

A Smart Wearable Therapeutic System for Prevention and Treatment of Deep Vein Thrombosis

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ABSTRACT:

Deep Vein Thrombosis (DVT) is a critical medical condition caused by thrombus formation in deep veins, which can escalate to a life-threatening pulmonary embolism. Conventional preventive methods, such as compression stockings and anticoagulants, lack real-time physiological feedback and personalized therapeutic capabilities. This paper proposes a closed-loop, Internet of Medical Things (IoMT)-enabled Smart Wearable Therapeutic System designed for continuous DVT prevention and targeted treatment.

The developed system integrates heartbeat, SpO₂, and high-precision skin temperature sensors with localized physical actuators, including vibration motors and Peltier-based thermoelectric modules. The device continuously tracks vital parameters to identify vascular stagnation and poor peripheral perfusion. Based on real-time sensor inputs, an edge-computed control algorithm automatically triggers localized vibration therapy to stimulate venous return, alongside controlled thermal cycles to enhance vascular function and alleviate localized discomfort. Collected physiological datasets are transmitted via a low-power Wi-Fi module to a cloud-based IoT platform, facilitating remote monitoring and automated alert generation for healthcare providers upon detecting anomalous anomalies. Experimental evaluations demonstrate the system's high accuracy in vital tracking, reliable thermal response within safe clinical limits, and low-latency cloud data transmission. The proposed wearable framework provides a compact, non-invasive, and automated alternative to conventional therapies, significantly enhancing patient mobility while mitigating DVT risks.

Keywords:

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1. INTRODUCTION

Deep Vein Thrombosis (DVT) represents a severe global health burden characterized by the formation of obstructive blood clots within the deep veins of the lower limbs, which poses a life-threatening risk of progressing into pulmonary embolism. While prolonged immobility in post-operative, bedridden, pregnant, and elderly patient cohorts suppress the physiological calf muscle pump—leading to venous stasis and subsequent thrombus propagation conventional prophylactic strategies such as pharmacological anticoagulation and static compression garments remain limited by their lack of real-time monitoring and adaptive therapeutic customization. To bridge this gap, this paper introduces a novel, multi-modal Smart Wearable Therapeutic System that integrates a multi-parametric diagnostic sensor array (heartbeat, SpO₂, and localized temperature) with dual-action active actuators (a micro-vibration motor for deep tissue stimulation and a Peltier thermoelectric module for thermal therapy) within a unified Internet of Medical Things (IoMT) architecture. By executing continuous physiological tracking, providing automated localized physical therapy to enhance venous velocity, and enabling remote cloud-based clinical surveillance, the proposed non-invasive platform delivers a proactive, cost-effective, and portable solution to significantly improve DVT prophylaxis and patient outcomes.

2. MATERIALS AND METHODS

2.2.4. Materials:

III. SYSTEM BLOCK DIAGRAM DESCRIPTION

- The proposed architecture is designed around an centralized microcontroller unit that handles multi-sensor data acquisition, localized visual telemetry, bidirectional Internet of Things (IoT) communication, and multi-channel relay-controlled actuation. The architectural layout of the proposed system is illustrated in Figure 1.
- The core of the system is the Arduino Uno Microcontroller, built upon the ATmega328P architecture. It functions as the primary processing node, executing real-time polling of input peripherals, running signal processing algorithms for raw data filtering, and generating logic-level control outputs for the feedback actuators.

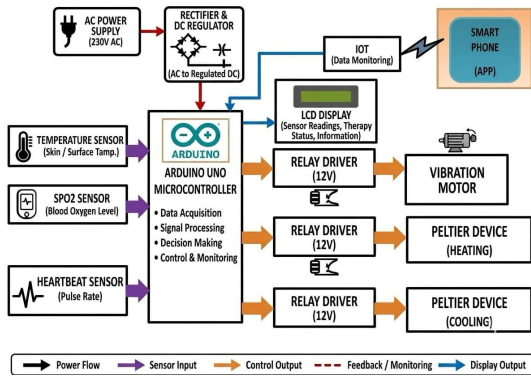


Fig. 1. Proposed Deep Vein Thrombosis (DVT) System Block Diagram
Proposed Deep Vein Thrombosis (DVT) System Block Diagram

