DOI: 10.21088/potj.0974.5777.19226.8

Physiotherapy and Occupational Therapy Journal
Volume 19 Number 2, April - June 2026

REVIEW ARTICLE

Converging Technologies in Cardiopulmonary Physiotherapy: A Review of VR, AR, AI, and IOT-Based Rehabilitation Frameworks and Clinical Outcomes: Comprehensive Review

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HOW TO CITE THIS ARTICLE:

Hemangkumar Sudhakarbhai Jani, Brijesh Varma, Riya Pancholi. Converging Technologies in Cardiopulmonary Physiotherapy: A Review of VR, AR, AI, and IOT-Based Rehabilitation Frameworks and Clinical Outcomes: Comprehensive Review. Therapy Jr. 2026; 19(2): 159-166.

ABSTRACT

Background: The integration of Virtual Reality (VR), Augmented Reality (AR), Artificial Intelligence (AI), and Internet of Things (IoT) technologies into cardiopulmonary physiotherapy represents one of the most consequential shifts in modern rehabilitation medicine. While individual modalities have attracted growing research attention, their deliberate convergence as a unified rehabilitation framework remains insufficiently synthesised.

Objective: To examine the clinical evidence, implementation challenges, and future directions of converging VR, AR, AI, and IoT technologies in cardiac and pulmonary rehabilitation.

Methods: A structured narrative review of 217 peer-reviewed articles (2001–2025) was conducted across PubMed/MEDLINE, Scopus, CINAHL, IEEE Xplore, and the Cochrane Library, synthesised thematically.

Results: Immersive VR consistently improves exercise adherence and psychological outcomes; IoT-based remote monitoring extends physiological supervision beyond clinical walls; AI systems advance protocol individualisation; AR augments procedural guidance and self-efficacy. Critical gaps persist in long-term outcome data, standardised protocols, equitable access, and data governance.

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Received: 22-04-2026 **Accepted:** 20-05-2026

Conclusions: Converging digital technologies hold substantive potential to reshape cardiopulmonary physiotherapy. Realising this demands interdisciplinary collaboration, representative clinical trials, and patient-centred, equity-informed implementation.

KEYWORDS

• Virtual reality • Augmented reality • Artificial intelligence • IoT • Cardiac rehabilitation • Pulmonary rehabilitation • Telerehabilitation • Digital health • physiotherapy

INTRODUCTION

Cardiovascular and pulmonary diseases remain the foremost contributors to global morbidity, mortality, and healthcare expenditure. Exercise-based cardiac rehabilitation (CR) and pulmonary rehabilitation (PR) carry decades of randomised controlled trial evidence confirming reductions in all-cause mortality, hospital readmission, and meaningful improvements in functional capacity and quality of life.[1,2,179,186] The paradox, however, is striking: fewer than one-third of eligible patients ever complete a structured, centre-based programme.[97,152] Geographic inaccessibility, transport barriers, time constraints, and the psychological burden of chronic illness conspire against engagement at every stage of the rehabilitation journey.

The COVID-19 pandemic accelerated a gathering transformation already underway. When centre-based programmes shuttered, technology-mediated platforms — some rudimentary, others surprisingly sophisticated — stepped into the breach.[97] What emerged was not a workaround but a structural reconsideration of how rehabilitation might be delivered, monitored, and personalised at scale. Against this backdrop, four technology streams have matured sufficiently to warrant a unified examination: VR, AR, AI, and IoT. Crucially, their convergence — rather than their individual deployment — represents the clinical frontier that this review examines.

METHODS

A structured narrative review was conducted across PubMed/MEDLINE, Scopus, CINAHL, IEEE Xplore, and the Cochrane Library using Boolean combinations of terms including virtual reality, augmented reality, artificial intelligence, IoT, wearable sensors, cardiac rehabilitation, pulmonary rehabilitation, and telerehabilitation. Searches were restricted to English-language, peer-reviewed publications from 2001 to 2025. Studies were eligible if they evaluated VR-, AR-, AI-, or IoT-based interventions in adult cardiopulmonary rehabilitation populations and reported on clinical outcomes, feasibility, adherence, or implementation experience. Editorials and healthy-volunteer-only studies were excluded. A total of 217 sources were thematically synthesised across five domains: VR, AR and extended reality, AI and machine learning, IoT and wearables, and convergent multi-technology frameworks.

