Exploring Effective Diagnostic and Therapeutic Strategies for Deep Vein Thrombosis in High-Risk Patients: A Study

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***Abstract*—Blood clots formed in blood vessels are termed as Thrombus. The pivotal strategy in diagnosing the early-stage thrombus, plays a vital role. Most commonly, blood clot occurs in the calf muscles of the lower extremities which leads to Deep Vein Thrombosis (DVT). Vulnerable patients are those who are involved in prolonged bed rest post-surgery, and the patients who are already affected with stroke, acute ischemia, cerebral palsy, etc. According to a report by the World Health Organization (WHO), nearly 900,000 people are affected annually, with approximately 100,000 dies each year At present blood clots can be identified using blood tests such as D-dimer blood tests, Cardiac Biomarkers and some imaging modalities like Doppler ultrasound, venography, Magnetic resonance imaging (MRI), computed tomography (CT). We have elaborately discussed the importance of emphasizing diagnostic yield and incidence of DVT, focusing on the risk factors available for DVT diagnostic and therapeutic techniques. The research addresses DVT incidence, diagnostic strategies, and therapeutic interventions; the efficacy of VR rehabilitation and treatment modalities; challenges related to artificial intelligence (AI)-based treatments; and explores the potential benefits of different game types in DVT management. This study aims to bridge the gap between research and real-time application by providing a wide range of strategies that comprise both basic and state-of-the-art techniques. It is a vital source for researchers and experts, providing perceptions into the effective development of advanced medical devices. The study concludes with a summary of point-of-care diagnosis, rehab therapy, and an exploration of various game types, providing future insights.**

***Keywords*—Diagnosis; DVT; game-based therapy; head-mounted display; rehabilitation therapy; virtual reality**

I. Introduction

A condition of blood clot formation in a deep vein is termed as Deep Vein Thrombosis (DVT). These blood clots sometimes occur within the lower legs, thighs, or pelvis; however, they will also occur within the arms. The common causes of DVT are blood vessel or venous injury from surgery and trauma, or inflammation from infections and injuries. DVT may be terribly serious, which may often result in the breakage of blood clots within the veins that can pass through the bloodstream and eventually block the arteries and end up in Pulmonary embolism (PE). Embolism may be severe and require immediate treatment. Fig.1 illustrates the formation of DVT in the calf muscles of the lower extremities. It develops mainly in elderly patients and is very rare in adults whose age is less than 30. Incidence of DVT is higher in women during their post-pregnancy period. It can be sometimes asymptomatic and hence not suspected. High-risk patients vulnerable to DVT include those with paralyzed, immobilized patients, bedridden patients, whether due to illness, surgery, or injury, face a higher likelihood of developing DVT due to prolonged immobility. People with recent injuries or traumatic conditions, particularly those affecting the lower limbs, and patients who have suffered a stroke are at increased risk due to impaired mobility and possible changes in blood flow. Stroke patients are similarly at risk because of reduced mobility and potential changes in blood flow. Musculoskeletal injuries, particularly ankle injuries, can contribute to the development of DVT. Elderly patients, especially those with additional risk factors like immobility or comorbidities, are particularly susceptible to DVT. And also COVID-19 can increase clotting due to its infection or usage of drugs. Cancer patients are also at elevated risk due to malignancy-associated hypercoagulability. If it is not diagnosed properly on time, it can lead to chronic venous disease or recurrent Venous Thromboembolism (VTE) and long-term consequences such as post-thrombotic syndrome and chronic thromboembolic pulmonary hypertension and cause heart attack and even death. DVT/PE, affecting an unknown global population, presents a significant concern. In the United States, approximately 900,000 people, at a rate of 1 to 2 per 1,000, may experience this condition annually. Alarmingly, the National Center on Birth Defects and Developmental Disabilities reports that DVT/PE leads to 60,000-100,000 fatalities among Americans each year, highlighting the substantial impact and public health implications of these vascular disorders [1]. Fig.2 shows the comparative demographic information between the age group and gender for both males and females with the help of the Centers for Disease Control and Prevention. The primary objective is to investigate and advance the understanding of diagnosis and treatment of DVT. It focuses on innovative diagnostic sensors, explores therapeutic interventions, and integrates Virtual Reality (VR) tracking games for ankle rehabilitation.

Primary causes of DVT include:

- Prolonged bed rest after surgery or treatment.
- Prolonged travel.
- Mild protein C deficiency.
- Blood clots due to hormonal replacement therapy and birth control pills.
- Ankle sprain or injury due to any traumatic condition.
- Cigarette smoking and Obesity due to an increase in the pressure of veins.
- Pregnancy and the post-pregnancy period.

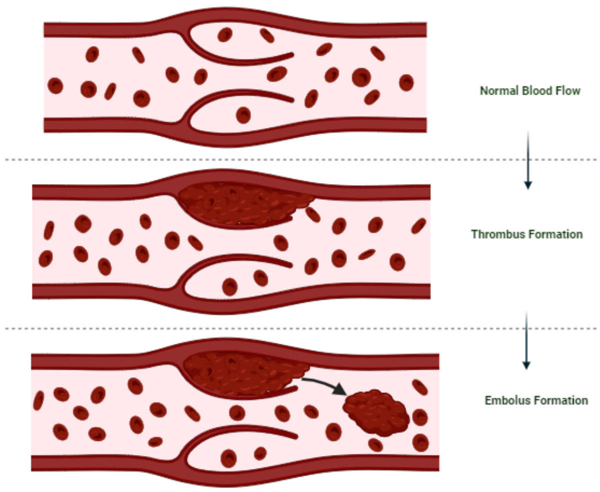

Fig. 1. Formation of DVT and PE.

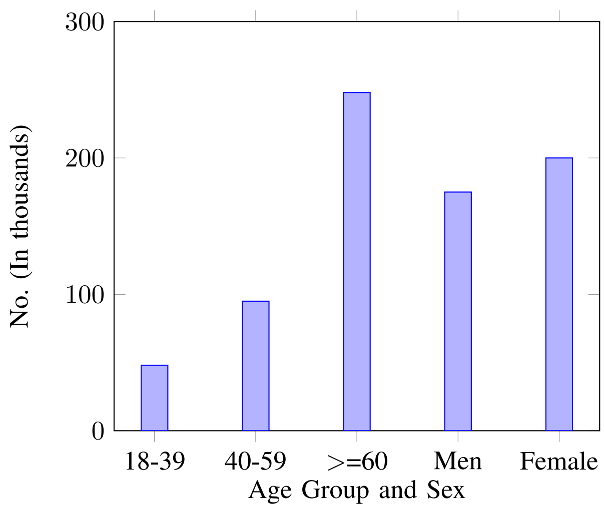

Fig. 2. DVT rate based on age and gender.

- General Anesthesia Surgery.
- Diabetes [2].

This study significantly contributes to understanding the progression of DVT through a comprehensive review of diagnosis and treatment strategies. It reviews existing invasive works, investigates survey findings, and gives an outline of a promising future scope. The discussion on DVT incidence and diagnostic yield, particularly emphasizing risk factors and clinical assessments of diagnostic sensors, enhances our knowledge in this critical medical area. The introduction of a VR tracking game for ankle rehabilitation devices provides an innovative approach to therapy engagement, addressing monotony issues in rehabilitation. Furthermore, the exploration of various game types (VR, augmented reality (AR), and artificial intelligence (AI)) and their benefits suggests a promising avenue for further investigation. The study highlights a gap in existing literature pertaining to the diagnostic aspects of invasive techniques and the specific integration of VR tracking games for ankle rehabilitation. Addressing these gaps, the study concludes with an endpoint summarizing the proposed advancements in understanding and addressing DVT, which may guide practical implementation and effectiveness of these proposed strategies.