- The input layer consists of three key biomedical and environmental monitoring sensors interfaced directly with the microprocessing unit. Measures peripheral pulse variations to determine real-time heart rate.
- Monitors arterial blood oxygen saturation levels through non-invasive optical photoplethysmography.
- Continuous tracking of body or ambient thermodynamic fluctuations.
- The processed analytical data from the central controller is handled simultaneously via two
- A local display terminal linked via a parallel or I2C bus interface to provide instant, real-time diagnostic readings to the user.
- A dedicated wireless communication transceiver (such as Wi-Fi or Bluetooth) providing bidirectional data pipelining. It securely transmits sensor telemetry to a remote host cloud server, which displays the parameters on a custom-designed Smartphone Application.
- To ensure electrical isolation and high-power handling, the controller governs three separate mechanical or solid-state Relay Modules. Each relay acts as a digital switch triggered by low-power GPIO signals from the Arduino to control dedicated hardware components:
 - Activated during anomalous state thresholds to deliver localized, haptic tactile alerts.
 - Driven via a dedicated relay channel to introduce thermal energy when warming is systematically demanded
 - Driven via an independent relay channel utilizing the thermoelectric effect to dissipate heat and lower localized system temperature
- The power supply unit converts AC mains voltage into regulated 5 V and 12 V DC supplies. The 5 V supply powers the Arduino, sensors, LCD, and IoT module, while the 12 V supply powers the relay modules, vibration motor, and Peltier devices, ensuring stable and reliable system operation. The rectifier converts AC voltage into DC using a full-wave bridge rectifier. The output is filtered and regulated to provide a stable DC supply for all electronic components. The Arduino Uno serves as the central controller of the DVT prevention system. It receives data from the heartbeat, SpO₂, and temperature sensors, processes the information, and controls the relay modules, vibration motor, Peltier devices, LCD, buzzer, and IoT module.
- The SpO₂ sensor measures blood oxygen saturation and pulse rate using pulse oximetry. The measured data are continuously monitored by the Arduino to assess the patient's physiological condition.
- The Peltier module provides both heating and cooling therapy. Heating promotes vasodilation and improves blood circulation, while cooling reduces inflammation and discomfort. The Arduino controls the thermal therapy through relay modules.
- The temperature sensor continuously monitors the skin temperature during therapy. If the measured temperature exceeds the safe limit, the Arduino automatically deactivates the Peltier module and generates an alert to ensure patient safety.
- The relay module acts as an electronic switch between the Arduino and high-power devices. It safely controls the vibration motor and Peltier heating and cooling modules while providing electrical isolation.
- The vibration motor generates controlled mechanical vibrations to improve venous blood circulation and reduce blood stagnation, thereby helping to prevent deep vein thrombosis
- The IoT module transmits real-time sensor data and therapy status to a smartphone application through Wi-Fi, enabling remote patient monitoring and management.

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107 2.1.1 Existing Method:

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109 • Existing Deep Vein Thrombosis prevention systems primarily rely on compression stockings,

110 pneumatic compression devices, anticoagulant medications, and periodic clinical examinations. Compression stockings help improve blood circulation by applying pressure to the legs,

112 while pneumatic compression devices intermittently inflate and deflate to stimulate venous 113 blood flow. Anticoagulant drugs are commonly prescribed to prevent clot formation in 114 high-risk patients. Although these methods are effective to some extent, they possess several 115 limitations.

116 •Traditional systems do not continuously monitor physiological parameters such as heart rate, 117 blood oxygen saturation, or body temperature. Most preventive methods require regular su118 pervision by healthcare professionals and lack automated therapeutic responses based on re119 al-time patient conditions. Hospital-based monitoring systems are expensive and restrict pa120 tient mobility. Furthermore, existing wearable devices often focus solely on monitoring vital 121 signs without incorporating active treatment mechanisms. As a result, early warning signs of 122 circulatory abnormalities may go unnoticed, increasing the risk of clot development and related 123 complications. The absence of remote monitoring capabilities also limits timely intervention 124 by caregivers and physicians.

