Devices and Data Workflow in COPD Wearable Remote Patient Monitoring
A Systematic Review

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Resumo

Introdução: Com o aumento global das taxas de prevalência e mortalidade da Doença Pulmonar Obstrutiva Crónica (DPOC) e o seu impacto socioeconómico, as atuais estratégias de gestão da doença parecem inadequadas, abrindo caminho para soluções tecnológicas, nomeadamente para a adoção da monitorização remota, tendo em conta o seu benefício na gestão de exacerbações de doenças crónicas. Dentro destaca-se uma categoria, os dispositivos *wearable*, pela sua disponibilidade e aparente facilidade de uso.

Objetivos: Avaliar as soluções existentes, tanto no mercado, como na área de investigação, relativas a dispositivos *wearable* utilizados na monitorização remota de pacientes com DPOC através de uma revisão sistemática, do ponto de vista da composição do dispositivo, fluxo de dados e descrição dos parâmetros coletados.

Métodos: Uma revisão sistemática foi realizada para identificar tendências destes dispositivos, através do desenvolvimento de uma estratégia de pesquisa abrangente, procurando pesquisar para além das *databases* convencionais e agregar diversas informações encontradas sobre o mesmo dispositivo. Para tal, foram seguidas as diretrizes PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), e a avaliação da qualidade dos estudos identificados foi realizada utilizando a ferramenta CASP (Critical Appraisal Skills Programme).

Resultados: A revisão resultou na identificação de 1590 referências, das quais 79 foram incluídas. Foram analisados 56 dispositivos *wearable*, com a ligeira maioria a pertencer à classe de dispositivos de *wellness*. Foi identificada heterogeneidade substancial nos dispositivos em relação à sua composição, local de uso e ao fluxo de dados em relação a 4 componentes considerados. Os dispositivos de monitorização clínica já evidenciam alguma relevância no mercado e, pouco mais de um terço, visam auxiliar pacientes com DPOC e profissionais de saúde na previsão de exacerbações. Ainda assim, é notória a falta do cumprimento das recomendações validadas, não estando disponíveis dispositivos que avaliem a totalidade dos sinais vitais recomendados.

Conclusão: A heterogeneidade identificada, apesar de esperada face à relativa novidade dos dispositivos *wearable*, alerta para a necessidade de regulamentação do desenvolvimento e investigação destas tecnologias, especialmente do ponto de vista estrutural e de recolha e transmissão de dados.

Palavras-chave

Medicina Digital; Telemonitorização; DPOC; Dispositivos Wearable; Fluxo de Dados

Abstract

Background: With global increase in Chronic Obstructive Pulmonary Disease (COPD) prevalence and mortality rates, and socioeconomical burden continuing to rise, current disease management strategies appear inadequate, paving the way for technological solutions, namely remote patient monitoring (RPM), adoption considering its acute disease events management benefit. One RPM's category stands out, wearable devices, due to its availability and apparent ease of use.

Objectives: To assess the current market and interventional solutions regarding wearable devices in the remote monitoring of COPD patients through a systematic review design from a device composition, data workflow, and collected parameters description standpoint.

Methods: A systematic review was conducted to identify wearable device trends in this population through the development of a comprehensive search strategy, searching beyond the mainstream databases, and aggregating diverse information found regarding the same device. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were followed, and quality appraisal of identified studies was performed using the Critical Appraisal Skills Programme (CASP) quality appraisal checklists.

Results: The review resulted on the identification of 1590 references, of which a final 79 were included. 56 wearable devices were analysed, with the slight majority belonging to the wellness devices class. Substantial device heterogeneity was identified regarding device composition type and wearing location, and data workflow regarding 4 considered components. Clinical monitoring devices are starting to gain relevance in the market and slightly over a third, aim to assist COPD patients and healthcare professionals in exacerbation prediction. Compliance with validated recommendations is still lacking, with no devices assessing the totality of recommended vital signs.

