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Effect of stump flexion contracture with and without prosthetic alignment intervention towards postural stability among transtibial prosthesis users

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Abstract. Knee flexion contracture on a stump side is a phenomenon in which the stump cannot move in normal range of motion (ROM) or cannot be fully extended. This study has 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 transtibial 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). Higher reading of the index indicates lesser stability. Each of the subjects had been tested in three different sessions that 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 compared to Visit 1 and Visit 3. The OSI during Visit 2 was also found significantly higher compared to Visit 3. In Visit 2, the degree of contracture was significantly improved with 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 knee. This finding explained that the alignment set up based on the adaptation with the stump's ROM can contribute positively in maintaining postural stability.

1. Background

Knee contracture or flexion contracture on the stump is one of the common problems occurred among the below knee amputees. It refers to the situation in which the patient cannot fully straighten the knee or in other words, the range of motion of the joint is limited from normal [1]. It 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 [2]. The significant characteristics of contracture are limitation of joint mobility and increasing resistance of the joint to passive ROM which is the movement of joint applied by external power, either by someone or by exercise machine [3]. 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 [4].

In overcoming the contracture, most of the efforts are focused on treating the contracture itself, decreasing the contracture angle or prevent it from becoming worse. For transtibial amputation cases, the amputees are advised to avoid placing pillow under the knee. An extension board is commonly used to be placed across the back of the knee joint to ensure the extension position [5]. Besides, stretching the soft tissues which can be done actively or passively is also very helpful to overcome the contracture.

Active stretching means the amputee actively moves the joint in full range of motion. Meanwhile, passive stretching refers to the using of a splint or orthotic device to forcing the joint in extended position [6].

For an amputee who is going to proceed with a prosthesis, the presence of stump 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 while using the prosthesis [6]. However, 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 [4]. The prosthetic alignment can be defined as the positioning of the socket in relation with the other components of the prosthesis such as ankle joint and shank tube [7]. Generally, good alignment of a prosthesis will contribute to an energy efficient and smooth gait pattern. [8]. For the amputees with stump contracture, the alignment that should be concerned is the sagittal plane. It is the anteroposterior positioning of the socket with regard to the foot. 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 [9].

Prosthetic alignment is also vital in retaining postural balance either during walking or quiet standing [10]. 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, human body is believed to orientate the CoM, which is a virtual point equivalent to total body mass [11][12]. 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 [13]. Indeed, balance of an individual can be assessed by measuring the displacement of CoP, by getting the Stability Index (SI). It is a standard deviation reading that assesses the path of sway around the zero point from the center of the platform. The unit is in degree. Therefore, it indicates the degree of foot displacement in sagittal and frontal plane motions [14]. SI which consists of OSI, APSI, and MLSI are measured by BSS. BSS has been developed with advantages and is a convenient technology in studying postural stability. The system is available for multi-range of people, easy to administer, and simple to interpret [15][16].

There were a lot of research had been done in order to study on the postural control during quiet standing among amputees. Ku et al. had done a systematic review regarding the factors that contributed 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 was asymmetry in body weight distribution between the sound and the artificial legs [17]. Katch et al. and Salsabili et al. had proven the 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 [16][18]. According to Colne et al., increase in BMI could possibly reduce the ability of the muscles to generate sufficient force in order to control the CoM displacement [19]. Another potential factor that was affecting postural balance was age. The elderly population had been found to exhibit greater postural sway [17].

