Effectiveness of virtual reality based respiratory physiotherapy in patients with chronic bronchopulmonary disorders: a systematic review

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Abstract

Chronic bronchopulmonary disorders are among the leading causes of morbidity and mortality worldwide, significantly affecting pulmonary function, physical endurance, psychological well-being, and quality of life. Conventional respiratory physiotherapy and pulmonary rehabilitation remain essential therapeutic approaches for managing chronic respiratory diseases. however, long-term patient adherence is frequently poor due to monotony, lack of motivation, transportation difficulties, and limited accessibility to specialized rehabilitation centers. In recent years, virtual reality (VR) technology has emerged as a promising adjunctive tool in rehabilitation medicine, offering immersive, interactive, and gamified therapeutic experiences that enhance patient engagement and adherence. The present systematic review evaluates the effectiveness of VR-based respiratory physiotherapy in patients with chronic bronchopulmonary disorders including chronic obstructive pulmonary disease (COPD), asthma, bronchiectasis, interstitial lung disease, cystic fibrosis, and post-COVID pulmonary dysfunction. Evidence from studies published during the last decade demonstrates that VR-assisted respiratory rehabilitation significantly improves pulmonary function, exercise tolerance, respiratory muscle performance, dyspnea perception, psychological health, and overall quality of life. Additionally, VR-based interventions promote motivation, reduce anxiety associated with physical activity, and facilitate home-based tele-rehabilitation. Despite promising outcomes, challenges related to cost, technological limitations, cybersickness, and lack of standardized protocols remain significant barriers to widespread implementation. Future integration of artificial intelligence, wearable biosensors, and telehealth systems may further enhance the effectiveness and accessibility of VR-based respiratory physiotherapy.

Keywords: Virtual Reality, Respiratory Physiotherapy, Pulmonary Rehabilitation, Chronic Bronchopulmonary Disorders, COPD, Asthma, Post-COVID Rehabilitation, Tele-Rehabilitation, Respiratory Therapy, Gamification.

Introduction

Chronic bronchopulmonary disorders constitute a major global public health burden and are associated with substantial morbidity, mortality, disability, and healthcare expenditure worldwide (Nici et al., 2020). Diseases such as chronic obstructive pulmonary disease (COPD), asthma, bronchiectasis, cystic fibrosis, interstitial lung disease, and post-viral pulmonary syndromes significantly impair respiratory function and negatively affect physical, psychological, and social well-being (Singh et al., 2019). Persistent airway inflammation, bronchial remodeling, mucus hypersecretion, alveolar destruction, fibrosis, and impaired gas exchange contribute to progressive dyspnea, chronic fatigue, reduced exercise tolerance, and decreased quality of life in affected individuals (Bhatt & Dransfield, 2018). COPD alone is projected to become one of the leading causes of mortality globally due to increasing exposure to tobacco smoke, occupational pollutants, biomass fuel combustion, urbanization, and aging populations (McCarthy et al., 2018). In addition to pulmonary dysfunction, chronic respiratory diseases frequently contribute to anxiety, depression, sleep disturbances, social isolation, and reduced functional independence (Molina et al., 2021). Pulmonary rehabilitation has emerged as one of the most effective evidence-based non-pharmacological interventions for chronic respiratory disorders and is strongly recommended by international respiratory societies (Toussaint et al., 2018). Conventional respiratory physiotherapy focuses on improving airway clearance, respiratory muscle strength, thoracic mobility, breathing efficiency, oxygen utilization, and cardiovascular endurance through diaphragmatic breathing, pursed-lip breathing, inspiratory muscle training, aerobic conditioning, and

endurance exercises (Freitas et al., 2021). These rehabilitation interventions significantly improve exercise capacity, dyspnea perception, pulmonary mechanics, and psychological well-being among patients with chronic respiratory diseases (Gomes Neto et al., 2021). However, despite substantial clinical benefits, long-term adherence to pulmonary rehabilitation programs remains a major challenge due to boredom, lack of motivation, transportation barriers, financial limitations, poor accessibility to rehabilitation centers, and psychological distress associated with chronic illness (Lundell et al., 2021). Many patients discontinue rehabilitation programs prematurely because traditional respiratory exercises are repetitive and physically exhausting, particularly among elderly individuals and patients with advanced pulmonary dysfunction (Vieira et al., 2020). Consequently, researchers and clinicians have increasingly explored innovative digital healthcare technologies capable of improving patient engagement and rehabilitation adherence (Tait et al., 2022). Among these emerging technologies, virtual reality (VR) has gained substantial attention as a transformative rehabilitation tool capable of enhancing therapeutic effectiveness and patient motivation (Patel et al., 2023). VR-based respiratory physiotherapy integrates immersive computer-generated environments with therapeutic breathing exercises, biofeedback systems, wearable respiratory sensors, motion-tracking devices, and gamified rehabilitation tasks to create highly interactive rehabilitation experiences (Rutkowski et al., 2020). These systems encourage active patient participation while simultaneously improving respiratory mechanics, motor coordination, exercise tolerance, and psychological engagement (Howard, 2017). VR-assisted pulmonary rehabilitation may be immersive, semi-immersive, or non-immersive depending on the degree of sensory integration and technological sophistication (Levac et al., 2019). Immersive VR systems commonly utilize head-mounted displays, motion sensors, and three-dimensional digital environments to fully engage patients during rehabilitation sessions (Banos et al., 2021). In contrast, non-immersive systems often employ computer screens, gaming consoles, smartphone applications, and breathing-controlled games that are more affordable and accessible in routine clinical practice (da Silva et al., 2020). One of the major advantages of VR-based respiratory physiotherapy is the incorporation of gamification strategies that transform repetitive breathing exercises into enjoyable and motivating activities (Pinto et al., 2022). Real-time visual and auditory feedback provided by VR systems enhances breathing coordination, diaphragmatic activation, thoracic expansion, and respiratory muscle performance (Silva et al., 2021). Furthermore, immersive digital environments distract patients from dyspnea sensations and reduce anxiety associated with physical exertion, thereby improving exercise tolerance and rehabilitation adherence (Hoffman et al., 2019). Figure 1 illustrates the integration of respiratory exercises, immersive digital environments, biofeedback systems, wearable technologies, and patient engagement mechanisms involved in VR-assisted pulmonary rehabilitation (Zhang et al., 2021). The COVID-19 pandemic further accelerated interest in virtual rehabilitation technologies due to social distancing requirements, reduced access to outpatient healthcare facilities, and increasing prevalence of post-COVID pulmonary complications (Yeo et al., 2020). Many individuals recovering from severe COVID-19 infection experience persistent pulmonary fibrosis, dyspnea, fatigue, respiratory muscle weakness, exercise intolerance, and psychological distress requiring long-term pulmonary rehabilitation (Chen et al., 2022). Consequently, home-based VR-assisted respiratory rehabilitation emerged as a highly valuable telehealth solution capable of delivering supervised pulmonary physiotherapy remotely while minimizing infection risks (Wan et al., 2023). Recent studies suggest that VR-based pulmonary rehabilitation significantly improves exercise endurance, oxygen saturation, respiratory muscle strength, balance, quality of life, and emotional well-being among post-COVID patients and individuals with chronic respiratory diseases (Wu et al., 2024).

Figure 1. Conceptual Framework of Virtual Reality–Based Pulmonary Rehabilitation

Methodology

The present study was conducted using a systematic review methodology to critically evaluate available scientific literature regarding the effectiveness of virtual reality (VR)–based respiratory physiotherapy in patients with chronic bronchopulmonary disorders (Page et al., 2021). A comprehensive and structured literature search was performed using internationally recognized electronic databases including PubMed, Scopus, Embase, Web of Science, PEDro, Cochrane Library, and Google Scholar to identify relevant studies published between January 2016 and March 2026 (Higgins et al., 2022). The review process was designed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological transparency, reproducibility, and scientific rigor throughout the study selection and data extraction process (Liberati et al., 2018). A broad search strategy was adopted using combinations of keywords and Medical Subject Headings (MeSH) terms including “virtual reality,” “respiratory physiotherapy,” “pulmonary rehabilitation,” “chronic obstructive pulmonary disease,” “asthma,” “bronchiectasis,” “post-COVID rehabilitation,” “interactive breathing exercises,” “tele-rehabilitation,” and “chronic lung disease” to maximize identification of relevant articles (McCarthy et al., 2018). Boolean operators such as AND, OR, and NOT were employed to refine the search strategy and improve database sensitivity and specificity (Bramer et al., 2018). Studies included randomized controlled trials, comparative clinical trials, pilot studies, observational studies, systematic reviews, and meta-analyses investigating VR-assisted respiratory rehabilitation interventions in adult and pediatric populations (Howard, 2017). Only peer-reviewed English-language articles published within the last ten years were included to ensure contemporary relevance and methodological quality (Levac et al., 2019). Conference abstracts, editorial articles, letters to editors, duplicate publications, case reports with inadequate methodological rigor, and studies unrelated to respiratory rehabilitation were excluded from the final analysis (Laver et al., 2017). Eligibility criteria were carefully established to ensure consistency during study selection and minimize selection bias (Moher et al., 2018). Table 1 summarizes the predefined eligibility criteria used during screening and article selection (Nici et al., 2020). The literature search initially yielded a large number of citations from multiple databases, after which duplicate studies were removed using citation management software and manual verification techniques (Bramer et al., 2018). Titles and abstracts were independently screened by reviewers to identify potentially eligible studies for full-text assessment (Page et al., 2021). Full-text articles were then evaluated according to predefined inclusion and exclusion criteria focusing on patient population, intervention characteristics, rehabilitation outcomes, and methodological quality (Singh et al., 2019). Studies involving chronic respiratory conditions such as COPD, asthma, cystic fibrosis, bronchiectasis, interstitial lung disease, and post-COVID pulmonary dysfunction were prioritized because these disorders commonly require long-term respiratory rehabilitation and physiotherapy interventions (Freitas et al., 2021). Data extraction focused on study design, sample size, demographic characteristics, VR technology utilized, rehabilitation protocols, intervention duration, outcome measures, and reported clinical effectiveness (Rutkowski et al., 2020). Important outcome variables included pulmonary function tests, six-minute walk distance, respiratory muscle strength, dyspnea severity, oxygen saturation, exercise tolerance, psychological status, quality of life scores, and rehabilitation

