Telerehabilitation in cardiopulmonary physiotherapy: effectiveness, patient adherence, and future perspectives

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Abstract:
Telerehabilitation has emerged as an important technology-supported model for delivering cardiopulmonary physiotherapy beyond conventional hospital and rehabilitation-centre environments. Cardiovascular and chronic respiratory diseases frequently require prolonged exercise training, symptom monitoring, behavioural modification, education, and follow-up, yet participation in conventional rehabilitation remains limited by transportation difficulties, geographical barriers, cost, scheduling constraints, workforce shortages, comorbidities, and limited availability of specialized services. Telerehabilitation uses videoconferencing, mobile applications, wearable sensors, remote physiological monitoring, web-based exercise platforms, telephone support, and digital education to provide individualized rehabilitation while patients remain at home or in community settings. Current evidence suggests that home-based and remotely supervised cardiac rehabilitation can produce exercise-capacity, physical-activity, quality-of-life, and risk-factor outcomes comparable with conventional centre-based programmes in appropriately selected patients. In pulmonary rehabilitation, telerehabilitation appears particularly promising for chronic obstructive pulmonary disease, with evidence supporting comparable improvements in functional exercise capacity, dyspnoea, health status, and quality of life, although the magnitude of benefit varies according to technology, supervision, treatment intensity, and patient characteristics. Patient adherence is a major determinant of success. Convenience, reduced travel, individualized feedback, self-monitoring, digital reminders, and flexible scheduling may improve participation, while digital literacy, technology burden, social isolation, equipment requirements, and loss of face-to-face interaction may negatively influence adherence. Future cardiopulmonary telerehabilitation is likely to move toward hybrid, patient-centred models integrating physiotherapist supervision, wearable monitoring, artificial intelligence, remote risk stratification, and personalized exercise prescription. Telerehabilitation should therefore be considered not simply as a replacement for conventional physiotherapy but as an additional delivery pathway capable of extending the reach, continuity, personalization, and sustainability of cardiopulmonary rehabilitation.

Keywords:
Telerehabilitation, cardiopulmonary physiotherapy, cardiac rehabilitation, pulmonary rehabilitation, chronic obstructive pulmonary disease, cardiovascular disease, adherence, telehealth, wearable sensors, remote monitoring, home-based rehabilitation, digital health.

1. Introduction:

Cardiovascular and chronic respiratory diseases represent major causes of disability, reduced functional capacity, recurrent hospitalization, and impaired quality of life, creating a substantial requirement for long-term rehabilitation and secondary prevention. Cardiac rehabilitation incorporates structured exercise, cardiovascular risk-factor modification, education, psychological support, lifestyle counselling, and long-term self-management, whereas pulmonary rehabilitation combines exercise training, education, symptom management, nutritional and psychosocial support, and strategies for maintaining physical activity in individuals with chronic respiratory disease. Despite strong evidence supporting these interventions, participation remains inadequate because many patients cannot repeatedly attend hospital or community-based rehabilitation programmes. Transportation difficulties, distance from rehabilitation centres, work and family

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responsibilities, financial limitations, limited programme availability, frailty, multiple comorbidities, and geographic inequities may all interfere with participation. The development of telerehabilitation has therefore created an alternative method through which physiotherapists and multidisciplinary teams can deliver structured rehabilitation remotely. Telerehabilitation may include synchronous video-based sessions, asynchronous exercise platforms, telephone coaching, mobile applications, wearable activity trackers, heart-rate monitoring, pulse oximetry, blood-pressure monitoring, symptom diaries, remote electrocardiographic monitoring, and digital education. Importantly, telerehabilitation is not synonymous with unsupervised exercise, contemporary programmes can provide continuous or intermittent professional supervision and individualized progression. The 2023 American Thoracic Society guideline strongly recommends that appropriately selected adults with chronic respiratory disease should be offered a choice between centre-based pulmonary rehabilitation and telerehabilitation, reflecting growing evidence of comparable outcomes. Similarly, contemporary cardiovascular guidance recognizes home-based and remote cardiac rehabilitation as viable alternatives for selected patients who cannot attend facility-based programmes. The figure 1 illustrate initial clinical assessment and risk stratification followed by individualized exercise prescription, remote physiotherapist supervision, physiological monitoring, patient education, adherence support, outcome assessment, exercise progression, and multidisciplinary review.