In rehabilitation process, stump contracture is one of the major inhibitors for an amputee to acquire a prosthesis. It has been found that 10º is the maximum amount of stump contracture for the amputee to possess a great walking ability. With the degree more than that, 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 while making the prosthesis such as alignment and components [4][6]. However, there is still no study conducted regarding the influence of prosthesis alignment intervention towards the stump contracture effect. Therefore, in this study, the postural stability of below knee prosthesis users during quiet standing was evaluated at different degrees of stump contracture, with and without the intervention of prosthesis alignment adjustment. The study was carried out at Motion Analysis Laboratory & Centre for Prosthetics and Orthotics Engineering, University of Malaya. Two of the researchers are the prosthetist with at least three years experienced in handling amputees. The tests were conducted by using

BSS which also provides the stability index readings for both medial-lateral and anterior-posterior aspect (MLSI and APSI) and overall stability index (OSI) which was the combination of these two. Every subject (n=10) underwent the same tests for three different sessions (Visit 1, Visit 2, and Visit 3). The ROM of stump or prosthetic alignment were varied accordingly for each session. In Visit 1, the tests were conducted with the existence of stump contracture and alignment readjustment according to the standard by the researcher. Visit 2 would be proceeded when the subjects had achieved at least 5^0 of contracture improvement after the intervention of therapies and proper stump positioning without alignment readjustment. Meanwhile, the tests with prosthesis alignment readjustment according to the improvised ROM of stump were then conducted in Visit 3. Those three stability index readings, APSI, MLSI, and OSI obtained for every session were collected and compared. Thus, the influence of ROM of stump with and without prosthetic alignment intervention towards the amputees' postural stability during quiet standing can be determined.

2. Methodology

2.1. Ethics Approval and Consent
The experimental protocol for this work was approved by Ministry of Health Medical Research Ethics Committee (MREC), Malaysia. Written informed consent was granted by the participants from the authors for the publication. Approval ID: NMRR-16-2106-32880 (IIR). One registered prosthetist fabricated all the prostheses to avoid alterations due to manufacturing, alignment and fitting. All the procedure of socket making and fitting involves the Certified Prosthetics and Orthotics (CPO) which had been recognized by International Society of Prosthetics and Orthotics (ISPO).

2.2. Subjects Recruitment
This study was conducted on 10 subjects who fulfilled the required criteria:
Unilateral transtibial amputee.
1) The age is from 50 to 75 years old
2) Possession of stump contracture from 10º to 25º.
3) Good compliance in effort of reducing knee contracture. The minimum amount of stump contracture reduction before proceed with the second session is 5º.
4) Able to communicate individual perception regarding the prosthetic alignment.
5) The subjects are using the same endoskeletal prosthetic system, PTB socket with pelite liner, and SACH foot.
6) Minimum change of body weight throughout the experimental period. The maximum acceptable amount of change is 3kg.
7) Able to stand using the prosthesis independently.
8) Absence of any wound or injury on the residual limb.
9) Fulfil all the requirements listed above. The failure of a subject to fulfil any of the requirement will end up with disqualification.

2.3. Instrumentation
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 [20]. In this study, the subjects had been tested by using BSS machine in order to measure the stability index. It consists of a screen monitor which acts as a functional display for setting and controlling purposes. It also has a circular platform for a subject to stand in order to measure the displacement of CoP.

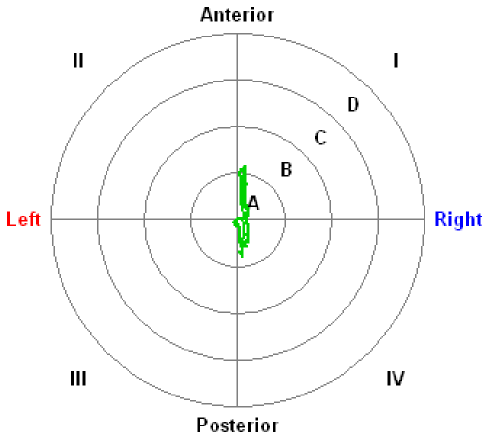

Figure 1. The displacement of CoP of a subject from the platform centre.

The software used in BSS machine to measure the stability indexes was Biodex software (version 3.1; Biodex® Medical System, Shirley, NY, USA). There were three aspects of stability indexes measured for the purpose of upright postural stability assessment which were OSI, APSI, and MLSI. The standard deviations (SD) of the CoM displacement from the zero point which was the centre of platform were presented by these three indexes [21]. The units were in degree. In other words, these stability index indicated the degree of feet displacement in sagittal and frontal plane motions. For the unstable posture, the stability index reading will be higher in correspond to the greater body movements while lower stability index indicated greater posture stability. The sampling rate was 20Hz.

