

Effectiveness of digital health interventions for chronic obstructive pulmonary disease: systematic review and meta-analysis

Miaoqing Zhuang

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Effectiveness of digital health interventions for chronic obstructive pulmonary disease: systematic review and meta-analysis

Miaoqing Zhuang¹

¹ Universiti Sains Malaysia Kelantan MY

Corresponding Author:

Miaoqing Zhuang

Universiti Sains Malaysia
Kubang Kerian, Kota Bharu, Kelantan, 16150, Malaysia
Kelantan
MY

Abstract

Background: Chronic obstructive pulmonary disease (COPD), characterized by dyspnoea, cough, and sputum production, significantly impacts patients' quality of life and functional status. To reduce the burden on both patients and healthcare utilization indicators, it is crucial to explore more effective management strategies. These strategies should include empowering patients to actively manage their condition. Digital health interventions have the potential to positively influence health behaviors and enhance self-efficacy, encouraging greater patient engagement in their care. By fostering self-management skills and improving self-efficacy, these interventions may also mitigate the strain on healthcare services.

Objective: This systematic review and meta-analysis aims to determine the effectiveness of digital health tools on quality of life, self-efficacy, functional outcomes, healthcare utilization indicators on COPD.

Methods: A systematic literature review was performed using predefined key search terms in the PubMed, EMBASE, Cochrane, and Web of Science databases up to 26 January 2025, to identify eligible randomized controlled trials (RCTs) involving digital health interventions for COPD patients. Two independent reviewers screened the literature according to the eligibility criteria and extracted data from the included articles. The outcomes assessed were quality of life, self-efficacy, functional outcomes, healthcare utilization indicators.

Results: This review included 17 studies involving 2,027 participants across 11 countries. In 11 of the trials, healthcare professionals were involved in digital health platforms usage, while 12 trials reported measures to ensure adherence to digital health interventions. Digital health tools designed for COPD patients mainly focused on two key areas: rehabilitation and self-management. The study participants were predominantly older adults. Meta-analysis results indicated that digital health interventions significantly improved quality of life at 3 months on COPD Assessment Test (CAT) (MD -1.65, 95% CI [-3.17 to -0.14]; $P = 0.03$), at 6 months on CAT (MD = -2.43, 95% CI: -3.93 to -0.94; $P = 0.001$) and St. George's Respiratory Questionnaire (SGRQ) (MD = 3.25, 95% CI: 0.69 to 5.81; $P = 0.01$), at 12 months on the CAT (MD = -2.53, 95% CI: -3.91 to -1.16; $P = 0.0003$), EuroQol 5 Dimensions (EQ-5D) (MD = 0.04, 95% CI: 0.01 to 0.07; $P = 0.02$), and EuroQol 5 Dimensions Visual Analogue Scale (MD = 5.88, 95% CI: 0.38 to 11.37; $P = 0.04$); General Self-Efficacy Scale at 3 months (MD = 1.65, 95% CI: 0.62 to 2.69; $P = 0.002$) and 6 months (MD = 1.94, 95% CI: 0.83 to 3.05; $P = 0.0006$); and Modified Medical Research Council Dyspnea Scale over 3 months (MD = -0.23, 95% CI: -0.36 to -0.11; $P = 0.0003$). However, no significant differences were observed in the 6-meter walk test (6 MWT), emergency department admissions, hospital admissions, emergency department admissions for COPD or hospital admissions for COPD.

Conclusions: Our research indicated that digital health interventions might offer potential benefits to COPD; however, their clinical effectiveness needs to be confirmed. Further studies employing robust methodologies are needed to evaluate their utility. Additionally, future research should include a greater number of older adult with COPD.

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Original Manuscript

Effectiveness of digital health interventions for chronic obstructive pulmonary disease: systematic review and meta-analysis

Miaoqing Zhuang^{1,2}, Intan Idiana Hassan², Wan Muhamad Amir Bin W Ahmad³, Xiaodong Liu⁴, Hongfang Chen⁵, Xiaona Zhang⁶, Yinuo Gao²

Abstract

Background Chronic obstructive pulmonary disease (COPD), characterized by dyspnoea, cough, and sputum production, significantly impacts patients' quality of life and functional status. To reduce the burden on both patients and healthcare utilization indicators, it is crucial to explore more effective management strategies. These strategies should include empowering patients to actively manage their condition. Digital health interventions have the potential to positively influence health behaviors and enhance self-efficacy, encouraging greater patient engagement in their care. By fostering self-management skills and improving self-efficacy, these interventions may also mitigate the strain on healthcare services.

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¹ Xi'an Jiaotong University City College, Xi'an, China

² School of Health Sciences, Health Campus, Universiti Sains Malaysia, Kelantan, Malaysia

³ School of Dental Sciences, Health Campus, Universiti Sains Malaysia, Kelantan, Malaysia

⁴ University of Electronic Science and Technology of China Chengdu, China

⁵ Xi'an Provincial Hospital of Traditional Chinese Medicine, Xi'an, China

⁶ Xi'an International Medical Center Hospital

Corresponding author: Intan Idiana Hassan, School of Health Sciences, Health Campus, Universiti Sains Malaysia, Kelantan, Malaysia.

Email: intanidiana@usm.my

Conclusion Our research indicated that digital health interventions might offer potential benefits to COPD; however, their clinical effectiveness needs to be confirmed. Further studies employing robust methodologies are needed to evaluate their utility. Additionally, future research should include a greater number of older adult with COPD.

Keywords Digital health, Systematic review, Interventions, telehealth, eHealth, COPD

Introduction

Globally, Chronic Obstructive Pulmonary Disease (COPD) stands as the third leading cause of death, having caused approximately 3.23 million deaths in 2019 and contributing to a loss of 74.6 million disability-adjusted life years (DALYs) [1]. The World Health Organization (WHO) estimates that around 384 million individuals are affected by COPD worldwide, with over 90% of this disease burden concentrated in low- and middle-income countries [2]. China bears one of the heaviest burdens of COPD globally. Research indicates that among the Chinese population aged 40 and above, the prevalence rate of COPD is 13.7%, equating to nearly 100 million patients [3]. In fact, COPD ranks as the third leading cause of mortality in China, accounting for about 911,000 deaths in 2017 [4]. The economic costs associated with COPD, both direct and indirect, are enormous. On a global scale, the annual cost related to COPD is estimated at \$2.1 trillion (accounting for 1.3% of the global GDP), with more than 60% of these costs attributed to direct medical expenses [5]. In China, the average annual direct medical expenditure per COPD patient ranges from \$1,800 to \$3,500, constituting 40%-60% of household income. This substantial financial burden significantly heightens the risk of "impoverishment due to illness" [6]. Additionally, COPD poses a significant public health burden, a situation expected to worsen in the future due to an aging population and a rise in the prevalence of adjustable risk factors for COPD.

The escalating global burden of COPD underscores the limitations of current primary prevention and disease management strategies, which may lack widespread adoption or sufficient effectiveness [4]. Evidence highlights the critical role of sustained, multidisciplinary care in improving outcomes for COPD patients, yet systemic barriers such as resource constraints and accessibility gaps continue to hinder the provision of comprehensive long-term management services. Consequently, innovative solutions capable of expanding healthcare reach, enhancing patient engagement, and supporting cost-effective long-term disease management are urgently needed to alleviate the socioeconomic impact of COPD. Advances in digital health tools, including telehealth platforms, wearable devices, and AI-driven monitoring systems, which offer unprecedented opportunities to drive behavioral modifications and improve disease self-management. These technologies, now utilized by billions worldwide, have gained momentum through rapid technological innovation, increased consumer adoption, and the paradigm shift toward remote care accelerated by the coronavirus disease 2019 pandemic [7]. Digital health tools provide scalable, user-friendly interfaces that facilitate remote monitoring, personalized interventions, and real-time clinician-patient communication while reducing reliance on in-person care. Their growing integration into healthcare systems demonstrates significant potential to bridge gaps in COPD management, particularly for populations in underserved or remote regions, ultimately fostering more equitable and sustainable care models.

