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Detection of Venous Thrombosis using Impedance Plethysmography and Body Composition Analysis

Anika Tasnim Ritu[1], Md. Rubel Basar[1] and Md. Rabiul Awal[2]

[1]Dept. of Electrical and Electronic Engineering, Bangladesh Army University of Engineering & Technology, Qadirabad, Natore-6431, Bangladesh.
[2]Dept. of Electronics and Instrumentation, Faculty of Ocean Engineering Technology, Universiti Malaysia Terengganu (UMT), Kuala Nerus 21030, Terengganu, Malaysia.

Abstract: Venous Thrombosis (VT) poses a significant medical challenge due to the risk of clot formation within veins, necessitating prompt detection for effective treatment and complication prevention. This study investigates an efficient approach combining Impedance Plethysmography (IPG) and Body Composition Analysis (BCA) to identify venous thrombosis. In this study, we chose four subjects on whom the experiments are being performed to detect the vein condition. We select the subjects through interviews with their written consent prior to conducting the experiment. Our critical observations on the measured parameters such as bio-electrical impedance, body mass index (BMI), fat percentage, water percentage, and other parameters provide valuable insights into the underlying causes of thrombosis formation in subjects. Experimental results also indicate that subject 3 exhibits notable variations in the impedance curve. On the other hand, the Cole-Cole plot indicates the presence of a thrombus in the popliteal or more proximal vein. An ECG analysis cross-examines the findings.

Keywords: *Deep Vein Thrombosis, Impedance Plethysmography, Body Composition Analysis*

Introduction: Venous thrombosis is the formation of blood clots within veins, commonly occurring in the deep veins of the legs (DVT). It poses significant health risks, including the potential for pulmonary embolism (PE), a life-threatening condition where a clot travels to the lungs. Additionally, DVT can lead to chronic venous insufficiency (CVI) and post-thrombotic syndrome (PTS), causing symptoms such as leg swelling, pain, and skin changes. Recurrence of DVT is common, further increasing the risk of complications and mortality. Beyond the individual health impact, venous thrombosis places a considerable economic burden on healthcare systems due to treatment costs and productivity loss [1]. Early detection, prevention, and appropriate management are essential for mitigating these risks and improving patient outcomes. Impedance plethysmography (IPG) and body composition analysis (BCA) are valuable tools in detecting venous thrombosis. The term "plethysmography" originates from the fusion of two ancient Greek words: "plethysmos," conveying the concept of increasing quantity, and "graphos," denoting writing or recording. IPG measures changes in electrical impedance to detect alterations in blood volume, particularly useful for diagnosing deep vein thrombosis (DVT) [2]. On the other hand, BCA evaluates body tissue distribution, offering insights into thrombosis risk factors such as obesity and fluid imbalance [3]. Together, IPG and BCA provide a comprehensive approach to thrombosis detection, combining direct evidence of blood flow changes with information about physiological factors predisposing individuals to thrombosis. Their non-invasive nature makes them suitable for screening and monitoring, potentially facilitating early intervention and treatment.

Early detection of venous thrombosis is critical for intervention, and this innovative method holds promise for improving diagnostic accuracy and patient outcomes. Validation studies are warranted to establish the reliability and efficacy of this approach in clinical settings. This research represents a significant step toward advancing the field of venous thrombosis detection and management.

Related Work on Thrombosis Detection: In the last decades, several works in the literature proposed a variety of methods to detect deep vein thrombosis. In [4], authors evaluate the effectiveness of a D-dimer protocol for the detection of venous thromboembolism (VTE), encompassing deep vein thrombosis (DVT) and pulmonary embolism (PE). D-dimer is a biomarker released during the breakdown of blood clots, and its elevated levels are indicative of ongoing thrombotic activity. In [5], a comprehensive overview of recent developments in the diagnosis of VTE, comprising DVT and PE is presented. The review synthesizes findings from various studies, including clinical trials and meta-analyses, to elucidate emerging trends in VTE diagnosis. It discusses advancements in imaging modalities such as computed tomography pulmonary angiography (CTPA) and ultrasound techniques that help to detect DVT. Authors in [6], provide a detailed exploration of plethysmography's role in diagnosing venous conditions. Plethysmography measures changes in limb volume, aiding in the assessment of venous insufficiency, deep vein thrombosis (DVT), and other venous disorders. It is also seen in the literature, how IPG is effective in diagnosing vascular diseases. IPG measures changes in electrical impedance to assess blood volume alterations, making it potentially valuable for diagnosing conditions like DVT and peripheral artery disease (PAD) [7]. Authors in [8], also justify how