2.4. Experimental Protocol

In this research, every subject underwent the experiment for three sessions (Visit 1, Visit 2, and Visit 3). For every session, the subjects were given a briefing about the experimental procedure and purpose so that they could easily cooperate throughout the experiment. Before the arrival of the subjects, the lab and the equipments were well prepared and the BSS was tested in order to make sure it was functional.

In Visit 1, demographic information especially related to amputation background were measured and recorded. In order to measure stump contracture angle, goniometer was used. The subject was asked to extend the knee as much as possible while the goniometer was placed at the mid patellar level laterally over the knee. The upper arms of the goniometer was pointed towards the greater trochanter while the lower arm was aligned parallel to the tibial bone.

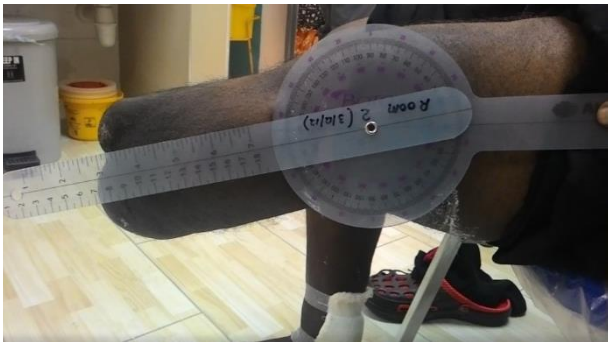

Figure 2. Positioning of goniometer during measuring knee contracture angle.

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Before the experiment started, the prosthetic alignment was checked again by the researcher according to the standard alignment set up procedure even when the subject was already satisfied with the previous alignment. This was to ensure the consistency of the experiment by providing the optimum alignment set up task to a single researcher with the same procedure and references. After the completion of the prosthesis aliment set up, the subject was allowed to walk around the lab with the prosthesis in order to get used to the new alignment setup. When the subject was ready, the postural stability experiment then started. All the subjects undergone bipedic stance test (BLS) for the experiment in order to evaluate the postural balance score under static level. This study used cross over study design at which all the subjects underwent the same procedures. In the experiment, the subjects were standing on the round platform of BSS with bare feet for both prosthesis and sound legs. They were asked to stand comfortably still with their arms crossed over their chest. The opening angle and heel placement of their feet were recorded to ensure the consistency throughout the experiments.

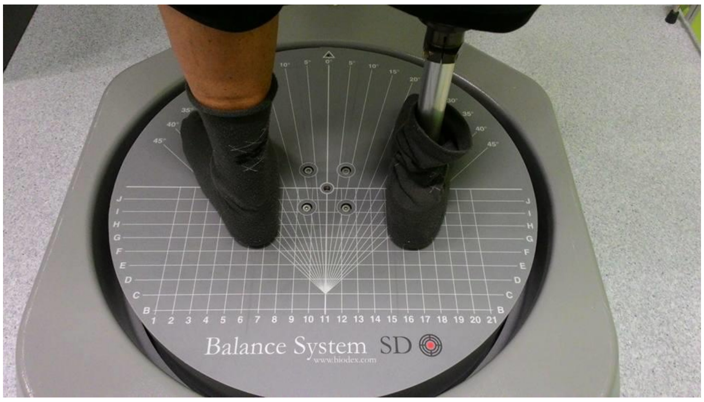

Figure 3. The comfortable feet position of a subject on the BSS platform.