The limitations and challenges in diagnosing and treating DVT conditions are significant:

- The existing system which involves detection of DVT using a light source is also an extra-corporeal technique.
- Early Detection: Identifying diseases early is challenging due to subtle or nonspecific symptoms.
- Imaging Accuracy: Variability in diagnostic imaging techniques.
- Accuracy of thrombolytic therapy diagnosis impacted by imaging methods, operator reliance, risks, and limited access to advanced technologies.
- Protocol Standardization: Lack of standardized diagnostic protocols across different healthcare facilities.
- Cost and Accessibility: Advanced imaging methods are expensive and less accessible in low-resource settings.
- Anticoagulation Management: Addressing difficulties in administering anticoagulant therapy effectively.
- Patient-related factors like immobility, body composition, prior medical conditions, anticoagulant therapy, and drug interactions also affect diagnostic accuracy.
- Individualized Treatment: Need for personalized treatment plans considering patient-specific factors.
- Resistance to Therapy: Managing cases where patients develop resistance to anticoagulant medications.
- Patient Compliance: Dealing with challenges related to patient adherence to long-term anticoagulation therapy.
- Complication Management: Difficulty in managing complications associated with DVT.
- Rehabilitation and Prevention: Improving rehabilitation strategies and preventive measures.
- Research and Development: Overcoming limitations due to limited clinical trials and slow adoption of innovative approaches.
- Technological Integration: Integrating new technologies into clinical practice effectively.
- Patient adherence, physical constraints, injury risk, resource demands, individual variations, costs, time limitations, limited long-term evidence, lack of standardization, and psychological factors.
- Consistent engagement in rehabilitation exercises is vital for severe DVT patients.
- Personalized treatment plans can be time-intensive and expensive.

Accurate diagnosis requires sequential clinical integration, functional assessment, pre-test clinical feasibility assessment, and confirmatory studies including D-dimer testing and diagnostic imaging [3]. Relapsed DVT is often suspected in patients who stop taking anticoagulants. Clinical symptoms can be confused with the development of post-thrombosis syndrome. Examining the direct imaging methods for thrombus formation using the ultrasound technique helps in the diagnosis of recurrent DVT and data monitoring [4]. According to the study by Tritschler, Tobias, et al. VTE management has improved significantly, enabling the diagnostic and therapeutic strategies tailored to the individual characteristics, preferences, and values of the patient who are prone to DVT [5]. Magnetic resonance direct thrombus imaging (MRDTI), which does not use intravenous contrast and has a 10-minute acquisition time, are used in distinguishing between acute recurrent DVT and chronic residual thrombotic DVT. The low incidence of VTE recurrence after negative MRDTI proves that MRDTI is a viable and reproducible diagnostic test [6].

Anticoagulants are medications used to treat DVT and PE, preventing clotting and thrombus growth. Heparin, low-molecular-weight heparin (LMWH), and warfarin are effective DVT reducers [7]. However, prolonged blood thinner usage can lead to risk factors such as bleeding susceptibility, menstrual bleeding, bowel movements, bleeding from the gums or nose, persistent bleeding, unusual bruising, and dizziness [8]. Despite various treatments, early identification of thrombus development is often lacking at the point of care. Increased awareness of risk factors and advancements in anticoagulant therapy have improved clinical evaluation and management of DVT patients. Direct oral anticoagulants (DOAC) are used to treat VTE and reduce bleeding factors. Increased use of agents like apixaban, rivaroxaban, dabigatran, and edoxaban also support the therapy [9] [10] [11]. Chopard et al. reported that DOAC are effective and reduces bleeding risk, but their high cost limits their use among some patients [12].

Adherence to Novel Oral Anti-Coagulants [NOAC dabigatran and rivaloxaban] on a large scale has an impact on Ischemic stroke (IS), major bleeding (MB), and DVT [13]. In multimodality therapy discussed by ZHAO, pharmacists addressed patients' drug treatment problems rationally, safely, and effectively. This study also showed that during pregnancy without thrombotic complications, the fetus was healthy and there was no recurrent thrombosis [14]. Atrial fibrillation (AF), DVT, and pulmonary embolism (PE) have been shown to be effective in the treatment of oral anticoagulant therapy and long-term persistence is highly associated with reduced adverse effects [15].

The quality of reports based on Randomized controlled trials (RCT) focusing on the use of anticoagulants rather than antiplatelet drugs for the prevention of venous thromboembolism remains inadequate [16]. Primary prophylaxis is the preferred mechanical method of using drugs to prevent DVT. Early detection with screening and treatment methods of asymptomatic DVT is a less commonly used approach. The study by Stubbs, M.J., Maria Mouyis, and Mari Thomas. outlines contraindications such as hemorrhage, coagulopathy patients, during surgery, thrombocytopenia and bleeding disorders, and discusses complications like renal failure and bleeding [17]. The systematic review summary provides basic results on the efficacy and safety of new direct oral anticoagulants (DOACs), thrombin inhibitors, and factor X inhibitors activated in DVT patients [18].

This work explores the diagnosis and therapy for early-stage DVT, with the thesis structured as follows: Section 1 provides a comprehensive introduction, delving into the strengths and objectives of our research about thrombus. Simultaneously, it reviews predominantly invasive pre-existing works, paving the way for a clear investigation into our survey and futurescope. In Section 2, the discussion shifts seamlessly to the incidence and diagnostic yield of DVT in patients with COVID-19, elaborating on associated risk factors. Moving to Section 4, we provide a brief description of the analysis and diagnosis of DVT, incorporating factors influencing both DVT and PE, as reviewed. Going on to Section 5, the focus is on clinical assessments of diagnostic sensors in DVT which are developed especially to perform conventional coagulation tests. Section 6 introduces dynamism, highlighting the creation of a VR tracking game for an ankle rehabilitation device to enhance therapy engagement and alleviate monotony from repetitive training. In Section 7, the study extends further, elucidating a list of screening and therapeutic interventions for DVT patients. Overall to AI-based Cogently guided treatment are discussed in Section 8. Section 9 will summarise our investigation about the point-of-care (diagnosis) and rehab therapy on the basis of the causes and signs, incidence and complication, rapid screening tests, designs, and evaluation, and furthermore, the types of games used and their benefits (VR, AR and AI). Section 10 discusses the future scope, discussing strategies to enhance non-invasive and non-contact therapeutic unit for early-stage DVT. Finally, Section 11 provides a conclusion to our work on DVT and its diagnosis and treatment approaches.

II. Point-of-Care Screening for DVT in Patients with COVID-19

A. DVT in Patients with COVID-19 and Methods of Diagonsis

The association between PE and DVT in patients with COVID-19 remains unclear, and the diagnostic accuracy of the PE D-dimer test is unknown. A study-level meta-analysis of PE and DVT incidence and an assessment of the diagnostic accuracy of the PE D-dimer test from multicentred individual patient data have been performed [19]. A single institutional study was conducted by Zhang, Li, et al. to assess prevalence, risk factors, prognosis, and potential thrombosis prophylaxis strategies at large referral and treatment centers. From January 29, 2020 to February 29, 2020, a total of 143 COVID-19 patients were tested. The prevalence of DVT is high and is associated with adverse outcomes in inpatients with COVID-19. Prevention of venous thromboembolism may protect patients with a Padua prediction score of 4 or higher after admission. The data presented indicate that COVID-19 is likely to be an additional risk factor for DVT among inpatients [20]. The prevalence of VTE in critically ill patients with COVID-19 is measured by venous ultrasound scanning of the lower extremities. A DVT screening on patients with five to ten days of admission revealed a 32% prevalence of VTE in critically ill patients with SARSCoV2 infection. 70% of the events occurred before the screening. Early screening may be effective in optimizing the care of ICU patients with COVID-19 [21].