Over the past decade, numerous trials evaluating digital health tools for COPD management, including remote monitoring platforms, wearable sensors, and AI-driven predictive models have emerged [8-10]. Despite growing adoption of these technologies among COPD patients, their impact on critical outcomes such as acute exacerbation rates, hospitalization frequency, and quality of life remains uncertain. Significant knowledge gaps persist regarding the utility and efficacy of specific digital health interventions tailored to COPD care. To date, only a limited number of narrative systematic reviews have explored the role of digital health tools in COPD management [11, 12]. For instance, one review focused on the effectiveness of home telemonitoring in improving health-related outcomes of patients with COPD[11], while another examined the potential of mobile health applications for average days of hospitalization [12]. In contrast, recent meta-analyses have

investigated broader digital health interventions, such as integrated telemonitoring interventions on severe COPD exacerbations [13], or mobile health applications in self-management of patients with COPD [14]. However, these analyses often encompass heterogeneous technologies (e.g., SMS reminders, web portals) without isolating the effects of advanced digital tools like AI-powered exacerbation predictors or sensor-based activity monitors. Notably, no systematic review or meta-analysis has exclusively evaluated the efficacy of targeted digital health tools (e.g., smart inhalers, remote pulmonary rehabilitation apps) in improving COPD-specific outcomes. Given the rising emphasis by the WHO on integrating digital solutions into chronic disease frameworks [15], a dedicated meta-analysis focusing on rigorously designed digital health interventions for COPD is urgently needed. Such a synthesis would clarify their clinical value, inform evidence-based implementation strategies, and address disparities in access to personalized COPD care.

This systematic review and meta-analysis aims to determine the effectiveness of digital health tools on quality of life, self-efficacy, functional outcomes, healthcare utilization indicators on COPD.

Methods

This systematic review and meta-analysis was conducted in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [16], and the 'PRISMA 2020 Checklist' was utilized (Appendix S1). The protocol for this study was registered in PROSPERO, the international prospective register for systematic reviews (CRD420251032053).

Search strategy

A systematic search of the PubMed, Embase, Cochrane, and Web of Science databases were conducted up to 26 January 2025 to identify relevant publications. The search utilized combinations of keywords and indexing terms, such as MeSH or Emtree, associated with the search domains. An automated electronic search was carried out using the MeSH terms identified in PubMed. The following MeSH terms keywords were included: “Pulmonary Disease, Chronic Obstructive” OR “chronic obstructive pulmonary disease” OR “chronic obstructive lung disease” OR “chronic obstructive airway disease” OR “chronic airflow obstructio” OR “Emphysema” OR “COPD” OR “COAD” AND “Tele” OR “Mobile Health” OR “mHealth” OR “eHealth” OR “biosensor” OR “remote monitoring” OR “Internet” OR “Smartphone” OR “Phone” OR “Mobile Application” OR “App” OR “Web” OR “website” OR “digital health” OR “online” OR “information technology” AND “self-management” OR “self care” OR “self management” OR “self monitoring” OR “self-monitoring” OR “self-care” AND “randomized controlled trial” OR “random controlled trial” OR “controlled clinical trial” OR “random” OR “trial”. A comprehensive search strategy for every database was outlined in the Supplementary material online, Appendix S2. Boolean operators were employed to merge and cross-reference across different domains. Furthermore, a manual search was conducted by examining the reference lists of reviews on related topics as well as selected articles.

Eligibility criteria

The specific eligibility requirements of inclusion criteria in the PICOS format were used as follows: 1) Population: COPD; 2) Intervention: intervention delivered via a web-based remote digital health management system; 3) Comparison: the control group that received only the usual care interventions and the intervention group that used the web-based remote digital health management system in addition to the usual care interventions; 4) Outcomes: impacts of interventions on overall or at least one type of relevant health-related outcomes (e.g., quality of life, self-efficacy, functional outcomes, healthcare utilization indicators and so on); and 5) Study Design: randomized controlled trials (RCTs). Since the inclusion of unpublished studies can potentially introduce bias [20], this systematic review and meta-analysis only considered publications from peer-reviewed journals.

The review excluded case reports, preprint papers, letters to editors, simulation studies, published conference abstracts, studies that are in languages other than English, research lacking adequate details on the measurement of the outcomes of interest, qualitative studies, surveys or reviews, studies describing protocols, along with those focusing solely on the interface or internal structure of apps, and studies based on webpages or websites without associated applications.

Study selection and data extraction

Two researchers separately reviewed the identified papers to reduce potential errors and bias throughout the selection process. Initially, the authors screened the title and abstracts of the potential papers against the set inclusion and exclusion criteria. Following this, the final selection of papers was made after thoroughly reading the complete manuscripts of the qualifying papers and their references. Any discrepancies were settled through discussions among the authors until a consensus was reached.

A structured data extraction form was utilized to gather the following details: the first author's name, year of publication, study type, participant demographics (age range, sex ratio, sample size and country), interventions for remote digital health management, intervention duration, involvement of healthcare professionals (HCPs), strategies implemented to ensure participant compliance, and outcomes. The corresponding authors were contacted to clarify or obtain any information that was unclear or missing.

Study quality evaluation

Two researchers performed the quality assessment independently. Any disagreements were resolved through discussion between the two researchers, and a third investigator independently reviewed the final decisions. The quality of the RCTs was evaluated by two researchers using the Cochrane Collaboration's tool for assessing risk of bias [17]. This tool addresses six domains of bias: selection bias, performance bias, detection bias, attrition bias, reporting bias, and other biases. The risk of bias was classified as high, low, or unclear, with reasons provided for each classification.

Statistical analysis

All meta-analyses were conducted using RevMan version 5.4 (The Cochrane Collaboration, Copenhagen, Denmark). The statistical indicators used included the standardized mean difference (SMD), odds ratio (OR), and 95% confidence interval (CI). An inverse-variance-weighted linear meta-analysis of SMD (Hedge's g) was carried out to evaluate the effect size of smartphone-based remote digital health management on changes in review outcomes, such as Self-efficacy/mMRC /6 MWT. In general, a Hedge's g value of less than 0.2 suggests a small effect, approximately 0.5 indicates a moderate effect, and greater than 0.8 signifies a strong effect. Heterogeneity among the results was assessed using the I^2 statistical test. The choice between a random-effects model and a fixed-effects model was based on the heterogeneity I^2 test, with I^2 values below 50% indicating the use of a fixed-effects model and values above 50% suggesting the use of a random-effects model [17]. Effect sizes were compared using z-tests, and a P-value ≤ 0.05 was considered statistically significant.

Results

Study selection

The PRISMA flow diagram (Fig. 1) illustrates the screening process and the criteria used for excluding papers. The initial search yielded 1206 citations, from which 63 duplicates were eliminated. Following the removal of duplicates, 1143 records were evaluated against the inclusion and exclusion criteria. Subsequently, 40 full-text manuscripts were examined for eligibility. Out of these 45 articles, 23 studies were excluded for various reasons. As a result, 17 records were ultimately included in this review.

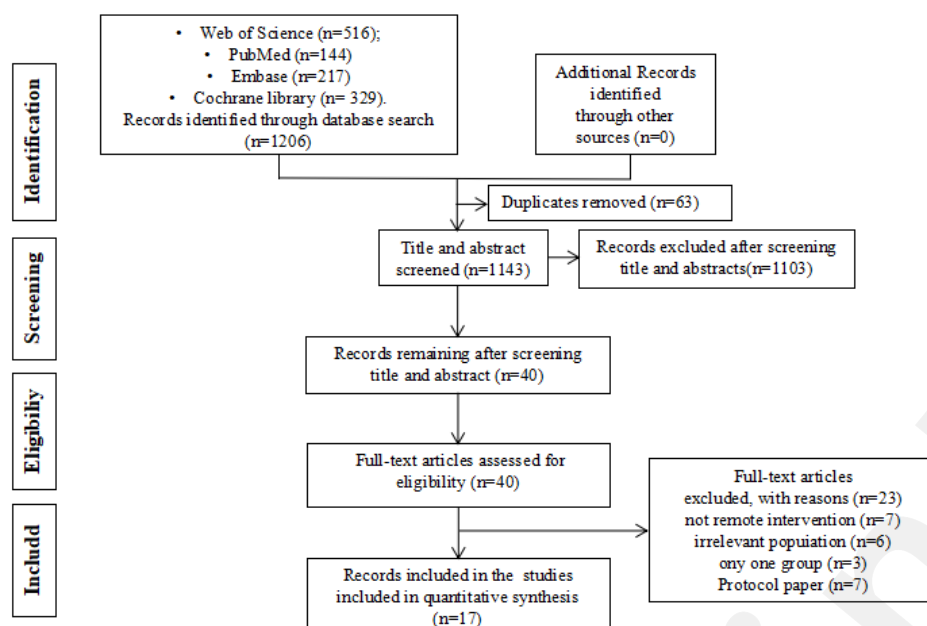


Fig. 1 The PRISMA (Preferred Reporting Item for Systematic Reviews and Meta-Analysis) flow diagram

Quality of study

Figures 2 and 3 show the risk of bias judgment of RCTs. All of studies [18-34] showed specific random sequence generation methods. Allocation concealment was rated as low risk of bias in 9 trials [21, 22, 24-26, 29-32] (53.0%) and unclear in 4 trials [18-20, 23] (23.5%). Given the nature of web-based remote digital health management interventions, blinding of researchers and participants is unreasonable, which inevitably leads to risk deviation. In total, only 9 trials [18-22, 27, 28, 31, 33] had a low risk of in complete outcome data, it's worth noting that there were 14 trials [18-28, 32-34] had a low risk of selective outcome reporting. The rates of dropout and attrition were within acceptable limits.