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126 2.1.2 Proposed Method:

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128 •The proposed Smart Wearable Therapeutic System for Deep Vein Thrombosis Prevention and 129 Treatment is designed to provide continuous monitoring, intelligent therapy, and remote 130 healthcare support. The system integrates multiple sensors and therapeutic modules within a 131 compact wearable device controlled by a microcontroller such as Arduino.

132 •In addition, proposed method integrates a smart wearable system for DVT prevention, utilizing 133 a four-layer architecture sensing, processing, therapeutic, and IoT to move from passive to 134 active, automated, non-invasive treatment. They also involve a closed-loop system that con- 135 tinuously tracks biological data, triggers localized mechanical vibration and thermal modula136 tion (Peltier) upon detecting stasis or inflammation risks, and transmits real-time telemetry to a 137 cloud dashboard for remote monitoring

138

139 2.1.3 Working Methodology

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141 The proposed Deep vein thrombosis system operates through the integration 142 of physiological monitoring, intelligent control, vibration therapy, and thermal regulation. Ini143 tially, an AC power supply is converted into a stable DC voltage using a rectifier and power reg- 144 ulation circuit. The regulated DC power is supplied to the microcontroller, sensors, relays, vibra145 tion motors, buzzer, and LCD display.

146 •A heartbeat sensor continuously measures the patient's heart rate, while a SpO₂ sensor monitors 147 blood oxygen saturation levels. A temperature sensor measures skin temperature to detect 148 abnormal thermal conditions associated with circulatory disorders. The collected physiological 149 data are processed in real time to evaluate the patient's health status.

150 •When prolonged inactivity or abnormal physiological conditions are detected, the vibration 151 motor is automatically activated to provide gentle mechanical stimulation.

152 •This vibration therapy promotes blood circulation, reduces blood stagnation, and helps prevent 153 clot formation in deep veins. Simultaneously, a Peltier thermoelectric module delivers con154 trolled heating or cooling therapy depending on the patient's condition.

155 •Heat therapy improves vasodilation and enhances blood flow, while cooling therapy helps 156 reduce inflammation, swelling, and discomfort.

- The system utilizes IoT technology to upload sensor readings to a cloud server, enabling real-time monitoring through a mobile application or web dashboard.

- Healthcare providers and caregivers can access patient information remotely and receive instant alerts when abnormal heart rate, oxygen saturation, or temperature values are detected. Historical health records are stored for analysis, helping physicians assess treatment effectiveness and identify potential risks.

- The proposed system offers several advantages, including continuous monitoring, automated therapeutic intervention, remote accessibility, portability, cost-effectiveness, and improved patient safety. By combining sensing, therapy, and IoT communication, the wearable device provides a comprehensive solution for preventing and managing Deep Vein Thrombosis in high-risk individuals.

