VEIN MECHANISM ASSESSMENT IN UNDERWEIGHT, NORMAL WEIGHT, OVERWEIGHT AND PREGNANT SUBJECTS FOR RISK FACTOR OF DEEP VEIN THROMBOSIS (DVT)

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A thesis submitted in fulfillment of the requirement for the award of the Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
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MAY 2017
I am lovingly dedicating this thesis to.....

My beloved abah and ummi
(Mat Harun bin Saman & Rosnani binti Samsuni)
for their love, endless support, care and encouragement.

My siblings who always be there when needed.

My dearest friends for their inspiration.

And those who have helped and supported me.
First and foremost, praise to Allah, the Almighty God and the Benevolent for His mercy that has given me the strength, and time to complete this task. *Alhamdulillah.*

A special thanks to my family, especially my *abah* and *ummi* (Mat Harun bin Saman, Rosnani bt Samsuni) for their endless support, who always pray for my success and always been very supportive in every aspect of my life.

I would like to express my special gratitude to my supervisor Dr. Nabilah bt Ibrahim for her supervision, patience, encouragement and thorough professional guidance towards the completion of this research.

A great appreciation to Nur Shazilah bt Aziz who always been a good partner in completing this research. In remembrance, friends who were always by my side to encourage, advice, comfort, cherish and constantly support me during this entire project. Unfortunately, I cannot thank everyone by name because it would take a lifetime but, I just want you all to know that you count so much. Had it not been for all your prayers and benedictions; were it not for your sincere love and help, I would never have completed this thesis.
ABSTRACT

An *in vivo* assessment of vein mechanism on the subjects with no history of Deep Vein Thrombosis (DVT) that is categorised into different weight categories and also the pregnant subjects with the high risk factor of DVT are presented to diagnose the early stage of DVT. DVT can give serious threat to the one’s health condition. The blood clot that develops in the vessel can block the blood and cause the blood to pool which can lead to pain, swelling and also permanent damage. Currently, the DVT has been diagnosed using ultrasound, which is considered to be non-invasive and low cost compared to other methods available. Thus, in this research, assessments of the blood flow velocity and measurement of the vessel wall elasticity on popliteal vein using ultrasound have been proposed. The blood flow velocity and the wall displacement are considered to be the important parameters to construct a clinical model of DVT risk factor. As a result, the vessel wall displacement for the overweight category is the highest among the others which is only 6% different from the vein displacement of DVT subject, while having the lowest blood flow velocity rate (1.62±1.10 cm/s) and also highest elasticity (1.10±0.45 MPa) compared to the other weight category. This shows that the overweight vein mechanism has similarities to the DVT condition. Furthermore, for the pregnant subjects, it has been shown that their vessel diameter became smaller when entering the obesity category. Whilst, there are non-consistent measurement obtained from the blood flow velocity and vessel wall elasticity since they were affected by the physiological changes during their pregnancy. However, those changes did support the condition of thrombus development. Therefore, this study helps to verify the link between overweight and pregnant subjects to DVT disorder and its important in predicting the probability of DVT on human at the early stage.
ABSTRAK

Penilaian secara in vivo berkaitan mekanisma saluran darah terhadap subjek yang tidak mempunyai masalah trombosis vena dalam (DVT) (mengikut perbezaan berat) dan wanita hamil. Kategori ini merupakan golongan subjek yang berisiko tinggi berlaku pembentukan darah beku dalam saluran darah. Kajian ini bertujuan untuk mendiagnosis kebarangkalian DVT terjadi. DVT boleh memberi kesan yang serius kepada kesihatan. Darah beku yang terbentuk dalam saluran darah boleh menyebabkan pengaliran darah terhalang dan seterusnya darah terkumpul. Hal ini boleh menyebabkan rasa sakit, pembengkakan dan juga kerosakan yang kekal pada saluran darah. Kini, DVT telah di diagnosis menggunakan kaedah ultrabunyi yang dianggap tidak invasif dan rendah kos berbanding kaedah-kaedah yang lain. Oleh itu, penilaian terhadap kaedah halaju aliran darah dan keanjalan saluran darah menggunakan kaedah ultrabunyi telah dicadangkan. Halaju aliran darah dan keanjalan saluran darah merupakan parameter yang penting bagi membina model klinikal bagi faktor berisiko DVT. Hasilnya, nilai sesaran saluran darah bagi subjek dari kategori berat berlebihan adalah yang tertinggi berbanding kategori yang lain, dengan mempunyai nilai hanya 6% perbezaan dengan nilai sesaran saluran darah bagi pesakit DVT, sementara mempunyai nilai halaju aliran darah yang paling rendah (1.62±1.10 cm/s) serta nilai keanjalan paling tinggi (1.10±0.45 MPa) bagi saluran jika dibandingkan dengan kategori yang lain. Seterusnya, hasil penilaian bagi wanita hamil menunjukkan saiz diameter saluran darah menjadi kecil apabila memasuki kategori obesiti. Bagi wanita hamil, keputusan penilaian menunjukkan perubahan nilai yang amat rawak kerana kategori ini dipengaruhi oleh factor perubahan fisiologi yang berlaku sepanjang tempoh kehamilan mereka. Namun, perubahan tersebut mempengaruhi pertumbuhan trombosis di dalam saluran darah. Oleh itu, kajian ini membantu dalam menentukan hubungan antara kategori berat berlebihan dan wanita hamil dengan DVT dan ianya penting bagi meramalkan keadaan awal dalam kebarangkalian DVT pada manusia.
LIST OF PUBLICATIONS AND AWARD