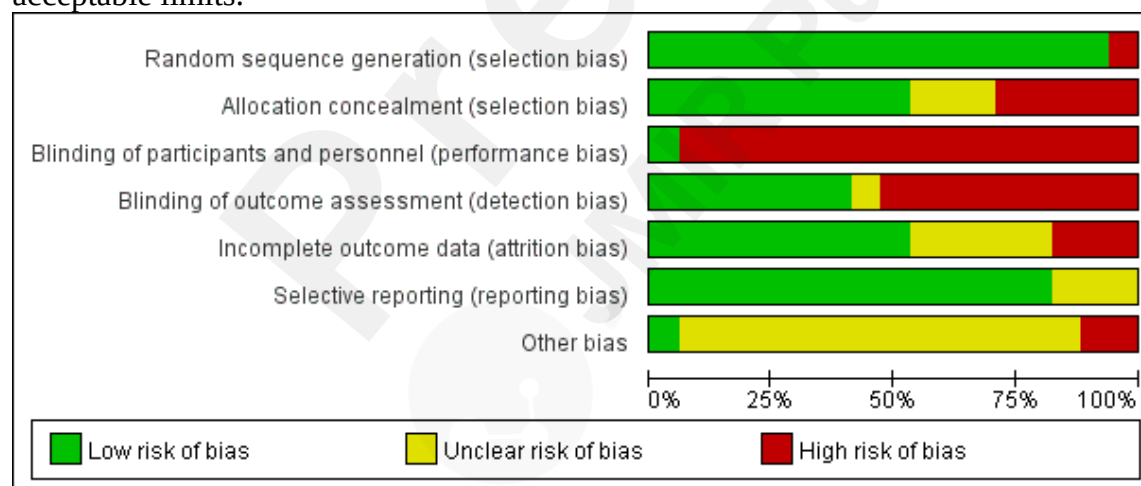


Fig.2 Risk of bias graph of RCTs: review authors' judgments about each risk of bias item presented as percentages The x-axis represents the percentage of studies that were found to be of low (green), unclear (yellow), or high (red) risk of bias for each domain

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Ali 2021	+	+	-	-	-	?	?
Benzo 2022	+	-	-	-	+	+	?
Bischoff 2019	+	?	-	-	?	+	?
De 2013	+	+	-	-	?	+	?
Farmer 2017	+	+	-	-	+	+	+
Jiang 2020	+	?	-	+	+	+	?
Kenealy 2015	+	+	-	?	?	+	?
Moy 2015	+	+	-	+	+	?	?
Nguyen 2009	+	+	-	+	?	+	?
Nyberg 2019	-	-	-	-	+	+	-
Park 2020	+	-	-	-	+	+	?
Robinson 2021	+	-	-	+	-	+	?
Stamenova 2020	+	+	-	-	?	+	?
Tabak 2014	+	+	-	-	-	?	-
Wan 2017	+	-	+	+	+	+	?
Wang 2021	+	+	-	+	+	+	?
Zanaboni 2022	+	?	-	+	+	+	?

Fig.3 Risk of bias summary of RCTs

Characteristics of the included studies

Table 1 provides a summary of the specific information extracted from the included studies. A total of 17 studies were published between 2009 and 2023. All studies compared either the use of a single app/web or an app/web combined with additional participant support against a control group. Collectively, these studies involved 2027 participants, with sample sizes ranging from 17 [32] to 375 [28]. Geographically, five studies [28, 31-34] were conducted in USA; two in China [18, 21], Australian [20, 25], Netherlands [23, 29], Sweden [27, 30] and one in Korea [19], Norway [20], Denmark [20], England [22], Canada [24] and New Zealand [26]. In terms of study design, all of the studies were randomized controlled trials (RCTs). Fourteen articles [18-26, 28, 30, 31, 33, 34] reported clinical outcomes, whereas three [27, 29, 32] were pilot studies. Regarding the duration of interventions, four studies lasted three month or less [11, 12, 14, 16], nine studies [18, 19, 24-27, 30,

32, 34] lasted between 3 and 6 months, three studies [20, 21, 27] lasted between 6 and 12 months, and three studies [20, 22, 23] lasted 12 months or longer. All of participants in these studies were aged 60 years or older.

In 15 trials, the control group received standard care without the use of the app [18-23, 25-31, 33, 34]. In one trial, they received routine in-person follow-up appointments and access to a certified respiratory educator [24] or as per the physician's judgment based on current guidelines [30], while in four trials, they were provided with leaflets [22], paper action plan [23], COPD book [25], or an educational packet of 12 self-management themes [28]. Telephone follow-up was utilized in two trials [19, 26], and in one trial, the control group used the same app as the intervention group but with different functionality [32].

Involvement of HCPs and strategies to ensure adherence via a digital health tools management interventions

Eleven trials [18-22, 24, 26, 27, 29, 30, 32] included the participation of HCPs in digital health tools usage, while the remaining six trials [23, 25, 28, 31, 33, 34] did not provide specific information regarding HCP involvement in digital health tools usage (Table 1). The roles of HCPs varied across the trials; in most cases, HCPs were involved in prescribing rehabilitation or self-management training for patients [18, 19, 22, 27, 29, 30, 32], guiding the training process [20, 29], installing the digital health equipment and instructing patients on how to use them [21, 22, 25, 26, 29, 30], and reviewing the data [20, 22, 24, 26].

Three trials described approaches to enhance adherence to the digital health tools management interventions. The strategies involved checking progress [29], scheduling the follow-up meetings [30], sending regular SMS reminders and making periodic phone calls [32].

Digital health tools characteristics

Across the studies, a total of 17 distinct digital health tools were utilized. These tools were deployed across various types of digital platforms: one WeChat Official Account, five apps, seven websites, and four did not specify the platform's details. The functionality of these platforms varied significantly across the trials. Within the context of COPD management, digital platforms were employed in two key areas: self-management [19, 21-31] and rehabilitation [18, 20, 32-34].

Concerning self-management, the majority of digital health platforms' s feature functionalities such as self-monitoring, medication reminders, health information provision, assessment, feedback, access to health services, and social support. In the realm of rehabilitation, these digital health platforms are capable of tracking various physical activities and transmitting rehabilitation-related data to a server, allowing therapists to review this information. Notably, most of these tools require additional devices to fully realize their capabilities. Furthermore, certain tools facilitate patients' access to visual and auditory feedback on their exercises by displaying real-time information on connected device screens. An overview of digital health tools characteristics is provided in Table 2.

Table 1 Special information of the studies included

Studies	Country	Study design	Study type	Participants, n	Age	Intervention duration	Intervention and control arm	Involvement HCP	Measures to ensure intervention adherence	Outcome
(Jiang et al, 2020) [18]	China	Clinical outcome	RCT	E:53 C:53	E:70.92±6.39 C:71.83±7.60	6 months	Intervention: Lung rehabilitation intervention plan based on wechat Control: Routine outpatient rehabilitation	Respiratory experts, clinicians, rehabilitation practitioners, nurses	regularly calls	CAT mMRC SGRQ
(Park et al, 2020) [19]	Korea	Clinical outcome	RCT	E:22 C:20	E:70.45±9.40 C:65.06±11.12	6 months	Intervention: Smartphone-based self-management plan Control: telephone	A pulmonary physician and a nurse researcher	send SMS	6MWT Self-efficacy
(Zanaboni et al, 2023) [20]	Norway, Australia, Denmark	Clinical outcome	RCT	E:40 C:40	E:64.9±7.1 C:63.5±8.0	24 months	Intervention: Telerehabilitation Control: usual care	Physiotherapist	send SMS	6MWT, EQ-5D mMRC, CAT Self-efficacy
(Wang et al,	China	Clinical	RCT	E:39	E:63.2±7.5	12 months	Intervention:	A respiratory	not stated	CAT