Conclusions: The identified heterogeneity, despite expected considering the relative novelty of wearable devices, alerts for the need to regulate the development and research of these technologies, specially from a structural and data collection and transmission standpoints.

Keywords

Digital Health; Telemonitoring; COPD; Wearable devices; Data Workflow

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Lista de Acrónimos

GRP	Gabinete de Relações Públicas
UBI	Universidade da Beira Interior
COPD	Chronic Obstructive Pulmonary Disease
GOLD	Global Initiative for Chronic Obstructive Lung Disease
LMICs	Low Middle-Income Countries
HIC	High-Income Countries
USA	United States of America
FEV1	Forced Expiratory Volume in one (1) second
FVC	Forced Vital Capacity
CCQ	COPD Control Questionnaire
CAT	COPD Assessment Test
LTOT	Long-Term Oxygen Therapy
VAS	Visual Analog Scale
CRP	C- Reactive Protein
ABG	Arterial Blood Gases
WHO	World Health Organization
RPM	Remote Patient Monitoring
IoT	Internet of Things
WMDs	Wearable Medical Devices
WRPM	Wearable Remote Patient Monitoring
FDA	Food and Drug Administration
AI	Artificial Intelligence
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PROSPERO	International prospective register of systematic reviews
ANZCTR	Australian New Zealand Clinical Trials Registry
ACO	Asthma-COPD overlap
RCT	Randomized Control Trials
CASP	Critical Appraisal Skills Programme
NA	Not Available
Hy	Healthy Subjects
AECOPD	Acute Exacerbations of COPD
UK	United Kingdom
PA	Physical Activity
PAM	Physical Activity Metabolism
HR	Heart Rate
WBAN	Wireless Body Area Network
RR	Respiratory Rate
ECG	Electrocardiogram
FSS	Fatigue Severity Scale
EHR	Electronic Health Record
HCP	Healthcare Professional
MMRC	Modified Medical Research Council
DSS	Decision Support System

PPG	Photoplethysmogram
BLE	Bluetooth Low Energy
IMUs	Inertial Measurement Units
SNR	Signal-to-Noise Ratio
PPU	Portable Patient Unit
PDA	Personal Digit Assistant
GPRS	General Packet Radio Service
ADSL	Asymmetric Digital Subscriber Line
HPMU	Hybrid Power Management Units
RMS	Remote Monitoring System
EIT	Electrical Impedance Tomography
SpO2	Oxygen saturation
SEM	Sensor Electronic Module
ID	Identification
VO2	Oxygen Consumption
PDA	Personal Digit Assistant

1. Introduction

Chronic respiratory diseases are a worldwide leading cause of disability and death, with an estimated 544,9 million individuals affected in 2017, a 39,8% increase compared to 1990 data. (1) In this group, Chronic Obstructive Pulmonary Disease (COPD) is the most prevalent, accounting for 55,1% of chronic respiratory disease prevalence among men and 54·8% among women globally.(1)

Indeed, in 2019, using the COPD GOLD case definition, a large study estimated a 10.3% global prevalence rate of COPD alone, for population aged 30-75 years old, accounting for 391,9 million people worldwide.(2) The same study predicts that both the absolute number of COPD cases and COPD prevalence rate will continue to increase due to population growth and ageing in Low-and Middle Income Countries (LMICs), supported by the majority of studies on the same topic (2,3), which further identify global longer life expectancies as another reason for the increases.(1)

With an ageing population and rising disease prevalence, current COPD management strategies pose as inadequate. One strategy aiming to tackle this problem is the adoption of telehealth, namely remote patient monitoring (RPM), integrating a multitude of digital solutions for disease management, of which wearable devices are highlighted due to their wide availability and affordability (4), further enhancing patient autonomy empowerment, an emerging trend in the current guidelines, which emphasize self-management as a major component of chronic care.(3)

Thus, healthcare wearable technology paves the way to increase focus on patients' self-management with wearables' ease of use and affordability encouraging its quick adoption. Patients can use this technology to track and manage their diseases with changes in their vital signs acting as proxies for ensuing exacerbations, with the data being shared with healthcare professionals in an entirely remote process allowing for early event detection, crucial in COPD management, therefore preventing eventual life-threatening situations.