adherence rates (Gomes Neto et al., 2021). The methodological quality of included studies was evaluated using standardized evidence appraisal tools including the PEDro scale, Cochrane risk-of-bias framework, and PRISMA reporting checklist to ensure validity and reliability of findings (Higgins et al., 2022). The PEDro scale was particularly useful for assessing internal validity, randomization procedures, blinding techniques, attrition rates, and statistical reporting quality among physiotherapy-related clinical trials (Maher et al., 2017). Studies with higher methodological scores were considered more reliable for evidence synthesis and interpretation (Moseley et al., 2019). In addition, the risk of publication bias, incomplete reporting, and selective outcome reporting was critically evaluated during evidence appraisal (Sterne et al., 2019). Data synthesis involved qualitative comparison of intervention characteristics, rehabilitation outcomes, and technological approaches used in VR-based respiratory physiotherapy programs (Molina et al., 2021). Due to heterogeneity in patient populations, intervention duration, outcome measures, and VR technologies employed across studies, narrative synthesis methods were predominantly utilized instead of statistical meta-analysis (Vieira et al., 2020). Particular emphasis was placed on identifying patterns related to improvements in pulmonary function, respiratory endurance, exercise capacity, psychological well-being, patient motivation, and rehabilitation adherence associated with VR-assisted respiratory therapy (Patel et al., 2023). Furthermore, special attention was given to emerging applications of VR-based tele-rehabilitation following the COVID-19 pandemic because remote respiratory rehabilitation became increasingly important during periods of social distancing and restricted healthcare access (Yeo et al., 2020). Studies investigating home-based VR rehabilitation systems, wearable respiratory sensors, immersive breathing exercises, and gamified pulmonary rehabilitation platforms were extensively analyzed due to their growing significance in modern respiratory care (Wu et al., 2024).

Table 1. Inclusion and Exclusion Criteria for Study Selection

Inclusion Criteria	**Exclusion Criteria**
Studies published from 2016–2026	Studies before 2016
Peer-reviewed English articles	Non-English publications
VR-based respiratory rehabilitation studies	Non-respiratory rehabilitation studies
COPD, asthma, bronchiectasis, post-COVID disorders	Acute respiratory emergencies
Adult and pediatric populations	Conference abstracts/editorials

Pathophysiological Basis of Chronic Bronchopulmonary Disorders

Chronic bronchopulmonary disorders involve complex pathophysiological alterations affecting airway architecture, pulmonary mechanics, respiratory muscles, cardiovascular function, and systemic metabolism, ultimately leading to progressive respiratory insufficiency and reduced quality of life (Bhatt & Dransfield, 2018). Persistent airway inflammation, mucus hypersecretion, alveolar destruction, fibrosis, oxidative stress, and bronchial remodeling contribute significantly to airflow limitation and impaired pulmonary gas exchange in chronic respiratory diseases (McCarthy et al., 2018). Over time, these pathological changes result in progressive dyspnea, chronic fatigue, reduced exercise tolerance, respiratory muscle dysfunction, skeletal muscle wasting, and physical deconditioning among affected individuals (Singh et al., 2019). In chronic obstructive pulmonary disease (COPD), prolonged exposure to tobacco smoke, occupational pollutants, biomass fuel combustion, and environmental toxins causes emphysematous destruction of alveolar tissue and narrowing of small airways, resulting in hyperinflation and impaired oxygen diffusion capacity (Nici et al., 2020). Asthma is primarily characterized by chronic airway inflammation, bronchial hyperresponsiveness, reversible bronchoconstriction, and episodic airflow obstruction that contribute to recurrent respiratory symptoms and impaired pulmonary performance (Freitas et al., 2021). Bronchiectasis involves irreversible airway dilation, chronic infection, excessive mucus accumulation, and recurrent pulmonary exacerbations that progressively impair lung function and respiratory endurance (Toussaint et al., 2018). Similarly, post-COVID pulmonary dysfunction has emerged as a significant global healthcare challenge involving pulmonary fibrosis, endothelial dysfunction, reduced diffusion capacity, chronic fatigue, respiratory muscle weakness, and exercise intolerance in many recovered patients (Chen et al., 2022). Respiratory physiotherapy plays a vital role in minimizing these complications by improving ventilation, airway clearance, diaphragmatic activation, thoracic

expansion, oxygen delivery, respiratory muscle coordination, and functional exercise capacity (Gomes Neto et al., 2021). Conventional pulmonary rehabilitation programs commonly incorporate diaphragmatic breathing exercises, inspiratory muscle training, aerobic conditioning, endurance exercises, airway clearance techniques, and thoracic mobility training to optimize pulmonary function and physical performance (Lundell et al., 2021). Despite these clinical benefits, many patients perceive traditional respiratory rehabilitation programs as repetitive, monotonous, physically exhausting, and psychologically unengaging, which contributes to poor long-term adherence and reduced rehabilitation effectiveness (Vieira et al., 2020). Virtual reality (VR) technology has emerged as an innovative therapeutic strategy capable of overcoming these limitations by transforming conventional respiratory rehabilitation into highly engaging and interactive therapeutic experiences (Patel et al., 2023). VR systems integrate breathing exercises with immersive gaming environments, virtual cycling activities, obstacle navigation tasks, motion-based exercises, and biofeedback-guided respiratory training programs that encourage active patient participation and improve rehabilitation adherence (Rutkowski et al., 2020). These interventions stimulate multisensory neural pathways involving visual, auditory, proprioceptive, and motor feedback systems that enhance emotional engagement, neuroplasticity, respiratory coordination, and exercise tolerance during rehabilitation sessions (Howard, 2017). In addition, immersive VR environments reduce anxiety and dyspnea perception by diverting patient attention away from respiratory discomfort and increasing motivation toward rehabilitation participation (Hoffman et al., 2019). Figure 2 demonstrates how VR-assisted interventions improve respiratory muscle activation, pulmonary ventilation, thoracic mobility, exercise capacity, neuroplastic adaptation, and psychological motivation in patients with chronic bronchopulmonary disorders (Zhang et al., 2021).

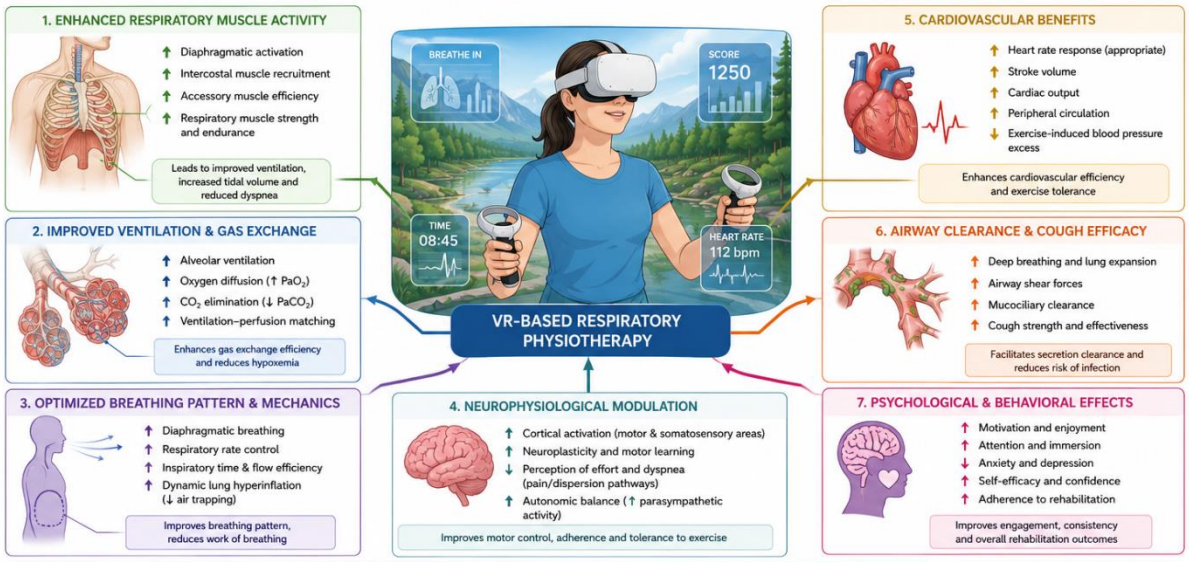

Figure 2. Physiological Mechanisms Involved in VR-Based Respiratory Physiotherapy

