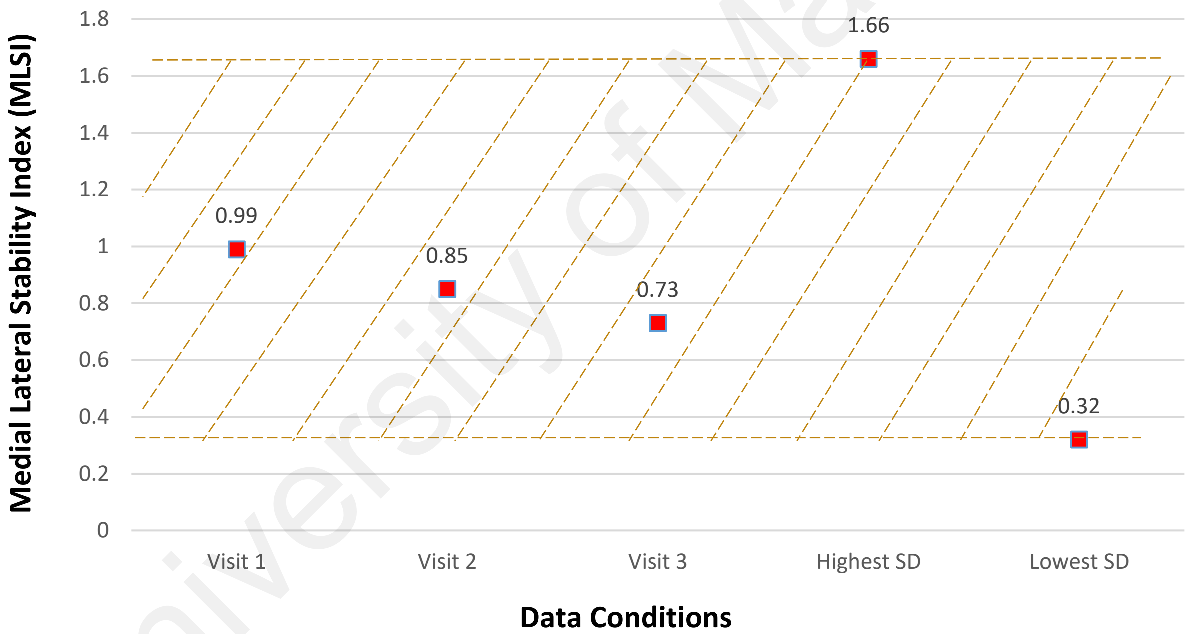

Figure 4.1: Suggested standard range of MLSI

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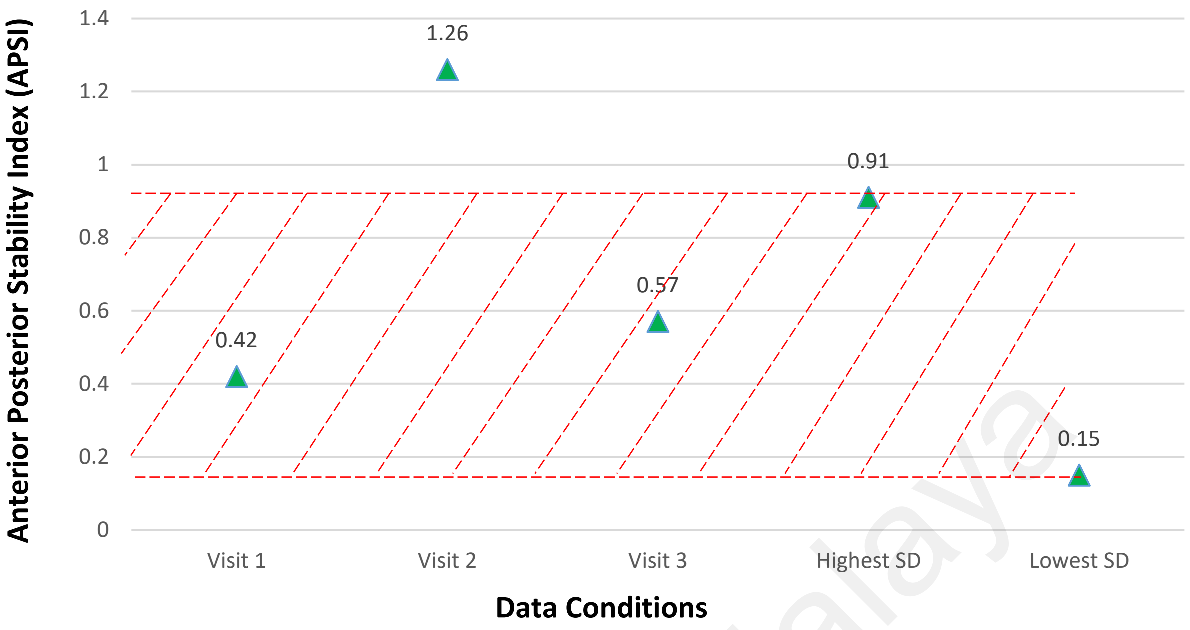