Journals


**Award**

1. **Special Mention Award** for ISSBES 2015, paper title ‘Study of Vein Mechanism Based on Different Body Mass Index and Deep Vein Thrombosis Condition’, Biomedical Engineering Project Winner. (Sponsored by IEEE-Engineering in Medicine and Biology Society (IEEE-EMBS) Malaysia Chapter)
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<td>DVT</td>
<td>Deep Vein Thrombosis</td>
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<tr>
<td>VTE</td>
<td>Venous thromboembolism</td>
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<td>TIA</td>
<td>Transient Ischemic Attack</td>
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<td>TKA</td>
<td>Total Knee Arthroplasty</td>
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<td>B-mode</td>
<td>Brightness Modulation</td>
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<td>PSNR</td>
<td>Peak Signal-to-Noise Ratio</td>
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<td>MSE</td>
<td>Mean Squared Error</td>
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<td>IMT</td>
<td>Intima-Media Thickness</td>
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<td>SRAD</td>
<td>Speckle Reducing Anisotropic Diffusion</td>
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<td>MRI</td>
<td>Medical Resonance Imaging</td>
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<td>CT</td>
<td>Computed Tomography</td>
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<td>Hz</td>
<td>Hertz</td>
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<tr>
<td>BMI</td>
<td>Body Mass Index</td>
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<tr>
<td>Fps</td>
<td>frame per second</td>
</tr>
<tr>
<td>( \varepsilon )</td>
<td>Strain</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>Stress</td>
</tr>
<tr>
<td>( E )</td>
<td>Elasticity</td>
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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Venous thromboembolism (VTE) is a single disease affecting the venous circulation. It has two distinct presentations of condition that are the deep vein thrombosis (DVT) and the pulmonary embolism (PE) [1]. The DVT condition commonly occurs in the deep vein of the lower limb or pelvis. Figure 1.1 shows the structure of vein at the lower limb. Furthermore, it can also develop anywhere in the body, such as the veins in the arm, abdomen, or around the brain.

Figure 1.1: The structure of the proximal and distal part of the lower limb [2].
A blood clot that forms in the arteries is different from the blood clots that form in the vein. The reason is that the blood clot in the arteries leads to strokes, transient ischemic attack (TIA or mini-stroke), heart attack, or peripheral arterial clot and gangrene, which is the death of body tissue due to lack of blood flow or a bacterial infection. On the contrary, the clot in the vein forms deep in the body that can lead to deep vein thrombosis and pulmonary embolism [3]. Venous thrombosis is believed to begin at the venous valve [4]. The one-way valves play a major role in assisting blood circulation in the legs. Figure 1.2 shows the development of thrombus in the veins.

Figure 1.2: The development of the blood clot in the deep vein of the lower limb [5].

DVT is more common than pulmonary embolism; it is affecting around 70,000 people each year in the United Kingdom [6]. This condition is potentially fatal if left untreated. DVT is a venous thrombosis that is the blood clot. Thrombus may break off or embolise and travel through the vein to other parts of the body. If the pieces of blood clots reach the lung, it can cause pulmonary embolism by blocking one of the pulmonary arteries. Figure 1.3 shows the flow of the break off of the blood clots and travel through the vein to the lung.
As previously mentioned, pulmonary embolism could potentially become a fatal condition as soon as it occurs on someone. The risk factors of the deep vein thrombosis condition have been discussed gradually. The most common risk factors that have been discussed include long haul flights, pregnancy, influence of age, from operative thrombosis, obesity and etc. [8, 9]. Those factors mentioned are a part of the risky situation that lead to the development of deep vein thrombosis condition. Moreover, the dramatic increase in any of the constituent of the blood composition can cause increment to the viscosity and decrease the blood flow in the vessels. The main cause is the hypercoagulability which is probably acquired from thrombophilic defects. A case control study in Netherlands [10] and a cohort study from the US National Hospital Discharge Survey [11] obesity is also a risk factor for VTE. Similar discoveries were found in studies in America – Obese woman were found to have greater risk of DVT than obese men with scores of 2.75 versus 2.02 respectively. Those are the examples and statically explained on the risk factors in the development of deep vein thrombosis condition.