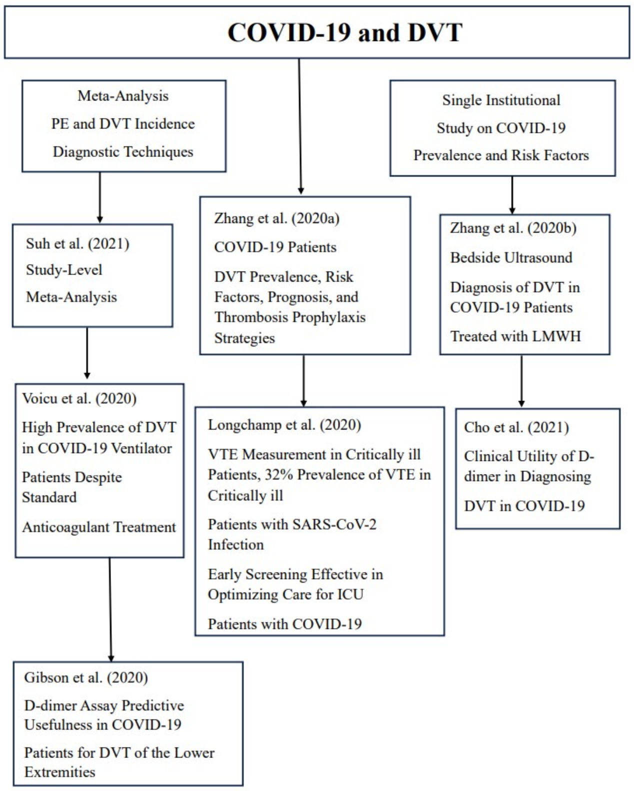

Fig. 3. Association between COVID-19, DVT, and PE: Major studies and findings.

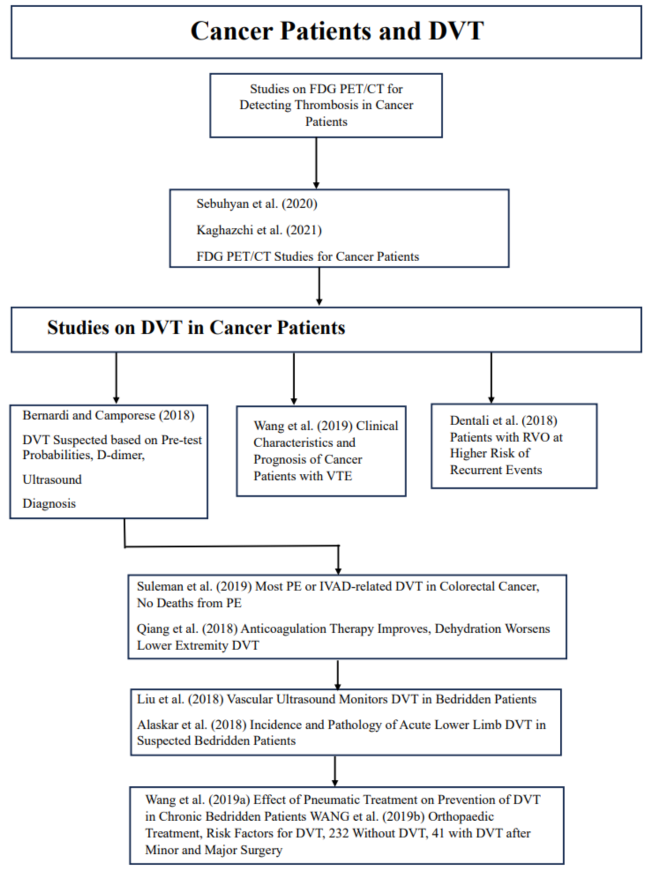

Fig. 4. DVT in cancer patients: Comprehensive studies and insights.

Despite standard prophylactic anticoagulant treatment, patients with SARSCoV2 ventilators have a very high prevalence of DVT, including a high proportion of potentially life-threatening proximal DVT. This indicates the need for close monitoring of DVT and more intensive risk/benefit assessment of anticoagulant therapy in this population [22]. Cho et al. studied the clinical utility of D-dimer in diagnosing DVT in patients with COVID-19, potentially limiting the need for duplex venous ultrasound examination [23]. The predictive usefulness of the D-dimer assay in patients with coronavirus infection 2019 syndrome for DVT of the lower extremities has been demonstrated [24]. They have evaluated the applicability of bedside ultrasound in the diagnosis of DVT in COVID-19 patients treated with low molecular weight heparin (LMWH) [25]. Fig.3 and Fig.4 simplified block diagram outlines the major studies and their findings addressing the association between COVID-19, DVT, and PE, as well as studies related to DVT in cancer patients.

B. Diagnosis of DVT in Patients with Cancer

Patients with cancer are at a significantly higher risk of VTE. Hence, studies were conducted to evaluate the ability of FDG (Fluorodeoxyglucose) PET/CT to detect thrombosis in cancer patients. It shows that thrombi in cancer patients can be detected before clinical symptoms by FDG PET/CT [26] [27]. DVT is suspected based on pre-test probabilities, D-dimer, and ultrasound diagnosis [28]. Wang et al. analysed the clinical characteristics and prognosis of cancer patients with venous thromboembolism. Incidental pulmonary embolism (IPE) in cancer patients is not uncommon. Most VTE events occur within the first six months after the cancer diagnosis, and nearly half of the deaths occur within the first three months after VTE diagnosis [29]. Patients with residual vein obstruction (RVO) are at a higher risk of recurrent events [30]. DVT patients had lower adverse outcomes, while cancer-associated DVT had serious and comparable outcomes. Further, understanding the lower risk of cancer-associated DVT could aid in designing non-invasive devices [31].

C. Lower Extremity DVT in Bedridden Patients

Liu et al. studies showed that anticoagulation therapy improves and dehydration worsens lower extremity DVT; Vascular ultrasound can conveniently and flexibly monitor DVT in the lower extremity of bedridden patients [32]. Alaskar et al. conducted a study to determine the incidence and pathology that increased the risk of developing acute lower limb DVT in suspected bedridden patients for lower limb Doppler ultrasonography [33]. Cao et al. investigated whether risk factors for DVT were affected by resting periods and identified different risk factors in groups with different resting periods [34]. The various pneumatic treatment for DVT/PE involves initial management, primary treatment, and secondary prevention. Initial management occurs within 5-21 days, primary treatment lasts 3-6 months, and secondary prevention extends beyond 3-6 months. Wang et al. investigated the effect of various pneumatic treatment times on the prevention of DVT in patients with severe chronic bedridden. Compression stocking may significantly increase thigh deep vein blood flow velocity, reduce the incidence of DVT, and not increase the incidence of skin pressure injury in chronic bedridden patients [35]. Using orthopaedic therapy, researchers studied and analysed the risk factors for DVT. Two groups of patients were treated with orthopaedic treatment, with 232 not having DVT and 41 having DVT after minor and major surgery [36]. Narkhede and Nageswaran developed a system that electrically stimulates the nerves that connect to the calf muscles, which can cause the legs to contract and relax, which eventually implies pressure on the veins and keeps blood flowing and helps prevent DVT [37].