Figure 4.2: Suggested standard range of APSI

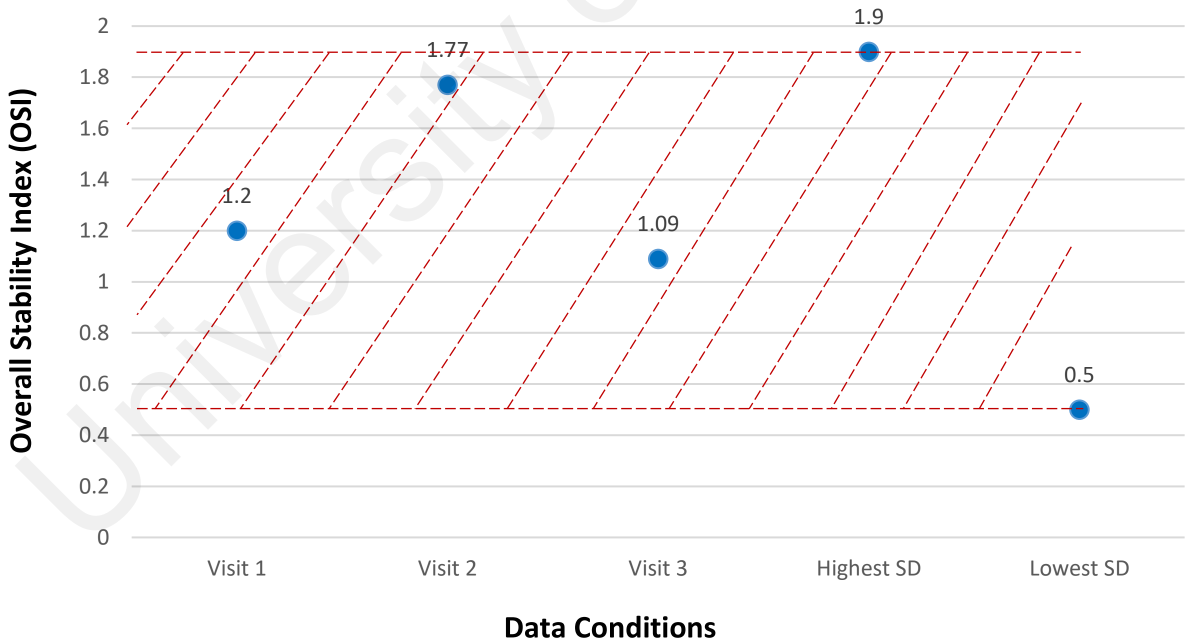

Figure 4.3: Suggested standard range of OSI

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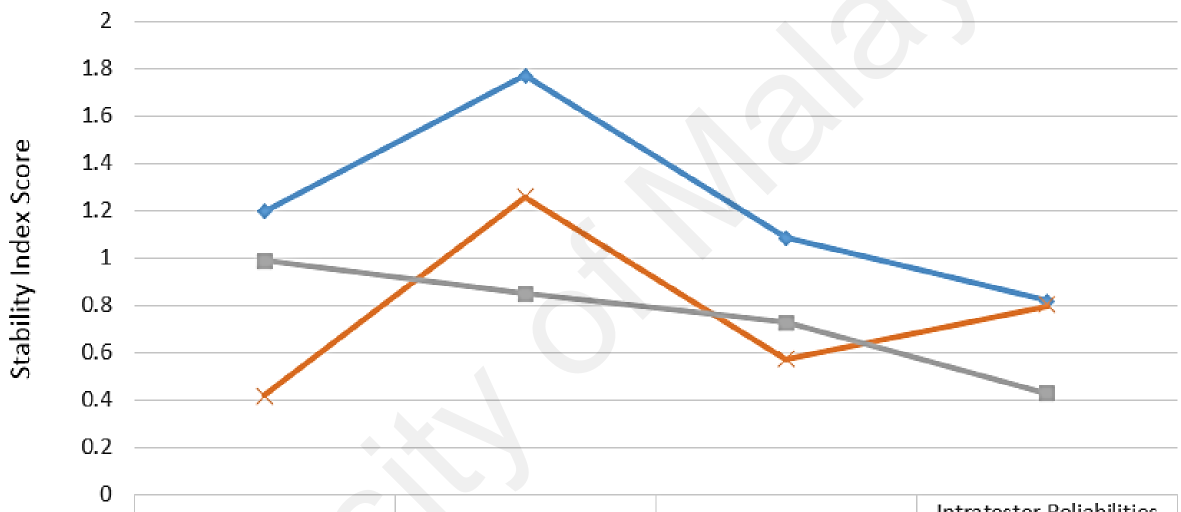
In order to study the normal pattern of postural stability during quiet standing, Arnold and Schmitz (1998) had carried out a research towards 19 healthy subjects with no history of lower limb injury. The study was also conducted by using BSS (Arnold, 1998). As the outcome of the research, they have found the intratester reliabilities value for APSI, MLSI, and OSI which were 0.80, 0.43, and 0.82 respectively. Figure 4.4 shows the stability indexes obtained from their research plotted together with the stability index readings from the current research.



	Before Contracture Improvement (Visit 1)	After Contracture Improvement (Visit 2)	After Alignmnent Intervention (Visit 3)	Intratester Reliabilities by Arnold and Schmitz (1998)
OSI	1.2	1.77	1.09	0.82
APSI	0.42	1.26	0.57	0.8
MLSI	0.99	0.85	0.73	0.43

Figure 4.4: Stability indexes (APSI, MLSI, OSI) in Visit 1, Visit 2, and Visit 3 with the intratester reliabilities value found by Arnold and Schmitz (1998)

The intratester reliabilities value show the smallest SI reading in the medial-lateral aspect which indicates more stability compared to the amputee subjects in this research. Same goes for the OSI value but the difference was not significant. This is due to the high reading of APSI since it is accounting 95% of the OSI variance and closely related to the OSI reading compared to MLSI (Arnold, 1998).

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Since the intratester reliability values of the postural stability score found by Arnold and Schmitz (1998) were based on the normal healthy subjects without any lower-limb injuries history, it was expected that all the SI readings would be lower than those three visits. However, the outcomes of postural stability test are subjective. They could be affected by several other factors such as age, BMI, training effect, and body structure. Furthermore, the healthy and amputee subjects have different lower limbs structure and control which is believed to be the vital factor of the SI variation when compared.

The study about postural control has been widely done by researchers. Biomechanical factors are the most vital components that should be taken into account in postural control study. According to Chiari et al. (2002), there are several biomechanical factors that have been proven influencing postural stability control such as body weight, height, the base of support (BoS), foot width, and the opening angle of the feet/out-toing angle. These findings suggested that the prosthetic components and alignment setup should be considered as the vital biomechanical factors in any postural stability study among lower limb amputees. Therefore, in this study, the feet opening angle was adjusted according to the standard alignment setup with the agreement from the subjects during alignment adjustment process. This will provide maximum stability to the subjects when using the prosthesis (Boone, 2012).

To maximize the consistency of the study, the type of prosthetic foot used by the subjects in this research was fixed to Solid Ankle Cushioning Heel (SACH) foot. This was due to the potential effect caused by the prosthetic ankle activities of different type of foot towards postural stability control (Ariffin, 2015). Besides that, the experiment had been carried out on the same particular day and time for all the three sessions for each subject to ensure the efficiency and consistency of the study. Different daily physical activities might be carried out on the different days. Therefore, the related

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muscles conditions, focus, and consciousness should be the same as much as possible for those three sessions (Jorgensen, 2012; Ku, 2014).