Their visual were maintained by looking straight ahead at the screen monitor. During the postural stability test, the subjects were asked to place their feet in comfortable and stable position on the BSS platform while simultaneously maintained the position of a moving pointer at the center point on the screen monitor. The pointer was moving according to the displacement of CoP. To ensure the consistency and precision of this study, the subjects were allowed to practice the balance training once so that the learning effect could be minimized. Therefore, the difference between the trials would not be related to the learning effect. Three successful trials were conducted for each subject with 20 seconds duration each. The subjects were allowed to rest for 20 seconds in between the trials. The stability index readings were calculated and averaged by Biodex software. The handrails attached on the BSS were only being used to prevent falling in case if the subject lost balance. For a successful trial, handrails should not be used at all.

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Figure 4. A subject during experiment

The results and data obtained were then recorded. After the experiment, a stump contracture splint was given to every subject together with the exercise list in order to reduce the stump contracture. The subjects were advised to wear the knee contracture splint all the time as when the prosthesis was not used while the exercise list should be done at least two sessions per day. The next session (Visit 2) was conducted at least on the next four weeks, based on the knee contracture improvement (5º minimum).

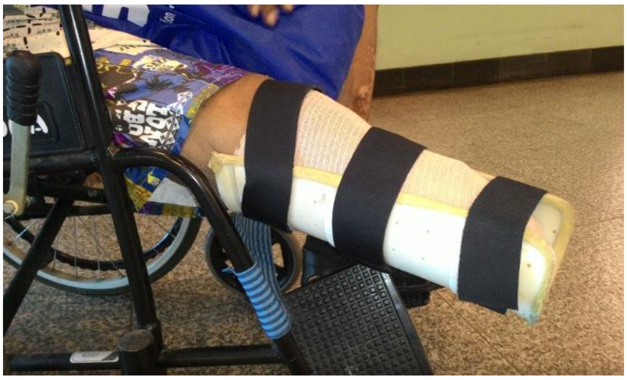

Figure 5. A subject was wearing stump splint after completing the first session experiment.

In Visit 2, the subject's body weight was measured again to ensure there was no significant difference with the reading during Visit 1 (less than 3kg difference). The angle of stump contracture was also measured again and recorded. The experiment would only be proceeded as the stump contracture improved with at least 5º. The same postural stability test as in Visit 1 was then carried out. Upon the completion of the experiment and all three stability index were obtained, the alignment of the prosthesis was adjusted again starting from static to dynamic alignment according to the improvised stump contracture angle. The next session (Visit 3) was then carried out on the following week. The purpose was to obtain the stability index readings when the subject already get used to the new alignment setup and gained full control of it.

During Visit 3, the subjects' body weight and knee contracture angle were measured again in order to ensure no significant changes. The postural stability test was then carried out as in Visit 1 and Visit 2. The OSI, MLSI, and APSI were then recorded and tabulated together with the readings obtained in the previous sessions.

2.5. Prosthetic Alignment

For transtibial prosthetic alignment setting, there were two parts that could be adjusted. Those were socket adaptor and foot adaptor. The alignment of a prosthesis was done according to two standard procedures, starting from static alignment and followed by dynamic alignment. In static alignment, the adjustment was made when the subjects wore the prosthesis and in standing position [22]. This alignment setting was based on the researcher's observation when the subjects were standing and in respond to their comments [7]. Proper alignment was determined based on the consideration of the anteroposterior and mediolateral positioning of socket and foot, prosthesis height, and foot rotation [4].

Dynamic alignment is more subjective compared to the static alignment. The researcher set up the alignment based on the observation on the subjects using prosthesis during walking. Dynamic alignment setting was also made based on the respond to the subjects' comments. There were two standard guides which had been used by the researcher to get the optimum dynamic alignment:

2.5.1. Prosthetist Judgment. The judgment was made based on the knowledge of the causes of gait deviation, experience, understanding of the loading concept on the stump, and the subjects' feedbacks [23].