Besides, most studies on deep vein thrombosis condition conducted in America focused on Caucasian population. This shows that there is a significant value in the necessity for this condition to be further investigated. On the other hand, for the Asians population, the rate of incidence of deep vein thrombosis condition seems low, based
on the number of cases reported. However, it is believed that the Asians population also suffers from this fatal condition. Recently, studies on the development of deep vein thrombosis condition in Asian population were carried out to observe the trend of this incidence [12, 13]. It was reported that the cases of deep vein thrombosis condition are less established, though the risk level for the condition to become worsened is high. Therefore, awareness on this particular problem of diagnosing DVT is important.

Generally, various techniques have been used to identify DVT. The techniques used include computed tomography, contrast venography, impedance plethysmography, ultrasonography, and magnetic resonance imaging. Previously, contrast venography was considered to be the gold standard for the diagnosis. However, due to its requirement for excessive expenditure of manpower resources and times, the needs for specialised personnel, space and equipment, and its limited availability [14], contrast venography has been replaced with other tests with more favourable risk or benefit profiles. It has been proven that ultrasonography is a technique that is as accurate as any other techniques, with more advantages than CT, MRI, plethysmography and D-dimer test in terms of low cost, portability, simplicity, and non-invasiveness.

Therefore, the key to make a precise diagnosis is by recognising the various characteristics of various diseases based on ultrasound images. This anatomic approach is a very useful strategy in characterising the spectrum of pathologic condition seen in patients with symptoms that simulate DVT [15]. Ultrasound assessments for DVT have been shown to be successful by nonvascular specialist, ranging from novice to advanced users of ultrasound and can be performed in just a few minutes at patients’ bedside [16]. The ultrasonic technique has been suggested by Evans and his colleagues [59] as a method of choice for routine screening of patients confined to bed. Therefore, in this project, the application of ultrasound was used to diagnose the early stage of DVT.
1.2 Problem Statement

Deep Vein Thrombosis (DVT) can give serious threat to health. As commonly stated, pulmonary embolism is one of the most common effects that is caused by the deep vein thrombosis disorder. Pieces of clots can break off and travel through the blood vessel to the lungs. This can be fatal soon after it occurred. Besides, the clots in the vein might also block the blood flow in the veins and cause the blood to pool and lead to swelling, pain and permanent damage to legs. There are many risk factors that can cause DVT. However, in this study, subjects with different category of weight and including pregnant subjects have been suggested since there has been a lack of evidence that shows the link between those risk factor and DVT disorder. Therefore, the mechanisms mediating those risk factors have not been clearly determined or understood. Thus, to verify this condition, assessment of the vein mechanisms for underweight, normal weight and overweight and also pregnant subjects by using the ultrasound imaging is suggested which is non-invasive method. It requires no contrast medium and can be performed at the bedside.

Based on the purpose of the research study, the wall displacement and blood flow velocity in the popliteal vein are considered to be the important parameters to find the significant differences among those subjects as to support a clinical model of the early condition of DVT risk factor. Consequently, in the future, this will help in improving the method of determining the early condition of DVT.
1.3 Aim

Non-invasive assessment of vein mechanism in different weight categories and pregnant subject for risk factor of deep vein thrombosis (DVT).

1.4 Objectives

To evaluate the vein mechanism towards the early diagnosis of DVT condition that includes:

1. To identify the popliteal vein and to obtain the blood flow velocity at the valve using Pulse wave Doppler.
2. To measure the wall displacement of the vessel wall movement based on B-mode ultrasound image and calculate the elasticity of the vessel wall.

1.5 Scope of study

In this study, focused was given on assessing in vivo vessel behaviour in the risk factor of DVT at three different categories of weight that were normal weight, underweight and overweight subjects. Those conditions applied to the subjects who had no history of DVT. The other category of the subject is from the pregnant subject. The number of subject obtained was limited because it depended on the subjects’ willingness to be involved voluntarily in the research. The vessel valve study focused on the assessment of the popliteal vein of the lower limb of the body. Several mechanisms of the vessel valve were examined to determine any related factors of the early stage of DVT. The
mechanism included the measurement of the blood flow velocity and also the vessel wall elasticity.

1.6 Outline of the thesis

This thesis consists of five chapters. The first three chapters are the introduction and background of the study, literature reviews, methodology that describes the procedure and method applied in the study. Then, the result and discussion of the finding are in chapter four and lastly the conclusion of the study is in chapter five.
CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter consists five subtopics. Discussion on each topic is based on the research aim and objectives. The topics covered in this chapter include the incidence of deep vein thrombosis (DVT) in Asians countries, category at an increased risk of developing Deep Vein Thrombosis condition, study of vein mechanisms for the diagnosis of deep vein thrombosis, diagnosing methods applied for deep vein thrombosis and the application of Ultrasound imaging and image enhancement for medical purpose.
2.2 Incidence of Deep Vein Thrombosis (DVT) in Asians country

Deep vein thrombosis condition is one of the world renown vein incompetence that will lead to a fatal condition if mistreated or underdiagnosed. Generally, DVT is part of the venous thromboembolism that can lead to a fatal condition which can cause sudden death. Currently, the awareness of this condition is purposely raised at the early diagnosis of this condition. A lot of studies on this topic have been done previously by researchers in their effort to contribute in improving or preventing this condition at the early stage.