Minimum change of body weight also had become one of the vital conditions before proceeding with the following sessions. In this study, the weight change between the sessions was limited to 3kg. It was due to the finding that the change in body weight would cause the change in postural stability capability. The reduction in body weight was proven to improve the postural control (Teasdale, 2007). Besides that, the falling risk would be greater as the body weight increase which indicates poor stability control (Corbeil, 2001).

In the aspect of age, the subjects' age in this study was limited from 50 to 68 years old and the amputation cause for all of them was diabetes mellitus. The selection based on these criteria was made on purpose in order to narrow down the optimum dynamic alignment setup so that the outcomes would be more consistent (Zahedi, 1986). It was because Zahedi et al. (1986) have found that the wide range of alignments could satisfy the youngster subjects and those alignments can be considered as optimum alignments in clinical situation which means not only accepted by the patients, but also satisfy the prosthetist judgment. Furthermore, according to McClenaghan et al. (1996), there was a significant difference in postural stability control in medial-lateral aspect between the elderly and young adult population. In order to narrow down the variation of the results obtained, while also avoiding high standard deviation, the findings from the literature were referred and studied. As a result, the age of the subjects in the criteria had been limited from 50 to 75 years old.

Prior to the experiments, the subjects were allowed to do balance training using Biodex Stability System once. According to Ku et al. (2012), proprioception and vestibular equilibrium might be influenced by the learning process. Therefore, the results obtained later might be affected. However, a practice trial would be crucial to

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ensure the understanding of the subjects about the experimental procedure. To minimize the influence of the learning factor, the test was performed three times per session so that the data collected would be standardized and more accurate (Ku, 2012).

Among of the strengths of this study were the selection of the subjects and the devices. They were carefully chosen and set based on fixed criteria in order to ensure the consistency of the experiments and the accuracy of the result. As mentioned, a subject who exceeded the weight change limit was not being recalled for the next session. The prosthetic foot used by the subjects were also fixed to Solid Ankle Cushioning Heel (SACH) type as there was evidence that revealed the contribution of different prosthetic foot types towards SI (Ariffin, 2015). Meanwhile, in the prosthetic alignment aspect, it was set up by a single experimenter, under the supervision of a three-years experienced Certified Prosthetist and Orthotist (CPO). Besides using his experience, the adjustments were also made based on the published and acknowledged literature (Zahedi, 1986) (Bowker, 2004) (Edelstein, 2011). Therefore, the accuracy and consistency in term of the prosthetics alignment setup in this study were optimized.

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CHAPTER 5: CONCLUSION & RECOMMENDATION

Chapter 5 summarizes the important findings in this research, especially those which are related with the research objectives. Hence, the status of the objectives will be known. Besides result summarization, this chapter also includes the limitation of study and the recommendations that could improve future studies and rehabilitation progress among below knee amputee population.

5.1 Conclusion

This study has proven that the postural stability index for the below-knee prosthesis users is not affected by the acceptable stump flexion contracture condition if the prosthetic alignment is properly adjusted. In this study, the acceptable range of the contracture refers from 0° to $14.5^{\circ} \pm 3.171^{\circ}$ maximum. Even if the range is not fully covered from the readings obtained by the subjects, there is no significant scientific prove or reason that could cause the postural stability control to be compromised if the contracture reading is below than the maximum value. Therefore, the first research objective is achieved.

However, when the prosthetic alignment was not set according to the ROM of the stump, the postural stability control in anterior-posterior aspect was compromised. The improvement in ROM of the stump is proven to be ineffective to gain more postural stability control. In addition, the improper prosthetic alignment also has worsened the APSI readings as shown during Visit 2, even with the improvised stump ROM. Meanwhile, based on the APSI reading obtained from Visit 1, this study has proven that the prosthetic alignment intervention is able to compensate the adverse effect of the stump flexion contracture towards postural stability control during quiet standing. By these findings, the second research objective is achieved.

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The aspect that is most affected by the improper prosthetic alignment according to the stump flexion contracture condition is sagittal plane (anterior-posterior aspect). This study has proven that within the acceptable range of contracture condition, the postural stability control in the frontal plane (medial-lateral aspect) is not significantly affected.

