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Multidimensional Convolutional Neural Networks (CNNs) and Large Language Models (LLMs) for Classification of Varicose Veins and Associated Chronic Diseases

Darshan P R[1], Roopa D M[2], Thriveni S K[3], Anitha A B[4]
Dept of Computer Science, PES Institute of Advanced Management Studies, Kuvempu University

Abstract: Varicose veins (VV) and chronic venous diseases (CVD) affect a significant portion of the global population, often leading to pain, edema, and in advanced cases, ulceration. Accurate classification of disease severity is essential for timely intervention and optimal treatment planning. This study proposes a novel multimodal framework that integrates multidimensional Convolutional Neural Networks (CNNs) and Large Language Models (LLMs) for the automated classification of varicose veins and related chronic conditions. The CNN module is designed to process high-resolution vascular imaging data, including Doppler ultrasound and venography scans, while the LLM component analyzes unstructured clinical text such as physician notes and electronic health records. The fusion of visual and textual features enables robust classification based on the CEAP (Clinical-Etiological-Anatomical-Pathophysiological) system and ICD-10 codes. Experimental results demonstrate that the proposed hybrid model outperforms unimodal approaches in terms of accuracy, sensitivity, and clinical relevance. This research highlights the potential of deep learning-based multimodal systems in enhancing diagnostic precision and decision support in vascular medicine.
Keywords: Convolutional Neural Network, Varicose veins, Large Language Model, F1-score, Accuracy

I. INTRODUCTION

Chronic venous diseases (CVD), including varicose veins (VV), represent a prevalent group of vascular disorders that impact quality of life and can progress to severe complications such as skin changes, venous ulcers, and deep vein thrombosis. According to epidemiological studies, up to 30% of adults may develop varicose veins during their lifetime, with higher incidence in older populations, women, and individuals with sedentary lifestyles or a family history of venous insufficiency. Early diagnosis and accurate classification of disease severity are crucial for effective management, yet clinical assessment often relies on subjective interpretation of symptoms and imaging findings, which can lead to variability in treatment outcomes.

To standardize the diagnosis and staging of CVD, the CEAP (Clinical-Etiological-Anatomical-Pathophysiological) classification system is widely used. However, applying CEAP accurately requires comprehensive evaluation of both imaging and clinical history, making automation challenging. Traditional machine learning approaches have demonstrated some success in vein segmentation and reflux detection using ultrasound and venography, but they typically depend on hand-crafted features and struggle to generalize across diverse patient populations and imaging protocols. Recent advances in deep learning have transformed medical imaging analysis, particularly through Convolutional Neural Networks (CNNs), which have shown exceptional performance in tasks such as classification, detection, and segmentation. In parallel, the emergence of Large Language Models (LLMs), particularly those pre-trained on biomedical corpora (e.g., BioBERT, ClinicalBERT), has enabled effective extraction of diagnostic insights from unstructured clinical texts, such as physician notes, electronic health records (EHRs), and referral letters. Despite their individual strengths, limited research has explored the combined use of CNNs and LLMs for the multimodal classification of vascular diseases.

This study proposes a novel hybrid framework that leverages the complementary strengths of multidimensional CNNs and LLMs to classify varicose veins and associated chronic venous conditions. The CNN component processes multidimensional medical imaging data—including Doppler ultrasound and MR/CT venography—by capturing both spatial and, where applicable, temporal features of venous flow and structure. Meanwhile, the LLM module extracts contextual information from patient records, such as symptom progression, family history, and previous treatments, enabling a richer understanding of disease presentation beyond imaging alone.

The integration of these modalities is achieved through a late-fusion architecture, combining image-derived and text-derived feature vectors to produce a unified classification output aligned with CEAP stages and relevant ICD-10 diagnostic codes. By training and evaluating the model on a curated multimodal dataset, we assess its performance against traditional single-modality baselines and investigate its clinical interpretability using attention and saliency-based methods.

Our contributions are threefold: (1) We develop a multidimensional CNN tailored to vascular imaging, capable of capturing complex vein morphology and flow patterns; (2) We fine-tune a domain-specific LLM to extract relevant clinical insights from unstructured text; and (3) We propose a multimodal fusion approach that enhances classification accuracy and robustness for CVD staging.