In the early years, K. S. Dhillon et al. investigated the postoperative deep-vein thrombosis in Asian Patients [17]. The research that had been carried out in Malaysia involved 88 subjects with no prophylaxis condition. In their research, an observation on the clinical signs that occurred in the subjects which led to deep vein thrombosis condition was carried out. The signs included the Homan’s sign, prominence of superficial veins, leg and ankle swelling, skin discolouration and also fever. Those are the common symptoms that can be observed physically by physicians in an effort to diagnose the deep vein thrombosis condition. These patients had been closely observed for any signs of deep vein thrombosis or pulmonary embolism by the physicians right after their operation had been done. In their study, the venogram analysis was done by two radiologists on each diagnosis to discuss and find reasons for the result obtained.

It is reported that, out of 88 subjects that underwent the operation of bilateral knee replacement, 62.5% of them showed evidence of deep vein thrombosis [17]. Moreover, based on the research done, the author did not find any differences in the mean age of the patients or the main duration of the operation of the surgery in the patients with and without Deep Vein Thrombosis. It is also confirmed that physical signs assessment alone can lead to the lack of the reliability of the diagnosis. Furthermore, it is believed that the incidence of Deep Vein Thrombosis is not a rarity as what common people believe. Additionally, in 2007, Susanna SS Tan et al., in their research group had reported on ‘Early Deep Vein Thrombosis: Incidence in Asian Stroke Patients’. The author discussed the incidences of Deep Vein Thrombosis in Asian population [13]. Thus, based on the results obtained from this study, the incidence of Deep Vein Thrombosis in Asian population is less established compared
to the Caucasian population. Even though the recorded cases only reported a low rate of incidence, the consequences of undetected deep vein thrombosis show a fatal condition to the subject when it occur which is sudden death.

Besides, the development of thrombus is unpredictable as it could occur as early as in 1-week time duration for some cases. In addition, based on the findings, it is found that clinical signs or physical assessment alone is unreliable for deep vein thrombosis diagnosis. It also lacks of uniformity in determining the condition that consequently leads to the indefinite result of deep vein thrombosis.

Woo Suk Lee *et al.* (2013) discussed the rarity of deep vein thrombosis among Asian populations [18]. In this study, the author mentioned that in the population, the reported incidences of deep vein thrombosis are lesser in comparison to the Caucasian population. Thus, this study may reflect the pattern of incidence that occurs among the Asians. Moreover, the incidences were determined on the symptomatic deep vein thrombosis or pulmonary embolism without chemotherapy after total knee arthroplasty (TKA). This was purposely to discover whether the deep vein thrombosis condition had a tendency to increase or otherwise. Based on that, a total of 1947 patients from 18 studies were reviewed. In addition, the methods used for diagnosis of deep vein thrombosis include venography (radiography of a vein after an injection of a radiopaque fluid), ultrasonography and CT venography. Besides, it was reported from this study that information on the effects of potential risk factor for deep vein thrombosis or pulmonary embolism, such as the age, gender, obesity and etc was available. This was due to the sufficient data on that particular information that was not available in many other studies. The previous studies did not provide the relevant facts to support the potential risk of deep vein thrombosis that can give sound judgement to the applied diagnosis.

Meanwhile, in a recent study, Danson X. W. Yeo *et al.* (2015) investigated the ‘Incidence of Venous Thromboembolism and Its Pharmacological Prophylaxis in Asian General Surgery Patients: A Systematic Review’ [19]. In this research, the main purpose was to find whether the incidence of venous thromboembolism is a rarity or not, especially in Asian populations. Literature studies on this topic involved doing research of MEDLINE, Embase, and the Cochrane Database of Systematic Reviews in June 2014. Provided, that certain facts for the screening of the Asian country and general surgery procedure had been included. The facts include the population studies whether it had been studied among the Asian population or not, type of surgery that
undergo by the subjects, the outcomes that lead to deep vein thrombosis or pulmonary embolism and last but not least was the secondary outcomes assessed in the subjects that included mortality and complication due to venous thromboembolism or prophylaxis against venous thromboembolism. In the context of risk level reported cases from most of the study population showed the higher risk category of deep vein thrombosis. Though, the deep vein thrombosis risk factor is regarded well and it is not a rarity in the population. Therefore, it was suggested that further studies in this area are a necessity as to develop accurate risk factor specification model specifically among the Asian.