2021) [21]		outcome		C:39	C:64.4±7.0		Plans based on mobile health apps Control: usual care	nurse		Self-efficacy
(Farmer et al, 2017) [22]	England	Clinical outcome	RCT	E:110 C:56	E:69.8±9.1 C:69.8±10.6	12 months	Intervention: Digital health system Control: usual care	Doctor, nurse or physiotherapist	postal reminders, telephone contact	SGRQ EQ-5D

Table 1 (continued)

Studies	Country	Study design	Study type	Participants, n	Age	Intervention duration	Intervention and control arm	Involvement HCP	Measures to ensure intervention adherence	Outcome
(Bischoff et al, 2019) [23]	Netherlands	Clinical outcome	RCT	E:35 C:41	E:69.3±8.8 C:65.9±8.9	12 months	Intervention: Smart mobile Health Program Control: paper action plan	Not stated	Regularly calls	EQ-5D EQ-5D VAS
(Stamenova et al, 2020) [24]	Canada	Clinical outcome	RCT	E:41 C:20	E:71.98±9.52 C:72.78±9.16	6 months	Intervention: Remote monitoring Control: routine in-person follow-up appointments and access to a certified respiratory educator	A respiratory therapist	Regularly calls	Emergency department admissions or for COPD, Hospital admissions or for COPD
(De et al, 2013) [25]	Australian	Clinical outcome	RCT	E:36 C:35	E:71 C:74	6 months	Intervention: Remote monitoring Control: usual care	Not stated	Regularly calls	Emergency department admissions or for COPD, Hospital

admissions or
for COPD

Table 1 (continued)

Studies	Country	Study design	Study type	Participants, n	Age	Intervention duration	Intervention and control arm	Involvement HCP	Measures to ensure intervention adherence	Outcome
(Kenealy et al, 2015) [26]	New Zealand	Clinical outcome	RCT	E:98 C:73	E:62-83 C:60-77	6 months	Intervention: Telemedicine Control: usual care	Three respiratory physicians, two respiratory nurse specialists and one respiratory nurse practitioner	Not stated	Self-efficacy SGRQ
(Nyberg et al, 2019) [27]	Sweden	pilot study	RCT	E:43 C:40	E:65±7 C:71±8	12 months	Intervention: Remote self-management Control: usual care	Four asthma/COPD-nurses, one district nurse, one dietician and one physiotherapists	Not stated	CAT mMRC EQ-5D
(Benzo et al, 2022) [28]	USA	Clinical outcome	RCT	E:188 C:187	E:69.335±9.53 C:68.676±9.53	3 months	Intervention: Remote monitoring Control: usual care	Not stated	Regularly calls	mMRC
(Tabak et al, 2014)	Netherlands	pilot study	RCT	E:12 C:12	E:64.1±9.0 C:62.8±7.4	3 months	Intervention: Telemedicine program	A chest physician or	Regularly calls	6MWT EQ-5D

[29]							Control: usual care	nurse practitioner	EQ-5D VAS	
(Ali et al, 2021)	Sweden	Clinical outcome	RCT	E:110	E:71.1±9.8	6 months	Intervention:	Not stated	Regularly calls	Self-efficacy
[30]				C:112	C:70.4±9.1		Digital-based intervention			
							Control: usual care			

Table 1 (continued)

Studies	Country	Study design	Study type	Participants, n	Age	Intervention duration	Intervention and control arm	Involvement HCP	Measures to ensure intervention adherence	Outcome
(Moy et al, 2015) [31]	USA	Clinical outcome	RCT	E:144 C:77	E:67.0±8.6 C:66.4±9.2	3 months	Intervention: Internet-mediated pedometer based intervention Control: usual care	Not stated	Not stated	SGRQ
(Nguyen et al, 2009) [32]	USA	pilot study	RCT	E:8 C:9	E:64.0±12 C:72±9	6 months	Intervention: Mobile phone based rehabilitation Control: Routine rehabilitation	Nurses	Send SMS	SGRQ
(Wan et al, 2017) [33]	USA	Clinical outcome	RCT	E:57 C:52	E:68.4±8.7 C:66.8±7.9	3 months	Intervention: Web-based pedometer intervention Control: Individual pedometer intervention	Not stated	Not stated	6MWT SGRQ mMRC
(Robinson et al, 2021)	USA	Clinical outcome	RCT	E:93 C:92	E:69.2±7.2 C:70.4±7.3	6 months	Intervention: Web-based exercise	Not stated	Follow-up, in-person	6MWT SGRQ

[34]	routine		
	intervention	assessments	mMRC
	Control: usual care		

Table 2 Special information on digital health tools characteristics

Studies	Digital health tools name	Generally objective	Specific objective	Devices	Main feature of the digital health tools
(Jiang et al, 2020) [18]	PeR	Rehabilitation	Improve quality of life, symptoms, and exercise self-efficacy	WeChat official account	PeR management on the basis of evaluation, including respiratory training, sports training, diet guidance, medication knowledge.
(Park et al, 2020) [19]	SASMP	Self-management	Self-care behavior	An Android platform (version 2.3 Gingerbread)	Education, exercises, self-monitoring of symptoms and exercise, and social support.
(Zanaboni et al, 2023) [20]	Not stated	Rehabilitation	Reducing hospital readmissions	A treadmill, a pulse oximeter, a tablet computer, and a holder for the tablet computer	1) An integrated intervention consisting of exercise training at home, telemonitoring, and self-management. 2) Access the individual training program, fill in a daily diary and a training diary, review historical data, exchange electronic messages, schedule videoconferencing sessions, and facilitate individual goal setting and goal attainment.
(Wang et al, 2021) [21]	Not stated	Self-management	Quality of life, self-management behaviour and exercise and smoking cessation behaviour	No device	1□Provided knowledge and information support to participants. 2□Provided visual aids to teach participants skills to manage the disease. 3□Provided motivational support to participants, which included a peer support chat room and an expert support portal.
(Farmer et al, 2017)	EDGE	Self-management	Improve quality of life and clinical outcomes	Android tablet computer (Samsung Galaxy Tab)	1) Provide monitoring and self-management support. 2) Complete the symptom diary and recorded their oxygen

[22]	running the app software and a Bluetooth-enabled oximeter probe	saturation and heart rate. 3) Set alerts when the vital sign value go above (or below)
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Table 2 (continued)

Studies	Digital health tools name	Generally objective	Specific objective	Devices	Main feature of the digital health tools
(Bischoff et al, 2019) [23]	Not stated	Self-management	The number of exacerbation-free weeks	A mobile phone, a pulse oximeter (CMS50D, Contec Medical Systems), a spirometer (PiKo-1 monitor, nSpire), and a forehead thermometer (FTN, Medisana AG)	Provide predictions of early exacerbation onset and timely treatment advice without the interference of health care professionals.
(Stamenova et al, 2020) [24]	Not stated	Self-management	Self-management	A custom tablet computer, a Pulsewave wrist cuff monitor (which measures blood pressure), an oximeter, a weighing scale, and a thermometer	1□Record their vitals by the Cloud DX platform. 2□Provide a written version of a personalized COPD action plan.
(De et al, 2013)[25]	Health HUB	Self-management	Reduce the incidence of hospitalizations and emergency department (ED) presentations	No device	1□Measure and record their vital signs (blood pressure, weight, temperature, pulse, and oxygen saturation levels) on a daily basis. 2□Transmitted signs automatically via telephone to a secure Web site where they were monitored each day by the telehealth nurse.
(Kenealy et al, 2015) [26]	Health HUB	Self-management	Quality of life, self-care, hospital use, costs and the experiences of	A LCD	Entering the data into a commercially-available electronic device that uploaded data once a day to a nurse-led monitoring station peer support chat room and an expert support portal.

patients, informal carers and health care professionals.					
(Nyberg et al, 2019) [27]	COPD Web	Self-management	Increasing PA	No device	The COPD Web includes, texts, pictures, and videos as well as interactive components such as a tool for registration of PA, including automated feedback.