Types of Virtual Reality Used in Respiratory Physiotherapy

Virtual reality (VR) systems used in pulmonary rehabilitation can be broadly classified into immersive VR, semi-immersive VR, and non-immersive VR systems, each offering distinct technological characteristics and therapeutic applications in respiratory physiotherapy (Massetti et al., 2018). These VR modalities differ in terms of sensory engagement, patient interaction, equipment complexity, and degree of environmental immersion during rehabilitation sessions (Howard, 2017). Immersive VR systems provide complete sensory immersion through the use of head-mounted displays, motion-tracking sensors, three-dimensional virtual environments, and advanced audiovisual feedback technologies that create highly realistic therapeutic experiences for patients with chronic respiratory disorders (Banos et al., 2021). In immersive VR environments, patients interact with computer-generated surroundings through body movements, respiratory patterns, upper-limb activities, and breathing-controlled exercises, thereby enhancing emotional engagement and rehabilitation participation (Levac et al., 2019). These systems are particularly effective in improving patient motivation, exercise adherence, respiratory coordination, and psychological involvement during pulmonary rehabilitation sessions (Patel et al., 2023). Immersive VR may additionally stimulate neuroplasticity and sensorimotor integration by activating multiple neural pathways simultaneously through visual, auditory, proprioceptive, and vestibular stimulation (Hoffman et al., 2019). However, despite these therapeutic benefits, some users experience cybersickness, dizziness, nausea, headaches, visual fatigue, and motion-related discomfort during prolonged immersive VR sessions, especially elderly patients and individuals with vestibular sensitivity (Laver et al., 2017). Semi-immersive VR systems represent an intermediate form of virtual rehabilitation that utilizes large projection screens, wall-mounted displays, interactive motion sensors,

and audiovisual feedback systems to provide moderate environmental immersion without completely isolating the patient from the physical environment (Faria et al., 2020). These systems reduce the likelihood of cybersickness while still promoting patient engagement, physical activity, respiratory coordination, and rehabilitation adherence (Molina et al., 2021). Semi-immersive VR is particularly suitable for patients who may not tolerate fully immersive head-mounted systems but still benefit from interactive digital rehabilitation experiences (Freitas et al., 2021). Non-immersive VR systems are currently the most widely used VR modality in respiratory physiotherapy due to their affordability, accessibility, ease of implementation, and minimal technological complexity (Rutkowski et al., 2020). These systems commonly involve computer games, smartphone applications, Nintendo Wii, Xbox Kinect platforms, breathing-controlled games, and motion-based exergaming activities that integrate respiratory exercises with enjoyable interactive tasks (da Silva et al., 2020). Non-immersive VR interventions effectively combine diaphragmatic breathing exercises, balance training, upper-limb coordination, aerobic conditioning, thoracic mobility exercises, and inspiratory muscle training within engaging virtual environments (Vieira et al., 2020). Breathing-controlled gaming platforms are particularly useful because they encourage patients to perform respiratory exercises repeatedly while maintaining high levels of motivation and enjoyment during rehabilitation sessions (Silva et al., 2021). Figure 3 illustrates various technological devices including head-mounted displays, respiratory sensors, gaming consoles, wearable biosensors, projection systems, and telemonitoring technologies commonly utilized in VR-assisted respiratory physiotherapy programs (Zhang et al., 2021). Several clinical studies have demonstrated that non-immersive VR systems significantly improve patient motivation, exercise participation, treatment adherence, respiratory endurance, and functional exercise capacity compared to traditional pulmonary rehabilitation approaches (Gomes Neto et al., 2021). Gamified breathing exercises encourage longer rehabilitation participation, increased exercise intensity, and reduced perceived dyspnea by diverting patient attention away from respiratory discomfort and fatigue (Pinto et al., 2022). Furthermore, many non-immersive VR systems support home-based tele-rehabilitation programs, allowing healthcare professionals to remotely monitor patient performance, oxygen saturation, respiratory patterns, and rehabilitation adherence through integrated digital platforms (Yeo et al., 2020). The increasing integration of wearable biosensors, artificial intelligence algorithms, cloud-based telehealth systems, and real-time physiological monitoring technologies is expected to further enhance the effectiveness, personalization, and accessibility of VR-based pulmonary rehabilitation in the future (Wu et al., 2024).

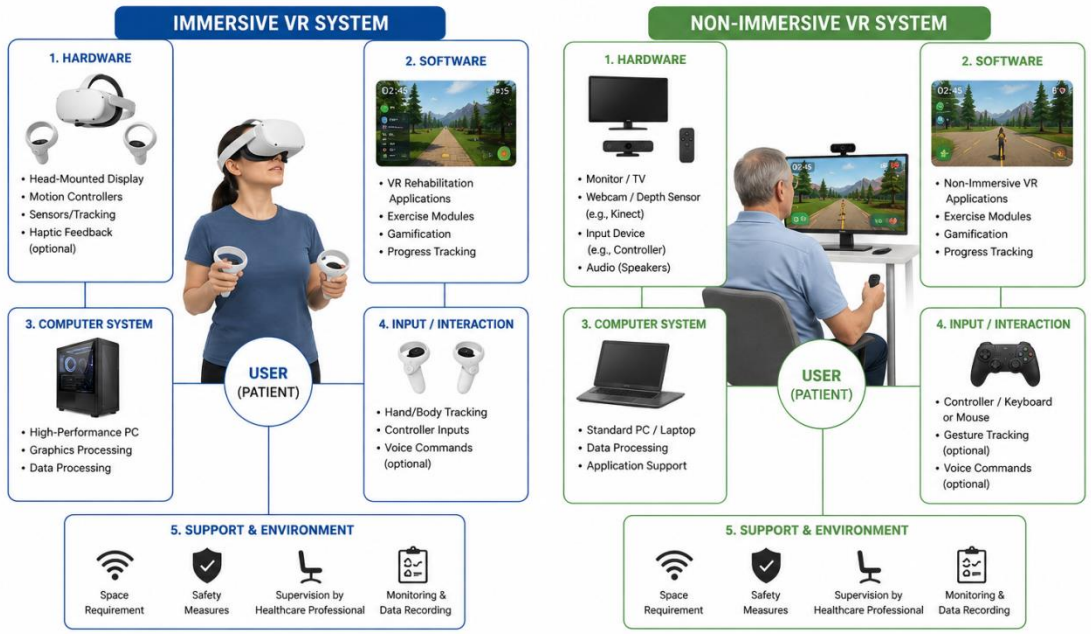

Figure 3. Components of Immersive and Non-Immersive VR Systems in Pulmonary Rehabilitation

Mechanisms of Action of VR-Based Respiratory Physiotherapy

The therapeutic effectiveness of virtual reality (VR)–based respiratory rehabilitation involves multiple physiological, neurological, biomechanical, and psychological mechanisms that collectively contribute to improved pulmonary function, exercise tolerance, and rehabilitation adherence in patients with chronic bronchopulmonary disorders (Gomes Neto et al., 2021). One of the primary advantages of VR-assisted respiratory physiotherapy is gamification, which transforms repetitive and monotonous therapeutic exercises into enjoyable, motivating, and interactive rehabilitation activities that increase patient participation and long-term treatment compliance (Pinto et al., 2022). Gamified rehabilitation environments encourage active

engagement by integrating breathing exercises with virtual challenges, movement-based tasks, reward systems, and real-time performance feedback that enhance motivation and reduce exercise-related boredom (da Silva et al., 2020). Increased emotional involvement and patient engagement during VR sessions significantly improve rehabilitation adherence and overall therapeutic effectiveness compared with conventional pulmonary rehabilitation protocols (Vieira et al., 2020). Real-time visual and auditory feedback provided by VR systems enhances respiratory coordination, diaphragmatic activation, thoracic mobility, and breathing pattern synchronization during therapeutic exercises (Silva et al., 2021). Interactive breathing tasks stimulate inspiratory and expiratory muscle activation through guided respiratory maneuvers, breathing-controlled games, and virtual biofeedback mechanisms that improve ventilatory efficiency and respiratory muscle endurance (Freitas et al., 2021). These interventions also facilitate improved thoracoabdominal coordination and optimize breathing mechanics in patients with chronic respiratory dysfunction (Rutkowski et al., 2020). Furthermore, VR-based respiratory rehabilitation stimulates neuroplasticity and sensorimotor integration pathways within the central nervous system by simultaneously activating visual, auditory, proprioceptive, vestibular, and motor neural networks during rehabilitation activities (Levac et al., 2019). Enhanced coordination between cortical motor centers, peripheral respiratory musculature, and sensorimotor pathways may improve breathing synchronization, postural control, exercise performance, and motor learning processes among respiratory patients (Howard, 2017). Repetitive VR-guided respiratory exercises may additionally strengthen neural adaptation and improve autonomic regulation involved in respiratory control mechanisms (Massetti et al., 2018). Another important therapeutic mechanism involves the psychological effects of immersive VR environments, which function as powerful distraction techniques capable of reducing anxiety, dyspnea perception, emotional distress, and exercise-related fear during physical activity (Hoffman et al., 2019). Immersive digital environments divert patient attention away from sensations of breathlessness and fatigue, thereby improving tolerance to pulmonary rehabilitation sessions and increasing confidence in physical performance (Banos et al., 2021). Reduction in dyspnea-related anxiety further encourages greater participation in aerobic conditioning and respiratory training programs among patients with chronic respiratory disorders (Molina et al., 2021). Figure 4 demonstrates the progressive enhancement in functional exercise capacity, respiratory endurance, and rehabilitation performance observed among patients participating in VR-assisted respiratory physiotherapy interventions (Zhang et al., 2021). Several advanced VR rehabilitation systems additionally incorporate wearable biosensors, pulse oximetry devices, respiratory flow meters, motion-tracking systems, and heart rate monitoring technologies that enable continuous physiological monitoring during rehabilitation sessions (Tait et al., 2022). These integrated monitoring systems allow healthcare professionals to assess respiratory performance, oxygen saturation, heart rate variability, breathing patterns, and exercise intensity in real time, thereby facilitating personalized rehabilitation adjustments based on individual patient responses and clinical progression (Wu et al., 2024). The integration of artificial intelligence and cloud-based telemonitoring platforms within VR rehabilitation systems may further improve treatment personalization, remote supervision, rehabilitation safety, and long-term clinical outcomes in pulmonary rehabilitation programs (Patel et al., 2023).