III. Analysis and Diagnosis of DVT

The coagulation in porcine blood by using a micro-optical sensor has been evaluated by Liu, Qiang, et al. [38]. They developed an artificial blood circulating apparatus and a miniature optical sensor to conduct blood clotting tests and oxygen saturation tests respectively. Work done in [39], effectively recognized blood vessels in the body using thermal and near-IR spectral bands. Also, the spatiotemporal steps of heating the skin surface to determine the location of blood vessels beneath the skin surface were detected. A magneto-elastic sensor has been utilized in monitoring the therapeutic anticoagulants of the blood clotting stage which emits magnetic flux and can be detected by the viscosity changes during the blood coagulation of the rat's blood sample. The magnetoelastic sensor (MES) strip oscillates at a wide frequency range when it vibrates with a certain applied magnetic field at resonance frequency of the blood sample [40]. The time-dependent mechanisms of thrombus formation were invented and the non-contacting blood visualization of thrombus formation was developed by Matsuhashi et al. The team devised an optical coherence tomography system with a wavelength of 1330 nm to reduce the attenuation of light intensity by erythrocytes. 3-D image of a thrombus was developed after capturing 2-D images of thrombi, using a stereo-OCT system [41]. Also light reflection rheography (LRR) method was revealed for screening patients with suspected DVT. LRR is a non-invasive method to examine the DVT with the help of an IR beam, which detects the number of backscattered rays by indirectly measuring the amount of blood present in a volume of the skin. It relates that an increase in the amount of reflected light is an indication to the presence of less blood to absorb the incoming IR light. The LRR probe is effective and accurately gives results; however, it is not suitable for bedridden patients because suffers ankle edema, pain of the foot and ankle [42].

Kim, Young-Hoo, et al. investigated factors influencing DVT and PE after mechanical compression devices, determined the occurrence of DVT, analysed relevant factors, and examined the development of DVT and PE [43]. Artificial neural networks have been used to develop a system in which patients would be able to self-diagnose themselves for blood clots and it's type. This persuades the patient to proceed with further diagnosis [44]. The development of DVT in patients taking low-dose anticoagulant therapy for ischemic stroke has been summarized by [44]. To ensure quality, screening methods such as study selection, data extraction methods, and bias risk assessment were carried out using predetermined criteria [45]. The study analyzed the effects of antiplatelet and anticoagulant agents on DVT in 272 patients undergoing rehabilitation. After physical examination, symptoms such as blockages, swelling, skin redness, discomfort and pigmentation. D-dimer assay and venous duplex ultrasonography were used to diagnose DVT [46]. Raskob et al. discussed the importance of enhancing patient adherence to successful VTE diagnosis and the need for comprehensive DVT and PE observation to provide data on the prevalence, incidence, benefits, drawbacks, and applicability of different techniques [47]. According to Ren et al., there are various detection techniques that have been developed for multiple research applications. They are as follows: Measurement of force, stress, and strain; monitoring of various chemical indices; consideration of different biomedical parameters such as the degradation rate and force conditions of artificial bone; multiple physiological indices such as ammonia level, glucose level, bacteria growing factors, and sometimes even coagulation factors [48].

A lab-on-a-chip (LoC) system has been employed to determine blood coagulation time. The first is a vibrating fibre embedded in the data that performs as a mechanical resonance employing distant magnetic actuation, and the second is a pick-up fibre that serves as a photodetector [49]. Llenas et al. and his team laid the technological groundwork for a diverse platform capable of recreating the specific characteristics found in vascular malignancies. Vessel-on-a-chip microfluidic technologies have been used less often to investigate the unique characteristics and physiological functions of the vascular networks. This technology might be used to study the dynamic processes associated with vascular disorders or to screen new pharmaceutical formulations, among other things [50]. Table I examines the outcomes and precision of the developed systems designed for thrombus assessment.

IV. Sensors for Thrombus Detection

Imaging techniques in light and electron microscopy allow for unprecedented perspectives on blood coagulation. The 3D structure of clots formed from reconstituted prelabelled blood components was determined, which provided new information on the effects of clot contraction on erythrocytes [51]. Images of fluorescently labelled platelets were obtained in real-time during whole blood perfusion, whereas the global electrical impedance of the sample of blood was monitored simultaneously between a pair of specially designed gold microelectrodes. Optical and electrical data techniques were combined to analyse the thrombus formation and identify weakening and detaching platelet aggregates [52]. Table II evaluates the outcomes and accuracy of the developed systems for thrombus detection. Blood coagulation is essential to predict the risk of hemorrhage and thrombosis during cardiac surgical procedures. The blood coagulation process under temperature and hematocrit variations using a microfluidic chip has been analyzed. An analysis of the impedance change of a blood sample during coagulation was conducted by Lei et al. to determine the starting time of blood coagulation. They focused on developing valuable clinical equipment for routine coagulation tests [53]. Blood coagulation monitoring was based on

TABLE I. SUMMARY OF METHODOLOGIES, FINDINGS, APPLICATIONS, ADVANTAGES, LIMITATIONS, AND OTHER DETAILS FROM VARIOUS SOURCES

Paper	Methodologies	Findings	Applications	Advantages	Limitations	Other Details
[38]	Light reflection rheography	Noninvasive DVT screening	Screening for DVT	Noninvasive, simple test using light reflection	Limited validation data, may require further clinical trials	Test based on light reflection, potential cost-effectiveness
[39]	Optical imaging and analysis	Optical clot detection	Blood clot detection	High-resolution imaging, potential for early detection	Limited experimental evidence, scalability challenges	Focus on optical imaging techniques for clot detection
[40]	Ultrasound imaging	Ultrasound for DVT diagnosis	DVT diagnosis	Widely available, real-time imaging	Operator-dependent, unable to assess clot age	Emphasizes ultrasound as a diagnostic tool for DVT
[41]	Photopl-ethysmography	Investigates the potential of photoplethysmography in detecting DVT	DVT detection	Noninvasive, cost-effective	Accuracy affected by skin pigmentation, limited depth penetration	Explores the use of photoplethysmography for DVT
[42]	Light reflection rheography	Noninvasive DVT screening	Screening for DVT	Easy to perform, potential for widespread use	Limited clinical validation, sensitivity concerns	Focuses on a noninvasive test using light reflection
[43]	Near-infrared spectroscopy	Explores near-infrared spectroscopy for DVT detection	DVT detection	Noninvasive, potentially sensitive to clot composition	Limited depth of penetration, variability in signal interpretation	Focuses on near-infrared spectroscopy for DVT
[44]	Machine learning and ultrasound	Uses machine learning with ultrasound for DVT detection	DVT detection	Potential for improved accuracy, automated analysis	Dependency on high-quality data, interpretability of models	Combines machine learning and ultrasound for DVT detection
[45]	Contrast-enhanced ultrasound	Discusses contrast-enhanced ultrasound for DVT diagnosis	DVT diagnosis	Enhanced visualization of vascular structures	Contrast agent-related risks, cost	Emphasizes the use of contrast-enhanced ultrasound
[46]	Neural networks for blood clot detection	Explores the use of neural networks for detecting blood clots	Blood clot detection	Potential for pattern recognition, adaptability	Dependence on training data, black-box nature	Focuses on neural network applications for clot detection
[47]	Magnetic resonance imaging (MRI)	Discusses MRI for DVT diagnosis	DVT diagnosis	High-resolution imaging, multiplanar views	Cost, limited access, contraindications (e.g., metal implants)	Emphasizes the use of MRI for DVT
[48]	Ultrasonography and compression sonography	Compares ultrasonography with compression sonography for DVT diagnosis	DVT diagnosis	Real-time imaging, compression helps detect flow abnormalities	Operator dependence, limited by obesity or anatomical factors	Compares two diagnostic methods for DVT
[49]	Duplex ultrasound	Evaluates the role of duplex ultrasound in diagnosing DVT	DVT diagnosis	Simultaneous imaging, assesses blood flow and structures	Operator-dependent, limited for obese patients	Focuses on the effectiveness of duplex ultrasound for DVT
[50]	Machine learning and ultrasonography	Investigates machine learning with ultrasonography for DVT detection	DVT detection	Potential for automated analysis, enhanced accuracy	Dependency on data quality, model interpretability	Combines machine learning and ultrasonography for DVT detection

a micro-electromechanical film bulk acoustic resonator. The coagulation stages were indicated by comparing the frequency responses. Glycerin solutions were used to map the frequency-viscosity relationship. A commercial coagulometer was used to compare the measured consistency with the co-efficient of variation [54].