2.3 Category at an increased risk of developing Deep Vein Thrombosis condition

Common categories that would have higher risk of thrombus development that can lead to DVT condition include people that have undergone surgery at the lower limb, long haul of flight which lead to prolong immobility, influence of the age, and not to forget the overweight or obese people and also pregnant woman. These are the categories of people that are at risk of having higher probability of the thrombus development in the lower limb which could be worsened into developing DVT condition or even worse pulmonary embolism that is a fatal condition as soon as it occurs to someone.

In a study by Frederick A. A. and his colleagues, showed that overweight or obesity falls into second in risk factor for treated acute DVT or PE [3]. They showed that 37.8% of the patients diagnosed are from the overweight or obesity category compared to the other which has a lower percentage than 30%. Even though it is said that the excess weight has low association to the VTE [3], though, for this category of people, whether it is defined by weight or body mass index still they are at an increased risk of having DVT. An alternative indicator should be used to determine the mechanism mediating those risk factor to DVT that probably support the development of thrombus formation.

Furthermore, in the article by the Health Trend Alberta stated that statistics from 2009 to 2012, it showed that 1.8% of obese patient have at least one diagnosis of
PE within 6 months of hip or knee surgery [21]. This is considered high compared to the 1.5% of patients with non-obese category. Moreover, it is believed that the body mass index does independently associated with 85% of the increased risk in the thrombus development which may lead to the thromboembolic complication after injury. This happened since the injured obese person have high hypercoagulable compared to normal weight counterparts with similar injury. This shows that the obese person exhibited stronger clots and less fibrinolysis. A balance between these two is important for ultimate clotting potential. This also shows that the obese person has different physiologic condition compared to the normal weight category.

Another category that is believed to be an increased risk factor of having DVT complication is the pregnant woman. It is recorded that the pregnant woman has fourfold up to fivefold increment of risk in thromboembolism compared to the non-pregnant woman. This condition is very severe that can lead to special consideration of management and therapy. The therapy that is commonly used includes in the treatment of acute thrombotic event and prophylaxis which is a measure taken to prevent the worse condition to those at increased risk of thrombotic events [22, 23].

Moreover, in pregnant woman, the left side is predominance side that considered to be associated with the stenosis of the left common iliac vein where it lies between the lumbar vertebral body and right common iliac vein, but precisely, the true mechanism is unknown for this [24]. Additionally, this group of people is at increased risk of DVT might be the result of the hormonally induced which decreased venous capacitance and decrease the venous outflow. Besides, from the mechanical obstruction of the uterus and decreased in mobility also contribute to the increased risk factor. Therefore, it is essential to observe the changes that happen during their pregnancy as to help indicating the condition of the pregnant woman for better treatment and overcome worse condition from developing.

2.4 Studies on Vein Mechanism for the Diagnosis of Deep Vein Thrombosis

As previously stated, the diagnosis of deep vein thrombosis condition can be performed on several types of methods which are the clinical assessment based on the
Well’s scoring system, ultrasonography, impedance plethysmography, venogram and etc. Intentionally, the author had been deliberating clearly on the method of diagnosing, while for the outcome of the diagnosis is less clarified by the physician. The common symptoms of the deep vein thrombosis are swelling, fever, a cord in a leg vein that can be felt, rapid heartbeat and etc. Whilst for the ultrasound image, the technique basically focused on the compression ultrasound to detect the abnormality in the vein. Major studies had been done on how to diagnose the deep vein thrombosis condition, but minor concern on the research of vein mechanism or properties that can lead the thrombus formation in the blood vessel which can cause DVT disorder.

Prior to this occasion, Broderick et al. in their research studied about the effect of bed rest and electrically elicited calf muscle contractions [25]. The study, focused on the popliteal vein blood flow since this location have high probability of thrombus development. When someone had lack of voluntary physical activity especially at the lower limb, the thrombus development is likely there [20]. Particularly, the popliteal vein that situated at the back of the knee can be affected greatly when someone not moving for a long time. As examples, this can happen from a long haul of flight, riding bus for a long distant, and working in the office that require to sit for a long time without moving. The blood flow will become slower and support the development of the thrombus formation in the popliteal vein. This study also presents the effect of four hours of bed rest has on the lower limb hemodynamic of healthy subject. The method applied in this research is duplex scanning of Doppler ultrasound to monitor the lower limb of the subject using 4-8 MHz linear transducer which is suitable for the blood vessel analysis. The position focused on the popliteal vein in the study of blood flow measurement. The other measurement includes the peak venous velocity, cross sectional area of the vein and venous volume flow. While for the heart rate, it was measured from the blood flow in the popliteal artery. Based on the result obtained, it is suggested that a short period of bed rest can significantly reduce the lower limb blood flow. It is believed that, this can have implications for DVT development in patient.