*2.5.2. Subjects' Evaluation. T*he researcher referred to the verbal feedbacks and subjects' perception regarding the prosthetic function and satisfaction in order to obtain the optimum alignment. The subjects were asked to describe perception of the prostheses in both sagittal and coronal plane based on their feelings when using the prostheses. Further verbal explanation were given by the researcher to ensure the subjects' understanding with the perception should be given by them. The evaluations regarding the perception during ambulation were made in three aspects. Those were early stance sagittal dynamic, late stance sagittal dynamic, and coronal dynamic.

2.6. 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 normally distributed. In order to determine the occurrence of significant difference of 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, paired t-test was performed to determine whether the contracture readings for were significantly different with each other. This was because the population of samples were correlated with each other. The significance level was accepted at $p \leq 0.05$ for both ANOVA and paired t-test analysis. The statistical analysis was done by using statistical software Minitab Express 1.5.0 (Version 1.5.0, Minitab Inc, Pennsylvania, USA).

3. Results

The experiments had been successfully done toward 10 below knee amputee subjects in between eight weeks period. The range of activity level among the subjects was started from K1 until K3. The mean of age among them was 57.2 years old with standard deviation of 6.25. All of them were using their own prosthesis along the experiments. The prosthetic alignment setting was redo in Visit 1 by one of the researchers who is a certified prosthetist in order to maximize the consistency of the experiments. The selected subjects were fulfilled all the required criteria as mentioned in Methodology. The demographic data for all the subjects in this experiment are as shown in Table 1.

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Table 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		
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		
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		
Activity level (K-Level)	K1	K3	K1	K2	K2	K2	K2	K1	K3	K3		
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

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

Table 2. Mean and standard deviation of stump contracture, MLSI, APSI, and OSI.

	Visit 1	**Visit 2**	**Visit 3**
	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 difference 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).

Based on the result of repeated measures ANOVA, during Visit 2, the stability index for anterior-posterior aspect (APSI) was significantly different from the index obtained during Visit 1 and Visit 3 in which p=0.007 and p<0.0001 respectively. Similarly for OSI between Visit 2 and Visit 3, based on the post hoc test, the index reading obtained in Visit 2 was significantly higher than Visit 3 (p<0.0001). Meanwhile, it has been found that the OSI reading was increased by 47.5% in Visit 2 compared to Visit 1. However, the increasing percentage was proven insignificant (p=0.0643). 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. The stump contracture readings for all the subjects from Visit 1 until Visit 3 are as shown in Table 3.

Table 3: The degree of stump flexion contracture of all subjects for every session (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≤0.05) while no significant difference between Visit 2 and Visit 3 (p>0.05).

As mentioned in the required criteria list, the minimum requirement of flexion contracture possession was 10^0 while the maximum was 25^0 for the first session. In Visit 1, the maximum reading was exhibited by Subject 6 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). Based on paired t-test statistical analysis, the mean contracture reading during Visit 2 was significantly lower than Visit 1 (p<0.0001) which indicates the good commitment 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 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 be proceeded.

4. Discussion

In effort of studying biomechanical factors that bring significant influence towards postural stability among amputees, numerous studies has 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 [14][24][25][26]. However, there is still no study regarding the correlation between below knee stump contracture with postural stability among the amputees. Since the stump contracture is one of the most common issues among the transtibial amputees, this study had been conducted to investigate the correlation between ROM of the stump with postural stability while using the prosthesis, with and without the intervention of alignment setting. The aim of this study was to determine whether the limited ROM of stump could possibly affect the postural stability control during quiet standing among the below knee amputees. The influence of the prosthetic alignment also could be identified whether it can compensates the limited ROM of the stump by bringing back the standard postural stability as for the standard ROM. The findings of this research would be very helpful to the rehabilitation professionals and amputees themselves for the rehabilitation programme.

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., there are several biomechanical factors that had been proven influencing postural stability control such as body weight, height, base of support (BoS), foot width, and opening angle of the feet/out-toing angle [10]. These findings suggested that the prosthetic components and alignment setting 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 were adjusted according to the standard alignment setting with the agreement from the subjects during alignment adjustment process. This will provide maximum stability to the subjects when using the prosthesis [27].