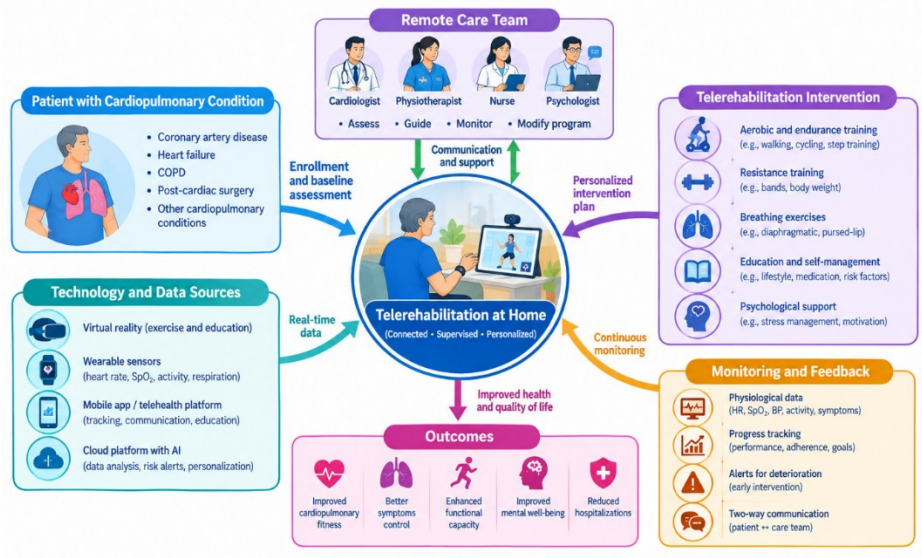

Figure 1. Conceptual framework of cardiopulmonary telerehabilitation

The clinical importance of telerehabilitation extends beyond accessibility. Rehabilitation is inherently behavioural and requires repeated engagement over weeks, months, and sometimes years. A patient may understand the importance of exercise but still fail to maintain activity because of fatigue, breathlessness, fear of exertion, low self-efficacy, depression, lack of feedback, or competing daily responsibilities. Remote rehabilitation can integrate therapeutic exercise into the patient's normal environment, allowing physiotherapists to observe movement, modify exercise intensity, monitor symptoms, and provide feedback without requiring repeated travel. This may be particularly valuable for individuals with chronic obstructive pulmonary disease (COPD), heart failure, coronary artery disease, post-cardiac intervention status, pulmonary hypertension, interstitial lung disease, and other chronic cardiopulmonary conditions. However, effectiveness cannot be assumed merely because technology is available. The clinical value of telerehabilitation depends on appropriate patient selection, safety screening, reliable monitoring, therapeutic content, professional supervision, technology usability, and sustained patient adherence. Recent evidence suggests that the strongest models combine multiple digital components rather than relying on a single application or passive monitoring device.

2. Telerehabilitation Models and Their Role in Cardiopulmonary Physiotherapy:

Telerehabilitation in cardiopulmonary physiotherapy can be broadly divided into synchronous, asynchronous, and hybrid models. Synchronous telerehabilitation involves real-time communication between the patient and physiotherapist through video or audio platforms. During a session, the physiotherapist can assess exercise technique, observe breathing patterns, modify resistance or aerobic workload, provide pacing strategies, and respond to symptoms. Asynchronous rehabilitation allows patients to complete prescribed exercises independently while data are uploaded to a digital platform for later review. The physiotherapist may

subsequently provide feedback through messages, telephone calls, or scheduled consultations. Hybrid rehabilitation combines centre-based sessions with remote sessions and is increasingly regarded as a particularly attractive model because it preserves face-to-face assessment and clinical contact while allowing patients to perform a substantial proportion of their rehabilitation at home. Contemporary European cardiac rehabilitation guidance emphasizes patient-centred combinations of face-to-face, virtual, and remote care, while recognizing that initial assessment, risk stratification, and exercise safety remain essential components of professional care.

Table 1. Major models of cardiopulmonary telerehabilitation

Model	Main components	Advantages	Major limitations
Synchronous	Live video, real-time exercise supervision, physiological monitoring	Immediate feedback and clinical decision-making	Requires connectivity and therapist time
Asynchronous	App-based exercise, recorded videos, symptom diaries, digital feedback	Flexible and scalable	Reduced real-time clinical supervision
Telephone-supported	Telephone coaching, exercise prescription, symptom monitoring	Low technology requirement	Limited visual assessment
Wearable-supported	Heart rate, activity, SpO_2, blood pressure and other sensor data	Objective monitoring and feedback	Device cost, data quality and technical burden
Hybrid	Combination of centre-based and remote rehabilitation	Balances safety, flexibility and accessibility	Requires coordination between delivery settings

In cardiopulmonary physiotherapy, the central principle should remain clinically prescribed rehabilitation rather than technology-driven exercise. The physiotherapist first establishes diagnosis, contraindications, functional status, exercise tolerance, symptoms, medication considerations, psychological status, and patient goals. In cardiac populations, risk stratification and assessment of exercise tolerance are particularly important before progression toward unsupervised home exercise. In pulmonary populations, assessment may include dyspnoea, oxygen saturation, respiratory rate, exercise capacity, fatigue, exacerbation history, functional limitations, and the need for supplemental oxygen. Following assessment, the physiotherapist develops an individualized programme incorporating aerobic conditioning, resistance exercise, breathing strategies, flexibility, functional training, pacing, energy conservation, and self-management education. Digital technology subsequently becomes the mechanism through which the programme is delivered, monitored, and modified rather than the intervention itself. Figure 2 shows the Patient-centred cardiopulmonary telerehabilitation pathway. Another important advantage is continuity. Traditional rehabilitation often ends after a defined number of sessions, whereas chronic cardiopulmonary disease requires long-term behavioural maintenance. Digital platforms can continue monitoring activity and symptoms after formal rehabilitation has ended. In COPD, long-term telerehabilitation has demonstrated potential to maintain exercise capacity and reduce hospitalization or emergency-department presentations, indicating that remote rehabilitation may have a role extending beyond an initial rehabilitation course.