LITERATURE REVIEW AND SYNTHESIS

Virtual Reality: From Proof-of-Concept to Clinical Tool

VR's theoretical appeal in rehabilitation has always been straightforward: immersive environments distract patients from the discomfort of effortful exercise, enhance motivation through game-like reinforcement, and provide a safe simulation of real-world physical demands.[27] For many years, however, the clinical evidence lagged the concept. That evidence has now reached a threshold of cautious optimism. A 2022 meta-analysis by Chen and colleagues identified statistically significant improvements in exercise capacity and anxiety reduction in cardiac rehabilitation trials.[175] Jia and colleagues' overview of systematic reviews confirmed consistent psychological benefits, with variability in physical outcomes attributable to heterogeneity in deployed VR modalities.[40] Bashir and colleagues' meta-analysis corroborated significant reductions in anxiety and improvements in functional capacity.[204]

The distinction between immersive and non-immersive VR carries real clinical weight. Immersive VR via head-mounted displays attenuates perceived exertion during exercise and Colombo and colleagues demonstrated this effect in healthy adults, with direct translational relevance for patients limited by dyspnoea and fatigue.[206] Non-immersive, screen-based VR offers lower technical barriers, and Peinado-Rubia and colleagues' 2024 meta-analysis confirmed its effectiveness in cardiac rehabilitation.[20] In pulmonary rehabilitation, particularly in COPD, VR-complemented programmes improved lung function, exercise capacity, and dyspnoea ratings suggesting that VR's mechanism may be as much perceptual as physiological.[13,99] The Destination Cardiac Rehab trial at Mayo Clinic represents one of the most ambitious attempts to leverage virtual world platforms for culturally sensitive, community-informed rehabilitation, with randomised controlled trial data now emerging.[12] Yuenyongchaiwat and colleagues' RCT further demonstrated simultaneous improvements in cardiopulmonary performance and depression in phase I cardiac rehabilitation.[33] That said, small sample sizes, heterogeneous protocols, and absent long-term follow-up data remain pervasive limitations.[40,53,175]

Augmented Reality: Underexplored, Clinically Promising

AR's relative neglect in cardiopulmonary rehabilitation is, on reflection, surprising. Its ability to overlay therapeutic guidance and biometric feedback onto a patient's real-world visual field makes it inherently suited to home-based supervised rehabilitation — enabling real-time feedback without a clinic visit. Moghaddam and colleagues' randomised clinical trial of AR-based phase I cardiac rehabilitation post-CABG found significant improvements in self-efficacy — a robust predictor of long-term adherence.[22] Koulouris and colleagues' IoT-enabled AR exergaming platform demonstrated comparable feasibility and user engagement.[32] Blasco-Peris and colleagues' meta-analysis of exergaming versus conventional cardiac rehabilitation found comparable cardiorespiratory gains with superior patient enjoyment in the exergaming arm.[146] Petrakis and colleagues confirmed in a broad review that AR applications are technically mature but clinically under validated — a gap warranting concerted trial investment.[27]

Artificial Intelligence: Personalisation Beyond Manual Capacity

AI has fundamentally changed what 'personalised exercise prescription' might realistically mean. A physiotherapist managing thirty to forty patients cannot continuously adjust exercise parameters in real time based on individual physiological response — the cognitive bandwidth simply does not exist. AI addresses this constraint. Aharon and colleagues demonstrated that AI-driven personalised interventions meaningfully improved cardiac rehabilitation adherence.[141] Driesse, Gajane, and Barakova's WeHeart recommendation device illustrated how intelligent nudge systems can adapt prompts to individual behaviour patterns.[168] Schmitz and Bosch's TIMELY platform kept both patients and practitioners in the decision loop — an appropriate design that preserves clinical judgment while leveraging computational power.[101]

Federated learning: training AI models across distributed datasets without centralising sensitive patient data — offers particular promise given the scale of data needed and the privacy demands of health information.[7] Shoba and colleagues' cloud-based system guided by recurrent neural networks (RNNs) dynamically adjusts exercise plans based on continuous heart rate, blood pressure, and activity data.[29] This approaches the temporal reasoning of an experienced clinician, at least computationally. Raja, Loughran, and McCaffery's review is appropriately cautionary: AI systems have proliferated faster than their clinical efficacy has been established, with most evaluations focused on technical performance rather than patient outcomes.[117] The gap between algorithmic sophistication and demonstrated clinical value remains the field's central challenge.

IoT and Wearables: The Infrastructure of Remote Care

IoT is best understood not as a single technology but as an enabling infrastructure: extending the clinician's reach across the geographic and temporal distances separating most home-based patients from their providers. Li and colleagues' randomised pilot demonstrated the feasibility of real-time physiological surveillance under 5G IoT monitoring in cardiac rehabilitation.[9] The Intell IoT pivotal trial by Marketou and colleagues, one of the few named clinical trials in IoT-based cardiac rehabilitation found significant improvements in rehabilitation engagement and adherence versus conventional monitoring.[5] Antoniou and colleagues' meta-analysis of wearable-supported home-based CR found outcomes comparable to centre-based programmes with superior participation rates.48 Zhang and colleagues' RCT of smartwatch monitoring demonstrated significantly higher adherence in coronary heart disease patients.[100]

The infrastructure requirements of IoT-based rehabilitation, however, are not trivially met. Van Iterson, Laffin, and Cho's national analysis found a direct correlation between limited fixed-terrestrial broadband access and lower cardiac rehabilitation utilisation — framing the technology access gap as fundamentally a health equity problem.[152] Data privacy and governance frameworks lag considerably behind the pace of deployment, a risk that Mamodiya and colleagues' review of AI-enhanced AR/VR systems explicitly identifies as unresolved.[2]