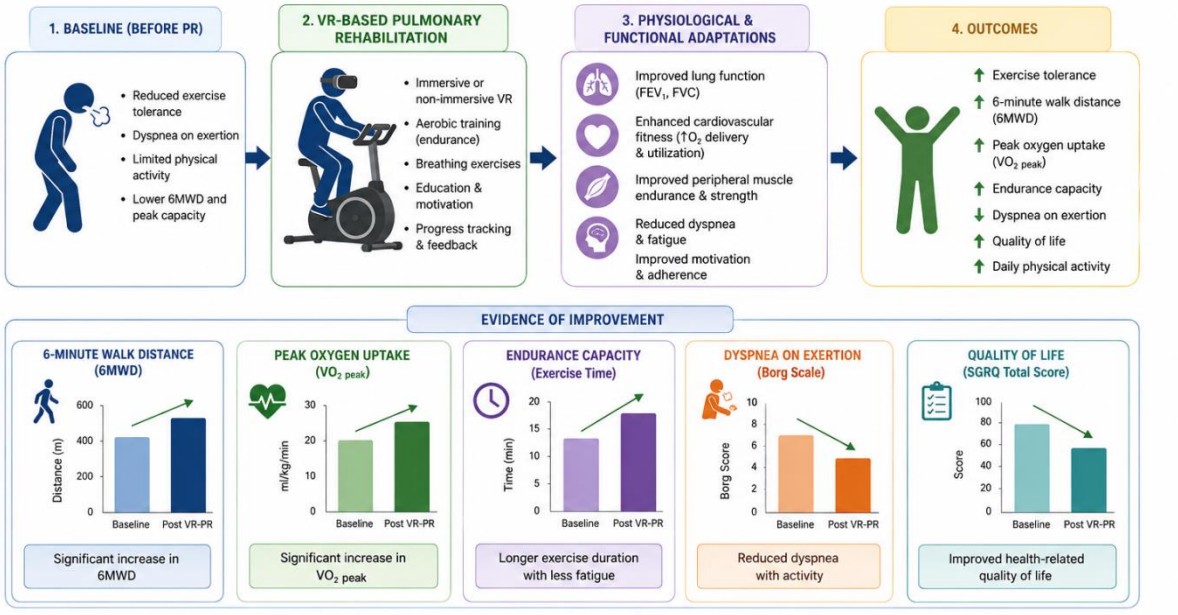

Figure 4. Improvement in Exercise Tolerance Following VR-Based Pulmonary Rehabilitation Clinical Applications in Chronic Obstructive Pulmonary Disease (COPD)

Chronic obstructive pulmonary disease (COPD) remains the most extensively investigated condition in virtual reality (VR)–assisted pulmonary rehabilitation research due to its high global prevalence, progressive respiratory impairment, and substantial impact on quality of life (McCarthy et al., 2018). COPD is characterized by persistent airflow limitation, chronic airway inflammation, emphysematous destruction, mucus hypersecretion, and respiratory muscle dysfunction that collectively contribute to dyspnea, fatigue, reduced exercise tolerance, and physical deconditioning (Bhatt & Dransfield, 2018). Pulmonary rehabilitation is recognized as an essential non-pharmacological intervention for COPD management because it improves respiratory function, exercise capacity, and psychological well-being (Nici et al., 2020). In recent years, VR-assisted pulmonary rehabilitation has emerged as a promising therapeutic strategy capable of enhancing patient motivation, rehabilitation adherence, and overall clinical outcomes among COPD patients (Rutkowski et al., 2020). Multiple randomized controlled trials and comparative clinical studies have demonstrated significant improvements in exercise capacity, dyspnea severity, respiratory muscle strength, aerobic endurance, thoracic mobility, balance, and health-related quality of life among COPD patients participating in VR-based rehabilitation programs (Gomes Neto et al., 2021). These interventions commonly integrate breathing exercises, virtual cycling, motion-based aerobic activities, upper-limb coordination tasks, inspiratory muscle training, and interactive exergaming platforms that transform conventional pulmonary rehabilitation into engaging therapeutic experiences (Vieira et al., 2020). Patients participating in VR-assisted cycling exercises, breathing-controlled games, virtual walking programs, and interactive motion-based activities consistently report greater enjoyment, satisfaction, motivation, and emotional engagement compared with traditional respiratory physiotherapy protocols (Pinto et al., 2022). Increased patient engagement during VR rehabilitation sessions contributes significantly to better treatment adherence, longer participation durations, improved exercise intensity, and enhanced rehabilitation outcomes in COPD populations (da Silva et al., 2020). Real-time visual and auditory feedback integrated within VR systems further improves breathing coordination, diaphragmatic activation, respiratory muscle synchronization, and ventilatory efficiency during pulmonary rehabilitation exercises (Silva et al., 2021). In addition to physiological improvements, VR-based pulmonary rehabilitation provides substantial psychological benefits for COPD patients who frequently experience anxiety, depression, social isolation, fear of exertion, emotional distress, and reduced self-confidence due to chronic dyspnea and functional limitations (Molina et al., 2021). Immersive VR environments incorporating relaxation exercises, mindfulness sessions, guided breathing activities, and virtual nature exposure have been shown to reduce psychological stress, improve mood, decrease dyspnea-related anxiety, and enhance emotional well-being during rehabilitation programs (Hoffman et al., 2019). VR interventions also function as effective distraction techniques that divert patient attention away from sensations of breathlessness and fatigue, thereby improving tolerance to physical activity and reducing fear associated with exercise participation (Banos et al., 2021). Several studies suggest that immersive virtual environments stimulate positive emotional responses and increase confidence in physical abilities, which may further encourage long-term participation in rehabilitation programs (Howard, 2017). In recent years, researchers have additionally explored home-based VR pulmonary rehabilitation systems for elderly COPD patients and individuals with mobility limitations who experience difficulty attending hospital-based rehabilitation programs (Lundell et al., 2021). Tele-rehabilitation platforms incorporating VR technologies enable remote supervision by healthcare professionals while minimizing transportation barriers, reducing healthcare costs, and improving accessibility to pulmonary rehabilitation services in rural and underserved regions (Yeo et al., 2020). These systems commonly utilize wearable biosensors, pulse oximetry devices, respiratory monitoring technologies, and cloud-based telehealth platforms to monitor patient performance, oxygen saturation, exercise tolerance, and rehabilitation adherence in real time (Tait et al., 2022). The integration of artificial intelligence, remote monitoring systems, and personalized digital rehabilitation protocols within VR-based pulmonary rehabilitation programs is expected to further improve clinical outcomes, treatment safety, and long-term disease management strategies for COPD patients in the future (Wu et al., 2024).

Applications in Asthma and Pediatric Respiratory Disorders

Asthma is one of the most prevalent chronic respiratory diseases affecting both children and adults worldwide and represents a major cause of morbidity, school absenteeism, reduced physical activity, and healthcare utilization across all age groups (Global Initiative for Asthma, 2023). Persistent airway inflammation, bronchial hyperresponsiveness, mucus hypersecretion, airway edema, and episodic bronchoconstriction significantly impair pulmonary function, breathing efficiency, and exercise tolerance in affected individuals (Freitas et al., 2021). In pediatric populations, recurrent wheezing, dyspnea, coughing episodes, and exercise-induced bronchospasm often negatively affect physical development, psychological well-being, academic performance, and social participation (Bhatt & Dransfield, 2018). Although pharmacological treatment including bronchodilators, corticosteroids, and anti-inflammatory medications remains the cornerstone of asthma management, respiratory physiotherapy and pulmonary rehabilitation serve as important