This study has also lead to the finding of the standard range of SI for the amputee population who have similar criteria. It could be used as a reference in future studies which is related to the postural stability control among the below knee amputees. Therefore, the third research objective is achieved.

Meanwhile, in postural stability control study, the biomechanical factors such as base of support (BoS), height, body weight, out toing angle, and foot width also should be considered as they have been proven to influence the stability index readings.

Regarding the contracture improvement methods, this study also has proven the effectiveness of the stretching exercises and the intervention of stump splint to improve the degree of the stump flexion contracture. The amputees themselves, however, need to comply and be consistent in the efforts to get the positive result. Besides that, the time needed for every amputee to improve the flexion contracture also might be vary. In this study, two weeks can be considered as still short for the subjects to reduce the flexion contracture as there were previous studies which shown that more than three months is needed to see the significant improvement in the results. However, it was still possible for this study to achieve the flexion contracture improvement target as the minimum improvement required was only 5^{0}.

5.2 Limitation of Study

The limitation of the subjects' criteria such as the contracture improvement in this study causes a restraint to the collected data. It became more prominent as the

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subjects were also from the same geographical area and most of them get the rehabilitation treatment from the same hospital. Therefore, the results' variation is narrow.

Finding a subject with stump flexion contracture condition who already has a prosthesis was quite a big challenge in this study. This is because most of the amputees who already have the prosthesis are in well rehabilitation progress, which means the stump is in the most efficient state and condition. For those who are in a slow rehabilitation progress, they were not recommended to have a prosthesis yet until they achieve the required rehabilitation state and condition.

5.3 Future Recommendation

The limitation of this study towards the degree of stump flexion contracture reduction achievement should be improved in future research. This is because, even when this study has led to some new findings, 5^0 of additional stump extension might still not be enough to look into more postural stability differences. Furthermore, certain errors could probably happen when measuring the contracture angle such as different positioning of goniometer and variation of effort when fully extending the stump. Even 1^0 or 2^0 of error, it could be considered as a large percentage of the degree in ROM improvement. Therefore, in future research, a higher degree of contracture improvement should be applied in the required criteria and its effect on postural stability index should be explored more. The subjects should also be recruited from different geographical areas and different treatment hospital so that there will be more varieties in the findings.

In the rehabilitation aspect, it is highly recommended even for the below knee amputees with stump flexion contracture condition to continue the rehabilitation treatment and programme with the prosthesis as long as the contracture is within the acceptable range. This is because the current findings have proven that the prosthetic alignment was still able to optimize the postural stability control if the contracture was still within the range. The inhibition from having the prosthesis will only demotivates the amputees to have an active lifestyle. However, the rehabilitation specialist and therapist should monitor the amputees consistently so that the rehabilitation progress will go as accordingly.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

The research in this thesis has led to the submissions of the following:

Journal

1. **M.F. Ghazali,** N.A. Abd Razak, N.A. Abu Osman and H. Gholizadeh. Awareness, potential factors, and related post amputation cares of stump flexion contracture among transtibial amputees. Turkish Journal of Physical Medicine And Rehabilitation (formerly published as Türkiye Fiziksel Tıp ve Rehabilitasyon Dergis). (Accepted)
2. **M.F Ghazali**, N.A. Abd Razak, H. Gholizadeh and N.A. Abu Osman. Influence of Stump Flexion Contracture towards Postural Stability among Below Knee Prosthesis Users. Technology and HealthCare. (Under Review)
3. **M.F Ghazali**, N.A. Abd Razak, H. Gholizadeh and N.A. Abu Osman. Post amputation cares of stump flexion contracture among transtibial amputees. Journal of Healthcare Engineering. (Under Review)

Conference

1. **M.F. Ghazali**, N.A. Abd Razak, N.A. Abu Osman and H. Gholizadeh. Effect of Stump Flexion Contracture with and without Prosthetic Alignment Intervention towards Postural Stability among Transtibial Prosthesis Users. International Technical Postgraduate Conference (Tech-Post), Faculty of Engineering, University of Malaya, Kuala Lumpur.

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