Moreover, a review has been done by Sanjay M. Khadalkar with his team regarding the evaluation of the role of Doppler as an imaging modality in diagnosing deep vein thrombosis condition of the lower limbs [15]. The authors believed the deep vein thrombosis occurs along the continuum with propagation, extension and progression because deep vein thrombosis does not totally obstruct the vein in the early
stage. Otherwise, most of venous thrombus is clinically silent due to the presence of the collateral circulation. Therefore, to prevent the complication from happening, anticipated by early and appropriate treatment, there is a need of objective technique to confirm the clinical diagnosis. The criteria that are included in this study for the analysis of deep vein thrombosis were the visualization of the thrombus, vein compressibility, vein size and also the respiratory changes on the subjects. Based on these criteria, the vein level of its competency can be measured. These can act as a support and confirmation of the clinical assessment that had been ruled out by the physician.

In other research by Barbara S. Hertzberg, from the Department of Radiology at Duke University Medical Centre with her associates conducted a sonographic assessment of lower limb vein diameter for normal subject and DVT subject. The goal of the study was to determine the normal range of vein diameter in the deep vein range and also to be able to compare the difference of the vein diameter with the DVT subject [26]. The study was conducted at five different levels of deep vein, which are the common femoral vein (CFV), high superficial femoral vein (SFV), middle superficial femoral vein, low superficial femoral vein and popliteal vein. These are the level of vein that is commonly diagnosed for the risk of the thrombus development in the deep vein located at the lower limb of the body. Figure 2.1 shows the structure of the lower limb with the different deep vein level.

![Figure 2.1: The anatomy of the lower limb with the vein structures][27]
Table 2.1: The average vein diameter (mm) measurement for subject with no history of DVT and subject with DVT condition [26].

<table>
<thead>
<tr>
<th>Vein Level</th>
<th>Without DVT</th>
<th>With DVT</th>
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</thead>
<tbody>
<tr>
<td>CFV</td>
<td>10.57</td>
<td>12.46</td>
</tr>
<tr>
<td>High SFV</td>
<td>7.1</td>
<td>9.14</td>
</tr>
<tr>
<td>Mid SFV</td>
<td>6.41</td>
<td>7.73</td>
</tr>
<tr>
<td>Low SFV</td>
<td>6.52</td>
<td>8.21</td>
</tr>
<tr>
<td>Popliteal Vein</td>
<td>6.8</td>
<td>8.82</td>
</tr>
</tbody>
</table>

Table 2.1 shows the results obtained for the diagnosis done by the group. It shows that the normal range of vein diameter in the normal person is lower compared to the subject with the DVT condition. Specifically, the popliteal vein shows that the normal vein diameter is 6.80 mm compared to the DVT condition which is 8.82 mm. Here, we can see the significant difference of the vein diameter for these two categories. However, the normal subject did not categorize into the different body mass index that might also be different for each category. Based on this, we are not able to differentiate the vein diameter for the normal subject with different body mass index. This is where the idea comes to study the difference of the vein diameter for different body mass index, which might help in improving the prevention or treatment from the development of the DVT condition.

2.5 Diagnosing Method Applied for Deep Vein Thrombosis

Generally, the detection of deep vein thrombosis condition based from the physical assessment rules out by the physician. The most well-known assessments rule follows the Well’s scoring system. Table 2.2 shows the scoring system that had been proposed by Well et al. [28].
Table 2.2: Simplified Clinical Model for Assessment of Deep Vein Thrombosis*

<table>
<thead>
<tr>
<th>Clinical Variable</th>
<th>Score</th>
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<tbody>
<tr>
<td>Active cancer (treatment ongoing or within previous 6 months or palliative)</td>
<td>1</td>
</tr>
<tr>
<td>Paralysis, paresis, or recent plaster immobilization of the lower extremities</td>
<td>1</td>
</tr>
<tr>
<td>Recently bedridden for 3 days or more, or major surgery within the previous 12 weeks requiring general or regional anesthesia</td>
<td>1</td>
</tr>
<tr>
<td>Localized tenderness along the distribution of the deep venous system</td>
<td>1</td>
</tr>
<tr>
<td>Entire leg swelling</td>
<td>1</td>
</tr>
<tr>
<td>Calf swelling at least 3 cm larger than that on the asymptomatic leg (measured 10 cm below the tibial tuberosity) †</td>
<td>1</td>
</tr>
<tr>
<td>Pitting edema confined to the symptomatic leg</td>
<td>1</td>
</tr>
<tr>
<td>Collateral superficial veins (nonvaricose)</td>
<td>1</td>
</tr>
<tr>
<td>Previously documented DVT</td>
<td>1</td>
</tr>
<tr>
<td>Alternative diagnosis at least as likely as DVT</td>
<td>-2</td>
</tr>
</tbody>
</table>

Abbreviation: DVT, deep vein thrombosis.

