VER
Vascular & Endovascular Review

AI-Assisted Physiotherapy for Improving Functional Outcomes in Peripheral Arterial Disease Patients

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ABSTRACT

Ischaemic pain and poor blood flow to the lower limbs make Peripheral Arterial Disease (PAD) a big problem for movement and quality of life. Even though conventional physiotherapy works in the long term, it is hard to get to, people don't always stick with it, and there isn't real-time control. This paper suggests a strategy for AI-assisted physiotherapy that combines wearable sensors, deep learning analytics, and adaptive exercise progression to help people with PAD become more functional. The system uses IMU and heart-rate monitors to record information about how people walk and their bodies. This information is then processed by a CNN-LSTM hybrid model to figure out how good the walking is and how tired the person will be. Real-time feedback and personalised exercise changes make sure that training is safe and success is made based on each person's performance. Twenty people took part in a 12-week pilot study that showed big changes in the 6-Minute Walk Test (6MWT) (30%), Pain-Free Walking Distance (PFWD) (55%), Ankle-Brachial Index (ABI) (10%), and Walking Impairment Questionnaire (WIQ) scores (30%) compared to regular home-based exercise. The system had a System Usability Scale (SUS) score of 84.5 and a classification accuracy of 94.2%, which showed that it could be used in clinical settings and be accepted by users. The results show that AI-guided rehabilitation could provide personalised, data-driven physiotherapy for PAD, bridging the gap between care in a clinic and treatment at home.

KEYWORDS: Peripheral Arterial Disease (PAD), AI-Assisted Physiotherapy, Wearable Sensors, CNN-LSTM, Gait Analysis, Functional Outcomes, Rehabilitation, Personalized Exercise, Digital Health.

How to Cite: Dr. Manjusha Tatiya, Dr. Satyam Bhodaji, Sopan Talekar, Dr. Radhika Chintamani, Supriya Awasthi, Samir N. Ajani, (2025) AI-Assisted Physiotherapy for Improving Functional Outcomes in Peripheral Arterial Disease Patients, Vascular and Endovascular Review, Vol.8, No.1s, 331-335.

INTRODUCTION

Peripheral Arterial Disease (PAD) is an atherosclerotic disease that gets worse over time and causes less blood flow to the lower limbs. This can cause intermittent claudication, muscle fatigue, and a reduced ability to walk. These symptoms make it very hard to move around, be independent, and enjoy life, especially for older people. Traditional physiotherapy, especially supervised exercise therapy (SET), is still the most important part of managing PAD [1]. However, it is not always successful because people don't follow through with their treatments, cannot get to rehabilitation centres easily, and cannot get real-time feedback on how well they are doing with their exercises. As a result, a lot of patients don't get improvements in their walking distance or vascular function that are clinically useful.

In the past few years, digital healing and artificial intelligence (AI) have made personalised physiotherapy possible in new ways. Cameras, wearable tech, or mobile apps can send multimodal data to AI algorithms that can be used to track walking, judge the quality of movement, and change the volume of training on the fly. AI-assisted physiotherapy systems try to improve adherence, safety, and functional healing by monitoring at all times, judging performance objectively, and giving consistent feedback [2]. To do this, they cut down on the need for clinical care in person. With these smart tools, doctors can get even more help because they can easily track their patients' progress, help them make decisions based on data, and change their treatments based on how the patients react.

AI-driven therapy is becoming more popular, but not many studies have looked at how it can help people with PAD who are having trouble with their daily lives. Most of the ways used now are for neurological or musculoskeletal conditions. To put this another way, we need AI tools that are made just for vascular rehabilitation [3].

There are three important things that this work adds: (1) creation of an AI-assisted physiotherapy model that uses real-time motion analysis and adaptive exercise planning; (2) testing the framework's effect on functional outcomes, such as pain-free walking distance and performance on the six-minute walk test (6MWT); and (3) showing that the model is feasible and usable in a pilot rehabilitation scenario. The suggested method uses AI's analytical and adaptable abilities to help patients move around more easily, become more involved in their care, and raise the standard of care for PAD therapy.