Table 2 (continued)

Studies	Digital health tools name	Generally objective	Specific objective	Devices	Main feature of the digital health tools
(Benzo et al, 2022) [28]	Not stated	Self-management	Improves the physical and emotional disease-specific QoL	A computer tablet, a Garmin Vivofit activity monitor and an oximeter (Nonin 3150)	1) Capture daily steps and self-report of symptoms. 2) Send and receive messages to/from the coach. 3) The data gathered on the tablet via Bluetooth (steps, compliance with daily exercises, messages, and symptoms) was transmitted to a server and, ultimately, to an online patient portal.
(Tabak et al, 2014) [29]	Condition Coach	Self-management	The number of hospitalizations, length of stay, and emergency department visits	An accelerometer-based activity sensor (Inertia Technology, Enschede, the Netherlands) and a smartphone (Desire S; HTC, New Taipei, Taiwan)	1) Activity coach for ambulant activity monitoring and real-time coaching of daily activity behavior. 2) Web-based exercise program for home exercising. 3) Self-management of COPD exacerbations via a triage diary on the web portal, including self-treatment of exacerbations. 4) Teleconsultation.
(Ali et al, 2021)[30]	Not stated	Self-management	General self-efficacy and hospitalization or death	No device	Comprising PCC using a combined digital platform and structured telephone support system
(Moy et al, 2015) [31]	Not stated	Self-management	Increasing PA	A computer with an internet connection, a USB port, and Windows XP, Vista, 7, or 8	A novel Internet-mediated, pedometer-based exercise intervention.
(Nguyen et	Not stated	Rehabilitation	Maximal workload, 6MW	An Omron HJ-112 digital	1) Develop an individualized exercise plan, were issued a

al, 2009) [32]	distance, HRQL or total steps	pedometer	pedometer and exercise booklet. 2) Instructed to continue to log their daily exercise and symptoms. 3) MOBILE-Coached also received weekly reinforcement text messages on their cell phones; reports of worsening symptoms were automatically flagged for follow-up.
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Table 2 (continued)

Studies	Digital health tools name	Generally objective	Specific objective	Devices	Main feature of the digital health tools
(Wan et al, 2017)[33]	ESC	Rehabilitation	Increasing PA	An Omron HJ-720 ITC pedometer	1) a pedometer and website which provided goal-setting, feedback, disease-specific education, and an online community forum or 2) Pedometer alone for 3 months.
(Robinson et al, 2021)[34]	Not stated	Rehabilitation	Increasing PA	Pedometer	Personalised, progressive step-count goals, feedback, online COPD-related education and social support via an online community

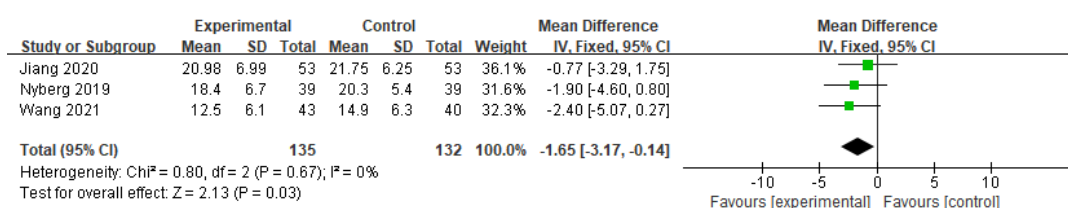


Fig.4 Meta-analysis results and forest plot of the digital health interventions on QoL assessed by CAT at 3 months

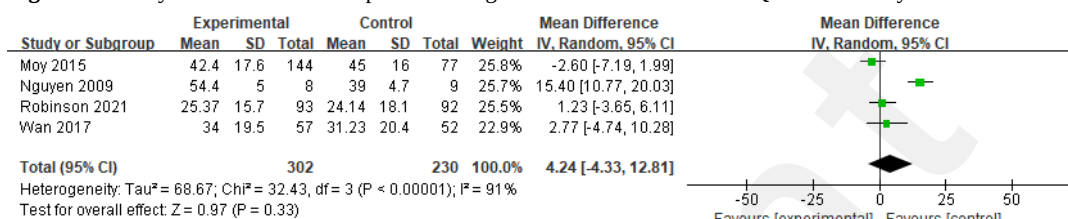


Fig.5 Meta-analysis results and forest plot of the digital health interventions on QoL assessed by SGRQ at 3 months

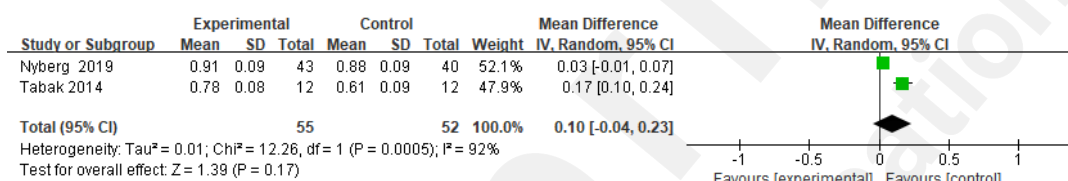


Fig.6 Meta-analysis results and forest plot of the digital health interventions on QoL assessed by EQ-5D at 3 months

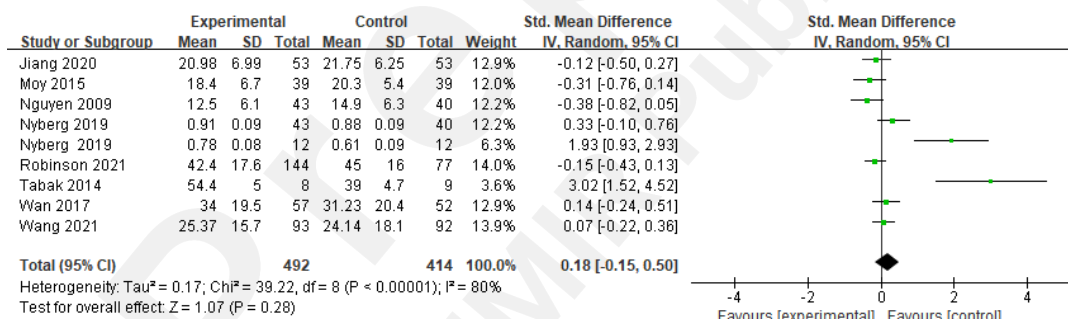


Fig.7 Meta-analysis results and forest plot of the digital health interventions on QoL at 3 months

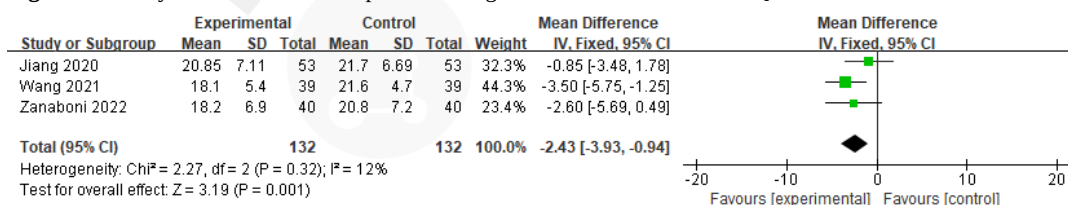


Fig.8 Meta-analysis results and forest plot of the digital health interventions on QoL assessed by CAT at 6 months

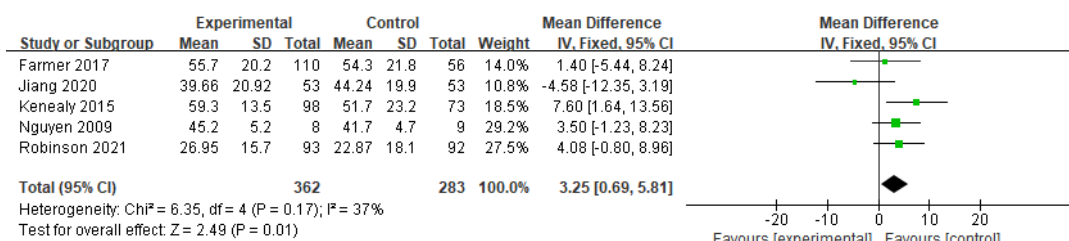


Fig.9 Meta-analysis results and forest plot of the digital health interventions on QoL assessed by SGRQ at 6 months

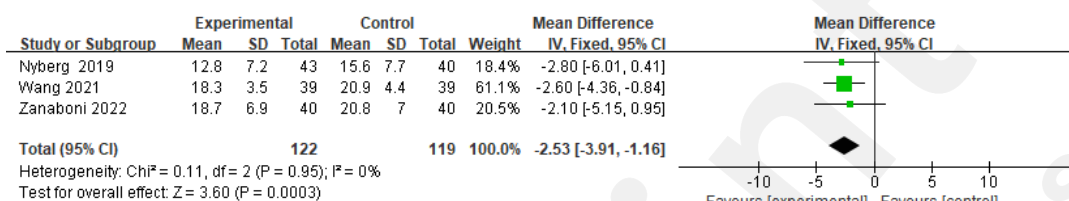


Fig.10 Meta-analysis results and forest plot of the digital health interventions on QoL assessed by CAT at 12 months