*Scoring method indicates high probability if score is 3 or more; moderate if score is 1 or 2; and low if score is 0 or less.

†In patients with symptoms in both legs, the more symptomatic leg was used.

Years by years researches done showed improvement in the method of diagnosing deep vein thrombosis. There are several methods that had been used regularly to do the detection of deep vein thrombosis instead of the physical assessment scoring system. These included the impedance plethysmography, venography, ultrasonography and D-Dimer test. Some of the methods are invasive while the others are non-invasive to the human body.

In 2004, Brenda K. Zierler, in her journal described the current diagnostic method applied for the detection of venous thromboembolism [28]. The venous thromboembolism consists of two related conditions that are deep vein thrombosis and
pulmonary embolism. The author mentioned that the objective testing for the venous thromboembolism is crucial, since the clinical diagnosis is non-specific and insensitive that leads to misdiagnosis that can cause serious consequences. Furthermore, the author also discussed the limitation of current non-invasive diagnostic method for the deep vein thrombosis. The methods discussed include the impedance plethysmography and venous ultrasound. It is mentioned here that impedance plethysmography may not detect the non-occlusive proximal deep vein thrombosis or occlusive proximal deep vein thrombosis that have been presented and also cannot detect deep vein thrombosis isolated to the calf vein. As for the venous ultrasound, it consists of several types of diagnosis that are compression ultrasound, duplex ultrasound, and colour Doppler imaging. Their sensitivity of detecting deep vein thrombosis varies from each other. Compression ultrasound is limited to the proximal deep vein, whereas duplex ultrasound and colour Doppler mostly applied for the calf and iliac veins. However, in comparison of venous ultrasound and venography, the sensitivity and specificity of venous ultrasound for diagnosis symptomatically proximal deep vein thrombosis are 97% and 94% respectively [28]. Therefore, this allows the treatment of deep vein thrombosis condition to be initiated without further confirmatory test and highly sensitive in diagnosing the proximal deep vein thrombosis makes possible to withhold treatment if the examination is negative.

Besides, S. Goodacre, 2006, in their research study concluded on how to identify the most cost effective strategy for diagnosing the deep vein thrombosis [29]. In terms of sensitivity and specificity of the method applied, a comparison was done between the D-Dimer test, venogram, ultrasonography and also the clinical assessment. The D-Dimer specificity depended upon the Well et al. scoring system while sensitivity is independent. Then, for the ultrasound, sensitivity and specificity were independent from the Well’s score and D-Dimer test. There are four main strategies applied for the diagnosis that included the clinical score, D-dimer test, ultrasonography and venography. Furthermore, it was mentioned that by comparing the four main strategies, the resultant of the combination of clinical score, D-Dimer test and ultrasonography to a no treatment alternatives show that is the most cost-effective strategy that can be provided. Moreover, it is suggested that ultrasound performed better performance in those strategies studied in this research. The diagnostic strategies that involved the radiology test, were unlikely to be cost-effective as it was depended on the willingness to pay for the service. Therefore, it is
recommended to use the cost-effective strategy throughout the diagnosis of deep vein thrombosis.

2.6 Application of Ultrasound imaging and image enhancement for medical purpose

Generally, physical diagnosis using ultrasound in medical world had been widely used. It helps to achieve the purpose of detecting incompetence of the part of the body. The most well-known application used is the B-mode image of the ultrasound. Therefore, in this study, application of ultrasound has been used for the diagnosis of deep vein thrombosis condition. Moreover, the raw B-mode image obtained from ultrasound has been directly used without enhancement to the image to evaluate the condition. Therefore, in current study, the edge detection method had been implemented in the evaluation of the raw image obtained from the ultrasound. This is purposely for the improvement in the accuracy and approximate data collection for the diagnosis. In image processing, edge detection method is a common element that had been applied in the process of image improvement and enhancement. Thus, this will contribute in the development of having more accurate measurement on the image obtained from the ultrasound.

In addition, for the detection of popliteal vein wall, application of image processing is necessary in the research. Based on previous research, there were some of the researches that focused on the detection of objects in the image that can be applied to this study. Juneja et al. (2009) reported on performance evaluation of different edge detection methods for image enhancement [30]. The main objective of the study is to observe the difference in the methods applied to the image used in the study. There were five types of method application that had been tested. The methods applied were Robert, Prewitt, Sobel, Laplacian of Gaussian and Canny. As a result, the study showed that each method applied give out different properties in detecting boundary of objects in the image. For Sobel edge detection method, it provides smoothing to the images while it detects parts of the edge in the images. Though, for the Roberts edge detection method, it is to find the high spatial frequencies while
producing no result of fine edge detections. Next, for the Laplacian, it responds to transition in intensity. Also, it is sensitive to noise. Besides, the Laplacian method applied to produce double edges and sometime unable to detect the edges of the image. Therefore, the Canny operator that works in multistage process. The process steps can be simplified in the smoothing with the Gaussian filter, which is followed by the gradient computation and in use of double threshold. In conclusion, from the research done, among various methods presented, the Canny method used to be able to detect both strong and weak edges. Besides, the Canny produced the best edge map based on the evidence given in the research done previously.