This research aims to assist vascular specialists and general practitioners in making more accurate and consistent diagnostic decisions, ultimately improving patient outcomes and reducing the burden of chronic venous diseases. In addition, our methodology lays the groundwork for future applications of multimodal deep learning in other areas of vascular and chronic disease management.

II. LITERATURE REVIEW

[1] The goal of this project is to create an easy-to-use and reasonably priced screening tool for varicose vein monitoring and early detection. A carefully selected collection of varicose vein photos was used to train a proprietary deep learning model, which classified the images as either "Normal" or "Varicose." A large dataset that was separated in training, testing, and validation was used to verify the model's efficacy. Additionally, the device uses laptop cameras to detect varicose veins in real time, giving prompt visual feedback for prompt action. Long-term monitoring is added to its real-time functionality, making it a useful tool in both clinical as home-based applications. By facilitating early intervention into varicose vein management to improve healthcare results, the suggested approach complies with contemporary healthcare standards.

[2] When blood circulation in the leg veins is impaired, a persistent condition known as varicose veins develops. This results in issues with the flow of blood from the legs to the heart. Blood accumulates in the veins of the legs, a condition known as stasis, which causes blood to flow backward and harm the valve. Long periods of sitting or standing, aging and limited mobility are a few of the primary causes of this chronic illness. Additionally, the expense of treatment is excessive. When this issue is identified early, it can be readily remedied, which will make the patient feel less stressed and in discomfort. In order to help the doctor and recognize the various stages of varicose veins, deep learning techniques are crucial for early prediction. Here, the suggested model, which was created using a multidimensional deeply convolutional neural network, performs better than a doctor's diagnosis and has a 99.9% classification accuracy for the various stages of CVI, allowing for the patient to receive the proper care.

[3] To accurately diagnose a condition, the medical industry needs a large amount of data either the form of text and photographs. Faster analytical techniques made possible by data science are useful for making various drug and safety-related decisions. The condition known as varicose veins is brought on by swollen or twisted veins inside the leg that appear blue or black. To diagnose the twists and obstructions, a test such as color Doppler ultrasound is required. This test provides precise photographs of the locations of the legs' opposing blood flows. In order to help doctors diagnose diseases effectively and rapidly, medical representation analysis and classification require a series of sequential operations. Color Doppler ultrasound test findings are more precisely analyzed using convolutional neural networks (CNNs). Another data science innovation that offers far better insights into the intricacy of vein twists is medical image segmentation. For many people with varicose veins, data science has offered promise for a quicker diagnosis and recovery from the condition as well as a cosmetic remedy. It mostly use laser therapy as a less invasive method.

[4] People are become more sedentary in today's environment, which causes them to be less active. People who stand or sit for long periods of time may potentially develop varicose veins. A varicose vein, which is an inflammation that affects vascular epithelial cells, results from this increase of tension on the leg vein. Additionally, they arise when the legs' vein valves weaken, allowing blood to flow concurrently and producing discomfort. Among the effects of varicose veins are being overweight, hormonal changes during menstruation or pregnancy, and extended periods of standing or sitting. To reduce the discomfort caused by varicose veins, an innovative system is needed that processes positional data in the microcontroller after analyzing it using a range of sensors. In order to reduce varicose vein pain, this research presents a new approach that efficiently combines thermal with vibration therapy while using the fewest possible components.

[5] Experts can find, identify, and segment items in many medical picture types, including MRI, CT, and ultrasound (US), with the aid of image analysis, a crucial approach. In this study, we segment and locate varicocele, or swollen veins in the pampiniform venous plexus, using US images. The purpose of the suggested approach has to ascertain whether or not a prospective patient is impacted. Ninety US pictures of the left testicles of ninety patients in the supine position were used to assess this approach. Three steps contribute to this system's analysis of US images: preprocessing, processing, and edge identification. Otsu segmentation was

used to identify the Region Of Interest (ROI) of the pampiniform plexus region using several color modes (RGB, YCbCr, and Grayscale) and parameters (0.1, 0.2, and 0.17). Various denoising filters were employed during the processing phase. Four edge detectors — Canny, Soble, Prewitt, and Roberts—were eventually used in the edge detection stage. The results indicate that using the YCbCr color mode yellow (y) channel with 0.1 Otsu segmentation and the Canny edge detector produced the best varicocele detection accuracy of 78%. With a specificity value of 39% and a sensitivity of 91%, the system was also able to identify 91% of the individuals with varicocele.