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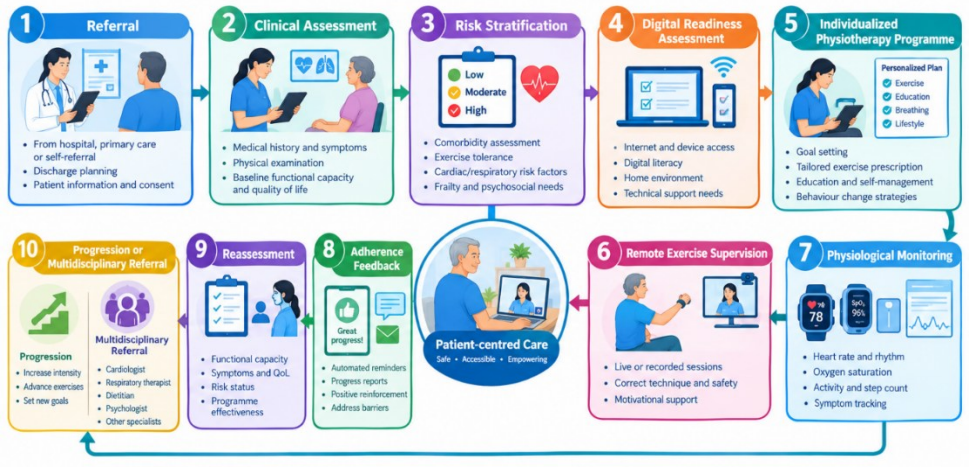

Figure 2. Patient-centred cardiopulmonary telerehabilitation pathway

3. Effectiveness of Telerehabilitation in Cardiac Rehabilitation

Cardiac rehabilitation is one of the most established applications of telerehabilitation. Patients recovering from myocardial infarction, coronary revascularization, chronic coronary disease, heart failure, and other cardiovascular conditions frequently require prolonged exercise training and behavioural modification. However, conventional cardiac rehabilitation is substantially underused. Home-based and digitally supported programmes have consequently been investigated as mechanisms for increasing participation while maintaining clinical effectiveness. The 2023 Cochrane review comparing home-based and centre-based cardiac rehabilitation included 24 randomized trials involving 3046 participants and concluded that appropriately supervised home-based programmes, including those supported by digital technologies, produced outcomes broadly similar to centre-based rehabilitation for mortality, exercise capacity, and health-related quality of life. A systematic review and meta-analysis of home-based cardiac telerehabilitation in coronary heart disease included 14 randomized controlled trials and 2869 participants. Compared with usual care, telerehabilitation improved six-minute walking distance, daily step counts, exercise habits, and several quality-of-life outcomes, while outcomes were generally comparable with conventional centre-based cardiac rehabilitation. Similarly, a 2024 network meta-analysis involving 46 randomized trials found that telehealth cardiac rehabilitation improved peak oxygen uptake, six-minute walking distance, moderate-to-vigorous physical activity, and adherence. Importantly, combinations of technologies appeared particularly useful: wearable devices combined with smartphone applications ranked highly for improving aerobic capacity, while smartphone applications combined with instant communication tools were strongly ranked for adherence. These findings have important implications for physiotherapy. Cardiac telerehabilitation is most effective when it preserves the core components of conventional rehabilitation rather than reducing treatment to simple exercise videos. Patients require individualized aerobic and resistance training, education regarding exercise intensity and symptom recognition, behavioural counselling, and monitoring of risk factors. Remote physiotherapists can use heart-rate responses, perceived exertion, symptom reports, activity data, and functional tests to adjust exercise intensity. Digital communication may also allow rapid clarification when patients experience uncertainty about symptoms or exercise progression. Figure 3 depicts Cardiac telerehabilitation intervention pathway. Evidence also supports technology-assisted approaches following percutaneous coronary intervention. Zhong et al. reported that home-based cardiac telerehabilitation following percutaneous coronary intervention improved six-minute walking performance and several cardiovascular risk factors compared with control conditions, although quality-of-life effects were less consistent. In patients with heart failure, Gao et al. found that home-based cardiac telerehabilitation was associated with beneficial effects across several rehabilitation outcomes, supporting its role as an alternative approach for patients unable to participate in conventional programmes. The clinical evidence therefore suggests that telerehabilitation should not be considered inferior simply because exercise occurs outside a rehabilitation centre. For appropriately screened and stable patients, remote programmes can achieve similar physiological and functional outcomes while reducing logistical barriers. However, evidence is less certain in high-risk populations, and technology should not replace professional clinical judgement. Current cardiovascular guidance consequently supports home-based and remote rehabilitation particularly when centre-based participation is difficult, while emphasizing appropriate risk assessment and multidisciplinary management.