1.1. Thesis Rationale

With the increasing market of wearable solutions and its apparent role in COPD management, results the necessity to assess current technologies, from both a technical and a clinical standpoint. Although other reviews have been conducted on remote patient monitoring (5–8), they mainly focus on non-wearable technologies, that hinder the patient mobility and/or real time health status assessment whenever the patient leaves the comfort of his home or lack wider inclusion of wearable solutions.

Thus, it becomes crucial to expand on prior work to establish the current state of the art regarding wearable technologies utilised in the remote patient monitoring of COPD patients, examining the data parameters collected by each solution, device trends and clinical and technical set-ups of data management.

1.2. Thesis Objectives

To elaborate on the current state-of-the-art of Wearable Remote Patient Monitoring (WRPM) by conducting a systematic review on the wearable devices, set-up utilised, and data parameters collected in COPD interventions to answer the following questions:

1. What are the wearable devices utilised in wearable remote patient monitoring (WRPM) in Chronic Obstructive Pulmonary Disease (COPD) and how are they structured?
2. What are the clinical data parameters or other relevant data (environmental, etc.) collected in WRPM interventions in COPD?
3. How is the data collected, interpreted by health professionals and how are patients notified about its meaning?

2. Background

For a better comprehension of the themes included in this thesis, below I'll further elaborate on a) a general overview of COPD epidemiology, standard of care and emerging paradigm; b) telehealth and remote patient monitoring, and c) wearable devices in the medical field.

2.1. COPD – Definition and Epidemiology

COPD is defined as a heterogeneous lung condition characterized by chronic respiratory symptoms (dyspnoea, cough, expectoration) due to abnormalities of the airways (bronchitis, bronchiolitis), and/or alveoli (emphysema), that results in persistent and often progressive airflow limitation.(3,9)

In its 2023 Report, the Global Initiative for Chronic Obstructive Lung Disease (GOLD) adopted the recently proposed GETomics term coined by Agusti et al (10), which determines that COPD development is a result of a lifetime (T) exposure to cumulative interactions of an individual's genetic pool (G) with environmental (E) risk factors. Such hypothesis calls for the importance of understanding COPD risk factors.

Multiple influences have been linked as potential risk factors for COPD development with the most consensual being tobacco smoking and environmental exposure to noxious particles.(3) Cigarette smoking has been showed to have a causal relationship with COPD development risk (11) and smokers present a higher prevalence of respiratory symptoms, faster lung function decline and higher COPD mortality rate compared to non-smokers.(12,13)

Other types of smoking (such as water-pipe smoking and electronic cigarettes) (14,15) have been linked as COPD risk factors, and its prevalence, namely of electronic cigarettes usage, is increasing worldwide.(16) The same prevalence trend is verified in Portugal, as well as experimentation rates rising amongst adolescents (aged 13-18 years old) which are catching up with traditional cigarettes rates for the same age group (22% and 29%, respectively).(17)

As for the global mortality rate, COPD placed third overall in 2019, with an estimated 3 million annual deaths worldwide, if underdiagnosis deduction is considered.(3)

COPD also accounts for a substantial morbidity rate with a considerable social and economic burden. It was estimated that COPD alone accounts for a 38.6 billion euros annual expenditure in the European Union, representing 56% of the respiratory diseases cost, which in themselves account for 6% of the annual healthcare budget.(18) A similar estimate

was found in the United States of America, with COPD attributable costs expected to increase in the next 20 years.(19)

In addition, acute exacerbations are frequent in COPD and are responsible for the majority (estimated at 70%) of COPD-related healthcare costs, with cost increase directly related to episode's severity considering the higher probability of hospitalization, sometimes necessitating intensive care, and higher resource usage.(20,21)