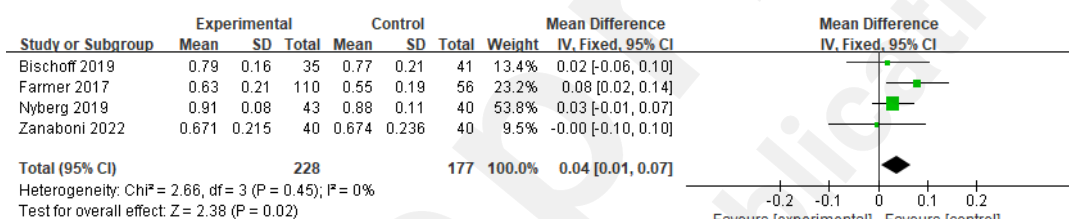


Fig.11 Meta-analysis results and forest plot of the digital health interventions on QoL assessed by EQ-5D at 12 months

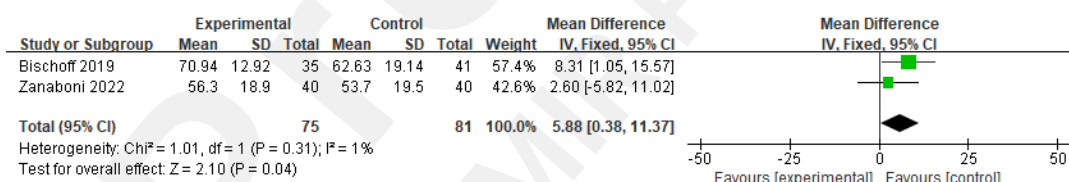


Fig.12 Meta-analysis results and forest plot of the digital health interventions on QoL assessed by EQ-5D VAS at 12 months

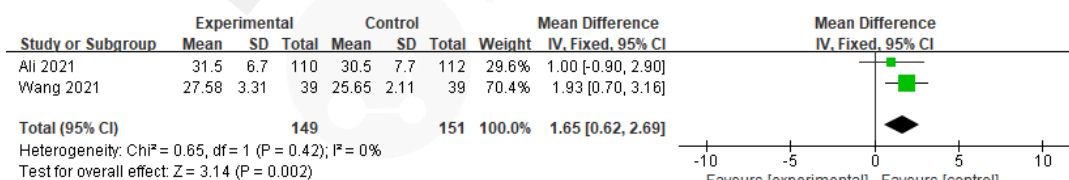


Fig.13 Meta-analysis results and forest plot of the digital health interventions on self-efficacy at 3 months

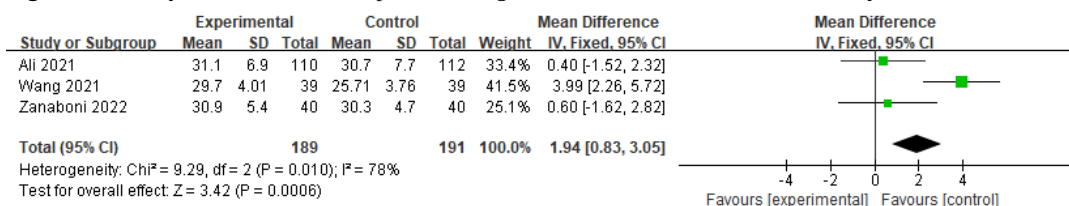
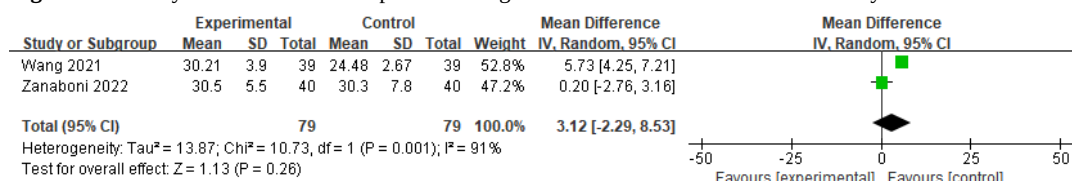
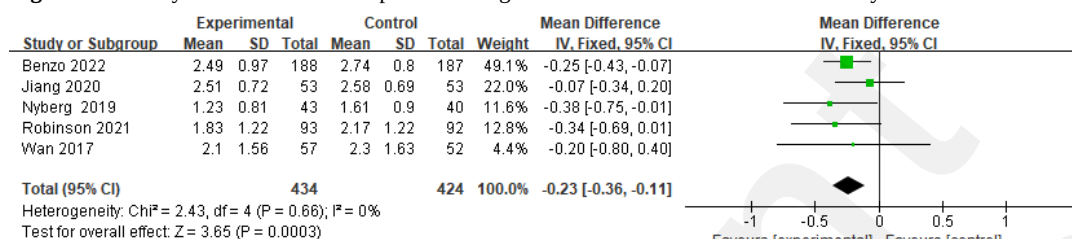
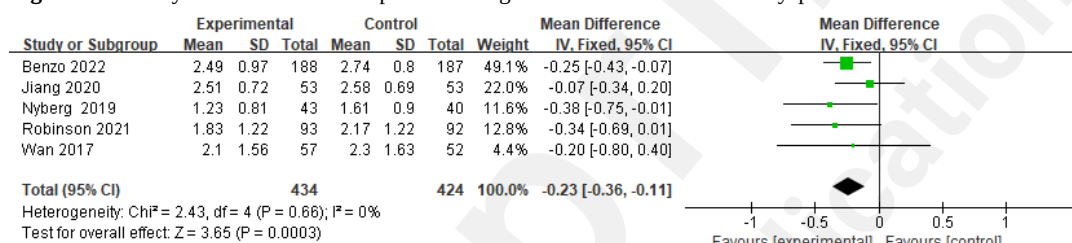
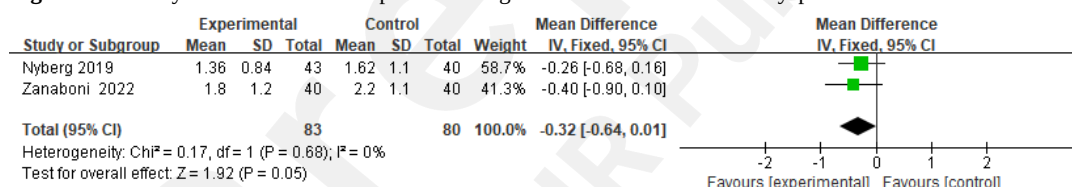
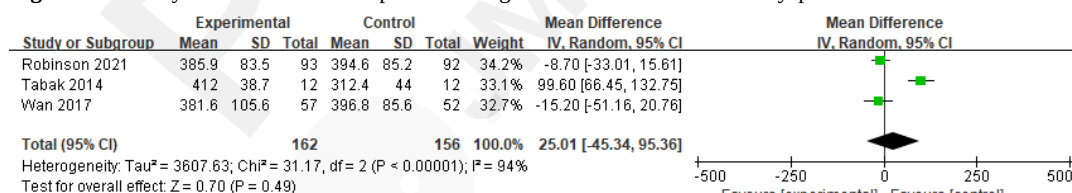
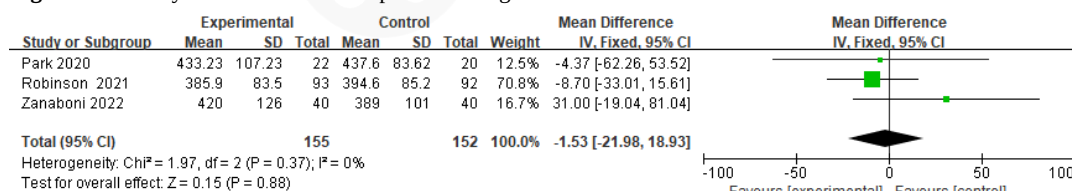


Fig.14 Meta-analysis results and forest plot of the digital health interventions on self-efficacy at 6 months**Fig.15** Meta-analysis results and forest plot of the digital health interventions on self-efficacy at 12 months**Fig.16** Meta-analysis results and forest plot of the digital health interventions on dyspnea at 3 months**Fig.17** Meta-analysis results and forest plot of the digital health interventions on dyspnea at 6 months**Fig.18** Meta-analysis results and forest plot of the digital health interventions on dyspnea at 12 months**Fig.19** Meta-analysis results and forest plot of the digital health interventions on 6MWT at 3 months**Fig.20** Meta-analysis results and forest plot of the digital health interventions on 6MWT at 6 months