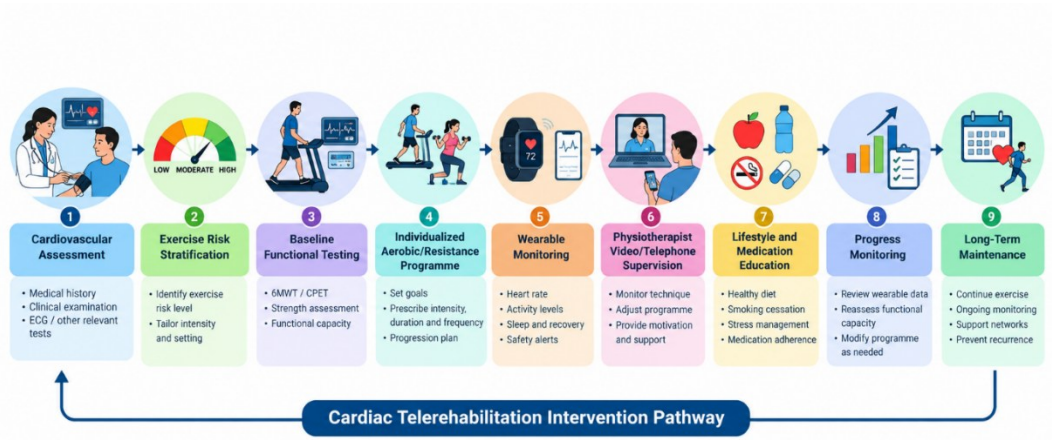

Figure 3. Cardiac telerehabilitation intervention pathway

4. Telerehabilitation in Pulmonary Physiotherapy and Chronic Respiratory Disease:

Pulmonary telerehabilitation has developed rapidly, particularly in COPD. Pulmonary rehabilitation is strongly recommended for patients with chronic respiratory disease because it improves exercise tolerance, symptoms, health status, and quality of life. Nevertheless, access remains inadequate. COPD patients may have severe breathlessness, mobility limitations, fatigue, anxiety about exertion, or geographical barriers that make frequent attendance difficult. Telerehabilitation allows pulmonary physiotherapy to be performed within the patient's home environment while retaining structured exercise progression and professional support. The evidence base has strengthened considerably. The Cochrane review of technology-supported pulmonary rehabilitation concluded that telerehabilitation can produce outcomes similar to traditional centre-based pulmonary rehabilitation, with high programme completion and no clear evidence of increased adverse events. The 2023 ATS guideline subsequently issued a strong recommendation for offering patients with stable chronic respiratory disease a choice between centre-based pulmonary rehabilitation and telerehabilitation. The guideline noted moderate-quality evidence for similar improvements in six-minute walking distance and lower-quality evidence for comparable quality-of-life and dyspnoea outcomes. A 2022 systematic review and meta-analysis by Isernia et al. found that telerehabilitation in COPD was effective in improving functional capacity, dyspnoea, and quality of life compared with no intervention, with evidence suggesting non-inferiority to conventional rehabilitation for functional capacity and quality of life. The review also highlighted substantial heterogeneity in the technology and supervision models used across studies. Dai et al. similarly demonstrated that telerehabilitation can influence physiological function and disease symptoms in chronic respiratory disease, although outcomes varied across intervention types. Randomized trials provide additional clinical support. Hansen et al. compared supervised pulmonary telerehabilitation with conventional pulmonary rehabilitation in patients with severe COPD and demonstrated that remotely delivered rehabilitation could provide clinically meaningful outcomes while addressing some of the barriers associated with attendance. Bourne et al. similarly compared an online pulmonary rehabilitation programme with face-to-face pulmonary rehabilitation and provided evidence supporting the feasibility of online delivery. Cerdán-de-las-Heras et al. also demonstrated the feasibility of technology-supported pulmonary rehabilitation in COPD, while subsequent research extended the application to idiopathic pulmonary fibrosis.

Table 2. Evidence for telerehabilitation across major cardiopulmonary populations

Population	Principal outcomes	Overall evidence	Clinical implication
Coronary heart disease	Exercise capacity, physical activity, QoL	Moderate and growing	Suitable alternative for selected stable patients
Heart failure	Exercise capacity, symptoms, QoL	Promising but heterogeneous	Requires individualized monitoring
Post-PCI	6MWD and cardiovascular risk factors	Favourable	Useful during home recovery
COPD	Exercise capacity, dyspnoea, QoL	Strongest pulmonary evidence	Viable alternative to centre-based PR

Interstitial lung disease	Exercise capacity and functional outcomes	Emerging	Appropriate in selected stable patients
Pulmonary hypertension	Exercise capacity and symptoms	Limited	Requires specialist risk assessment
Mixed cardiopulmonary disease	Functional capacity and self-management	Developing	Hybrid multidisciplinary models likely preferable

A particularly important development is long-term pulmonary telerehabilitation. Zanaboni et al. followed 120 patients with COPD for two years and found lower rates of hospitalizations and emergency-department presentations in both telerehabilitation and unsupervised home-training groups than in standard care. The telerehabilitation group also maintained clinically meaningful improvements in exercise capacity. These findings indicate that telerehabilitation may be valuable not only for initial rehabilitation but also for long-term maintenance.