In Portugal, the same epidemiologic trends are verified. There are 130 000 COPD patients registered in Portugal's National Health Service, but due to the high national number of smokers, the estimated number of COPD patients is around 700 000.(22) This underdiagnosis suspicions was later confirmed by a Portuguese study.(23)

Mortality rate wise, COPD places fifth in the Portuguese leading causes of mortality data with 3054 deaths (2.7%) in 2020. (22) As for the socioeconomic burden in 2020, an estimated 1.6 billion euros were spent with COPD, the sum of 400 million euros, 500 million euros and 700 million euros for direct costs, indirect costs and DALY's lost cost, respectively.(24)

In short, both COPD's prevalence and absolute number of patients affected are increasing. This trend is verified both in High-Income Countries (HIC), like the majority of the European Union and USA, and in LMIC. It also carries a significant mortality and morbidity rate, establishing itself as a an increasingly costly and health resources consuming disease.

2.2. COPD – Standard of Care

Following COPD's symptomatology history and documentation, the diagnosis should be suspected in patients presenting dyspnoea, chronic cough, and/or sputum production, with or without risk factors exposure history (namely smoking and noxious particles environmental exposure).(3)

COPD's shortness of breath is the most prevalent and characteristic symptom of the disease whilst cough and expectoration are present in up to 30% of the patients. These symptoms may be present without airflow obstruction and the opposite may occur as well. Although, airflow obstruction is the defining factor for definite COPD diagnosis which is assessed through forced spirometry testing.(3)

Hence, according to the GOLD guidelines,(3) forced spirometry is the gold standard for diagnosis confirmation (with airflow obstruction confirmed when the patient obtains a post-bronchodilator ratio of FEV1 (Forced Expiratory Volume in one (1) second)/FVC

(Forced Vital Capacity) <0.7). Progressive shortness of breath deterioration results in greater symptom severity and frequency leading to activity limitation and withdrawal from family and friend's circle with ensuing higher depression levels.(17)

COPD's initial patient assessment combines all the aforementioned factors: a) airflow obstruction severity grading in one of four categories (GOLD 1-4) through spirometry testing, b) symptom severity assessment through clinical approved scale usage, such as the CCQ (COPD Control Questionnaire) scale or the CAT (COPD Assessment Test), c) exacerbation history and d) presence of concomitant chronic diseases.(25)

Thus, this combined assessment strategy ultimately categorizes COPD patients in 4 categories through the Refined ABCD Assessment Tool which allows tailoring of individual therapeutic strategies and guidance of its escalation and de-escalation.(3) Despite this being the most consensual approach to COPD initial assessment, in 2023, an evolved tool is proposed, the ABE Assessment Tool, which combines the C and D categories of the previous tool to further demonstrate the clinical relevance of COPD exacerbation episodes.(3) The ABE Assessment Tool still awaits clinical research.

Following COPD's assessment, disease management includes multiple approaches that should be addressed in order to provide a multi-directional personalised therapy. These include risk factors exposure reduction(3), especially tobacco cessation interventions through guided and supportive counselling, influenza and pneumococcal vaccination, proven to reduce COPD mortality and exacerbation frequency(26–29), pharmacological treatment and non-pharmacological treatment to assist symptomatic control, reduce frequency and severity of exacerbations and reduce overall mortality.(3)

In the pharmacological treatment category, after categorizing the COPD patient in one of the previously mentioned GOLD group, adequate management optimization is obtained through a combination of bronchodilators, which act on bronchial smooth muscle cells promoting its relaxation and consequent dilation of the airways, and anti-inflammatory drugs, which decrease local and systemic inflammation. These agents are usually administered through inhalators, requiring initial education and follow-up review on its correct usage.(3) Periodic follow-up is also required to escalate or deescalate therapy.