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Corresponding author details: Anika Tasnim Ritu
E-mail address:anika.eee16.ruet@gmail.com
Tel: +8801303223167

IPG is an effective method to assess the implications of arterial influence on IPG's ability to accurately detect venous thrombosis and other vascular conditions. On the other hand, authors in [3,9] suggest a positive correlation between obesity and VTE risk, with abdominal obesity potentially posing a greater risk due to its influence on inflammation, coagulation, and venous hemodynamics. The studies contribute to our understanding of the complex relationship between obesity and VTE, highlighting the importance of addressing obesity as a modifiable risk factor in VTE prevention efforts. So, from the above literature, it can be seen that IPG and BCA are effective methods to detect DVT [10].

Correlation of Parameters with Venous Thrombosis Detection: The measured parameters in this work are bio-electrical impedance, BMI, fat percentage, and water percentage which are closely correlated with the detection of venous thrombosis due to their reflection of changes in blood volume and tissue distribution, which are indicative of thrombotic events. Bio-electrical impedance measures the resistance of body tissues to a small electrical current, with changes indicating alterations in blood volume and flow. In venous thrombosis, an increase in impedance signals reduced blood flow due to a thrombus. BMI is a key measure for classifying weight categories and is relevant as high BMI is linked to increased venous pressure and a higher risk of blood stasis and clot formation, making it a significant risk factor for venous thrombosis. Fat percentage measures the proportion of body mass that is fat tissue, with excess body fat, particularly visceral fat, contributing to increased venous pressure and inflammation, both risk factors for thrombosis. Water percentage indicates body water mass, with proper hydration being crucial for blood viscosity and volume. Abnormal water retention or dehydration can affect blood flow dynamics, contributing to thrombus formation. These parameters provide a comprehensive assessment of a patient's vascular and overall health status, aiding in risk stratification, early detection, and intervention. Their combination enhances the predictive value for venous thrombosis, allowing for tailored treatment plans and regular monitoring to track disease progression and treatment effectiveness, ultimately leading to better prevention and management of venous thrombosis.
So, this work explores a novel approach as it combines IPG and BCA for early detection of venous thrombosis, providing a non-invasive, comprehensive diagnostic tool that enhances early intervention and patient outcomes. The suggested approach combines physiological risk variables and direct blood flow measurements to provide a more thorough analysis since it blends IPG and BCA. This dual approach potentially increases diagnostic accuracy compared to existing methods that typically use only one of these techniques.

Proposed System Overview: The venous thrombosis detection system's workflow is illustrated in Fig. 1. The process initiates with subject selection, followed by impedance acquisition using a source meter. Body composition parameters are collected using body stat which allows the data analysis and calculation of statistical features. Several waveforms are plotted to finalize the decision of venous thrombosis detection using IPG & BCA. In addition, a cross-check was performed using Electrocardiogram (ECG) analysis for the suspected subject.

Subject Selection: A detailed interview was conducted to assess the health conditions, eating habits, previous health issues, and current discomfort of potential participants. Following the interviews, four subjects were selected based on predetermined criteria aligning with the objectives of the study.

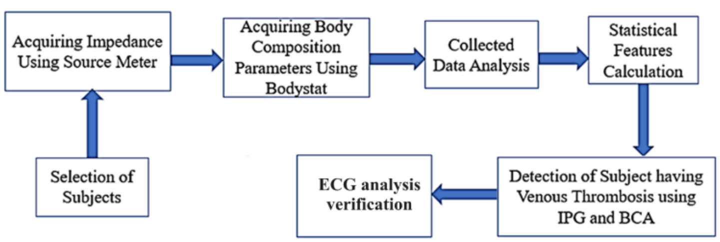

Fig. 1: Workflow of the proposed thrombosis detection system.

Physical Parameters Documentation: The selected subjects underwent physical parameter measurements including physical appearances, weight, height, hip and waist. The measurements are meticulously documented. The physical parameters of the selected subjects are presented in Table 1.

Table 1. Physical parameters of the selected subjects

Parameters	Subject-1	Subject-2	Subject-3	Subject-4
Physical Appearance	Thin & short	Taller	Fatter & average height	Thinner and average height
Height (meter)	1.6	1.83	1.65	1.7
Weight (kg)	56.75	84	101.5	50.5
Hip (inch)	35	43	47	33
Waist (inch)	31	38	45	31
Mean Height	1.695			
Mean Weight	73.188			

Data Collection: Impedance and body composition data were acquired using a source meter and bodystat equipment. The source meter provided precise impedance measurements, while the bodystat equipment facilitated the assessment of body composition metrics such as fat percentage, muscle mass, and hydration levels.