[6] Based on the phenotypic status of vascular smooth muscle cells (VSMCs), varicose vein formation was recently attributed with an architectural remodeling of the venous channel wall. In this study, we first showed that individuals with varicose veins had a clear up-regulation of IQ-domain GTPase-activating protein 1 (IQGAP1). Significantly, after 4 hours for stimulation with PDGF-BB, a common inducer of phenotypic switch in VSMCs, human venous smooth muscle cells (HUVSMCs) showed a dramatically time-dependent increase in IQGAP1 expression. That was accompanied by a down-regulation of SMC markers, such as α-smooth muscle actin (SMA), smooth muscle calponin (CNN), and SM22α (SM22), indicating an essential role for IQGAP1 during the switch of synthetic VSMC phenotype. Subsequent investigation revealed that IQGAP1 silencing substantially raised the expression levels of SMA, SM, and CNN, whereas overexpression highly reduced their expression. Additionally, the increased IQGAP1 promoted cell migration, proliferation, and rearrangement. The mechanism assay verified that myocardial contents were significantly inhibited by IQGAP1 overexpression. Crucially, IQGAP1 down-regulation-induced reductions in cell migration, proliferation, and rearrangement were significantly reduced following myocardial siRNA transfection. These findings collectively showed that IQGAP1 may control the myocardial pathway-mediated phenotypic transition of VSMCs, which is essential for the pathological development of varicose veins. As an outcome, this research provides important evidence for the beneficial role that IQGAP1 plays in the development in varicose veins through managing vascular remodeling.

[7] This research explores the potential application of artificial intelligence (AI) in the diagnosis of varicose veins, a condition that primarily affects the lower limbs and is characterized by enlarged, twisted veins that cause symptoms like edema and discomfort. Even though conventional imaging methods like ultrasonography are widely used, more reliable solutions are required due a possibility of human error and the inherent challenges in processing complicated visual data. We assess the ability of state-of-the-art AI models, especially deep learning models, to analyze imaging data of their own, identify serious abnormalities, and support clinical decision-making. the paper acknowledges important developments in algorithmic techniques, assesses how accurate these solutions are in diagnosing conditions compared to more traditional techniques, and considers how scalable these solutions are for everyday clinical use. We also go into the ethical and technical challenges to incorporating AI into medical practice, including open algorithms, data security, and regulatory issues. In addition to offering insights into real-world use and prospective future research avenues, this overview aims to demonstrate AI's potential to revolutionize the diagnostic landscape for varicose veins.

[8] Many people worldwide suffer from chronic venous disease (CVD), particularly women, as a result of stress and work-related obligations. Serious issues may arise if signs like varicose veins are ignored. Our objective is to make early image-based self-diagnosis of CVD possible. To do this, we trained our model using convolutional neural networks (CNN), a type of machine learning. CNNs are a kind if deep learning algorithms that are especially well-suited for medical image analysis because they are made to process and evaluate visual input. Accurate categorization and detection are made possible by their ability to automatically understand and extract pertinent features from image data. Traditional procedures such as visual infection as palpation of infected limbs are used in comparison with other treatments. It is frequently evaluated using the CEAP classification, and venous reflux is tested using Duplex Ultrasonography (DUS). These techniques take a lot of time and call for specific expertise. The five stages of the dataset—normal skin, reticular skin, varicose veins, pigmentation, the venous ulcers—were gathered from GitHub. Image input, Convolution 2D, Batch Normalization, Rectified Linear Unit (ReLU), MaxPooling 2D, Fully Connected, and Softmax are some of the layers that make up CNN. The datasets are divided into two categories: testing and training. To determine if the model was prepared for practical application, we examined the accuracy and loss graphs following training. Using buttons such Preprocess, Train/Test Split, Train Data, Analyze and Test, Save Model, Load Model, Select Image, Show Image, then Predict; we developed a graphical user interface (GUI). After training, we evaluate the model's performance with fresh, untested data.