As for the non-pharmacological treatment, it proves complementary to pharmacological therapy and should be implemented simultaneously with it. It should include education and self-management strategies, pulmonary rehabilitation, exercise training and oxygen therapy.

Long-Term Oxygen Therapy (LTOT) plays a crucial role in selected patients with oxygen saturation and/or partial pressure of oxygen levels below cut-off values and with or without hypercapnia or other pre-established breathing impairment signs(3) with non-invasive ventilatory support considered in patients with pronounced persistent hypercapnia.(30) Although, LTOT is not only crucial in home-care and outpatient management for severe resting hypoxemia and severe chronic hypercapnia(3), but is also utilised in acute exacerbation episodes.

2.3. COPD – Acute Exacerbations

COPD patients frequently experience disease exacerbations, up to four times per year, presenting to acute care units in worsening acute condition caused by respiratory symptoms aggravation with increased local and systemic inflammation resulting in Emergency Room episodes and subsequent hospitalization.(31) These events are responsible for most of COPD related health expenditures and negatively impact quality of life of both the patient and their family.(17,32)

In order to better approach acute exacerbation management, it is mandatory to define these episodes. In 2021, an updated definition was proposed, describing an exacerbation episode as "an event characterized by dyspnoea and/or cough and sputum that worsen over ≤14 days, which may be accompanied by tachypnoea and/or tachycardia and is often associated with increased local and systemic inflammation caused by airway infection, pollution, or other insult to the airways."(33)

Hence, the GOLD 2023 report, validating The ROME Proposal, suggested a new approach to exacerbations assessment by recommending its evaluation at point of contact with healthcare facilities, through assessment of a patient's presenting clinical parameters which then tailor the classification as a mild, moderate or severe exacerbation episode.(3) The parameters proposed are a self-assessed dyspnoea intensity scale (a VAS 0 to 10 dyspnoea scale), respiratory rate, heart rate, oxygenation saturation level and blood CRP level and, to determine ventilatory support need, arterial blood gases (ABG) measurement or equivalent, if available. Both CRP and ABG or equivalent measurement are fundamental for distinction between moderate and severe exacerbations.(3) **Table 1** summarises clinical parameters changes in COPD patients when experiencing an exacerbation compared to health subjects and COPD patients during their baseline state. The parameters indicating variable ranges result from the individual variability between patients on LTOT, and systemic inflammation levels influenced by multiple variables.(3,34)

Further adaptations or inclusions to these clinical parameters have been proposed, such as an eventual more specific marker than CRP for lung inflammation level assessment(3) and self-reporting or direct assessment of cough worsening and sputum production.(33)

Table 1. Clinical Parameters Comparison between Healthy Subjects and COPD Patients. CRP – C-Reactive Protein; brpm – Breaths per minute; bpm – beats per minute; SpO_2 – Oxygen Saturation; $PaCO_2$ – Carbon Dioxide Arterial Pressure; *Moderate Exacerbation parameters were considered (at least 3 must be present)

	Healthy Person	COPD Patient (Baseline)	COPD Patient (Exacerbation)*
Respiratory Rate	12-18 brpm	< 24 brpm	≥ 24 brpm
Heart Rate	60-100 bpm	< 95 bpm	≥ 95 bpm
SpO_2 (Resting)	97–99 %	Variable	< 92 %
CRP Blood Level	< 10 mg/dL	Variable	≥ 10 mg/dL
$PaCO_2$	33-45 mmHg	Variable	> 45 mmHg
FEV1/FVC Ratio (Post Bronchodilator)	> 0.7	< 0.7	< 0.7

Table constructed with data from (3,34,35)

2.4. COPD – New Paradigm

Although, a trend verified for both COPD and chronic respiratory diseases in general, is their neglected status from health-care providers and policy makers when compared to other prominent chronic diseases, such as cardiovascular diseases and diabetes.(1,2)

The high smoking prevalence and ensuing COPD prevalence rise expectations issues the fact that current strategies remain inadequate.(1) Such assumption should alert government and health organizations to focus on measures to address the gradually growing tobacco industry (2) and call for more effective COPD diagnosis globally and more efficient monitoring of COPD evolution and exacerbation assessment and prediction to provide a multi-directional approach.