Data Visualization: The collected data were processed and plotted to visualize the results effectively. Graphs were generated to illustrate impedance values and various body composition parameters for each subject. This visualization aided in the interpretation of results and facilitated comparisons between subjects. Finally, the subject having venous thrombosis was detected using IPG and BCA.

Experimental Setup and Data Collection:
Acquiring Impedance using Source Meter: In this work, we employ a source meter device to conduct an experimental investigation utilizing Robert Patterson's four-electrode approach. Four electrodes are positioned on the forearm; two of the electrodes are utilized to pass the excitation current, while the other two are used to sense voltage. This technology uses alternating current (AC) currents since they have a reduced contact resistance between electrodes and arteries. Because skin conductivity sharply declines at frequencies in the MHz and GHz range, the frequency f must be selected carefully. However, frequencies lower than 1 kHz cause cardiac dysrhythmia, produce muscle contractions and interact with the neurological system. Commercially available devices use frequencies between 20 and 100 kHz as a compromise [11]. The current electrodes are placed within the voltage-sensing electrodes, which detect the voltage and allow for the calculation of the body's impedance change using Ohm's law [12]. To improve the method's accuracy in impedance plethysmography, some factors need to be taken into consideration. Due to their superior electrical stability, disc electrodes should be used instead of tape electrodes. Compression of the limb by tape electrodes can significantly impact blood flow measurements, causing errors due to diffusion resistance. To mitigate these errors, the distance between the current electrode and the nearest potential electrode should be at least 1.5 times the limb's radius (R) for tape electrodes and 2.3 times R for disk electrodes. Disk electrodes are preferred in impedance plethysmography due to their superior impedance stability [13,14]. Impedances are measured using both a source meter and a Bodystat device, both of which operate on the principle of impedance plethysmography (IPG) [15,16].

Acquiring Body Composition Parameters using Bodystat: The body composition parameters are obtained using Bodystat Multiscan 5000 which also works on the principle of IPG. The Multiscan is a bioelectrical impedance spectroscopy (BIS) device used to measure body composition, hydration levels, and fluid overload volume in liters. It is particularly useful for conditions such as dialysis, cachexia, sarcopenia, and lymphoedema. The device utilizes four Bodystat 0525 carbon-coated electrodes for each measurement.

Fig. 2: Experimental setup for acquiring data using source meter and body composition analysis.

Results and Discussion: Using a source meter we obtain the body impedance in two locations. The first location is to the left side of the sternal borderline (+) to the left leg (-) of the selected subjects and measured impedances are shown in Table 2 and demonstrated in Fig. 3. The second location is the right hand (+) to the right leg (-) of the selected subjects and the measured impedances are shown in Table 3 and demonstrated in Fig. 4. These two locations are preferred because the impedance variations are more observable in these two locations.

Table 2. Measured impedances to the left side of the sternal borderline (+) to the left leg (-) of the selected subjects using Source meter

Observation No.	Impedance (MΩ)			
	Subject 1	Subject 2	Subject 3	Subject 4
1.	3.390	1.159	4.914	7.324
2.	3.681	1.654	8.853	8.234
3.	3.886	1.731	5.271	7.880
4.	4.047	1.773	13.981	8.776
5.	4.160	1.890	4.246	7.931
6.	4.244	1.925	10.718	8.872
7.	4.318	1.942	5.416	7.610
8.	4.381	1.932	14.271	8.476
9.	4.419	2.072	4.454	7.133
10.	4.450	2.031	11.017	8.034

Table 2 and Fig. 3 present the measured impedance variations among the subjects up to count 10. It is evident from the collected data that, impedances varied in a small range from 3.39 to 4.45 for subject 1, 1.15 to 2.03 for subject 2, and 7.32 to 8.8 for subject 3. Most of the variation showed an upward trend. However, a large-scale impedance variation is detected for subject 3. It varies from 4.2 to 14.27 with no trend (upward or downward) unusual pattern.

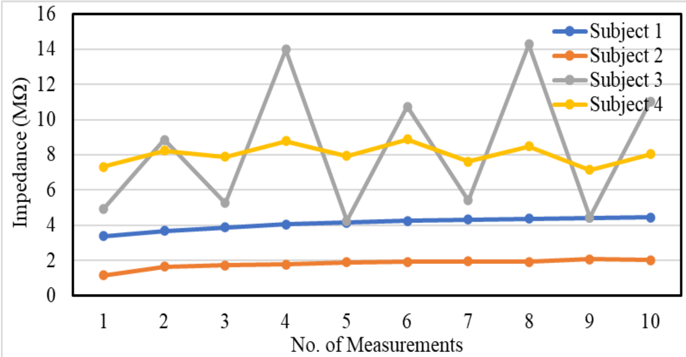

Fig. 3: Variation of impedance to the left side of the sternal borderline (+) to the left leg (-) of the selected subjects using Source meter.