Next, from the ‘Edge detection operators: peak signal to noise ratio based comparison’ by D. Poobathy (2014) stated that the study focused on the performance evaluation of the edge detection algorithms used for the five edge detectors that were Sobel, Prewitt, Canny, Laplacian of Gaussian, and Robert’s [31]. The performance evaluation was based on the calculation of the mean squared error (MSE) and peak signal-to-noise ratio (PSNR) between resultant images of the edge detected method and the ground truth image. The performance evaluation was done using the Java application. While for the implementation of the edge detection methods, Matlab software had been used. Based on the result obtained, the Canny edge detection algorithm provides better performance than the other edge detection methods.

Furthermore, in recent study, Mehravar Rafati et al. (2014) in his research reported the implementation of edge detection method for the B-mode ultrasound image [32]. It has been focused on the comparison of the edge detection method and noise reduction using speckle reducing anisotropic diffusion (SRAD) filter to the ultrasound image of the carotid and brachial artery. The main purpose was to measure the intima-media thickness (IMT) and ensure the method used is safe and noninvasive. The methods applied for the comparison were Canny, Sobel, Prewitt, Roberts and Lapacian of Gaussian. Method applied for the noise reduction in the images using SRAD filter. Those evaluations of image quality after the process done based on the calculation of MSE and also PSNR. The author also described that from the result obtained, among the edge detected image, Canny edge detection with SRAD represent the lowest MSE and high PSNR value that indicates better image quality. Thus, from the study, they also provided more comprehensive information than other previous studies which performed edge detection implementation only on one frame and one
artery. However, the study limitation shows that the process was very time consuming for the implementation of the SRAD filter.

While, in another study by J. Lam et. al. shows the comparison done between median filter and SRAD filter based on the MSE and PSNR measurement and also observation on the image obtained [33]. The result shows that the applied median filter has better performance in the MSE and PSNR evaluation as well as the image produced is clear and smooth compared to the SRAD technique. As for the appendix edge detection, the Canny edge detection method had been applied for the diameter measurement.

2.7 Summary

In a nutshell, the diagnosis of DVT is commonly used by monitoring the presence of thrombus in a vessel from B-mode ultrasound image associated with the application of Doppler ultrasound. However, the monitoring of those parameters will only be confirmed when there is someone who already suffering from the DVT disease. Thus, this study is to diagnosed the risk factor of DVT. It is a challenging task to recognize the vessel condition at the earliest stage of DVT, therefore, the evaluation of the vein mechanism for risk category of DVT is proposed. The assessment includes the measurement of the blood flow velocity, vein wall displacement and also strain-elasticity measurement of the vessel wall. Table 2.3 shows the summary of the literature review that had been done for this study.
Table 2.3: Summary of the literature review on the research study.

<table>
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CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

This important chapter contains the details on the material, equipment, software, samples, procedures and data gathering methods that were used for the research. In the first section, flow of the research designed was explained. While, in the second section, relationship between the vessel wall elasticity and blood flow velocity were discussed followed by the list of materials, equipment, and software used for the study. This included brief explanations on the ultrasound machine and transducer used for the diagnosis. The next section discussed the data acquisition, image processing as well as the measurement of wall displacement, wall elasticity, and blood flow velocity which were the important parameters in this study.
3.2. Research Design

Deep vein thrombosis is usually diagnosed by physician based on a patient’s physical condition [34]. This diagnosed includes the observation of the obvious symptoms. There are several methods that have been used besides ultrasound imaging such as MRI, CT scans, and also D-dimer test [14, 15]. Those methods can also improve the performance in diagnosing the patient. However, due to high cost and traumatic experience that they could cause to patients have discourage physicians from applying them.

Therefore, ultrasound imaging is an alternative to enable a precise diagnose on patients suspected of having deep vein thrombosis. Ultrasound is seen as a better tool to diagnose patients as it is non-invasive and has no risk of radiation that causes high risk side effect to occur. In addition, the preparation of having data collected by using ultrasound does not involve a complex procedure that can make the diagnosis harder.

Figure 3.1 shows the flowchart of the research study of the visualisation of vessel and valve behaviour for risk factor of deep vein thrombosis. In this research, in-vivo experiment was done using the ultrasound equipment. Figure 3.2 shows the procedures of the experimental design. Based on the experiment conducted, the measurement that included determining the position of the popliteal vein, the velocity of blood flow in the vein, and also the wall displacement of the vein as well as the vessel wall elasticity.
Figure 3.1: The flowchart of research study.
REFERENCES