Convergent Platforms and Hybrid Models: The Clinical Frontier

The most consequential development in the current literature is the emergence of architectures that weave multiple technologies together. Postolache and colleagues described an IoT-VR system in which sensor-derived physiological data dynamically informs virtual exercise game parameters in real time.[27] The PATH-I trial by Claes and colleagues combined app-based self-monitoring, teleconsultation, and personalised exercise feedback in a hybrid model, demonstrating improvements in physical activity and health status.[112] The Smart HEART trial attributed improvements in physical function and health behaviours to the system's capacity for continuous, individualised feedback.[66] The AHA's 2023 Science Advisory identified AI, IoT, and immersive technologies as priority research domains and called for standardised digital rehabilitation evaluation frameworks.[86] The 2025 consensus statement by Hughes and colleagues articulated conditions for appropriate technology-mediated delivery and the safety monitoring protocols required.[51]

Hybrid models: combining centre-based and technology-mediated delivery: have attracted considerable policy attention post-pandemic. The attend trial found comparable clinical outcomes and superior patient satisfaction in the hybrid arm versus standard care.[142] Ganeshan and colleagues' analysis confirmed that patient preference is strongly heterogeneous: some value the social structure of centre-based care, others find flexibility essential.[115] Shah and colleagues found that virtual cardiac rehabilitation achieved comparable outcomes at meaningfully lower cost.[35] Azad's systematic review of telerehabilitation cost-effectiveness reached similar conclusions, though the evidence base for health economic analyses remains limited.[144] Chong, and Karthikesu's meta-analysis found that convergent multi-modality platforms produced superior adherence and outcomes versus single-modality interventions — suggesting that integration itself is a clinically meaningful variable.[214]

Persistent Gaps and the Research Agenda

An honest appraisal of this literature reveals a field that is technically exciting and methodologically immature in ways that demand frank acknowledgement. The most pervasive limitation is the absence of long-term outcome data: the overwhelming majority of studies report endpoints at six to twelve weeks, providing no insight into whether gains from VR or AI-guided exercise are maintained at six months or beyond.[5,21,33] Median sample sizes are small: frequently fewer than thirty participants: and populations skew toward younger, more digitally literate adults, systematically underrepresenting the older, lower-income, and minority communities who bear the greatest cardiovascular and pulmonary disease burden.[23,108,152] Protocol heterogeneity across VR, AI, and IoT studies is so marked that cross-study comparison and clinical guideline development remain impractical.[53] Ethical governance of IoT-generated physiological data: questions of ownership, secondary use consent, and algorithmic transparency: has not received the sustained scholarly attention the stakes demand.[2,29]

DISCUSSION

The synthesis presented here supports cautious but genuine clinical optimism, tempered by a clear-eyed recognition of what the evidence does not yet tell us. The strongest case can be made for VR as a motivation and adherence tool, for IoT-based monitoring as a safe and feasible alternative to centre-based supervision, and for hybrid delivery as a viable model for diverse populations.

What emerges with equal clarity is that no single technology operates most effectively in isolation. The platforms producing the most compelling evidence integrate multiple modalities: IoT data streams feeding AI algorithms that dynamically adjust VR exercise environments, all monitored in real time by clinical teams. Physiological monitoring without adaptive response is surveillance. Immersive exercise without physiological feedback is entertainment. AI personalisation without patient engagement is computation without clinical effect. It is the integration that generates the clinical value, and this should guide how health systems evaluate and invest in digital rehabilitation platforms.

The equity dimension is not a formality. Technology-mediated rehabilitation extends access only when the infrastructure like broadband, devices, digital literacy support, culturally adapted content is provided rather than assumed. A cardiac rehabilitation programme accessible only to patients with smartphones, reliable internet, and digital fluency does not solve the access problem; it replicates it in digital form.[152] This demands policy commitment well beyond individual trial design.

Adequately powered RCTs with extended follow-up, representative populations, standardised intervention reporting, and patient-centred endpoints must succeed the pilot studies that currently dominate this literature. Health economics analyses from a system rather than trial perspective are needed. Regulatory frameworks for AI-driven clinical decision support must develop in parallel with the technologies themselves, not after deployment. And the patient voice systematically solicited, not appended must shape technology development from the outset.[23,108]

CONCLUSIONS

Cardiopulmonary physiotherapy stands at a genuine inflection point. Converging VR, AR, AI, and IoT technologies are producing rehabilitation platforms capable of extending evidence-based exercise therapy to patients who would otherwise receive none, personalising prescription with a precision manual process cannot match, and sustaining engagement through mechanisms conventional programmes have struggled to activate. The evidence base, while still maturing, now demands serious clinical attention.

Equally, this review has documented with candour the gaps that must be closed before these technologies fulfil their potential: long-term outcomes, scalability beyond academic settings, equitable access, robust data governance, and meaningful regulatory oversight. The cardiopulmonary physiotherapist of the coming decade will practise in a landscape shaped by these tools. Engaging with them critically, advocating for their equitable implementation, and demanding the rigorous evidence they deserve is, in every sense, a professional responsibility.

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