A study on concepts for customizing biomaterials' blood responses included many ways to either entirely exclude interaction of the target surface with blood components or control the reaction of the blood clots, platelets, and leukocytes. Antioxidative surfaces have been created with the goal of essentially mimicking the anticoagulant capabilities of epithelium by immobilizing heparin, which reflects some of these cells' anticoagulant properties, and coating surfaces with them to form the optimum blood compatibility of the device [55]. Ultrasonography (USG) with color doppler imaging can detect DVT. The risk factors, such as arterial hypertension, congestive heart failure, stroke severity, and level of consciousness were examined using USG by Bembenek et al. Their research revealed that DVT occurs most often in acute mild-to-severe stroke patients in medical environments. Patients with pre-stroke dependency and an elevated serum C-reactive protein (CRP) level are more likely to develop DVT, regardless of stroke severity. According to their research, it may be reasonable to give such patients extra attention and proper DVT prophylaxis to avoid thrombotic complications of life-threatening potential [56]. The color Doppler and pulse wave Doppler machines were used to examine DVT in patients with acute stroke, hemorrhagic stroke subtype, old age, severe stroke, and severe lower limb disability. This will aid in the early detection and intervention of silent DVT as well as the prevention of Pulmonary thromboendarterectomy (PTE) [57]. D-dimer cross-sectional studies were performed to estimate sensitivity and specificity using ventilation/perfusion (V/Q) scintigraphy, computerized tomography pulmonary angiography (CTPA), selective pulmonary angiography, and magnetic resonance pulmonary angiography (MRPA) [58]. Stephens has developed a contrast agent to identify clots in the AF of patients, which could be used to find thrombus in other parts of the body [59]. Pre and post-blood clot conditions by evaluating the actuation of the helical microrobot at a distance were analysed [60]. Fig.5 shows a schematic representation of thrombus visualization techniques. magnetomotive optical coherence tomography (MMOCT) is a new method for contrasting magnetic agents with high magnetic permeability to human tissue [61].

The magnetic actuation along with phase-sensitive optical monitoring of nanoscale displacements, mostly through MMOCT, was employed by Oldenburg et al. Their results proved that the MMOCT platform has applications for fundamental approaches to thrombus formation dynamics, which can be used to correlate clot viscoelastic behavior with erythrocyte activity and evaluate platelet efficacy as a hemostatic therapeutic intervention. Detection and assessment of blood clot elastic modulus using superparamagnetic iron oxides (SPIO-RL platelets) were major challenges [62]. Li et al. integrated coagulation factors, residence duration, and shear stress to enhance a thrombosis model. Simulation results, aligning closely with testing and observational data, identified vulnerable areas for thrombus development. This approach contributes to establishing effective therapeutic strategies [63].

V. AR, VR AND ROBOTICS IN DVT THERAPY

The functions and angles of the major human body joints are tracked and evaluated. Simple rotation movements around each joint's degree of freedom (DOFs) and the joint angles could be monitored. The angle of the upper limb and lower limb relative to the vertical direction has been determined by calculating absolute and relative angles [64]. A rotating position sensor and a min-max scaling (MMS) filter were utilised to analyse the finger isometric contraction and adduction/abduction movements. This helped to make the VR interaction possible. The position sensors were placed on the metacarpophalangeal (MCP) joints to control and enable hand motion-tracking. The performance is evaluated in terms of accuracy, latency, and finger length variations, and compared to existing method with immersive VR interaction methods [65]. Shin et al. investigated the incidence and risk factors for VTE in hip fracture patients with a delay of greater than 24 hours before surgery. The overall VTE risk and the median time from injury to CT scan were determined [66]. The effectiveness of a modular impedance controlled lower leg device in the rehabilitation of post-stroke hemiparesis was proven to be beneficial by enabling ankle robotic feedback training. This enhances chronic hemiparetic gait velocity and proprioceptive ankle impulse control. In addition to walking speed, accuracy, and smoothness, the effects of various types of feedback and reward on motor and cognitive performance

TABLE II. COMPARISON TABLE OF RESULTS AND ACCURACY OF DEVELOPED SYSTEMS

Reference	Method	Patients involved	Sensitivity	Positive predictive value	Negative predictive value	Accuracy	Result
[42]	light reflection rheography (LRR)	61	96.4 %	79 %	97.1 %	98.8 %	Simple 10 minutes diagnostic method with high sensitivity and negative predictive value.
[43]	mechanical compression device	874 patients (1434 knees)	93.2%	77%	88.2%	94.6%	No thrombi and PE after 6 months of treatment.
[44]	'nftool' software system	360 samples	96.7%	89.4%	96.7%	99.99 %	Type of blood clot disease identified .

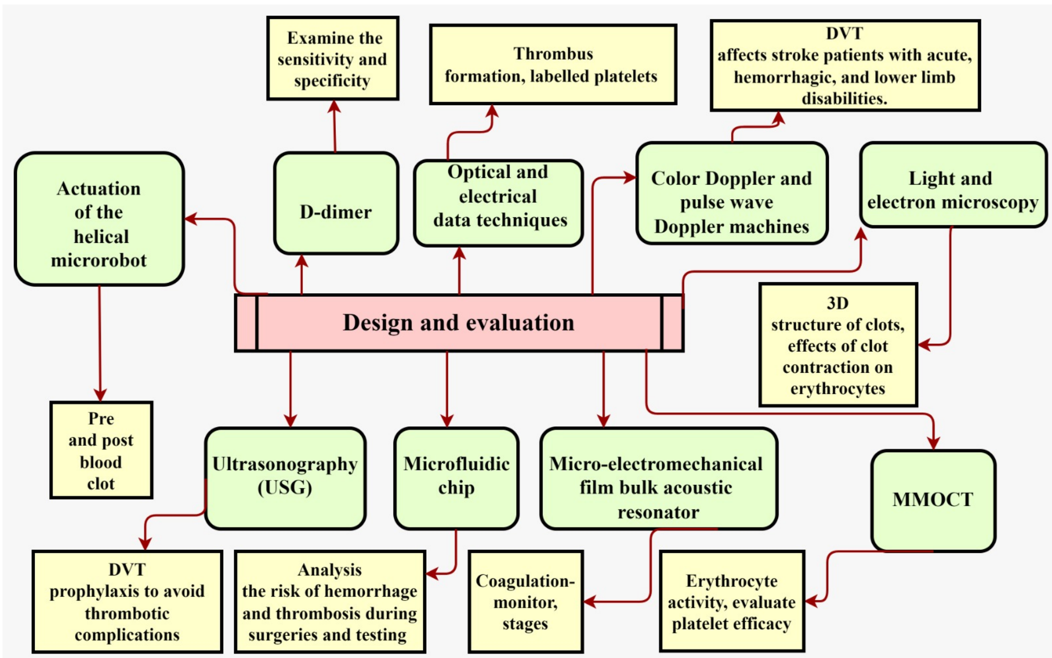

Fig. 5. A simplified block diagram of the assessment of DVT diagnostic techniques.

were explored [67]. Monaco et al. developed the robotics NEUROBike for neurorehabilitation to assist bedridden post-stroke patients to recover their walking abilities, particularly by observing the mechanical structure, control architecture, and kinematic models implemented in the control algorithm [68]. Ahn and Hogan performed the realistic analysis of a robot-assisted motion that utilised the spontaneous kinetics of walking while simultaneously facilitating the patient's performance rehabilitation [69].