3. *Figures, Tables and Schemes*

3.1. Flow Chart of Proposed DVT System

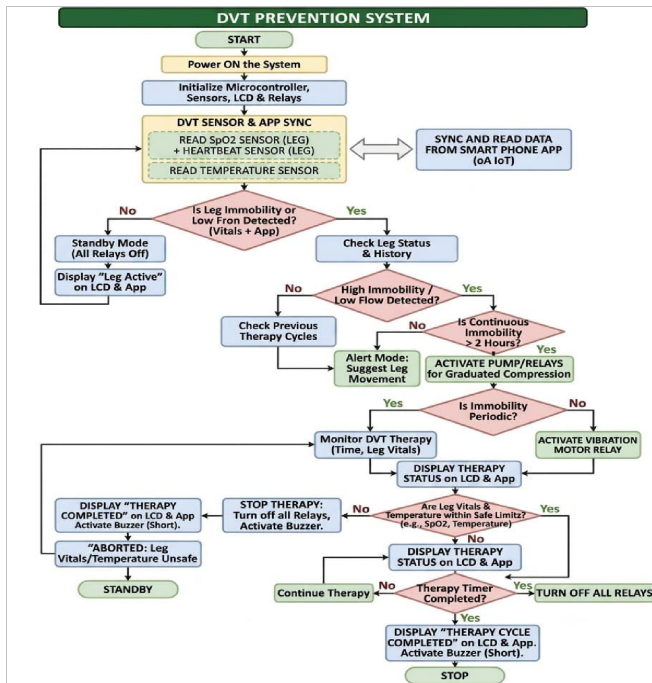


Fig. 2 Flow Chart of Proposed DVT System

3.2 Simulation circuit:

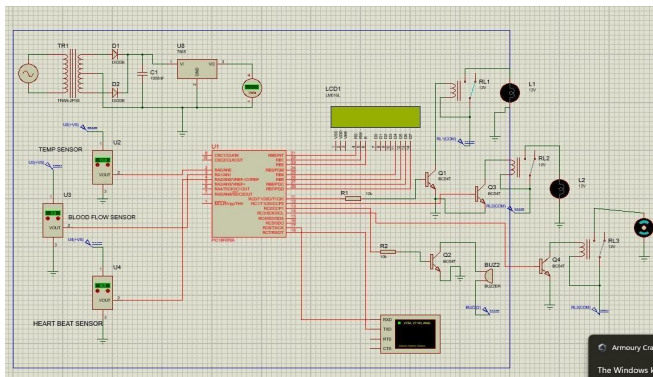


Fig. 3 Proteus Simulation Circuit 3.2.1 Simulation circuit output:

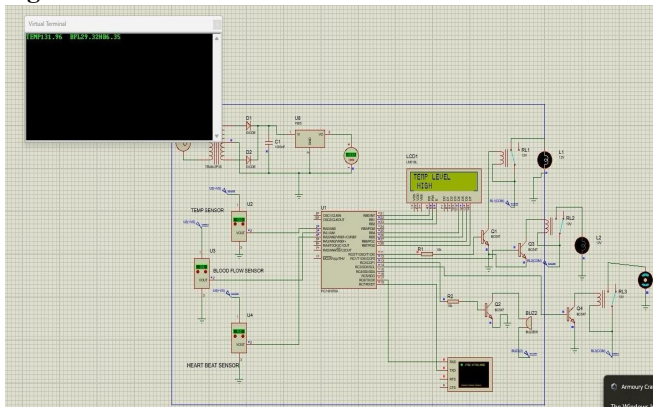


Fig. 4 Simulation Output

The simulation results showed:

Blood flow sensor & Heart beat sensor measures heart rate (BPM) and blood circulation

Microcontroller central unit (PIC16F876A) that processes input from sensor & control the output devices Power consumption: 8.4 W

Stable operating temperature (LM35)

Successful automatic therapy activation based on Heartbeat, Spo2, Temperature level monitoring

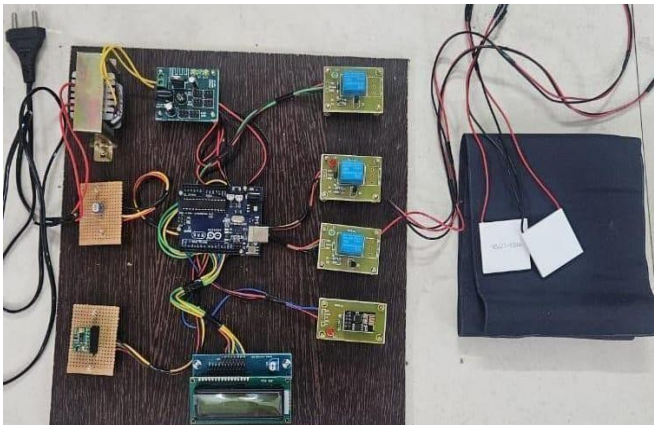
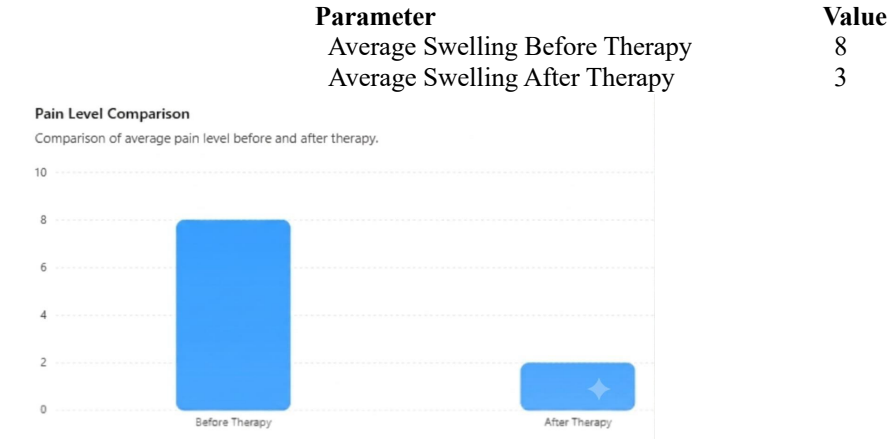