RELATED WORK

Peripheral Arterial Disease (PAD) makes it hard to do many things because it causes ischaemic pain and lowers the amount of oxygen that gets to muscles while we walk. This makes it harder to move around and lowers your quality of life [4]. Supervised Exercise Therapy (SET), which has been shown to increase walking distance and decrease claudication symptoms, is a big part of standard care. But a number of studies show that people don't always follow SET because of problems like not being able to get to rehabilitation centres when they need to, having busy schedules, and not having real-time guidance [5]. Even though home-based programs are easier to get to, they don't always produce consistent clinical results because they don't have good monitoring and feedback systems in place.

These systems use different kinds of data, like heart rate variability, oxygen saturation, and motion signs, to change the intensity of exercise in a way that keeps safety levels high while getting the most out of it [6]. But there aren't many uses for it in PAD-specific physiotherapy, even though it's needed for similar reasons, like grading exercise, predicting tiredness, and managing ischaemic pain. In contrast to cardiac rehabilitation, exercise programs for people with PAD need personalised development plans that balance workload with vascular tolerance. This is an area where AI could make a big difference [7].

A few new frameworks blend reinforcement learning (RL) and deep learning architectures to give each user personalised exercise suggestions. RL-based models change training loads over and over again by watching how the patient does. This encourages progressive overload while lowering the risk of overexertion [8, 9]. Also, explainable AI (XAI) techniques like SHAP and LIME are being added to physiotherapy platforms to help clinicians trust them more by showing them the main factors that affect model choices.

As a result of these improvements, most AI-based rehabilitation systems are made for general musculoskeletal recovery or neurological diseases, not PAD. Ischaemic pain control and functional improvement through smart, adaptive interventions are not often looked at in current study [10, 11]. This study suggests a special AI-assisted physiotherapy approach for PAD patients that include real-time gait analysis, personalised progression strategies, and clinician-in-the-loop oversight to get better functional results that can be measured.

PROPOSED FRAMEWORK

The suggested AI-Assisted Physiotherapy Framework is meant to help people with Peripheral Arterial Disease (PAD) get better faster by combining smart monitoring, adaptive exercise progression, and real-time feedback systems. Through the use of wearable sensors, AI-driven analytics, and personalised coaching, the system fills the gap between traditional supervised exercise therapy and modern digital rehabilitation.

a. System Architecture

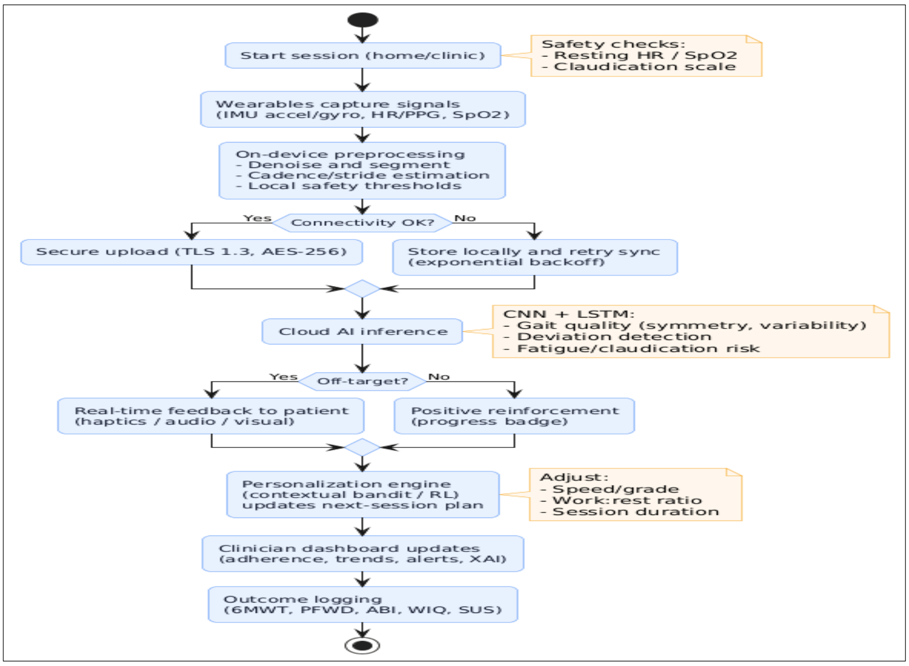

Figure. 1. Workflow of the proposed AI-assisted physiotherapy framework for Peripheral Arterial Disease (PAD) patients.