5. Patient Adherence, Engagement and Satisfaction:

Adherence is arguably the most important behavioural determinant of telerehabilitation effectiveness. A theoretically effective exercise programme cannot produce meaningful clinical benefits if patients do not complete the prescribed sessions. Conventional cardiopulmonary rehabilitation faces well-recognized barriers, including transportation, work commitments, distance, fatigue, illness-related limitations, cost, and limited programme availability. Telerehabilitation can reduce many of these barriers because patients can exercise at home at a convenient time and avoid repeated travel. However, moving rehabilitation into the home also transfers responsibility for participation to the patient, creating new challenges involving motivation, digital competence, technology use, and self-regulation. A 2024 systematic review of real-time video telerehabilitation across physiotherapy populations found that attendance and exercise adherence were at least comparable with in-person care, with pooled evidence suggesting higher attendance and adherence in the telerehabilitation groups. In cardiac rehabilitation, a 2019 meta-analysis found that mobile applications increased the likelihood of completing rehabilitation, with application users demonstrating approximately 1.4-fold higher adherence than controls. More recent evidence has strengthened this association, particularly when applications are combined with communication tools and wearable monitoring. Pulmonary rehabilitation presents a more complex picture. Aubrat et al. reviewed adherence in COPD telerehabilitation and found reported adherence values ranging from approximately 21% to 93.5%, highlighting substantial heterogeneity in how adherence is defined and measured. Several studies showed adherence comparable with or higher than conventional pulmonary rehabilitation, while dropout rates were sometimes lower in telerehabilitation. Patient satisfaction was generally favourable. Figure 4 illustrates Determinants of adherence to cardiopulmonary telerehabilitation. Positive factors should include convenience, flexibility, feedback, goal setting, remote supervision, family support, self-monitoring, reminders, and reduced travel. Negative factors should include digital literacy problems, technical failures, low motivation, social isolation, disease exacerbation, equipment burden, privacy concerns, and inadequate professional contact. Adherence is influenced by more than convenience. Patients are more likely to continue rehabilitation when they perceive the intervention as meaningful, achievable, safe, and personally relevant. Goal setting should therefore be individualized. For example, a patient with COPD may value walking to the local market without severe breathlessness rather than achieving an abstract exercise target. A patient following coronary intervention may prioritize returning to work or climbing stairs independently. Physiotherapists should connect exercise targets with functional goals and use measurable progress indicators. Technology acceptance is another determinant. A systematic scoping review of home-based cardiac telerehabilitation found generally favourable usability, utility, and acceptance, but identified system quality, facilitating conditions, and patient-specific factors as important influences on technology use. Thus, a technologically sophisticated platform is not necessarily superior. The most effective system may be the simplest one that the patient can reliably use.

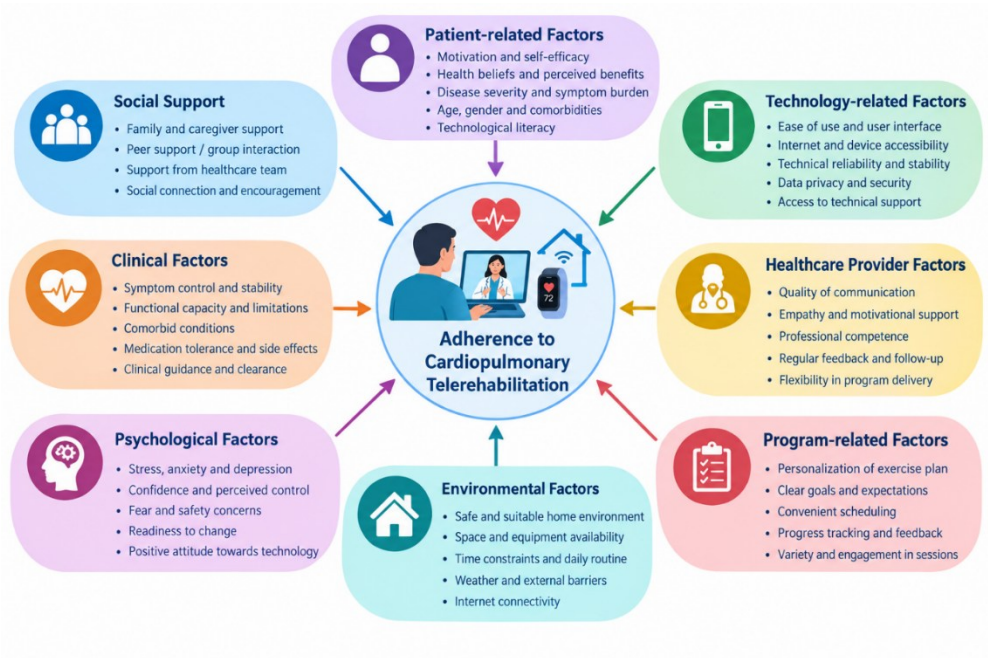

Figure 4. Determinants of adherence to cardiopulmonary telerehabilitation

6. Physiological Outcomes, Functional Capacity and Quality of Life:

The principal physiological goal of cardiopulmonary physiotherapy is to improve functional capacity and enable patients to perform daily activities with less symptom burden. In cardiac rehabilitation, common outcomes include peak oxygen uptake, six-minute walk distance, heart-rate response, blood pressure, physical activity, muscular strength, and exercise tolerance. In pulmonary rehabilitation, six-minute walking distance, incremental shuttle walking, sit-to-stand performance, dyspnoea, respiratory symptoms, and health-related quality of life are frequently assessed. Evidence from cardiac telerehabilitation is generally favourable. Li et al. found improvements in peak oxygen uptake, six-minute walking distance, physical activity, and adherence across different telehealth cardiac rehabilitation models. Wearable devices combined with smartphone applications appeared particularly promising for improving aerobic capacity. Ramachandran et al. reported that home-based cardiac telerehabilitation improved six-minute walking distance and daily step count compared with usual care, while producing outcomes comparable to centre-based rehabilitation. In COPD, the evidence is similarly encouraging but more heterogeneous. Isernia et al. reported beneficial effects of telerehabilitation on functional capacity, dyspnoea, and quality of life, while a 2025 meta-analysis involving 18 randomized trials and more than 3000 patients suggested that telerehabilitation may be particularly useful for reducing dyspnoea and psychological symptoms, although differences in exercise capacity and quality of life compared with face-to-face rehabilitation were not uniformly significant. A 2024 systematic review of web-based pulmonary telerehabilitation found increased daily step counts but no substantial differences in several conventional walking, dyspnoea, and quality-of-life measures, reinforcing the importance of intervention design rather than assuming that every digital programme will be effective. The variability in outcomes highlights an important principle: telerehabilitation is a delivery method, not a standardized treatment. Two programmes may both be labelled “telerehabilitation” while differing markedly in exercise intensity, supervision, duration, frequency, technology, feedback, and patient interaction. A passive application providing generic exercise videos should therefore not be considered equivalent to a physiotherapist-supervised programme incorporating individualized exercise prescription and physiological monitoring. Quality of life is another major outcome. Cardiopulmonary disease affects physical functioning, emotional well-being, social participation, independence, and confidence. Remote rehabilitation can improve quality of life by increasing activity and self-efficacy, but digital contact should not completely eliminate interpersonal interaction. Patients with chronic cardiopulmonary disease may experience anxiety, fear of breathlessness, depression, or social isolation, making therapeutic communication an important component of physiotherapy.