complementary therapeutic strategies for improving respiratory muscle function, thoracic mobility, ventilation efficiency, airway clearance, and overall quality of life (Nici et al., 2020). Conventional respiratory rehabilitation programs commonly include diaphragmatic breathing exercises, inspiratory muscle training, relaxation techniques, aerobic conditioning, posture correction, and breathing control exercises to optimize pulmonary performance and reduce symptom severity (Toussaint et al., 2018). However, children with asthma frequently demonstrate poor adherence to breathing exercises and rehabilitation programs due to boredom, limited motivation, fear of breathlessness, poor understanding of disease management, and anxiety associated with physical activity (Molina et al., 2021). Virtual reality (VR)–based respiratory physiotherapy has therefore emerged as an innovative and engaging rehabilitation strategy capable of transforming traditional pulmonary rehabilitation into enjoyable therapeutic experiences that improve long-term treatment adherence and patient participation (Patel et al., 2023). Through gamified breathing exercises, immersive digital environments, breathing-controlled games, and real-time audiovisual feedback systems, VR technologies encourage active involvement and emotional engagement during respiratory therapy sessions (da Silva et al., 2020). Several pediatric studies have demonstrated that breathing-controlled VR games significantly improve inspiratory flow rates, breathing coordination, thoracic expansion, respiratory endurance, and asthma symptom control among children with chronic respiratory disorders (Silva et al., 2021). In many VR rehabilitation interventions, patients perform diaphragmatic breathing exercises or inspiratory muscle training to control virtual objects such as balloons, animated characters, racing cars, underwater divers, flying birds, or digital obstacle courses that respond to respiratory effort and breathing patterns (Pinto et al., 2022). These game-based activities effectively reduce monotony, increase rehabilitation enjoyment, and improve patient motivation during respiratory physiotherapy sessions (Vieira et al., 2020). Figure 5 demonstrates the use of gamified respiratory training systems designed to improve breathing coordination, inspiratory control, exercise participation, and pulmonary endurance among children with chronic respiratory disorders (Zhang et al., 2021). VR interventions additionally contribute to significant psychological improvements in pediatric respiratory patients who frequently experience anxiety, fear of exercise-induced bronchospasm, social isolation, low self-esteem, emotional stress, and reduced confidence in physical activity participation (Hoffman et al., 2019). Immersive VR environments provide effective distraction from respiratory discomfort while simultaneously promoting relaxation, emotional engagement, and positive reinforcement during pulmonary rehabilitation exercises (Banos et al., 2021). Several studies have reported reductions in anxiety scores, emotional distress, and exercise-related fear together with improvements in psychological well-being and self-confidence following VR-assisted rehabilitation interventions in asthmatic children (Howard, 2017). In addition to asthma, VR-assisted respiratory rehabilitation has shown promising therapeutic outcomes in cystic fibrosis, pediatric bronchiectasis, neuromuscular respiratory disorders, and post-viral pulmonary dysfunction (Rutkowski et al., 2020). Patients with cystic fibrosis often require long-term airway clearance therapy, inspiratory muscle training, and repetitive respiratory exercises that can become psychologically exhausting and physically monotonous over time (Lundell et al., 2021). VR-based physiotherapy improves rehabilitation adherence in these patients by integrating airway clearance exercises with engaging exergaming activities, breathing-controlled virtual tasks, and interactive aerobic conditioning programs (Massetti et al., 2018). Research further suggests that VR rehabilitation may enhance participation in physical activity among children with chronic respiratory disorders who frequently avoid exercise because of fear of dyspnea, fatigue, or symptom exacerbation (Levac et al., 2019). VR-assisted exercise training encourages gradual aerobic conditioning, balance training, upper-limb coordination, and cardiovascular endurance development within safe, enjoyable, and motivating virtual environments, thereby improving exercise tolerance and physical fitness in pediatric respiratory populations (Gomes Neto et al., 2021). Furthermore, the increasing integration of wearable biosensors, tele-rehabilitation technologies, remote monitoring systems, and artificial intelligence within VR rehabilitation platforms is expected to further enhance personalized respiratory care and accessibility to pediatric pulmonary rehabilitation services in the future (Wu et al., 2024).

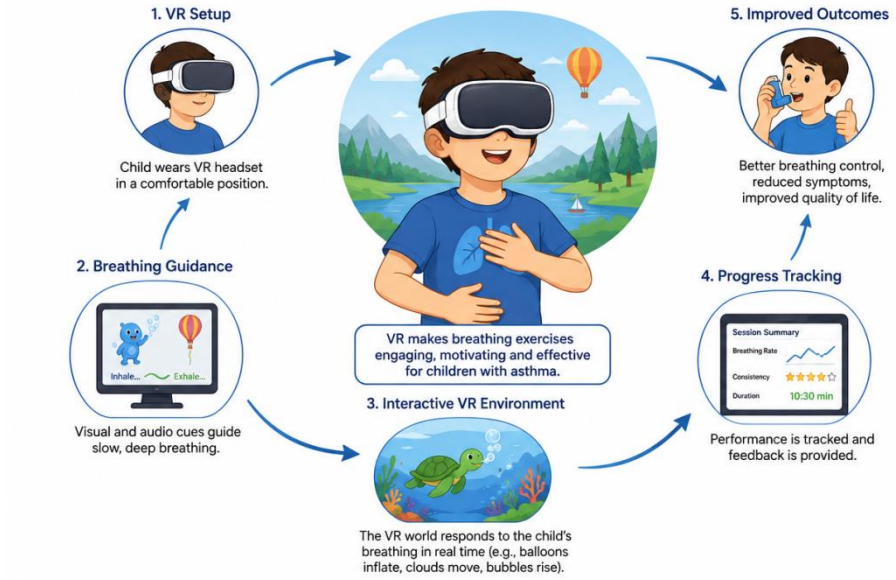

Figure 5. Virtual Reality–Assisted Breathing Exercises in Pediatric Asthma Rehabilitation

Post-COVID Pulmonary Rehabilitation

The COVID-19 pandemic significantly transformed global healthcare systems and accelerated the rapid development and adoption of digital rehabilitation technologies worldwide (Yeo et al., 2020). A substantial proportion of patients recovering from severe COVID-19 infection continue to experience persistent respiratory dysfunction, impaired pulmonary capacity, chronic fatigue, skeletal muscle weakness, exercise intolerance, dyspnea, anxiety, depression, and post-viral pulmonary fibrosis that collectively reduce functional independence and long-term quality of life (Chen et al., 2022). Post-COVID syndrome, often referred to as "long COVID," is characterized by prolonged respiratory symptoms, reduced diffusion capacity, impaired diaphragmatic function, cardiovascular deconditioning, and neuropsychological disturbances that may persist for several months after acute infection (Al Chikhanie et al., 2021). Pulmonary rehabilitation therefore became an essential therapeutic strategy for restoring respiratory performance, exercise tolerance, physical endurance, and psychological well-being among post-COVID patients (Nici et al., 2020). However, traditional pulmonary rehabilitation programs were severely disrupted during the pandemic due to infection control measures, social distancing requirements, quarantine regulations, reduced outpatient healthcare services, and concerns regarding viral transmission in rehabilitation facilities (Lundell et al., 2021). Consequently, virtual reality (VR)–based tele-rehabilitation emerged as a highly valuable alternative for delivering respiratory physiotherapy remotely while maintaining patient safety and continuity of care (Wan et al., 2023). VR-assisted post-COVID pulmonary rehabilitation programs commonly incorporate breathing exercises, inspiratory muscle training, aerobic conditioning, balance training, thoracic mobility exercises, relaxation therapy, mindfulness training, and guided meditation within immersive and interactive digital environments (Patel et al., 2023). These interventions enable patients to safely perform rehabilitation exercises within their homes while maintaining continuous communication and supervision through telemonitoring systems and cloud-based healthcare platforms (Tait et al., 2022). Several recent clinical studies have demonstrated significant improvements in respiratory endurance, oxygen saturation, six-minute walk distance, pulmonary function, fatigue severity, exercise capacity, and psychological health following VR-assisted pulmonary rehabilitation among post-COVID patients (Wu et al., 2024). Interactive breathing exercises integrated within VR systems enhance diaphragmatic activation, thoracic expansion, inspiratory muscle performance, ventilatory efficiency, and breathing coordination while simultaneously reducing anxiety associated with dyspnea and physical exertion (Freitas et al., 2021). Gamified rehabilitation activities further improve patient motivation and long-term adherence by transforming repetitive respiratory exercises into engaging therapeutic experiences (Pinto et al., 2022). Figure 6 illustrates how healthcare providers can remotely monitor respiratory performance, oxygen saturation, exercise tolerance, rehabilitation adherence, and physiological responses using integrated VR telehealth systems and wearable biosensors (Zhang et al., 2021). An important advantage of VR-assisted tele-rehabilitation is the increased accessibility of pulmonary rehabilitation services for patients living in rural, geographically isolated, and underserved regions where specialized rehabilitation centers may be unavailable (Molina et al., 2021). Home-based VR rehabilitation systems significantly reduce transportation barriers, healthcare costs, infection exposure risks, and travel-related fatigue while maintaining continuity of rehabilitation care and clinical supervision (Rutkowski et al., 2020). Elderly individuals and patients with severe physical limitations particularly benefit from remote rehabilitation programs because they often face

considerable difficulty attending conventional hospital-based pulmonary rehabilitation sessions (Vieira et al., 2020). Furthermore, immersive relaxation environments integrated within VR systems may alleviate psychological distress associated with post-COVID syndrome, including post-traumatic stress, sleep disturbances, depression, emotional exhaustion, and social isolation (Hoffman et al., 2019). Virtual mindfulness sessions, guided breathing exercises, meditation programs, and virtual nature exposure environments may improve autonomic regulation, emotional recovery, stress management, and overall psychological resilience among recovering patients (Banos et al., 2021). Emerging evidence additionally suggests that VR-based rehabilitation may positively influence neurocognitive recovery by stimulating multisensory neural pathways and promoting sensorimotor engagement during rehabilitation activities (Howard, 2017). Despite encouraging outcomes, several limitations remain in current post-COVID VR rehabilitation research, including relatively small sample sizes, short intervention durations, heterogeneity in rehabilitation protocols, technological variability, and limited long-term follow-up data (Gomes Neto et al., 2021). The absence of standardized rehabilitation guidelines and differences in VR equipment, patient populations, and outcome measures also complicate comparison between studies and limit the generalizability of findings (Levac et al., 2019). Future multicenter randomized controlled trials involving larger patient populations and standardized intervention protocols are therefore necessary to establish the long-term effectiveness, safety, cost-efficiency, and clinical applicability of VR-assisted pulmonary rehabilitation in post-COVID respiratory care (Page et al., 2021).