Table 3. Measured impedances to right hand (+) to right leg (-) of the selected subjects using Source meter

Observation No.	Impedance (kΩ)			
	Subject 1	Subject 2	Subject 3	Subject 4
1.	76.874	339.044	687.53	108.276
2.	87.495	368.099	776.391	121.867
3.	92.619	388.58	851.706	127.59
4.	94.932	404.68	780.095	132.597
5.	94.891	416.03	899.786	137.515
6.	96.663	424.416	908.57	141.368
7.	98.608	431.826	825.18	143.679
8.	98.029	438.115	924.455	144.184
9.	98.376	441.856	940.410	144.892
10.	99.781	445.018	840.100	146.893

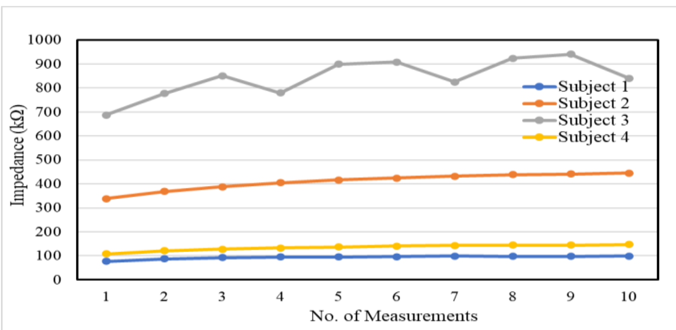

Fig. 4: Variation of impedance to the right hand (+) to right leg (-) of the selected subjects using Source meter.

A similar pattern can be seen From Table 3, and Fig. 4. It is evident that the impedance variation is higher in the case of subject 3 only which indicates that there must be some hindrance in the blood flow path. The hindrances can be the presence of thrombosis in the veins which is further supported by body composition analysis.

Table 4. Body composition parameters of the selected subjects.

Parameters	Subject-1	Subject-2	Subject-3	Subject-4	Normal Range
Fat (%)	14.2	20.6	27.5	1.8	12-18
Lean (%)	85.8	79.4	72.5	98.2	82-88
WATER (%)	84.6	45.9	49.6	51.9	55-65
ECW (%)	23	22.4	17.1	36	26
ICW (%)	61.6	23.6	32.5	15.8	34
BMI(KG/M*2)	22.3	27.2	37.2	17.4	20-25
BFMI(KG/M*2)	3.2	5.6	10.2	0.8	2-5
FFMI(KG/M*2)	19.1	21.6	27	17.1	18-22

Table 4 presents the body composition parameters obtained through bodystat analysis for the selected subjects. It is evident that the levels of Fat (%), BMI, BFMI, and FFMI significantly exceed the normal range for subject 3 which I demonstrated in Fig. 5. These findings suggest that subject 3 is afflicted with obesity, a condition known to predispose individuals to cardiovascular diseases and potentially contribute to thrombosis formation in the veins. A comprehensive analysis of whole-body impedance at 50 different frequency points using bodystat can be conducted to corroborate this hypothesis.

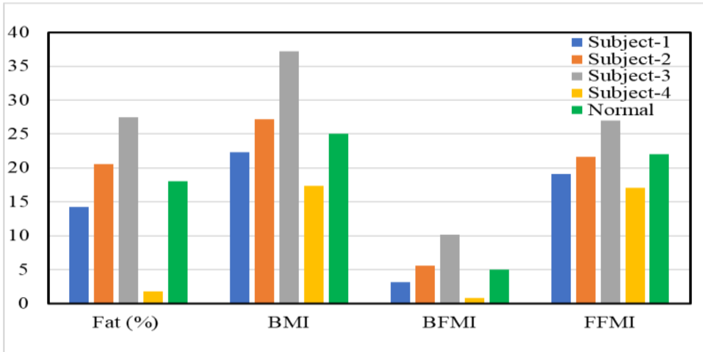

Fig. 5: Comparison of fat percentage, BMI, BFMI, and FFMI of the selected subjects.

The value of impedances of the whole body for the selected subjects is measured in 50 different frequency points ranging between 5kHz to 1000 kHz. The bioelectrical impedance curve is plotted from the measured impedances, as shown in Fig. 6.