Low et al. developed a robotic ankle exercise support (robotic arm sock) for stroke patients at high risk of developing DVT. In stroke patients, the device was tested with traditional treatments, an intermittent pneumatic calf pump, and ultrasound Doppler. Investigation revealed that the soft extension actuators in our soft robotic sock could provide enough tensile force for ankle actuation. The robotic sock device was also shown to improve femoral venous blood flow in the ipsilateral limb [70]. After total knee arthroplasty (TKA), the incidence of thromboembolic and hemorrhagic disorders were analysed by Hamilton et al., while employing mechanical prophylaxis and preoperative risk evaluation. Mechanical prophylaxis, was effective for low-risk patients. This includes audio/video (AV) impulse lower extremity, compressive stockings, and early ankle mobility. Medications were only given to the patients who were at high risk. The mechanical treatments based on risk stratification were evaluated to ensure that they are both safe and effective after TKA [71]. Silva et al. evaluated the state-of-the-art ankle-foot orthoses utilising additive manufacturing. Their work suggested that evaluating the employed production techniques, customisation phases, mechanical qualities, and bio-mechanical aspects in humans would give vital insights for future study [72].

A. Proprioceptive Home Rehab

Ren et al. designed and developed a prototype for intensive passive and active movement training in acute or haemorrhagic stroke patients. Early in-bed rehabilitation improved neuroplasticity and helped patients develop motor controllability to enhance dorsiflexion motion, according to their studies [73]. Pasqual et al. proposed the gaming environment for ankle movement in two DOFs. The game is similar to classic Pong with slight changes. The two-player options are also given. The game was tested on healthy subjects and showed that it helps in ankle rehabilitation therapy. It is critical to recognize the calibration of dorsiflexion new ankle movement and to improve the low impact on the control factors [74].

Researchers investigated the viability of framework rehabilitation robots. According to their research, platform-based robots used in rehabilitation have some promising outcomes. Of all the types of these robots, the immersive VR-based Rutgers Ankle and the Hunova were identified as the most effective ones for the therapy of individuals with neuropsychological issues and certain other musculoskeletal ankle injuries. However, the challenge lies in accurately assessing the efficacy of platform based robotic rehabilitation systems [75]. Developing a VR tracking game for an ankle rehabilitation device make the therapy more engaging and to remove the monotony from the repetitive training. This game was tested on five healthy volunteers, providing two DOF. It was a simple game that has proven to be very effective in ankle rehabilitation [76]. Agyeman and Al-Mahmood developed wearable technology for patients with limb disabilities. The design focuses on three attributes: ensuring proper device connection, managing the connection status for server communication, and generating a server ID or IP address. A microcontroller processes sensor data transmitted via Wi-Fi to the server using web applications. The server imports data into its database, facilitating management of the gaming environment [77]. Table III scrutinizes remote assistance and its impact on enhancing the quality of patients' lives.

A new rehabilitation method created by J. A. Garcia and K. F. Navarro to improve the effectiveness of three games to promote ankle rehabilitation has been described. The provisioning and ongoing real-time monitoring of the mobile augmented reality (MAR) reinforcement networks, which aid in enhancing motion range during the training phase, are observed. These games are reported to improve overall balance restoration, mobility, and muscle strength [78]. Burdea et al. conducted a case study on the effectiveness of game-based lower leg rehab for children with cerebral palsy (CP). They found that robotic ankle training games improved gait by triggering specific gaming sequences for patients' ankle motions, thereby enabling the development of smart gaming structures for rehabilitative devices [79].

Rugsters ankle CP has been shown to be effective in providing ankle strengthening treatment and increased control for children suffering from CP. A significant improvement in ankle kinetics, efficiency, and persistence has also been observed in gait performance [80]. The task based VR gaming simulations are used to assess a rehabilitation approach that simultaneously exercised the upper extremities. They are developed with virtual targets in interactive entertainment by neural control mechanisms [81]. Alexandre and Postolache created a set of artificial smart gloves that allow for real-world interactions with therapeutic gamification for upper extremity rehabilitation. Using the Bluetooth wireless communication protocol, the processor of the Arduino Nano embedded platform is interconnected to the sensing part [82]. The quality of motor rehabilitation by involving patients in their training schedule was reported to be improved. An intuitive user interface based on the Leap Motion Controller was uesd to operate a 3D gaming engine. By using real data from neuromuscular rehab, it could allow therapists and patients to determine the proper motions. Moreover, VR offers patients an easy-to-use and customizable way to analyse data, which may be used for brain stimulation or treatment [83]. Do et al. designed a soft pneumatic robotic glove to assist stroke patients. Silicone platinum is used to create the soft actuator material. By controlling the air pressure inside the fingers, it can handle the force, bending angle, and fast response time [84].

B. Immersive VR-based Ankle Rehab

Borghese et al. designed a video game to adhere to clinical requirements and meet the doctors' and patients' expectations by monitoring patients at various stages with therapists' support [85]. An SVM classifier and pressure distribution data have been used to analyze compensatory pattern recognition in stroke patients during robotic neurological rehabilitation. Real-time observation using pressure data aims to minimize torso compensation. Analysis of data from robot-assisted stroke patients determines the effectiveness of haptic feedback in reducing compensation during tasks [86]. An interactive home-based rehabilitation system for patients who recover from knee replacement surgeries has been developed and tested. The patients' progression with the help of wireless inertial sensors was examined by the therapist, using triple axial magnetometer, and accelerometer [87]. Kyto et al. developed the supportive haptic device for providing the therapy for the stroke patients in a household environment and customising and motivating their activities [88]. The joint movements in both forward and inverse kinematic models at different angles are evaluated as motion controls. Measurements and recordings are made in real-time for rehabilitation training and assessment of haptic interactive tasks, aiding in the design and proposal of rehabilitative devices [89].

C. Immersive AR-based Ankle Rehab

An intelligent user interface has been developed that enables people to perform rehabilitation exercises on their own while being supervised offline by a therapist and healthcare providers. A sleeve AR is a novel approach to real-time, active feedback that employs multiple projection surfaces to provide effective visualizations. It provides patients with appropriate guidance and enables them to implement their rehabilitation training autonomously and is capable of recreating simple arm movements easily by mimicking the therapist's movement patterns [90]. Condino et al. developed the first wearable AR and was introduced in an application for shoulder rehabilitation based on Microsoft HoloLens and highlighting real-time markerless tracking of the user's hand. WiFi802.11ac and Bluetooth 4.1 LE wireless technology was applied in providing network connectivity. The Virtual Magnetic 3D Cursor is a custom script that was created to provide a hand-controlled cursor for our AR rehab gaming app [91]. Park et al. in their research proved that the following two factors have to be ensured for effective implementation of AR innovation for telemonitoring-remote assist guidance;improving patient's health [92].