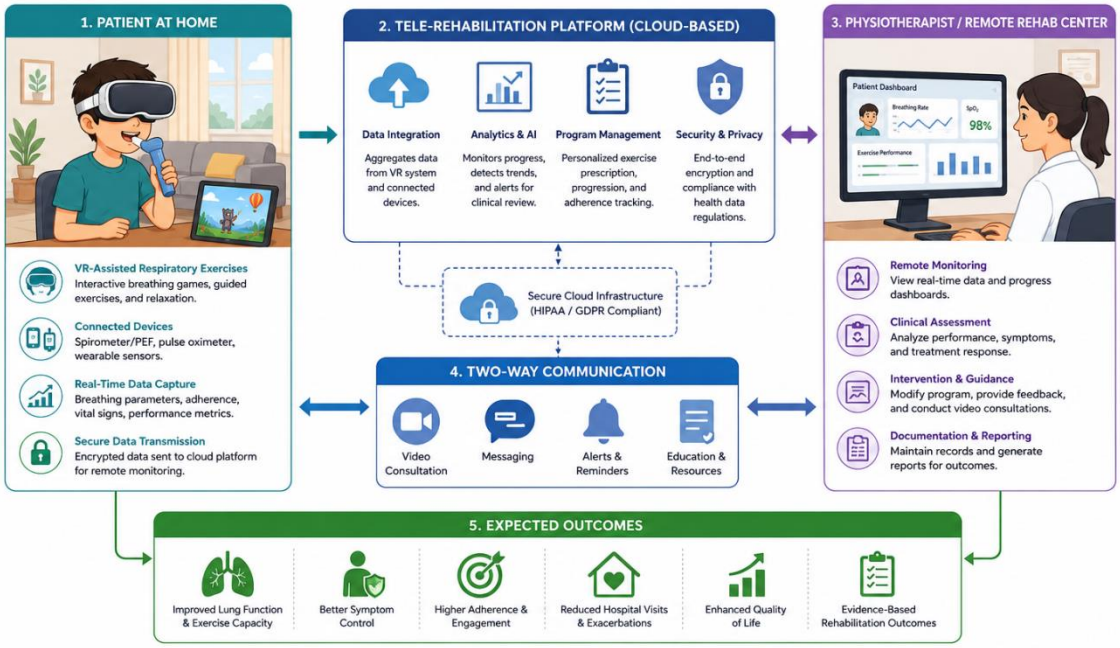

Figure 6. Tele-Rehabilitation Model Integrating Virtual Reality with Remote Respiratory Physiotherapy

Psychological and Cognitive Benefits of VR-Based Respiratory Physiotherapy

Chronic bronchopulmonary disorders not only impair physical health and pulmonary function but also exert profound psychological, emotional, and cognitive effects that significantly reduce overall quality of life and functional independence (Molina et al., 2021). Persistent dyspnea, chronic fatigue, exercise intolerance, recurrent hospitalizations, and social limitations frequently contribute to anxiety, depression, panic disorders, sleep disturbances, emotional exhaustion, reduced self-esteem, and impaired cognitive performance among patients with chronic respiratory diseases (Bhatt & Dransfield, 2018). Psychological distress further worsens rehabilitation adherence, reduces motivation toward physical activity, and contributes to sedentary behavior, thereby creating a vicious cycle of physical deconditioning, worsening respiratory symptoms, and declining psychological well-being (Singh et al., 2019). Chronic respiratory patients often develop fear-avoidance behaviors because of previous experiences of severe breathlessness and exercise-induced respiratory discomfort, which may further limit participation in rehabilitation programs and daily activities (Freitas et al., 2021). Virtual reality (VR)–based respiratory physiotherapy offers unique psychological advantages by combining rehabilitation exercises with immersive distraction techniques, emotionally engaging digital environments, and interactive multisensory experiences that enhance patient motivation and emotional engagement during therapy sessions (Patel et al., 2023). Unlike conventional physiotherapy programs that are frequently perceived as repetitive and monotonous, VR rehabilitation transforms breathing exercises into enjoyable therapeutic experiences that reduce perceived exertion and fear associated with respiratory

discomfort (Pinto et al., 2022). Immersive VR environments stimulate multiple sensory pathways simultaneously, including visual, auditory, vestibular, proprioceptive, and motor systems, thereby creating highly engaging rehabilitation experiences that divert attention away from dyspnea sensations and exercise-related anxiety (Levac et al., 2019). These multisensory interactions reduce anticipatory anxiety associated with physical activity and improve tolerance to rehabilitation exercises among patients with chronic respiratory diseases (Howard, 2017). As a result, many patients are capable of tolerating higher exercise intensity, longer rehabilitation sessions, and more consistent participation in pulmonary rehabilitation programs (Gomes Neto et al., 2021). Several clinical studies have demonstrated significant reductions in anxiety, depression, emotional distress, and perceived stress scores among COPD and post-COVID patients participating in VR-assisted respiratory rehabilitation interventions (Hoffman et al., 2019). Relaxation-focused VR modules incorporating virtual forests, beaches, waterfalls, mountains, underwater environments, and meditative landscapes help regulate autonomic nervous system activity and reduce sympathetic overactivation associated with chronic stress and respiratory discomfort (Banos et al., 2021). Guided breathing exercises combined with calming virtual environments may additionally improve emotional regulation, heart rate variability, relaxation responses, and overall psychological resilience in patients experiencing chronic pulmonary symptoms (Yeo et al., 2020). In addition to emotional benefits, VR interventions may positively influence cognitive functioning in chronic respiratory patients who frequently experience cognitive impairment secondary to chronic hypoxia, systemic inflammation, sleep disturbances, and reduced cerebral oxygenation (Tait et al., 2022). Respiratory diseases such as COPD and post-COVID syndrome are commonly associated with impaired attention, memory deficits, executive dysfunction, reduced psychomotor speed, and decreased cognitive flexibility that negatively affect daily functioning and rehabilitation participation (Chen et al., 2022). Interactive VR exercises stimulate cognitive engagement, motor learning, problem-solving abilities, sensorimotor coordination, and neurocognitive activation, thereby potentially enhancing neuroplasticity and cognitive resilience among patients with chronic respiratory disorders (Massetti et al., 2018). Research further suggests that VR rehabilitation significantly improves patient confidence, self-efficacy, and emotional empowerment during pulmonary rehabilitation programs (Rutkowski et al., 2020). Successfully completing VR-guided breathing tasks, virtual exercise challenges, obstacle navigation activities, and gamified rehabilitation exercises increases confidence in physical abilities and promotes greater participation in daily activities and social interaction (Vieira et al., 2020). The integration of mindfulness techniques within VR rehabilitation systems represents another promising therapeutic advancement in respiratory physiotherapy (Silva et al., 2021). Table 2 summarizes the Psychological Benefits Associated with VR-Based Respiratory Rehabilitation, Guided meditation sessions, paced breathing exercises, relaxation-focused virtual environments, mindfulness training modules, and virtual biofeedback systems may improve emotional regulation, sleep quality, autonomic balance, and stress management among individuals with chronic bronchopulmonary diseases (Wu et al., 2024). Emerging evidence indicates that combining pulmonary rehabilitation with immersive mindfulness-based VR interventions may provide synergistic physiological and psychological benefits capable of enhancing both respiratory recovery and long-term mental well-being in chronic respiratory populations (Wan et al., 2023).

Table 2. Psychological Benefits Associated with VR-Based Respiratory Rehabilitation

Psychological Outcome	Observed Benefit
Anxiety	Significant reduction
Depression	Improved emotional well-being
Motivation	Increased rehabilitation adherence
Fear of exertion	Reduced activity avoidance
Self-confidence	Improved self-efficacy
Quality of life	Enhanced social participation

Technological Innovations in VR Respiratory Rehabilitation

Technological innovation continues to drive the rapid evolution of virtual reality (VR)–assisted pulmonary rehabilitation and significantly expand its clinical applications in chronic respiratory care (Patel et al., 2023). Early VR rehabilitation systems were primarily limited to simple gaming platforms, motion-based exercises,

and non-immersive respiratory training activities. however, recent technological advancements now incorporate sophisticated wearable biosensors, artificial intelligence algorithms, haptic feedback systems, respiratory monitoring devices, cloud-based telehealth platforms, and immersive three-dimensional rehabilitation environments (Wu et al., 2024). Wearable respiratory sensors integrated within modern VR systems enable real-time monitoring of breathing patterns, respiratory rate, oxygen saturation, thoracic expansion, inspiratory flow, heart rate variability, and physical activity levels during pulmonary rehabilitation sessions (Tait et al., 2022). These technologies allow healthcare professionals to remotely assess patient performance, rehabilitation adherence, physiological responses, and disease progression while simultaneously individualizing rehabilitation intensity according to patient needs and clinical status (Rutkowski et al., 2020). Artificial intelligence (AI) has emerged as one of the most promising advancements in VR-assisted pulmonary rehabilitation because AI-driven systems can continuously analyze patient-generated physiological data and automatically adapt rehabilitation programs according to respiratory capacity, fatigue levels, exercise tolerance, symptom severity, and functional recovery progression (Zhou et al., 2023). Personalized rehabilitation protocols generated through machine learning algorithms may substantially improve treatment effectiveness, patient engagement, long-term adherence, and clinical outcomes in individuals with chronic bronchopulmonary disorders (Chen et al., 2022). Haptic feedback technology represents another innovative component of advanced VR rehabilitation systems because tactile sensory stimulation enhances sensorimotor integration, breathing coordination, and respiratory muscle activation during therapeutic exercises (Levac et al., 2019). Haptic devices provide tactile sensations synchronized with breathing movements and rehabilitation tasks, thereby improving thoracic expansion exercises, diaphragmatic activation, posture correction, and inspiratory muscle training performance (Howard, 2017). When combined with motion-tracking systems and immersive visual environments, haptic technologies may further optimize respiratory rehabilitation by improving proprioceptive feedback and exercise precision (Massetti et al., 2018). Cloud-based tele-rehabilitation platforms additionally facilitate continuous communication between patients and healthcare professionals through remote supervision systems, digital monitoring dashboards, and real-time rehabilitation tracking technologies (Yeo et al., 2020). Remote supervision improves rehabilitation adherence, enables early identification of clinical deterioration, and allows clinicians to modify rehabilitation protocols promptly according to patient responses and physiological changes (Lundell et al., 2021). These technologies are particularly beneficial for elderly individuals, immunocompromised patients, mobility-limited populations, and individuals living in geographically isolated or underserved regions where access to specialized pulmonary rehabilitation services may be limited (Molina et al., 2021). Furthermore, integration of cloud computing, wearable technologies, AI-assisted analytics, and telemonitoring systems within VR rehabilitation platforms is expected to enhance accessibility, personalization, safety, and long-term effectiveness of pulmonary rehabilitation programs in the future (Gomes Neto et al., 2021).