7. Home-Based Rehabilitation, Remote Monitoring and Digital Technology:

Home-based cardiopulmonary rehabilitation has become increasingly sophisticated. Early programmes relied mainly on telephone calls and paper exercise diaries. Current systems can incorporate smartphones, tablets, smartwatches, chest-worn heart-rate monitors, pulse oximeters, blood-pressure monitors, activity trackers, digital scales, symptom questionnaires, and cloud-based dashboards. Physiotherapists can potentially monitor

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exercise dose, daily activity, heart-rate response, oxygen saturation, symptom trends, and adherence without requiring the patient to travel to a clinic. The figure 5 connect the patient with smartphone/tablet, wearable activity tracker, heart-rate monitor, pulse oximeter, blood-pressure monitor, exercise platform and secure cloud dashboard, with data flowing to the physiotherapist and multidisciplinary team. Wearable technology is particularly relevant to exercise prescription. Activity data can demonstrate whether the patient is meeting daily movement goals, while heart-rate and perceived-exertion information can help physiotherapists assess exercise intensity. In cardiac populations, wearable technology can also support long-term physical-activity monitoring. In pulmonary populations, pulse oximetry may assist selected patients requiring oxygen or monitoring for exertional desaturation. However, physiotherapists must recognize that consumer-grade devices can produce inaccurate readings, especially during movement or in individuals with poor peripheral perfusion. Technology should therefore supplement, rather than replace, clinical assessment. Antoniou et al. reviewed wearable-sensor-supported home cardiac rehabilitation and concluded that wearable technology represents a promising adjunct or alternative to conventional centre-based rehabilitation, although evidence for superiority across outcomes remains inconsistent. Similarly, smartphone-supported pulmonary rehabilitation has shown potential for maintaining physical activity after formal rehabilitation. Spielmanns et al. demonstrated that smartphone application use can support physical-activity maintenance after pulmonary rehabilitation in COPD, emphasizing the potential of digital tools beyond the initial intervention period. Remote monitoring also allows earlier recognition of deterioration. Increasing dyspnoea, declining daily activity, reduced oxygen saturation, abnormal heart-rate responses, sudden weight changes in selected heart-failure populations, or repeated symptom alerts may trigger physiotherapist or medical review. However, monitoring systems must have clear escalation protocols. Generating large quantities of physiological data without a defined response pathway can increase workload without improving outcomes.

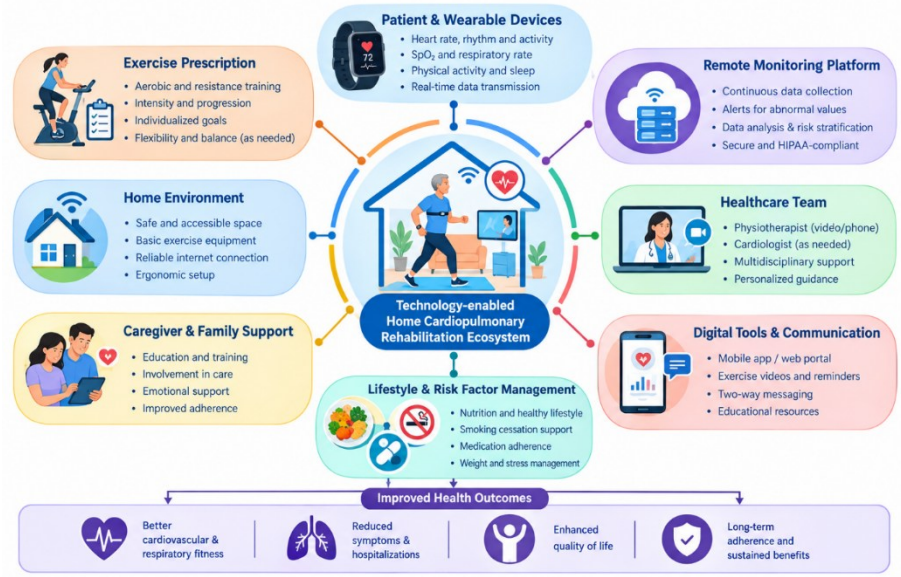

Figure 5. Technology-enabled home cardiopulmonary rehabilitation ecosystem

8. Safety, Clinical Implementation and the Role of the Physiotherapist:

Safety is a central consideration in cardiopulmonary telerehabilitation. Remote exercise lacks some of the immediate physical resources available in a hospital gymnasium, including continuous clinician observation, emergency equipment, and rapid access to medical personnel. Therefore, patient selection and pre-exercise risk stratification are essential. Patients should be screened for unstable cardiovascular disease, uncontrolled symptoms, recent acute events, severe exercise intolerance, uncontrolled arrhythmias, acute respiratory exacerbation, severe oxygen desaturation, and other conditions requiring direct medical supervision. Evidence nevertheless suggests that supervised home-based cardiac rehabilitation can be safe in appropriately selected populations. A systematic review of home-based cardiac rehabilitation reported a very low incidence of severe exercise-related adverse events, with no deaths or hospitalizations attributable to exercise in the included studies. Pulmonary telerehabilitation studies have similarly not identified major safety concerns compared with conventional rehabilitation, although reporting standards remain inconsistent.