D. Other Modalities to Sense and Rehabilitate with DVT Rehabilitation

Rehabilitation therapy is provided to patients with hemiparetic CP by combining physical exercises with a variety of video games. The information is evaluated and analysed based on the performance and progress of the collection of the data [93]. Sadihov et al. developed a technique for immersive rehabilitation with haptic feedback in VR. They introduced a system combining Kinect and a haptic glove, designed using

TABLE III. EVALUATIONS OF CLINICAL FINDINGS

Study author(s)	Type of study	Number of patients	Treatments involved	Primary outcomes and endpoints
[73]	Clinical study	10 Participants	Rehabilitation - Wearable robotic device.	Improve motor function.
[74]	Original study	N/A	Therapeutic Intervention- Game Communication.	Assists ankle movement.
[75]	Systematic Review	156 Subjects 26 studies	N/A	To prove that platform-based robotic rehabilitation systems are effective.
[76]	Original study	5 Participants	Rehabilitation-VR based robot.	Improve the ankle movement.
[77]	Original study	N/A	Wearable technology - early stage of the injury.	Helps to improve the stroke patients upper and lower limb.
[78]	Original study-Comparative review	N/A	Mobile Augmented Reality - home-based rehab.	Deliver the training exercises for ankle sprain.
[80]	Case study	7 year old boy with CP 36 sessions	Robot controller - Rutgers Ankle.	Improving the quality life of children with CP.
[81]	Original study	12 Subjects	Robotic rehab - gaming simulations for hemiparesis.	Haptic assistance.

Unity3D and OpenN. The interactive haptic rendering algorithm enhances integration, offering patients motion-dependent haptic feedback during rehabilitation exercises [94]. Weber et al. developed a humanoid robot to showcase human-robot interaction. The sensor glove uses an inertial measurement unit (IMU) to measure movements and orientation, which will aid in the design and proposal of rehabilitative devices [95].

In the rehabilitation process, 3D motion capture sensors were used to analyse clinical parameters such as the angle of inclination of the neck, arm, forearm, posture, pushing force at the foot, and so on [96]. Ambient Assistance Living (AAL) refers to a set of intelligent environmental techniques, methods, and technologies that enable the elderly to live independently without being bothered by intrusive behavioural patterns [97]. Rego et al. designed a serious gaming platform that includes features such as natural and multimodal user interfaces, competent. This was implemented to boost patients during cognitive rehabilitation. Motion capture systems, haptic technology, and a biofeedback network was used to track and measure the DOF [98]. To improve motor learning and generalization to other tasks, as well as promote occupational practice in a more contextually relevant environment, there has been some controversy between VR and AR [99]. Mekbib et al. showed that VR-based therapeutic systems could enhance motor functions in stroke patients during physical therapy. This technology has been an ideal technique for contributing to the design and development of rehabilitative devices, ultimately assisting in the formulation of rehabilitation strategies [100]. Clothing-based rehabilitation and assistive devices can achieve high DOF and complex movements, benefiting from the direct guidance and attachment to human bodies. Flexible piezoelectric materials (polyvinylidene difluoride (PVDF)) are successfully used as sensing elements in rehabilitation and assistive devices [101]. Wang, Yanzhuo, et al. introduced an innovative cable-driven lower limb rehabilitation robot (CDLLRR). This advanced system was capable of effectively assessing the characteristics of gait movement, system stability, position tracking, and feasibility, thereby significantly contributing to the improvement of rehabilitation strategies [102].

E. Performance Measures for Rehabilitative Devices

The performance measures in stroke rehabilitation are primarily concerned with the process of care, specifically prevention, assessment, education, treatment (setting selection, and treatment standards) [103]. Fig.6 shows that comparative diagram of observation and screening methods used for DVT patients. Using different sensors, therapists accurately estimated patients' rehabilitation status, enabling them to create a follow-up treatment plan. This allows them to control location and movements in a virtual space, improving mobility and rehabilitation strategies [104]. The fuzzy control algorithm is capable of detecting an emergency, such as a rapid muscle spasm or twitch, and stop the robot immediately to prevent further harm to the impaired limb in case of emergency [105]. A multistage rehabilitation robot, specifically designed for hemiplegic lower limbs, has been developed to augment both tracking performance and motion control, thereby playing a significant role in the advancement of rehabilitation strategies [106]. Khalid et al. designed a simple and light rehabilitation device with low inertia and a less threatening design to enhance its mobility. Motor learning and ankle plasticity in patients with dropped ankles were promoted using such systems [107].

Zhou et al. developed a robot-assisted gait training platform with a human-computer interaction interface, where electromyography signal, joint torque, and joint angle were acquired. The effects of the robotic system's neuromuscular facilitation rehabilitation technique were investigated [108]. The patient's participation during rehabilitation training was encouraged [109], where a fuzzy algorithm was employed to change the impedance factors that influenced the human exoskeleton interface torques. For the swing phase of the training, an adaptive impedance control-based patient cooperative rehabilitation training strategy was used. Niikura et al. reported the prevalence of VTE being followed by complex lower-limb fracture surgery without pharmacological prophylaxis. Contrast-enhanced imaging can detect PE and is thus routinely used in high-risk patients with significant injuries or pelvic and acetabular fractures [110]. Dao and Yamamoto examined the safety of AIRGAIT, a gait-training robotic orthosis. They categorized frequent system issues into sensor failures, actuator malfunctions, and power supply interruptions. Their proposed control system identifies failures and applies techniques to reduce accident risks [111].

Ultrasonography is used to assess the effects of Electrical muscle stimulation (EMS) on venous blood flow in the lower extremity of ICU patients. Each method of prophylaxis has drawbacks, and none of them completely prevents DVT. EMS may be a new and effective method of preventing DVT in in-patients [112].

A modified computed torque controller has been proposed to improve the tracking performance based on a mathematical model with two DOF. The use of actuator configurations based on the human musculoskeletal system provided the system with more power and redundancy [113]. Robot-administered therapy, including classroom therapy, back-drivable robots, and sensorimotor training, are key technologies for reducing impairment and facilitating the development of rehabilitative devices [114].

It is highly effective to restore joint range of motion, mus-

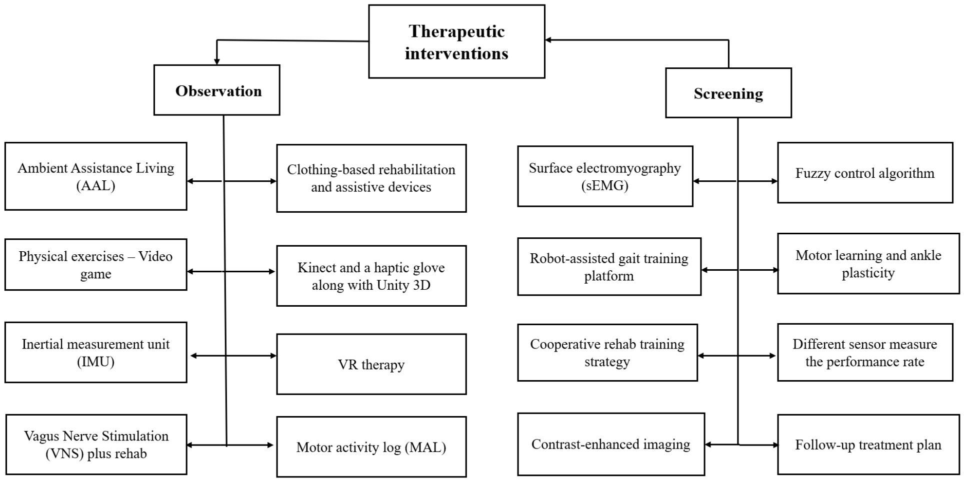

Fig. 6. Observation and screening strategies for DVT patients.

cular strength, neuromuscular coordination, and gait analysis in patients suffering from various foot and ankle problems [115]. Ren et al. addressed the implementation of a wearable ankle robotic platform for intensive active and passive gait analysis for acute stroke patients. To assist the patients with motor relearning, the isometric torque generation mode with real-time feedback was used. Here the wearable robotic device extended the ankle efficiently and safely throughout its range of motion, all the way to the extreme of dorsiflexion [116]. Table IV illustrates the comparative methodologies utilized in different techniques. The patient transmits control signals to the device and the exoskeleton provides the majority of the mechanical power required to complete each task. The decrease in mid-lateral forces could indicate the capacity to improve a much more physiological gait while trying to prevent lateral movement [117].