In order to maximize the consistency of the study, the type of prosthetic foot used by the subjects in this research were 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 [24]. Besides that, the experiment had been carried out on the same day and at the same time for all three sessions for every 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 muscles conditions, focus, and consciousness should be the same as much as possible for those three sessions [17, 28].

In this study, stump contracture improvement was necessary for every subject before being proceeded to Visit 2. In order to gain the improvement, the interventions of stump splint and stretching exercises had been implemented to the subjects. However, the positive results were only applied for those who were comply with the interventions. Ten out of 14 subjects exhibited the contracture improvement as according to the required 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 four to eight week 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 [2, 6].

Minimum change of body weight also had become one of the vital conditions before proceed with the following sessions. The weight change between the sessions was limited until 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 [29]. Besides, the falling risk would be greater as the body weight increase which indicates poor stability control [30].

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 assess the path of CoP sway around zero point from the center of the platform. It consists of APSI, MLSI, and OSI. OSI is the tilt degree combination for both medial-lateral (ML) and anterior-posterior (AP) axes. This postural balance assessment with different ROM of stump could contribute a vital information in rehabilitation field since stump contracture is one of the biggest issues frequently emerge among the amputees [4, 6, 27].

Prior to experiments, the subjects were allowed to do balance training using Biodex Stability Sytem once. According to Ku et al., proprioception and vestibular equilibrium might be influenced by the learning process. Therefore, the results obtained later on might be affected. However, a practice trial would be crucial to ensure the understanding of the subjects about the experimental procedure. In order to minimize the influence of the learning factor, in one session, the test were performed for three times so that the data collected would be standardized and more accurate [14].

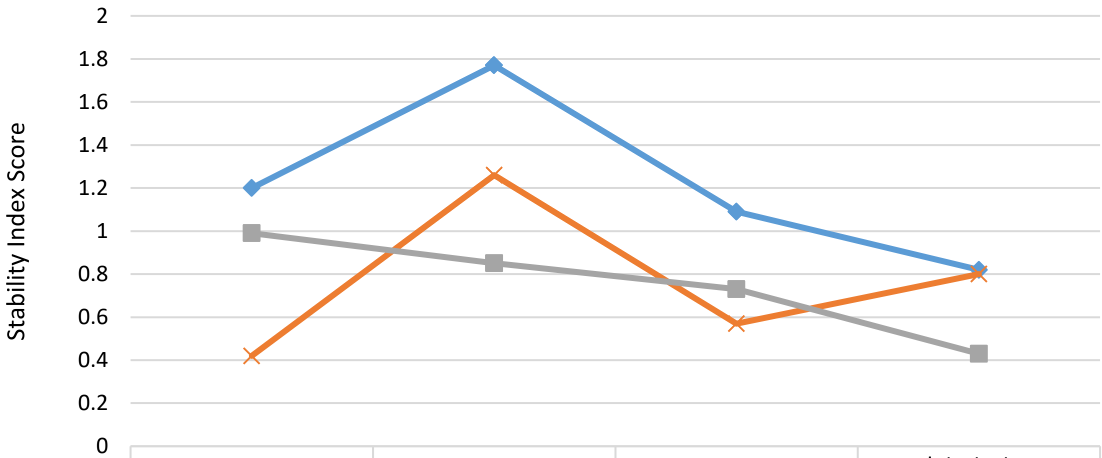
Previous research has found that the orientation of body plays a significant role in regaining postural balance [31]. It could be more vital as the orientation involve is at the lower segment of body which was the prosthetic alignment with respect to ROM of stump for this study. Thus, it was expected that the change in ROM of stump and the alignment set up will bring difference in postural stability index during quiet standing. This was 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 [4, 7]. This will significantly influence the CoP sway in AP axis.