Table 3. Clinical implementation framework for cardiopulmonary telerehabilitation

Implementation domain	Recommended approach
Patient selection	Confirm diagnosis, clinical stability and rehabilitation suitability
Risk assessment	Identify cardiovascular, respiratory and exercise-related risks
Baseline testing	Functional capacity, symptoms, vital signs and patient goals
Technology assessment	Check device access, connectivity and digital literacy
Exercise prescription	Individualized aerobic, resistance, breathing and functional training
Supervision	Synchronous, asynchronous or hybrid according to clinical risk
Monitoring	Symptoms, HR, SpO_2, BP, activity and perceived exertion where appropriate
Adherence	Goal setting, reminders, feedback, motivational strategies
Safety	Emergency plan, red-flag education and escalation pathway
Reassessment	Repeat functional and patient-reported outcome measures
Long-term care	Maintenance programme and periodic multidisciplinary review

The physiotherapist remains the central clinical professional even when rehabilitation is delivered digitally. Their responsibilities include assessment, exercise prescription, movement correction, progression, symptom interpretation, behavioural coaching, patient education, safety management, and communication with physicians, nurses, dietitians, psychologists, and other professionals. Technology cannot independently determine whether a patient's breathlessness represents expected exertional symptoms or an acute clinical deterioration. Similarly, an elevated heart rate may reflect exercise, anxiety, medication changes, arrhythmia, or another clinical issue. Interpretation requires clinical reasoning. Clinical implementation should also consider privacy and data security. Health information transmitted through applications, cloud platforms, and wearable systems must be handled according to applicable privacy and data-protection requirements. Patients should understand what information is collected, who can access it, and how it will be used. Digital inclusion is another major challenge. Older adults, individuals with limited education, patients with visual or cognitive impairment, and those living in areas with poor internet connectivity may struggle with sophisticated platforms. Consequently, telerehabilitation programmes should offer alternatives such as telephone support, simplified interfaces, caregiver involvement, and hybrid visits. Technology should reduce inequity rather than create another barrier.

9. Future Perspectives: Artificial Intelligence, Personalization and Hybrid Rehabilitation:

The future of cardiopulmonary telerehabilitation is likely to involve increasingly personalized and intelligent systems. Artificial intelligence may assist with identifying patterns in activity, heart rate, symptoms, adherence, and physiological responses. Machine-learning models could potentially identify patients at risk of rehabilitation dropout, predict exacerbations, recommend exercise progression, or generate individualized reminders. However, these applications remain developmental and require validation before they are incorporated into routine clinical decision-making. Figure 6 depicts the Future intelligent cardiopulmonary telerehabilitation model. Future systems may also move from simple monitoring toward adaptive rehabilitation. For example, an algorithm could identify that a patient consistently completes exercise at a lower perceived exertion than prescribed and alert the physiotherapist that progression may be appropriate. Conversely, repeated reductions in daily activity combined with increasing dyspnoea could prompt clinical review. Importantly, AI-generated recommendations should remain subject to professional verification. Hybrid rehabilitation is likely to become particularly important. Purely centre-based rehabilitation is

constrained by accessibility, whereas completely remote rehabilitation may reduce opportunities for physical examination, social interaction, and high-level clinical supervision. A hybrid model can combine initial face-to-face assessment, selected supervised centre-based sessions, remote exercise sessions, periodic reassessment, and long-term digital monitoring. The 2026 European Society of Cardiology cardiac rehabilitation guideline explicitly emphasizes patient-centred combinations of in-person, virtual, and remote rehabilitation to improve participation, adherence, and health equity. Another future direction is the integration of rehabilitation with primary care and chronic disease management. Rather than operating as an isolated programme, telerehabilitation could become part of a continuous digital care pathway connecting physiotherapists, cardiologists, pulmonologists, nurses, primary-care clinicians, dietitians, and psychologists. Such integration may allow rehabilitation to continue during periods when patients are unable to attend conventional services. Economic evaluation will also become increasingly important. Telerehabilitation may reduce travel costs, facility requirements, and clinician time per patient, but technology acquisition, platform maintenance, technical support, device replacement, data security, and staff training generate new costs. Cost-effectiveness therefore depends on the design of the programme and healthcare context. Evidence from cardiac telerehabilitation suggests that economic advantages are plausible, but more standardized long-term evaluations are needed.