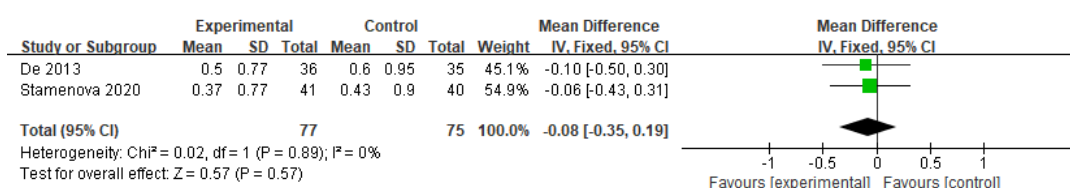


Fig.21 Meta-analysis results and forest plot of the digital health interventions on emergency department admissions

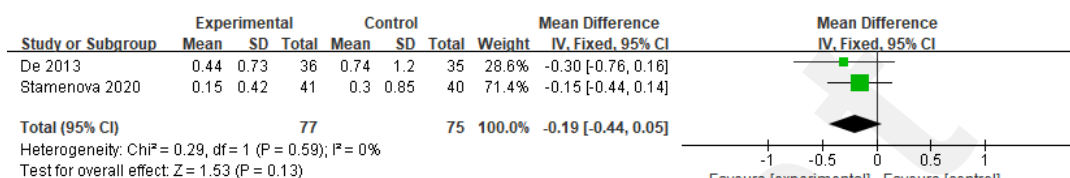


Fig.22 Meta-analysis results and forest plot of the digital health interventions on hospital admissions

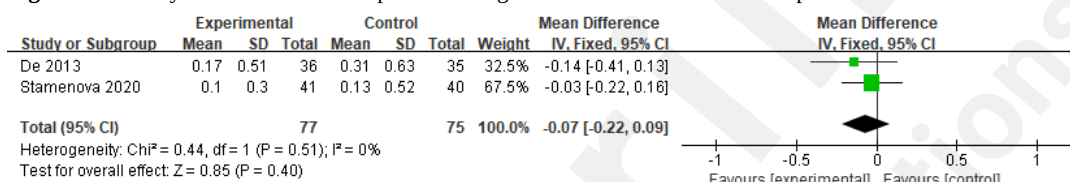


Fig.23 Meta-analysis results and forest plot of the digital health interventions on emergency department admissions for COPD

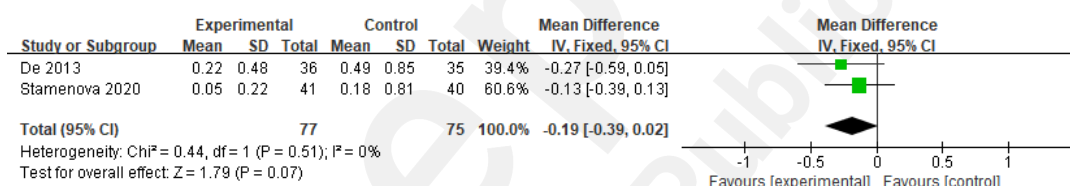


Fig.24 Meta-analysis results and forest plot of the digital health interventions on hospital admissions for COPD

Intervention effectiveness

Quality of life QoL

An array of QoL outcomes were measured across the trials, which included a COPD Assessment Test (CAT), St. George's Respiratory Questionnaire (SGRQ), EuroQol 5 Dimensions (EQ-5D) and EuroQol 5 Dimensions Visual Analogue Scale (EQ-5D VAS). And assessments are conducted at three different time points, which are 3 months, 6 months, and 12 months, respectively.

Among three studies with a total sample of 267 subjects were included in meta-analysis to assess the effect of 3 months of smartphone-based remote digital health management on CAT. Inverse-variance-weighted linear meta-analysis of MD (Hedge's g) on these trials indicated a mild effect size of -1.65 favouring smartphone-based remote digital health management. And MD was significant (MD -1.65, 95% CI [-3.17 to -0.14]; $P = 0.03$; Fig.4), with no statistical heterogeneity ($I^2 = 0\%$). Four studies with a total sample of 532 subjects were included in meta-analysis to assess the effect of 3 months of smartphone-based remote digital health management on SGRQ Meta-analysis for SGRQ (Fig.5) demonstrating a non-significant effect in favour of the smartphone-based remote digital health management (MD 4.24, 95% CI [-4.33 to

12.81]; $P = 0.33$), with a high statistical heterogeneity ($I^2 = 91\%$). And two studies with a total sample of 107 subjects were included in meta-analysis to assess the effect of 3 months of smartphone-based remote digital health management on EQ-5D Meta-analysis for EQ-5D (Fig.6) demonstrating a non-significant effect in favour of the smartphone-based remote digital health management (MD 0.10, 95% CI [-0.04 to 0.23]; $P = 0.17$), with a high statistical heterogeneity ($I^2 = 92\%$). The SGRQ and EQ-5D scores did not show statistically significant differences ($P > 0.05$), possibly due to high heterogeneity or the limited impact of the intervention on general health metrics. The overall effect (Fig.7) revealed that smartphone-based remote digital health management intervention couldn't effectively improve QoL, and the forest plot showed high heterogeneity among studies (MD 0.18, 95% CI [-0.15 to 0.50]; $P = 0.28$, $I^2 = 80\%$).

Three RCT involving 264 participants were synthesized to examine the efficacy of smartphone-based remote digital health management over 6 months on CAT scores (Fig.8). The meta-analysis revealed high statistically significant benefit for the remote intervention group compared to controls (MD = -2.43, 95% CI: -3.93 to -0.94; $P = 0.001$). Notably, the analysis detected low between-study heterogeneity ($I^2 = 12\%$), and another study examine the efficacy of smartphone-based remote digital health management over 6 months SGRQ scores (Fig.9), which also revealed high significant effect and low significant effect (MD = 3.25, 95% CI: 0.69 to 5.81; $P = 0.01$; $I^2 = 37\%$).

The results after 12 months of intervention were the same as those at 6 months, with the findings showing a statistically significant difference. Five studies with a total sample of 802 subjects were included in meta-analysis to assess the effect of 12 months of smartphone-based remote digital health management on CAT (Fig.10), EQ-5D (Fig.11) and EQ-5D VAS (Fig.12) demonstrating a high significant effect in favour of the digital health management ($P \leq 0.05$), with no or low statistical heterogeneity ($I^2 = 92\%$). This indicates that long-term intervention has a sustained effect on symptom relief and the improvement of overall health status.

Self-efficacy

Self-efficacy was also evaluated at 3, 6 and 12 months, using the General Self-Efficacy Scale (GSE). Analysis showed significant differences at 3 months (MD = 1.65, 95% CI: 0.62 to 2.69; $P = 0.002$; Fig.13) and 6 months (MD = 1.94, 95% CI: 0.83 to 3.05; $P = 0.0006$; Fig.14). Amongst the outcomes that were reported by two studies, no significant difference at 12 months (MD = 3.12, 95% CI: -2.29 to 8.53; $P = 0.26$) was observed between the two groups, with high statistical heterogeneity ($I^2 = 91\%$). (Fig.15).

Functional outcomes

Two functional outcomes were measured across the trials, which included Modified Medical Research Council Dyspnea Scale (mMRC) and Six-Minute Walk Test (6 MWT). Six studies with a total of 1392 patients were included in meta-analysis to assess the effect of digital health management on mMRC. Meta-analysis for mMRC all favoured the remote digital health management, and with a statistically significant differences over 3 months (MD = -0.23, 95% CI: -0.36 to -0.11; $P =$

0.0003; $I^2 = 0\%$; Fig.16) and 12 months (MD = -0.32, 95% CI: -0.64 to 0.01; $P = 0.05$; $I^2 = 0\%$; Fig.18) were observed between the intervention and control groups. Nevertheless, the results showed no significant differences at 6 months, and the forest plot showed medium heterogeneity among studies (MD = -0.17, 95% CI: -0.46 to 0.12; $P = 0.26$; $I^2 = 50\%$; Fig.17).

Meta-analysis for 6 MWT was favoured the use of the smartphone-based remote digital health management, but no significant differences at 3 months (MD = 25.01, 95% CI: -45.34 to 95.36; $P = 0.49$; Fig.19) and 6 months (MD = -1.53, 95% CI: -21.98 to 18.93; $P = 0.88$; Fig.20) were observed between the two groups.