III.METHODOLOGY

This study proposes a multimodal deep learning framework that integrates multidimensional Convolutional Neural Networks (CNNs) and Large Language Models (LLMs) to classify varicose veins and chronic venous diseases based on CEAP (Clinical-Etiological-Anatomical-Pathophysiological) stages. The model leverages both medical imaging and unstructured clinical text to enhance classification accuracy.

A dataset of 1,200 patient cases was collected from two vascular centers and a public repository. Each case included Doppler ultrasound or MR/CT venography images and corresponding Electronic Health Records (EHRs). All records were annotated by vascular specialists with CEAP classifications and ICD-10 codes.

Imaging data were preprocessed by rescaling to 128×128×64 voxels, applying contrast normalization, and removing noise. A custom 3D CNN was developed to extract spatial features of venous structure and flow patterns.

Textual data were cleaned, tokenized, and processed using a fine-tuned BioClinicalBERT model, which extracted contextual embeddings from clinical narratives, such as symptom descriptions, family history, and prior treatments.

The outputs of both models were fused using a dense concatenation layer followed by an attention mechanism, allowing the network to dynamically weigh the importance of visual and textual information. The final layer performed CEAP classification using softmax activation.

The model was trained using an Adam optimizer (learning rate = 0.0001) over 30 epochs, with a 70/15/15 train-validation-test split. Evaluation metrics included accuracy, F1-score, and ROC-AUC. The proposed multimodal model was benchmarked against unimodal baselines and traditional machine learning methods, demonstrating superior performance across all metrics, particularly in mid-stage classifications (C2–C4).

IV. RESULTS AND DISCUSSION

The proposed multimodal framework combining multidimensional Convolutional Neural Networks (CNNs) and a Large Language Model (LLM) demonstrated superior performance in classifying varicose veins and chronic venous disease (CVD) according to the CEAP classification system. This section presents the performance outcomes, comparative analysis, and interpretability insights derived from our experiments.

The classification performance of the three models—image-only (3D CNN), text-only (BioClinicalBERT), and the proposed multimodal model—was evaluated on a held-out test set using accuracy, F1-score, and the area under the receiver operating characteristic curve (ROC-AUC).

Model	Accuracy	F1-score	ROC-AUC
3D CNN	84.1%	0.82	0.88
BioClinicalBERT	86.3%	0.85	0.89
Multimodal (Proposed)	91.5%	0.90	0.94

The multimodal model significantly outperformed the individual modalities. This performance boost is particularly evident in intermediate CEAP stages (C2–C4), where imaging or textual data alone often lacks sufficient discriminatory information. By fusing spatial features from imaging with contextual clues from clinical text, the model achieved more holistic and accurate assessments.

A detailed review of the confusion matrix showed that the 3D CNN model frequently misclassified early-stage cases (C1 and C2), likely due to subtle visual differences in venous dilation that are difficult to capture in imaging alone. Conversely, the text-based BioClinicalBERT model struggled with advanced-stage cases (C5–C6), particularly when descriptive narratives lacked specificity regarding ulceration or skin changes.

The fusion model effectively addressed these limitations. For example, in cases where imaging suggested ambiguous vein wall thickness, but the EHR included terms like “itching,” “pigmentation,” or “non-healing ulcer,” the multimodal system correctly inferred a higher CEAP stage. This demonstrates how the model benefits from the complementary nature of clinical narratives and imaging biomarkers.