As shown in Table 2, APSI reading was higher than MLSI during Visit 2 when there was ROM improvement of the stump while the prosthetic alignment remain unadjusted. The improvement of ROM in this study was in sagittal plane which refers to the improving degree of extension. During quiet standing, both of the knees will be in full extension position they capable of. With more degree of extension during Visit 2 session, the previous alignment setting promotes the body's CoM to sway more in sagittal plane compared to the frontal plane. This was because the alignment setup was only matched with the previous ROM which was before the contracture improvement. The socket flexion and foot dorsiflexion were more than the required angle which lead to the excessive shifting of GRF vector posteriorly, promoting knee instability in sagittal plane [8, 32]. This might explain the higher SI in anterior-posterior aspect compared to the medial-lateral aspect.

Meanwhile, as shown in Table 2, the value 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., who claimed that the postural instability is usually associated with the body sway in lateral aspect [33]. Trunk and hip are the segments responsible in controlling balance in medial-lateral direction while the medial-lateral motion towards lateral direction is generated by pelvis segment [34]. In addition, based on Mayer et al. findings, the CoP sway was more prominence 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 [25, 26, 31]. Besides that, lower limb amputees commonly have problem with weight shifting in effort to maintain the postural stability in medial-lateral aspect [35]. Therefore, the higher reading of MLSI compared to APSI in our result was expected.

In Visit 2, the OSI readings was higher compared to Visit 1 and significantly higher compared to Visit 3 ($p<0.0001$). 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 is not readjusted according to it. This assumption is also supported by the low OSI reading during Visit 3. Meanwhile, the insignificant difference of OSI between Visit 1 and Visit 3 ($p=0.344$) 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.

Arnold and Schmitz (1998) had carried out a research towards 19 healthy subjects with no history of lower limb injury in order to find the normal pattern of postural stability using BSS. 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 6 shows the line plot of the stability indexes obtained from this research and the values found by Arnold and Schmitz (1998).



	Visit 1	Visit 2	Visit 3	Intratester Reliabilities
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 6: 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 medial-lateral aspect which indicates more stability compared to the amputee subjects in this research. Same goes to the OSI value but the difference is not significant. This might be due to the high reading of APSI since it is accounting 95% of the OSI variance and closely related with the OSI reading compared to MLSI [21].

Since the intratester reliabilities 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, it should be reminded that the outcomes of the postural stability test is a subjective matter which is affected by several other factors such as ages, 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 subjects' age in this study were 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 it could be more consistent. This was because Zahedi et al. had found that 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 patient, but also satisfy the prosthetist's judgment [23]. Furthermore, according to McClenaghan et al., 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 results obtained and at the same time avoiding high standard deviation, those were the reasons why the subjects below than 50 years old were excluded from this study [36].

The strength of this study was on the selection of the subjects and devices. These two aspects 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 exceed 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 were evidence that revealed the contribution of different prosthetic foot types towards SI [24]. The prosthetic alignment setup throughout this study were set by three years experienced Certified Prosthetist and Orthotist (CPO) who is also one of the authors. Besides using his experience, the adjustment were also made based on the published and acknowledged literatures [4, 7, 23].

However, the limitation of the subjects' criteria in this study cause a limitation to the collected data as well. This has become more prominent as the subjects were also from the same geographical area and most of them get the rehabilitation treatment from the same hospital. The limitation of this study towards the degree of stump contracture reduction achievement also should be improved in future research. This is because 5^0 of additional extension was not much. Furthermore, certain errors could probably happened when measuring the contracture angle such as different positioning of goniometer and variation of effort when fully extending the stump. Even the error was just 1^0 or 2^0, it is a large percentage from the degree of ROM improvement. Therefore, in future research, the higher degree of contracture improvement should be applied in the required criteria and its effect on postural stability index should be explored further.

5. Conclusion

This study has proved that the prosthetic alignment intervention was able to compensate the adverse effect of stump contracture towards postural stability during quiet standing. It also has been found that the stability could be worse if the prosthetic alignment was not properly set according to the ROM of the stump. A standard range of stability index for amputee population who had similar criteria with the subjects also has been obtained and could be referred in future study.

6. References

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