Limitations and Challenges

Despite substantial clinical promise and growing research interest, virtual reality (VR)–based respiratory physiotherapy continues to face several important limitations and implementation challenges that may restrict its widespread clinical adoption and long-term effectiveness (Molina et al., 2021). One of the primary barriers involves the high financial cost associated with advanced immersive VR equipment, head-mounted displays, wearable biosensors, respiratory monitoring devices, haptic feedback systems, and cloud-based telemonitoring infrastructure required for sophisticated pulmonary rehabilitation programs (Patel et al., 2023). Healthcare institutions in low-resource settings, developing countries, and rural regions may experience considerable difficulty implementing technologically advanced VR rehabilitation systems because of limited funding, inadequate infrastructure, and insufficient technical support services (Lundell et al., 2021). In addition to financial constraints, cybersickness remains another significant concern associated with immersive VR rehabilitation systems and may negatively affect patient comfort and rehabilitation adherence (Howard, 2017). Some patients experience dizziness, nausea, headaches, visual fatigue, motion sickness, disorientation, and vestibular discomfort during prolonged immersive VR sessions, particularly when exposed to rapidly moving virtual environments or prolonged sensory stimulation (Laver et al., 2017). Elderly patients, individuals with vestibular dysfunction, neurological disorders, or severe respiratory compromise may be particularly susceptible to these motion-related side effects, thereby limiting tolerance to immersive rehabilitation interventions (Banos et al., 2021). Technical complexity also represents a major limitation affecting widespread implementation of VR-assisted pulmonary rehabilitation programs (Tait et al., 2022). Many elderly patients with chronic respiratory diseases possess limited digital literacy and may require extensive instruction, technical guidance, and caregiver assistance to use VR systems effectively and safely during home-based rehabilitation sessions (Vieira et al., 2020). Technical malfunctions, software errors, equipment calibration difficulties, internet connectivity interruptions, hardware maintenance requirements, and limited access to technical support may further compromise rehabilitation continuity and patient adherence (Rutkowski et al.,

2020). Another major challenge involves the considerable heterogeneity present within current VR rehabilitation research literature (Gomes Neto et al., 2021). Existing studies vary substantially regarding patient populations, disease severity, intervention duration, rehabilitation protocols, outcome measures, technological platforms, and levels of VR immersion, making direct comparison between studies difficult and limiting evidence generalizability (Levac et al., 2019). Many clinical trials additionally involve relatively small sample sizes, short follow-up periods, and inconsistent methodological quality, thereby reducing the strength of evidence supporting the long-term effectiveness and sustainability of VR-based pulmonary rehabilitation interventions (Page et al., 2021). Table 3 summarizes the primary technological, clinical, financial, and methodological challenges associated with implementation of VR-assisted respiratory rehabilitation programs (Maher et al., 2017).

Table 3. Major Limitations of VR-Based Respiratory Physiotherapy

Limitation	Clinical Impact
High equipment and infrastructure cost	Limited accessibility in low-resource settings
Cybersickness and motion-related discomfort	Reduced patient tolerance and rehabilitation adherence
Technical complexity and low digital literacy	Difficulty using VR systems among elderly patients
Internet connectivity and software issues	Interruption of tele-rehabilitation continuity
Small sample sizes in current studies	Reduced strength of scientific evidence
Lack of standardized rehabilitation protocols	Difficulty comparing clinical outcomes
Limited long-term follow-up data	Uncertain sustainability of rehabilitation benefits
Ethical and cybersecurity concerns	Risks involving patient privacy and healthcare data

Ethical and privacy concerns related to digital healthcare data management also require careful consideration because tele-rehabilitation systems continuously collect sensitive physiological, behavioral, and clinical information that must be protected through robust cybersecurity frameworks, encrypted cloud storage systems, and regulatory compliance standards (Yeo et al., 2020). Breaches in patient confidentiality, unauthorized access to health records, and insecure telemonitoring systems may compromise patient trust and create significant medicolegal concerns within digital rehabilitation practice (Wu et al., 2024). Furthermore, disparities in internet accessibility, socioeconomic status, technological literacy, and healthcare infrastructure may contribute to unequal access to VR-assisted pulmonary rehabilitation services across different populations and geographic regions (Freitas et al., 2021). Future research should therefore focus on developing affordable, user-friendly, standardized, and clinically validated VR rehabilitation systems capable of improving accessibility, safety, long-term adherence, and evidence-based implementation in diverse respiratory care settings (Zhou et al., 2023).

Future Directions

Future developments in virtual reality (VR)–assisted respiratory physiotherapy are expected to significantly transform pulmonary rehabilitation and chronic respiratory disease management through rapid technological innovation and digital healthcare integration (Wu et al., 2024). The incorporation of artificial intelligence (AI), machine learning algorithms, wearable biosensors, robotics, cloud computing, and advanced telehealth infrastructure may facilitate highly personalized and adaptive rehabilitation experiences for patients with chronic bronchopulmonary disorders (Patel et al., 2023). AI-powered rehabilitation systems could automatically modify breathing exercises, exercise intensity, rehabilitation progression, and therapeutic difficulty according to real-time physiological responses including respiratory rate, oxygen saturation, thoracic movement, fatigue levels, and exercise performance (Tait et al., 2022). Continuous physiological monitoring through wearable respiratory sensors may additionally enable early detection of disease exacerbations, optimize rehabilitation outcomes, and improve long-term disease management strategies (Zhou et al., 2023). The development of affordable portable VR systems, smartphone-based rehabilitation applications, and lightweight wearable technologies may greatly expand access to home-based pulmonary rehabilitation in

developing countries and rural regions with limited healthcare infrastructure (Lundell et al., 2021). Future research should focus on large-scale multicenter randomized controlled trials evaluating long-term clinical effectiveness, patient satisfaction, safety outcomes, rehabilitation adherence, and cost-effectiveness of VR-assisted pulmonary rehabilitation interventions (Page et al., 2021). Standardization of rehabilitation protocols, technological platforms, and outcome measures will be essential for establishing evidence-based clinical guidelines and improving scientific comparability between studies (Gomes Neto et al., 2021). Furthermore, integration of VR with augmented reality (AR), mixed reality (MR), robotic rehabilitation systems, and advanced haptic feedback technologies may create highly realistic multisensory rehabilitation environments capable of maximizing patient engagement, respiratory training effectiveness, neuroplastic adaptation, and functional recovery in chronic respiratory disease populations (Levac et al., 2019).

Conclusion

Virtual reality–based respiratory physiotherapy represents an innovative and highly promising advancement in pulmonary rehabilitation for chronic bronchopulmonary disorders. Evidence from recent research demonstrates significant improvements in pulmonary function, respiratory muscle performance, exercise tolerance, dyspnea perception, psychological well-being, rehabilitation adherence, and overall quality of life among patients participating in VR-assisted rehabilitation programs. The immersive and interactive nature of VR technology transforms traditional respiratory physiotherapy into an engaging therapeutic experience that enhances motivation and long-term treatment compliance. VR interventions also facilitate tele-rehabilitation and home-based pulmonary care, thereby improving accessibility and reducing healthcare barriers for patients with mobility limitations or geographic isolation. Although challenges related to cost, technical complexity, cybersickness, and lack of standardization remain important limitations, ongoing technological advancements are likely to improve the feasibility and effectiveness of VR-assisted respiratory rehabilitation. Future integration of artificial intelligence, wearable biosensors, and personalized digital healthcare systems may revolutionize respiratory physiotherapy and chronic pulmonary disease management globally. Overall, current evidence strongly supports the incorporation of VR-based respiratory physiotherapy as a complementary component of modern pulmonary rehabilitation programs for patients with chronic bronchopulmonary disorders.