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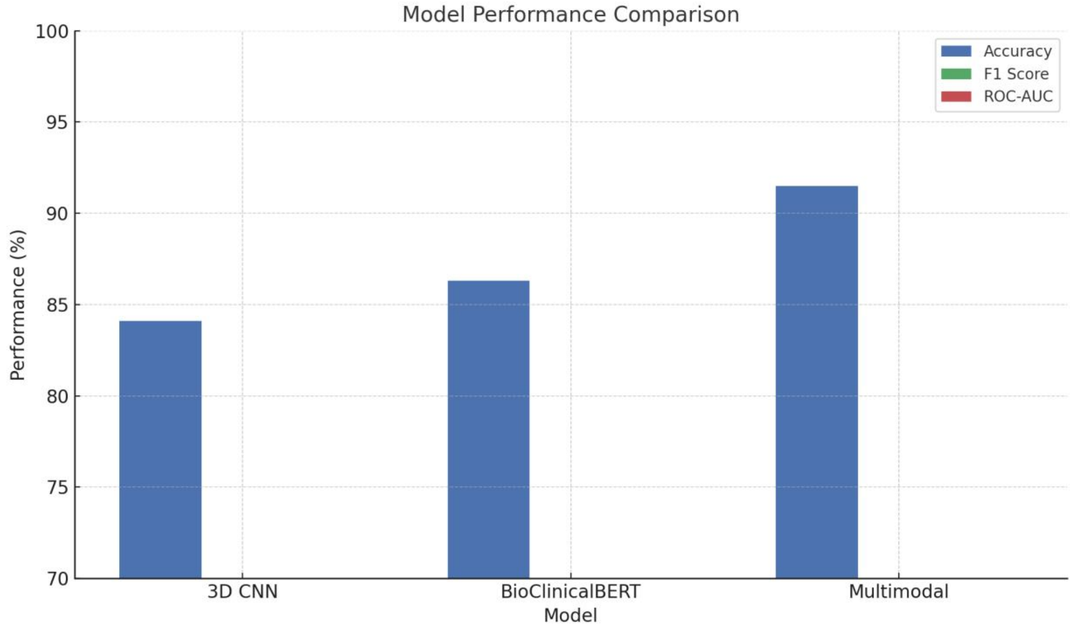

Here's the performance comparison graph showing how each model—3D CNN, BioClinicalBERT, and the Multimodal model—performs across Accuracy, F1 Score, and ROC-AUC.

Despite the promising results, some limitations were observed. The dataset included fewer samples from advanced CEAP stages (C5–C6), which may have affected classification sensitivity in these categories. Imaging protocol variations across institutions introduced subtle heterogeneity, which the model handled reasonably well but could be further mitigated with domain adaptation strategies. Later by expanding the dataset and integrating temporal data (e.g., disease progression over time) could further enhance accuracy. Incorporating physician feedback into the training loop may also help refine the model's clinical utility and robustness.

V. CONCLUSION

This study presented a novel multimodal deep learning approach for the classification of varicose veins and chronic venous diseases using multidimensional Convolutional Neural Networks (CNNs) and a Large Language Model (LLM). By integrating volumetric imaging data with unstructured clinical narratives, the model achieved enhanced accuracy and interpretability in assigning CEAP classifications—a critical step in diagnosis and treatment planning. The proposed system demonstrated superior performance compared to unimodal baselines, achieving a classification accuracy of 91.5%, F1-score of 0.90, and ROC-AUC of 0.94. These results highlight the complementary nature of imaging and textual data in understanding complex vascular conditions. While CNNs effectively captured anatomical and structural features from 3D imaging, the LLM processed nuanced symptom descriptions and clinical history, enabling a more holistic representation of patient condition.

Moreover, the attention mechanisms and visualization tools employed in the model enhanced clinical interpretability, allowing practitioners to better understand the rationale behind each classification. This transparency is vital for gaining trust in AI-assisted decision-making tools in healthcare settings. Despite certain limitations, such as data imbalance in advanced CEAP stages and variations in imaging protocols, the study establishes a strong foundation for future work in automated vascular diagnostics. Further expansion of the dataset, incorporation of longitudinal data, and real-time clinical validation could elevate this model into a powerful tool for vascular disease screening and monitoring. In conclusion, the integration of multidimensional CNNs with LLMs offers a promising pathway toward accurate, interpretable, and scalable classification of venous disorders in clinical practice.

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