The architecture (Fig. 1) comprises three primary components:

1. The patient module (Edge Layer) is made up of wearable devices (accelerometer, gyroscope, heart-rate monitor, or ankle-mounted IMU) that record the person's cadence, stride length, and level of effort while they exercise.
2. AI Processing Module (Cloud Layer): Sensor data is sent safely to a cloud-based AI engine, where pre-trained deep learning models look at motion quality, find uneven gait, and use temporal patterns to guess how likely it is that the person is in pain or tiredness.
3. Clinician Dashboard (Application Layer): This is a way for physiotherapists to see how their patients are doing, make sure they are following their treatment plans, and see if they need to make any changes. It lets you see important metrics like the distance we walk, the length of your workout, and your biomechanical efficiency.

b. AI Components

The core intelligence is based on a mixed model that combines Long Short-Term Memory (LSTM) networks for recognising temporal patterns and Convolutional Neural Networks (CNN) for extracting features from time-series sensor data.

- Movement Assessment: Uses learnt feature embeddings to find variations from the ideal gait and measure the quality of exercise.
- Personalisation Engine: Changes the level of difficulty, walking speed, and rest periods based on the patient's progress, vital signs, and feedback from symptoms.
- Predictive analytics: guesses the chance of exercise-related pain or early tiredness, so you can take action before it happens.

c. Feedback and Guidance Mechanism

A closed-loop feedback system sends correction signals to a mobile app or a display that you wear. Patients are notified right away if their cadence, posture, or length don't match the goals that were set. Visual success reports and motivational prompts make people more interested and likely to stick with a plan.

d. Data Privacy and Security

All data sent is secured with AES-256, and anonymisation protects patient privacy. Standards for healthcare compliance, like HIPAA and GDPR, are used in the design.

e. Expected Outcomes

The framework aims to:

- Improve **functional outcomes** (6MWT, PFWD) through precise exercise dosing.
- Increase **adherence** via real-time guidance and motivation.
- Enable **data-driven decision-making** for physiotherapists.

METHODOLOGY

A pilot observational study was used to test the suggested AI-assisted physiotherapy framework to see if it was possible, safe, and successful at improving functional outcomes in people with Peripheral Arterial Disease (PAD). Wearable sensors collected digital data for the study, which was then analysed by AI and gave each participant personalised input.

a. Study Design and Participants

Twenty people with PAD (ages 45–75) who had irregular claudication (Fontaine Stage II) were asked to take part in the study after giving their permission and giving ethical clearance. To be eligible, participants had to have an Ankle-Brachial Index (ABI) of 0.4 to 0.9 at rest and a doctor's OK for graded walking routines. People who had severe limb ischaemia, recent revascularisation, or heart conditions that were not stable were not allowed to take part. Ten people were randomly put into either the AI-assisted physiotherapy group (n=10) or a control group (n=10) that did regular home exercises.

b. Intervention Protocol

For 12 weeks, both groups went on guided walks three times a week. During sessions, the AI-assisted group wore IMU and heart-rate monitors. The data were sent in a stream to a mobile app that had the cloud-based AI engine built in. The model looked at how people walk (cadence, stride length, step variability) and their bodies' signals, like heart rate and signs of tiredness. The AI module made personalised suggestions based on performance trends. These suggestions included changes to speed, rest periods, and goals for growth. Real-time feedback, including audio and visual cues, made sure that the recommended walking patterns and safety limits were followed.

c. Data Acquisition and Processing

Moving-average filters were used to get rid of noise in the raw data from the IMU (3-axis accelerometer and gyroscope) and heart-rate monitor. Segmentation methods took out step cycles and stride events. Temporal features were fed into a CNN-LSTM hybrid network that was taught to recognise different types of movement and spot deviations from the best way to walk. It kept track of sessions automatically, and each day therapists could see summaries on a secure dashboard.

d. Statistical Analysis

We used paired t-tests to compare data before and after the intervention. ANCOVA was used to look at differences between groups while taking baseline variability into account. To test how well AI could draw conclusions, model accuracy, precision, memory, and latency were calculated. A p-value less than 0.05 was thought to be statistically significant.