References

1. Al Chikhanie, Y., Veale, D., Schoeffler, M., Pépin, J. L., Verges, S., & Hérengt, F. (2021). Effectiveness of pulmonary rehabilitation in COVID-19 respiratory patients. *Respiratory Physiology & Neurobiology, 287*, 103639.
2. Andrade, A. D., Mayo, N. E., Badley, E. M., & Brooks, D. (2019). Innovative technologies in pulmonary rehabilitation: A systematic review. *Journal of Clinical Medicine, 8*(8), 1120–1134.
3. Banos, R. M., Escobar, P., Cebolla, A., Guixeres, J., Alvarez Pitti, J., Lisón, J. F., & Botella, C. (2021). Using virtual reality to improve respiratory rehabilitation in chronic obstructive pulmonary disease. *International Journal of Environmental Research and Public Health, 18*(4), 1815–1828.
4. Benzing, V., & Schmidt, M. (2018). The effect of exergaming on executive functioning and emotional well-being. *Frontiers in Psychology, 9*, 1250.
5. Bhatt, S. P., & Dransfield, M. T. (2018). Chronic obstructive pulmonary disease and cardiovascular disease. *Translational Research, 194*, 43–56.
6. Burkow, T. M., Vognild, L. K., Krogstad, T., Bratvold, A., Risberg, M. J., & Brattvoll, M. (2018). Internet-enabled pulmonary rehabilitation and virtual respiratory rehabilitation systems for COPD patients. *Respiratory Medicine, 140*, 59–67.
7. Chen, Y., Li, W., & Zhang, Y. (2022). Virtual reality rehabilitation after COVID-19 infection: Current evidence and future directions. *Frontiers in Medicine, 9*, 876543.
8. Cikajlo, I., Rudolf, M., Goljar, N., Burger, H., & Matjačić, Z. (2017). Telerehabilitation using virtual reality task can improve balance in patients with chronic respiratory disorders. *Journal of NeuroEngineering and Rehabilitation, 14*(1), 54–63.
9. Cruz, J., Brooks, D., & Marques, A. (2017). Home telemonitoring effectiveness in COPD rehabilitation. *International Journal of Medical Informatics, 107*, 11–24.
10. da Silva, T. D., Ribeiro, M. F., Maldonado, I. L., & de Menezes, L. D. (2020). Gamified respiratory physiotherapy using virtual reality technologies. *Physiotherapy Research International, 25*(3), e1830.
11. Faria, A. L., Andrade, A., Soares, L., & Badia, S. B. (2020). Benefits of virtual reality based rehabilitation in chronic disease management. *Disability and Rehabilitation, 42*(22), 3191–3200.
12. Freitas, P. D., Ferreira, P. G., Silva, A. G., & Stelmach, R. (2021). Pulmonary rehabilitation enhanced by digital and virtual technologies. *Chest, 159*(2), 818–829.

13. Gomes Neto, M., Saquetto, M. B., Silva, C. M., Carvalho, V. O., & Conceição, C. S. (2021). Effectiveness of virtual reality exercise programs in pulmonary rehabilitation: A meta-analysis. *Respiratory Care, 66*(4), 584–593.
14. Hoffman, H. G., Meyer, W. J., Ramirez, M., Roberts, L., & Seibel, E. J. (2019). Virtual reality as an adjunctive therapy in chronic disease rehabilitation. *Annals of Behavioral Medicine, 53*(2), 121–128.
15. Howard, M. C. (2017). A meta-analysis and systematic review of virtual reality rehabilitation interventions. *Computers in Human Behavior, 70*, 317–327.
16. Jung, J., Cha, Y., Kim, S., & Lee, J. (2022). Respiratory telerehabilitation using virtual platforms in post-COVID patients. *Healthcare, 10*(6), 1044–1056.
17. Laver, K., George, S., Thomas, S., Deutsch, J. E., & Crotty, M. (2017). Virtual reality for stroke rehabilitation and chronic disease rehabilitation. *Cochrane Database of Systematic Reviews, 11*, CD008349.
18. Levac, D., Huber, M., & Sternad, D. (2019). Learning and transfer of complex motor skills in virtual reality rehabilitation. *Physical Therapy, 99*(9), 1124–1136.
19. Liao, Y. Y., Tsauo, J. Y., Huang, S. W., Cheng, H. M., Chen, H. C., & Lin, L. F. (2020). Virtual reality–based respiratory and balance training in patients with COPD. *Scientific Reports, 10*, 11499.
20. Lundell, S., Holmner, Å., Rehn, B., Nyberg, A., & Wadell, K. (2021). Telehealthcare in COPD rehabilitation during the COVID-19 pandemic. *European Respiratory Journal, 58*(3), 2100170.
21. Maddison, R., Rawstorn, J. C., Stewart, R. A. H., Benatar, J., Whittaker, R., Rolleston, A., & Jiang, Y. (2019). Effects of virtual reality exercise on chronic disease rehabilitation outcomes. *Journal of Medical Internet Research, 21*(5), e12425.
22. Massetti, T., da Silva, T. D., Crocetta, T. B., Guarnieri, R., de Freitas, B. L., Bianchi Lopes, P., Watson, S., Tonks, J., & de Mello Monteiro, C. B. (2018). Clinical utility of virtual reality in rehabilitation medicine. *Journal of Central Nervous System Disease, 10*, 1–10.
23. McCarthy, B., Casey, D., Devane, D., Murphy, K., Murphy, E., & Lacasse, Y. (2018). Pulmonary rehabilitation for chronic obstructive pulmonary disease. *Cochrane Database of Systematic Reviews, 2*, CD003793.
24. Mekki, M., Paillard, T., Sahli, S., Tabka, Z., & Trabelsi, Y. (2022). Home-based virtual pulmonary rehabilitation for chronic obstructive pulmonary disease. *International Journal of COPD, 17*, 233–244.
25. Molina, K. I., Ricci, N. A., de Moraes, S. A., & Perracini, M. R. (2021). Virtual reality interventions in chronic respiratory disease rehabilitation. *Pulmonology, 27*(5), 422–431.
26. Nici, L., Mammen, M. J., Charbek, E., Alexander, P. E., Au, D. H., Boyd, C. M., & ZuWallack, R. (2020). Official pulmonary rehabilitation guidelines. *American Journal of Respiratory and Critical Care Medicine, 201*(9), e56–e69.
27. Patel, S., Shah, P., & Kumar, R. (2023). Emerging role of immersive technology in respiratory physiotherapy. *Healthcare Technology Letters, 10*(2), 91–101.
28. Pinto, A., Almeida, J. P., Pinto, S., Pereira, J., & Oliveira, A. (2022). Gamification in pulmonary rehabilitation programs. *Respiratory Medicine, 191*, 106720.
29. Rutkowski, S., Rutkowska, A., Jastrzebski, D., Racheniuk, H., Pawełczyk, W., & Szczegielniak, J. (2020). Virtual reality rehabilitation in COPD patients. *Sensors, 20*(23), 6947.
30. Saposnik, G., Levin, M., & Stroke Outcome Research Canada Working Group. (2016). Virtual reality in rehabilitation medicine: Evidence and applications. *Stroke, 47*(1), e20–e21.
31. Silva, H., Lima, E., Ferreira, J., & Costa, R. (2021). VR-supported inspiratory muscle training in chronic pulmonary disease. *Journal of Rehabilitation Medicine, 53*(5), jrm00189.
32. Singh, S. J., Barradell, A. C., Greening, N. J., Bolton, C. E., Jenkins, G., & Preston, L. (2019). Pulmonary rehabilitation for chronic respiratory disease. *Thorax, 74*(7), 625–626.
33. Tait, J. L., Waheed, U., Saravanan, P., & Hoyle, M. (2022). Digital health technologies in chronic pulmonary disease management. *NPJ Digital Medicine, 5*(1), 77.
34. Toussaint, M., Boitano, L. J., Gathot, V., Steens, M., & Soudon, P. (2018). Respiratory physiotherapy in chronic pulmonary disorders. *European Respiratory Review, 27*(149), 170110.
35. Vieira, A. G., da Silva, S. M., de Souza, T. R., & Mendes, F. A. (2020). Exergaming and pulmonary rehabilitation outcomes in COPD patients. *Physiotherapy Theory and Practice, 36*(11), 1220–1230.
36. Wan, M., Luo, H., Wang, Y., & Huang, Y. (2023). Virtual reality pulmonary rehabilitation after COVID-19: A randomized trial. *Journal of Medical Internet Research, 25*, e41232.
37. Wootton, S. L., Hill, K., Alison, J. A., Ng, L. W., Jenkins, S., Eastwood, P. R., & Cecins, N. M. (2021). Interactive technologies for pulmonary rehabilitation delivery. *ERJ Open Research, 7*(1), 00790-2020.

38. Wu, J., Li, H., & Zhao, X. (2024). Artificial intelligence and virtual pulmonary rehabilitation systems. *Frontiers in Digital Health, 6*, 135790.
39. Yeo, T. J., Wang, Y. L., & Low, T. T. (2020). Telemedicine and respiratory rehabilitation during COVID-19. *The Lancet Respiratory Medicine, 8*(12), 1175–1177.
40. Zhang, H., Wang, Y., & Chen, X. (2021). Virtual reality respiratory training in chronic lung disease management. *Journal of Thoracic Disease, 13*(7), 4422–4433.
41. Zhou, Y., Liu, Y., & Feng, J. (2023). Home-based VR pulmonary rehabilitation: Clinical effectiveness and patient outcomes. *Respiratory Research, 24*(1), 88.
42. Zhu, Q., Li, J., Wang, T., & Chen, H. (2022). Interactive breathing exercises using virtual reality systems in respiratory rehabilitation. *Applied Sciences, 12*(4), 2011.
43. Zięba, M., Kowalski, P., & Krukowska, J. (2024). Advances in virtual rehabilitation technologies for chronic respiratory care. *Healthcare, 12*(3), 450.