F. *Cogently Guided Treatment for Recovery*

Roy et al. investigated the ankle stiffness, ankle sprains, and plantar fasciitis estimation which served as valuable asset for locomotors rehabilitation to improve ambulatory performance. The characteristics of sensorimotor function, gait analysis, stability, and motor function were evaluated by providing a customizable, adaptive, and quantitative assessment and rehabilitative tool [118]. The centrosymmetric analysis also showed that the hip and knee joints were affected by the illness in terms of interlimb coordination, but the ankle joint appeared to be largely unaffected from this perspective. The current study assessed healthy volunteers who were age and gender matched, and also utilized 3D computerized gait analysis to do point-by-point assessments of thigh and ankle joint angle changes [119].

Logistic regression analysis was used to investigate the various causes of postoperative PE, to identify perioperative risk factors associated with them, and to examine the effect of combining fondaparinux with mechanical prophylaxis on the prevalence of PE following total hip and knee arthroplasty [120]. An optoelectronic monitoring system is used for measuring thrombus formation, contraction, and size. These are computationally converted into a kinematic contraction gradient that can be evaluated [121]. A model for game generation was created for ankle rehabilitation that effectively addressed gamification, how the patient feels about the game, and visual observation of lower extremity practices that have already evolved, and adapts the game using a statistical methodology [122].

The study analyzed user performance and system usability in a 3D game-based rehabilitation system, aiding in the design and development of rehabilitation devices.

[123]. The ankle joint mechanism and control system using a series of elastic actuators based on the double tendon sheath transmission mechanism and torsion spring has been described by [124]. Girone et al. developed the World Tool Kit for deformities in lower limb rehabilitation, which is run on a computer system. This controls the device's gestures and output forces through the use of an RS232. The diagnostic functions such as evaluating the ankle's range of motion, effectively forcing exertion capabilities, and synchronization were performed [125].

VI. Comparative Summary

The aetiology of DVT is asymptomatic, and its major causes are high morbidity and mortality. The paper summarizes the techniques based on randomised controlled trials (RCT) focusing on the use of anticoagulant therapy, a D-dimer blood test, duplex ultrasound, venography, an MRI scan, compression stockings, prophylaxis strategies, and an optical coherence tomography system. A scalable technique to access the efficacy of evidence-based vulnerable therapy.

The main intention is to compare the existing works on the basis of causes and signs, screening tests, designs, and evaluation. Furthermore, the types of games used and their benefits (VR, AR, AI, robotics, assistive and wearable devices). Several research articles have been pubished so far on the diagnosis of DVT in the medical field, mostly invasive and also as an extra-corporeal technique. To evaluate the approach's

TABLE IV. Comparison Table of Methodology Involved in Various Rehabilitation Therapy

Reference	Method	Result /Values	Method involved
[65]	Low-latency haptic open glove (LLHOG)- Immersive VR interaction.	For flexion/extension, the average mean Absolute error (MAE) was 3.091; for adduction/abduction, it was 2.068.	Diagnostic techniques.
[76]	Game developed for ankle rehabilitation.	More intuitive movements of patients.	Rehabilitation therapy.
[77]	Wearable devices, games, IOT.	Stroke patients are assisted by gaming and wearable technology.	Rehabilitation therapy.
[78]	Mobile RehApp	Assisted physiotherapists and patients on ankle sprain rehabilitation.	AR Rehabilitation therapy.
[79]	Rutgers Ankle CP system.	A game-based robotic ankle training can enhance walking in children with CP.	VR Rehabilitation therapy.
[81]	Robotic-assisted arm training devices.	Upper extremity function of post-stroke patients is improved.	Robotically-assisted therapy.
[82]	Fabrication of a soft pneumatic finger- 3D model in CAD software.	Stroke patients supported by the fabrication.	Rehabilitation equipment.
[91]	Wearable AR application for shoulder rehabilitation, based on Microsoft HoloLens, with real-time markerless tracking of the user's hand.	20 healthy subjects were involved rehabilitation was provided by head-mounted displays (HMDs).	AR Rehabilitation therapy.
[94]	Expandable immersive VR platform -gesture based tactile rendering algorithm.	Interactive vibration patterns focused on the user's movement that improve immersion and generate sensory perception during rehabilitation therapy.	VR Rehabilitation therapy.
[100]	VR-based therapy systems.	Motor function of stroke patients is improved.	VR Rehabilitation therapy.
[116]	Wearable robotic device.	The patient is guided and inspired to participate actively in movement (extreme dorsiflexion training via game play).	VR based bed rehabilitation therapy.

feasibility, game-specific performance data from patients is collected and utilised to build a trained machine learning algorithm. The designed games allow for the unhindered evaluation of a patient's performance in a therapeutic environment. The proposed system permits remote follow-up assessments to be performed in a more convenient and user-friendly way.

Due to our consistent hypothetical and problem identification, the diagnostic techniques available for DVT in the medical field are mostly invasive. The existing system, which involves detection of DVT using a light source, is also an extra-corporeal technique. There are lots of therapy techniques available for DVT to ensure constant movement of the lower limb for a particular time period. However, these methods are monotonous and stressful.

VII. Discussion and Future Directions

Directions to advance the field of DVT diagnosis and improve patient rehabilitation: The current methods for diagnosing and treating DVT have limitations such as compatibility, accessibility, reliability, and accuracy. Advances in imaging modalities offer the potential for early detection. Combining these with new diagnostic tests and point-of-care techniques could lead to a more effective and accessible diagnosis. A new strategy emphasizes early identification and detection to improve patient outcomes and timely intervention. Future directions include advanced imaging practices, machine learning frameworks, long-term studies, IoT integration, early identification frameworks, real-time data, and rehabilitation through games. These developments aim to improve patient healthcare.

VIII. Conclusions

This review summarises our investigation of the diagnosis and rehabilitation therapy of DVT: causes and signs; incidence and complication; interpretation and prediction; rapid screening tests and designs; observations and evaluation; and furthermore, vulnerable and scalable therapy. This study focuses on DVT and its diagnosis and treatment methods; several research articles have diagnosed DVT on the basis of extra-corporeal techniques, which involve the use of anticoagulant therapy, a D-dimer blood test, duplex ultrasound, venography, an MRI scan, compression stockings, prophylaxis strategies, and an optical coherence tomography system. Current methods for diagnosing and treating DVT have limitations, but advances in imaging modalities and new diagnostic tests could improve early detection and patient outcomes. Future directions include advanced imaging practices, machine learning, long-term studies, IoT integration, early identification frameworks, real-time application, and rehabilitation through VR and AR games.

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