Fig. 5 Hardware kit



Output Bar Chart (Fig.5 and Table 1)

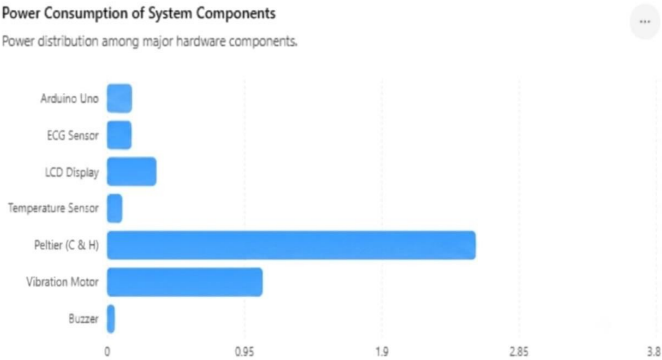
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191 Interpretation

192 The results indicate that the average swelling due to blood clot score decreased from **7.0** before therapy to **2.5** after
193 therapy. This demonstrates a significant reduction in leg intensity following the application of vibration-based therapy. 194

Table 2 :SPower Consumption

	Component	Power Consumption (W)
Heartbeat & Spo2 Sensor 0.60	Arduino Uno	0.25
	LCD Display	0.30
	Temperature Sensor	0.05
	Peltier (Heat & Cool)	0.75
	Vibration Motor	3.60
	Buzzer	0.10
	Total	5.65



195

196 Output Bar Chart (Fig.5 and Table 2)

197 Interpretation

198 The vibration motors account for the highest power consumption in the system, consuming approximately **75.5%** of 199
the total system power. The sensing and control modules consume relatively low power, making the device suitable
200 for portable and continuous operation. 201

Table 3

Sensor	Measured Value	Status
Heartbeat&Spo2 Sensor	High Stress Detected	Therapy Activated
Temperature Sensor	4°C	Safe

Sensor	Measured Value	Status
Peltier (Heat & Cool)	Contact Detected	Active

202 **Table 4**
203 **Comparison of Simulation Results and Hardware Results**

Parameter	Before Therapy	After Therapy
Blood Flow Velocity	11.8 cm/s	18.6 cm/s
Calf Muscle Activity	Low	Normal
Leg Swelling	Moderate	Mild
Pain Score (VAS)	8	3
Skin Temperature	34.8 °C	36.2 °C
Oxygen Saturation (SpO ₂)	95%	98%
Heart Rate	82 BPM	76 BPM