Healthcare utilization indicators

Healthcare utilization indicators included emergency department admissions, hospital admissions, emergency department admissions for COPD and hospital admissions for COPD. The overall effect revealed that smartphone-based remote digital health management intervention couldn't effectively reduce healthcare utilization indicators. Analysis showed no significant differences in emergency department admissions (MD = -0.08, 95% CI: -0.35 to 0.19; $P = 0.57$; Fig.21), hospital admissions (MD = -0.19, 95% CI: -0.44 to 0.05; $P = 0.13$; Fig.22), emergency department admissions for COPD (MD = -0.07, 95% CI: -0.22 to 0.09; $P = 0.40$; Fig.23) and hospital admissions for COPD (MD = -0.19, 95% CI: -0.39 to 0.02; $P = 0.07$; Fig.24), all of them with no statistical heterogeneity ($I^2 = 0\%$).

Discussion

Principal findings

This systematic review and meta-analysis aggregated data from 17 RCTs, encompassing a total of 2027 participants, to assess the efficacy of digital health interventions aimed at COPD. The digital health tools were mainly utilized for rehabilitation and self-management purposes. Although many trials included healthcare professionals in the intervention process, few elaborated on strategies to maintain participant adherence throughout the intervention period. Most participants were older adults. Our study results showed that the remote digital health intervention demonstrated significant effects in improving QoL. Specifically, the CAT score showed statistically significant improvements at 3 months, 6 months (CAT and SGRQ, respectively), and 12 months (CAT, EQ-5D, and its visual analog scale VAS, respectively). Additionally, the degree of dyspnea (mMRC) significantly decreased at 3 months and approached significance at 12 months. Self-efficacy (GSE) also improved significantly in the short term, particularly at 3 months and 6 months, but no significant changes were observed at 12 months. Despite these encouraging results, no significant improvements were observed in physical performance (e.g., the 6-minute walk test, 6MWT) or hospitalization rates. For instance, the 6MWT did not show significant effects at either 3 months or 6 months. Similarly, although there were trends toward reduced all-cause hospitalization rates and COPD-related hospitalization rates, these did not reach statistical significance. While these results are promising, they should be interpreted with caution due to differences in digital health tools characteristics, content variability, and the diverse methodologies and clinical settings across studies, alongside generally small sample sizes.

Effects of intervention duration on COPD patients' health outcomes

The overall effect suggested that the QoL of the group using digital health intervention was superior to that of the control group. Moreover, the effects at 12 months were superior to those at 3 and 6 months, indicating that long-term intervention has a sustained impact on the improvement of quality of life. This finding may be attributed to the benefits of this intervention approach, which offers a more intensive and prolonged treatment without requiring the therapist's online (face-to-face) presence. Instead, it ensures the patient's rehabilitative activities are monitored in an offline mode [35]. However, to generalize the effects of digital health on QoL in COPD patients, additional studies are required with a larger sample size, greater consistency in the devices used, and equal total training durations for both the remote digital health group and the control group [36].

In the second subgroup analysis, digital health interventions showed the greatest impact on dyspnea in COPD patients at the early stage (3 months), which may be attributed to patients' high adaptability and initial learning effects. However, no significant differences were observed at 6 months, suggesting a possible decline in novelty and the optimization of short-term adjustable factors reaching their limit. Notably, a marginally significant improvement was observed at the 12-month follow-up, indicating that long-term adherence to these tools may contribute to the gradual alleviation of chronic issues. Additionally, individual differences, external environmental changes, and characteristics of the study design itself may also be contributing factors to these observations. These findings not only highlight the dynamic nature of the effects of digital health interventions but also underscore their complexity. To further validate these results and explore the underlying mechanisms, future longitudinal studies should consider including larger sample sizes and more diverse patient populations. Moreover, a more detailed analysis of the changes in intervention effects across different time points is particularly crucial.

Subgroup analysis results indicate that at 6 months, digital health interventions significantly enhanced self-efficacy in patients with chronic obstructive pulmonary disease (COPD), but surprisingly, no significant effect was observed at 12 months. This unexpected finding may be due to patients perceiving that they had maximized their benefits within a 6 months period (thus experiencing the greatest benefit during follow-up), which occurred during the most active and engaged phase of participation. This contrasts with longer-duration trials, where participants' improvements may have plateaued, leading to no perceived ongoing symptom improvement. This finding aligns with Pierz et al. [37], who reported that digital health technologies enhance users' self-efficacy. These effects are attributed to features such as remote health management, improved patient-provider communication, personalized self-management recommendations, and decision support. However, the specific time-point effects need to be further examined in future studies.

Relationship with Previous Published Literature

Previous systematic reviews have evaluated the effectiveness of digital health interventions in various areas such as blood pressure control in non-dialysis chronic kidney disease [38], prevention of cardiovascular disease [39], hypertension

management[40], and weight management in children and adolescents[41]. Many of these reviews concluded that digital health interventions are effective tools that lead to positive outcomes. To our knowledge, five other systematic reviews have been published on this topic specifically for COPD patients [42-46]. One of these reviews was limited to the effects of digital health interventions for pulmonary rehabilitation in people with COPD [42]; the other focused on the role of digital health interventions for the self-management of COPD [43]; and the other review focused on the cost-effectiveness of digital health interventions for asthma or COPD [44]. Additionally, although two recent systematic reviews and meta-analyses aimed to assess the effects of home remote monitoring with mobile applications in patients with COPD [45, 46], they included interventions module focusing solely remote monitoring rather than other module (e.g., health education□ behavioral incentive□ social support) and the technologies do not involve electronic health records, wearable technology and data analysis platforms. Therefore, this systematic review is unique because it extends beyond previous reviews by including evidence from newly published studies that provide more comprehensive health management services.

Limitations

This study has several limitations that warrant consideration. Firstly, there may be language biases since the searches were conducted in English, which could restrict the cross-cultural applicability of our findings. Secondly, relying primarily on randomized controlled trials is challenging due to the nature of the available evidence. However, including quasi-experimental studies enables us to evaluate outcomes from digital health interventions that have not been adequately studied in RCTs. Generally, the inclusion of quasi-experimental studies is justified when more rigorous trials are lacking. Thirdly, the Scopus database was not retrieved, and it should be included in the future. So we searched PubMed, EMBASE, Cochrane, and Web of Science databases. Keyword searches in PubMed provide optimal update frequency and include early online articles; other databases rank articles by the number of citations as an indicator of importance. Additionally, due to the small number of studies, subgroup analyses were not conducted, and publication bias was not explored. Finally, variations in the number of participants, intervention duration, frequency, research tool, and follow-up times led to heterogeneity.

Practical implications for healthcare and further studies

Digital health interventions show potential as a valuable addition to standard clinical care for COPD. Nevertheless, the adoption of digital health tools in this population is still in its early stages. Further research is essential to evaluate the impact of such interventions. Moreover, it is crucial to determine whether the currently limited effectiveness remains consistent and to explore the conditions under which their benefits could be maximized. These are areas that warrant systematic investigation. Additionally, with the growing aging population, future studies should focus on older adults with COPD, who represent the largest group of potential users. Older adults need access to digital health tools to support them to live independently and the self-care of chronic diseases. Computer or smartphone ownership among individuals aged 65 and above has risen significantly [47]. However, according to the

European Union Commission's 2012-2020 eHealth Action Plan, the current mHealth environment lacks intuitive tools and services tailored for elderly patients [47]. Therefore, gaining insights into the needs of older adults with COPD is critical for designing, developing, and assessing digital health tools interventions for this demographic.

Conclusions

Our analysis revealed that digital health interventions may have the potential to improve QoL at 3 months, 6 months and 12 months. Additionally, the degree of dyspnea significantly decreased at 3 months and approached significance at 12 months. Self-efficacy also improved significantly in the short term, particularly at 3 months and 6 months. However, no significant differences were observed in the 6 MWT, emergency department admissions, hospital admissions, emergency department admissions for COPD or hospital admissions for COPD. Furthermore, there is insufficient generalizable evidence to confidently advocate for replacing conventional management strategies with digital health interventions for COPD. This limitation arises due to clinical and methodological variability across studies, small sample sizes, and inconsistencies in platforms functionalities, content, duration and follow-up protocols. Considering the global surge in digital health tools usage and the increasing adoption of eHealth solutions, additional research employing robust study designs, long-term follow-ups, and samples representative of older adults is essential to evaluate the long-term sustainability of digital health-based interventions.

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ORCID iDs: Miaoqing Zhuang <https://orcid.org/0009-0003-3801-191X>

Intan IdianaHassan <https://orcid.org/0000-0001-6907-8920>

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Supplementary Files