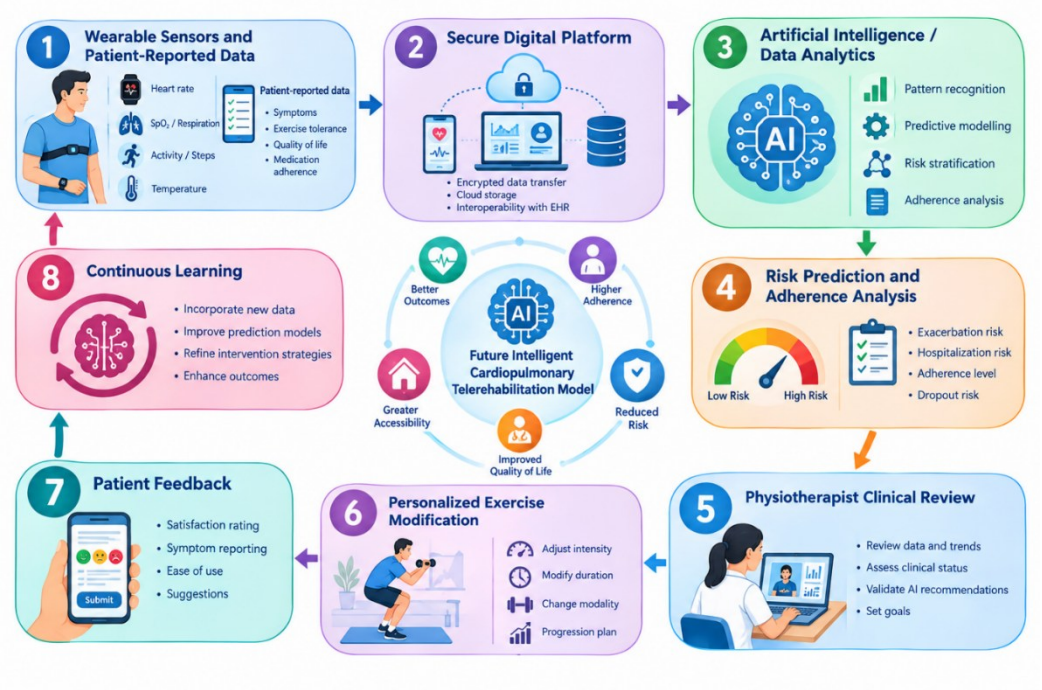

Figure 6. Future intelligent cardiopulmonary telerehabilitation model

10. Evidence Gaps, Challenges and Research Priorities:

Despite encouraging evidence, several important gaps remain. First, intervention heterogeneity makes comparison difficult. Studies differ in programme duration, frequency, exercise intensity, supervision, technology, monitoring, and outcome measures. A common reporting framework would allow researchers to determine which components are responsible for successful outcomes. Second, adherence is inconsistently defined. Some studies define adherence as attendance at scheduled sessions, whereas others calculate completed exercise minutes, percentage of prescribed exercises completed, application engagement, device wear time, or programme completion. Standardized adherence definitions are therefore required. Third, long-term evidence remains limited. Many studies assess outcomes immediately after an intervention lasting six to twelve weeks. Cardiopulmonary rehabilitation, however, is fundamentally a long-term behaviour-change intervention. Future studies should assess whether improvements persist for one, two, or more years and whether continued digital monitoring reduces hospitalization, exacerbation, cardiovascular events, or healthcare utilization. Fourth, high-risk patients are underrepresented. Much of the evidence is derived from clinically stable participants who can safely exercise at home. More evidence is required concerning patients with advanced heart failure, pulmonary hypertension, severe COPD, recent cardiovascular events, complex arrhythmias, and significant frailty. Such research must prioritize safety and should examine hybrid rather than purely unsupervised approaches. Fifth, equity requires greater attention. Women, older adults, economically disadvantaged individuals, rural populations, and people with limited digital literacy may be underrepresented in technology studies. Although telerehabilitation can reduce geographical barriers, it can also increase

inequity if patients lack smartphones, broadband access, reliable electricity, or digital skills. Future programmes should therefore adopt inclusive designs. Finally, future trials should compare not simply "telerehabilitation versus conventional rehabilitation" but different delivery models and their components. Important research questions include whether synchronous supervision is superior to asynchronous care for specific populations, whether hybrid programmes provide better long-term adherence, how much therapist contact is required, which wearable measurements are clinically useful, and whether AI-supported personalization produces better outcomes than standard digital rehabilitation.

11. Conclusion:

Telerehabilitation has progressed from an emergency alternative to conventional physiotherapy into a clinically relevant model for long-term cardiopulmonary rehabilitation. Current evidence indicates that appropriately designed and professionally supervised telerehabilitation can provide exercise-capacity, physical-activity, symptom, quality-of-life, and adherence outcomes comparable with conventional rehabilitation in many stable cardiac and respiratory populations. The strongest evidence is currently available for coronary heart disease and COPD, while evidence for other conditions such as pulmonary hypertension, interstitial lung disease, complex heart failure, and high-risk cardiovascular populations continues to develop. Patient adherence is one of the principal advantages as well as challenges of remote care. Convenience, flexible scheduling, reduced travel, continuous feedback, wearable monitoring, and personalized communication can improve engagement, but technology burden, digital inequity, poor connectivity, limited motivation, and inadequate professional contact can undermine participation. The role of the physiotherapist remains fundamental because technology cannot replace clinical assessment, exercise prescription, safety evaluation, progression, patient education, and clinical reasoning. Future cardiopulmonary rehabilitation is likely to adopt hybrid and patient-centred models integrating face-to-face assessment, remote physiotherapy, wearable sensors, smartphone applications, physiological monitoring, artificial intelligence, and long-term behavioural support. The objective should not be to replace rehabilitation centres with technology but to create a flexible continuum of care in which patients receive the right amount of supervision, at the right time, in the environment most compatible with their clinical needs and personal circumstances. In this context, telerehabilitation represents a promising strategy for expanding access, improving continuity, supporting adherence, and making cardiopulmonary physiotherapy more personalized and sustainable.

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