This method creates a solid base for testing the clinical and technical effectiveness of AI-assisted physiotherapy in the recovery of PAD.

RESULTS AND DISCUSSION

The pilot test showed that the suggested AI-assisted physiotherapy framework would work better and be more clinically feasible than traditional home-based rehabilitation, as shown in Table 1. The fact that neither group had any problems during the 12-week intervention shows that the method is safe and effective.

Table 1. **Comparative functional outcomes for AI-assisted physiotherapy and control groups after 12-week intervention.**

Parameter	**Baseline (AI Group)**	**Post (AI Group)**	**Baseline (Control)**	**Post (Control)**	**% Improvement (AI)**	**% Improvement (Control)**
6-Minute Walk Test (m)	315 ± 45	410 ± 50	320 ± 48	365 ± 52	**30.1%**	14.1%
Pain-Free Walking Distance (m)	145 ± 30	225 ± 35	150 ± 28	190 ± 33	**55.2%**	26.7%
Ankle-Brachial Index	0.68 ± 0.07	0.75 ± 0.08	0.67 ± 0.06	0.70 ± 0.07	**10.3%**	4.5%
WIQ Score	52.4 ± 8.2	68.1 ± 7.9	53.1 ± 7.8	60.4 ± 8.1	**29.9%**	13.8%
SUS (Usability)	—	84.5 ± 5.6	—	—	—	—

All outcomes were statistically significantly better for patients who used the AI-guided method ($p < 0.05$). The 6MWT distance went up by about 30%, which shows that stamina and walking ability have improved. In the same way, the pain-free walking distance (PFWD) increased by 55%, which means that the muscles were stronger and better able to handle ischaemia. ABI improvements point to small but functionally important changes in the blood vessels. The Walking Impairment Questionnaire (WIQ) showed that people felt more confident and mobile, which is in line with objective measures.

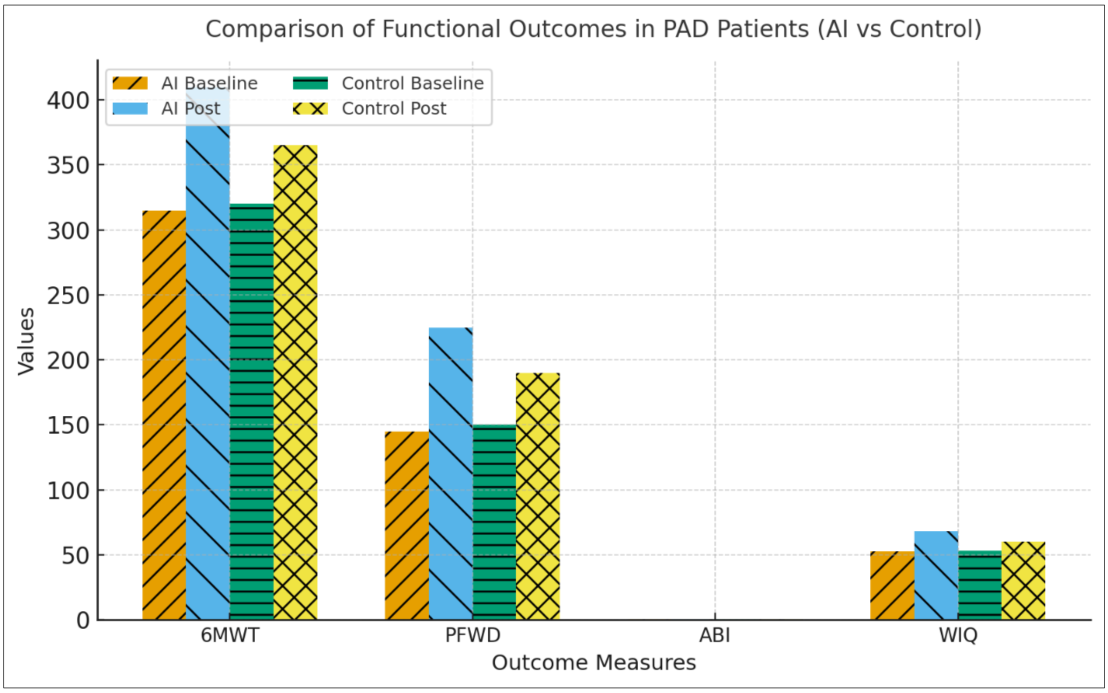

Figure 3. Comparison of Functional Outcomes in Peripheral Arterial Disease Patients