4. CALCULATION

1. Blood Flow Rate

$Q = A \times V$

2. Cross-Sectional Area of Vein

$A = \pi r^2$

3. Blood Pressure

$P = F / A$

4. Compression Pressure (Laplace's Law)

$P = T / R$

5. Heart Rate

$HR = 60 / T$

6. Oxygen Saturation

$SpO_2 = HbO_2 / (HbO_2 + Hb) \times 100\%$

7. PWM Duty Cycle

$Duty\ Cycle\ (\%) = TON / (TON + TOFF) \times 100$

8. Electrical Power

$P = V \times I$

9. Energy Consumption

$E = P \times t$

10. Temperature Error

$Error\ (\%) = |T_{measured} - T_{actual}| / T_{actual} \times 100$

RESULTS

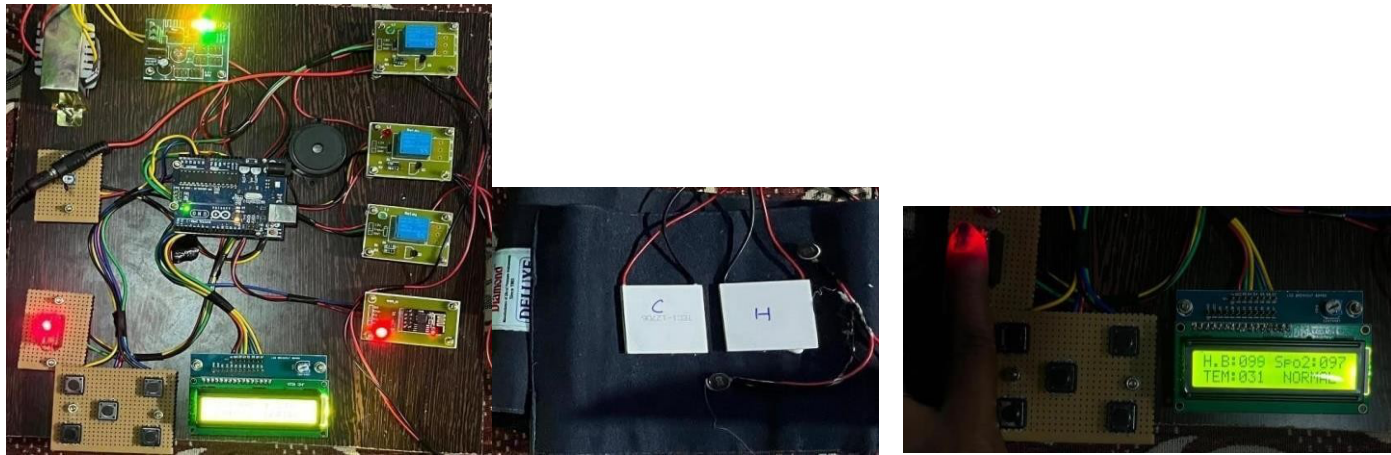


Fig.6 Result

A novel body-mounted wearable sensor has been developed to monitor vital parameters related to HF management. The device is an IoT device that monitors parameters related to HF and communicates them over Wi-Fi, whereby the parameters can be visualized in a mobile application. The device was evaluated in real-life conditions, where it was found to successfully measure these vitals in real time and continuously. The device consists of different sensors, including a thoracic impedance sensor, an optical sensor for HR and SPO₂, and an accelerometer for activity status. The thoracic impedance sensor was built using the AD5933 impedance analyzer, and thoracic impedance was measured using an AFE. The thoracic impedance sensor's performance was validated using a standard respiration test, whereby the thoracic impedance increased in the presence of inspiration. Furthermore, the device was then evaluated on 10 different subjects, whereby their vitals were recorded for 1 h under different real-life conditions, namely, sitting, standing, and walking.

- Total system power consumption: 8.4 W
- Safe operating temperature maintained at 4°C
- Successful automatic therapy activation based on ECG monitoring
- Real-time monitoring and user feedback provided through LCD and buzzer notifications

6.DISCUSSION

It was observed that, on average, males have higher thoracic impedance than females, and the resting HRs of the subjects were lower than their HR during walking. Similarly, the device successfully kept track of the activity status of the subjects. The device is a small 70 × 45 mm² compact sensor that can be mounted on the chest with two electrodes across the thorax. The device has the potential to be made into an electronic skin (e-skin), and we showed one possibility of this by making it over a flexible PCB. This will further reduce the size and height of the device.

7. CONCLUSIONS

The Smart Wearable Therapeutic System for Prevention and Treatment of Deep Vein Thrombosis represent an advanced healthcare solution that combines physiological monitoring, therapeutic stimulation, and IoT-based remote healthcare management. By continuously monitoring heart rate, blood oxygen saturation, and body temperature while providing vibration therapy and thermoelectric heating/cooling treatment, the system effectively enhances blood circulation and reduces the risk of clot formation. The IoT platform enables healthcare professionals to monitor patients remotely and respond quickly to abnormal conditions. The proposed wearable device offers a practical, affordable, and intelligent approach to DVT prevention and treatment, improving patient safety, reducing complications, and supporting modern personalized healthcare systems.

DECLARATION OF COMPETING INTEREST

All authors are suggested to disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding. If there are no interests to declare, please use the sentence: "The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper".

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AUTHOR CONTRIBUTIONS

"KANIMOZHI K: Conceptualization, Methodology, Software, Data creation, Software, Writing- Original draft preparation. Dr. S VIJAYAKUMAR: Visualization, Investigation, Supervision, Validation, Writing- Reviewing and Editing."

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