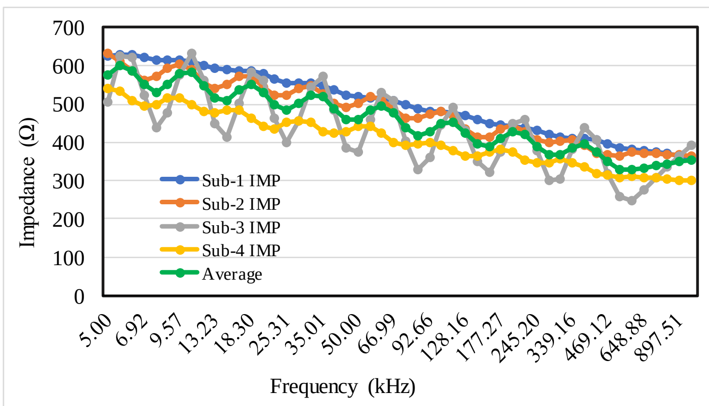

Fig. 6: Bioelectrical impedance plot of the selected subjects.

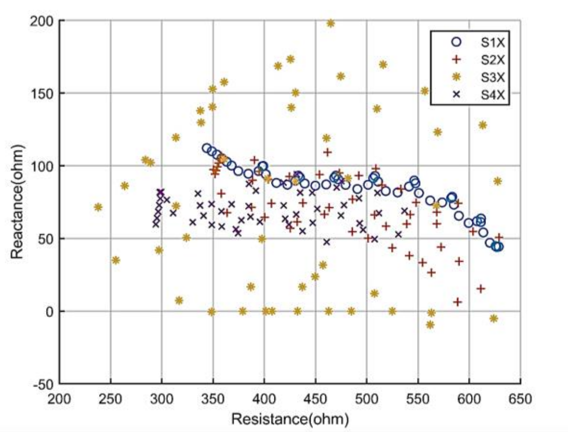

Fig. 7: Cole-Cole plot of the selected subjects.

Fig. 6 indicates that subject 3 impedance curve deviation from the average is high compared to others. It indicates a higher body fat percentage in subject 3 and presence of thrombosis in the vein. In addition, from Fig. 7, it is clear that subject 3 Cole-Cole plot is highly scattered. The change of impedance is more for subject 3 which indicates lower conductivity of blood, it also tells us there is the presence of a thrombus in the popliteal or more proximal vein [3]. It increases the risk of CVDs. So, obesity is one of the reasons that develop thrombosis in subject 3.

Table 5. ECG Analysis Result for Subject 3

Parameters	Subject 3
Vent Rate (BPM)	86
PR Int. (ms)	137
P/QRS/T Int. (ms)	99
QT/QTc Int. (ms)	372
P/QRS/T Axis (Deg.)	42
RV1/SV5 Amp.(mV)	0.35
RV5/SV1 Amp.(mV)	1.18
ECG Analysis Results	Sinus Arrhythmia
	Borderline abnormal ECG

To verify the observation from this work, an ECG analysis is performed. The findings are presented in Table 5. The ECG analysis shows Borderline abnormal ECG which refers to the found abnormality. Therefore, it can be concluded that subject 3 has mild thrombosis in the deep vein, possibly due to obesity. This inference is drawn from the significant fluctuations in impedances, indicating changes in blood volume, as identified through the combined utilization of impedance plethysmography (IPG) alongside body composition analysis (BCA).

Conclusion: In conclusion, the utilization of impedance plethysmography (IPG) in tandem with body composition analysis (BCA) presents a promising approach for detecting venous thrombosis. IPG and BCA offer complementary insights into thrombotic events by assessing blood volume and tissue distribution changes, respectively. Our study demonstrates the effectiveness of this combined approach through experiments conducted on four subjects, revealing significant impedance variations in the presence of thrombosis. Specifically, subject 3 exhibited pronounced impedance deviations and elevated body fat percentages, indicative of obesity-related thrombosis. These findings underscore the importance of early detection and intervention in reducing the risk of cardiovascular diseases associated with venous thrombosis. However, a key limitation of this study is the small number of subjects, which restricts the generalizability and reliability of the findings. Future research should include a larger cohort to confirm the results, improve the method's accuracy, and provide a clearer understanding of its effectiveness across diverse populations. Overall, our research contributes to advancing the field of venous thrombosis detection and highlights the potential of IPG and BCA as valuable diagnostic tools in clinical practice. The findings are justified with an ECG analysis.

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