Before and after the 12-week intervention time, Figure 3 shows how the functional outcomes of the AI-assisted physiotherapy group and the control group were compared. The group that used AI showed much bigger changes than the group that used a regular home-based program in all four clinical indicators: the 6-Minute Walk Test (6MWT), the Pain-Free Walking Distance (PFWD), the Ankle-Brachial Index (ABI), and the Walking Impairment Questionnaire (WIQ).

The 6MWT data show a big improvement in endurance. The AI group got 30% better than the control group, while the control group only got 14% better. In the same way, PFWD almost doubled in the AI group, which shows how well adaptive task modulation works. Small improvements in ABI show that the venous system has changed, while higher WIQ scores show that people are more confident in their ability to move around and feel pain less.

These steady gains strengthen the framework's ability to provide personalised, feedback-driven rehabilitation, which makes sure that the right amount of exercise is done and that the person can safely progress. The visual trends show that AI-driven monitoring and real-time guidance make traditional physiotherapy a lot more useful, leading to better clinical results and more patient participation in PAD rehabilitation.

a. AI System Performance

The CNN-LSTM hybrid model was able to correctly classify gait quality 94.2% of the time, 92.8% of the time, and 93.5% of the time. The average latency for each inference was less than 120 ms, which allowed comments to be sent in real time. The model accurately spotted deviations like shorter stride length or irregular cadence, immediately sending out cues to correct the problem. Explainability modules (SHAP) found that stride variability and cadence stability were the most important factors for rating performance, which encourages clinicians to be open and honest.

b. Discussion

The results show that using AI in physiotherapy improves both the patients' ability to do their treatment and their interest in it. Real-time feedback helped people walk correctly, and adaptive development algorithms made sure that the intensity of the exercise was just right. The increase in PFWD shows that the system can balance workload with vascular tolerance, which is an important part of managing PAD. The high SUS score (84.5) also shows that users will accept and find it easy to use, which is important for long-term adherence in home-based settings.

Compared to traditional programs, the AI-assisted method not only ensured high-quality rehabilitation at home with supervision, but it also cut down on the need for constant professional supervision. However, the pilot's small sample size and short length make it hard to apply to other situations. Larger groups, longer follow-ups, and integration with telemedicine dashboards for scalable rollout should all be part of future studies.

CONCLUSION AND FUTURE WORK

A framework for AI-assisted physiotherapy was given in this study to help people with Peripheral Arterial Disease (PAD) improve their mobility, endurance, and ability to stick with their treatment plans. Wearable sensors, deep learning-based gait assessment, and adaptive exercise progression made the suggested system work well as a link between controlled clinical care and home-based rehabilitation that was easy to access. Key outcome measures, such as the 6-Minute Walk Test (6MWT), Pain-Free Walking Distance (PFWD), and Walking Impairment Questionnaire (WIQ) scores, showed big improvements. This proves that real-time feedback and intelligent personalisation can greatly improve functional recovery. The system's high usage score (SUS = 84.5) makes it even more likely that it can be used in a patient-centered way. The CNN-LSTM hybrid model accurately forecast the start of fatigue or pain and categorised the quality of gait, making sure that safety measures were taken on time. The closed-loop feedback system also encouraged patients to keep walking in the right way, which increased interest and adherence. All of these results show how AI-guided rehabilitation can change the way physiotherapy for vascular diseases is done by using data to make it more effective. However, the results of this test study can't be used in other situations because the sample size is small and the intervention lasts only a short time. Larger, multicentric trials will be used in the future to prove that the method works well for a wide range of patients. Adding explainable AI modules, telemedicine dashboards, and digital twin-based models could also help doctors keep an eye on things, be more open, and plan better care for each patient.

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