One strategy developed to alleviate presential health services' burden and that may assist with earlier prediction was the adoption of telehealth strategies and programs to address COPD management.(7,36)

2.5. Telehealth and Telemedicine

In its most recent telemedicine implementation guide, the World Health Organization (WHO) defined telehealth as the broader application of technologies to distance education and other healthcare applications through electronic communication and information technologies to support healthcare services.(37)

Telemedicine arises as a component of telehealth, as the delivery of healthcare services where distance is a critical factor, using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries.(37)

The interaction between the healthcare professional (HCP) and the patient may occur synchronously, that is, in real-time, or asynchronously, where live interaction is not required and data is sent to the healthcare facility, with the latter being easier to organize and more cost-friendly.(38) Although, telemedicine's main benefit is the facilitation of healthcare access promoting universal health coverage by improving high-quality health services access regarding their setting, assuring equity in health services access.(38)

In the same manner, governments worldwide are incentivizing the creation and adoption of telehealth related policies and strategies. In a WHO global survey conducted in 2015, of 125 responding countries, 22% had a dedicated national telehealth strategy or policy and 35% referred to telehealth in their programmes, resulting in a total of 375 national telehealth programmes, with Europe having the highest relative proportion.(38) The Covid-19 pandemic largely contributed to the acceleration of telehealth adoption.(39)

One of the appliances of telemedicine is remote patient monitoring (RPM), otherwise known as telemonitoring.(37)

The scope of this thesis focuses mainly on this telemedicine application, Remote Patient Monitoring, and despite telemonitoring being used interchangeably, for effects of clarity, in this thesis, I'll refer to it as RPM.

2.6. Remote Patient Monitoring (RPM)

RPM enables healthcare professionals to remotely monitor individualised patients' conditions, often chronic conditions, using technologies such as connected medical devices and sensors and is often accompanied by communication channels for coordination of care or alerts to HCPs based on clinical parameters thresholds.(37)

Therefore, RPM poses a significant importance in chronic disease management where it can either provide timely notification of adverse events in the patient status to the healthcare organizations or store the information to be assessed in future visits or through remote consultation.(36) Hence, with the potential to alert for early symptomatic deterioration, it allows for earlier intervention, with ensuing decreased hospitalization rates and improved quality of life.(3) In addition, it may provide a broader longitudinal view of the patient status when compared with periodic appointments.(36)

The devices utilised in RPM interventions constitute an Internet of Things (IoT) system, with IoT being a system where internet connected devices collect and transmit data.(40)

Furthermore, in order to archive all the data collected to later analyse it, remote monitoring devices usually communicate with cloud platforms where patient information is stored to be readily accessed by healthcare professionals.(41)

Thus, RPM allows for a data-intensive approach to healthcare, generating a vast amount of health data used to identify patterns and allow clinical intervention decision-making, develop high-quality personalized treatment plans, and improve health outcomes for patients.(42)

Furthermore, remote monitoring has been successfully implemented in a multitude of chronic diseases, including COPD, and is an increasingly expanding market.(43)

2.7. RPM in COPD – Implementation Barriers

Remote monitoring presents itself as more than adequate for COPD management optimisation. Still, even though multiple studies and reviews have been conducted on RPM effectiveness and cost-effectiveness for COPD management(6,44,45), conflicting data due to study heterogeneity prevents a definite answer to its benefits.

Literature has shown that RPM may potentially reduce both COPD-related acute care costs and severity, with ensuing decrease of hospitalization rates, of COPD exacerbation episodes(44,46,47) and stable disease care(36,45,48) and increase patients' quality of life(47,49,50), but some studies have also questioned its cost-effectiveness and efficacy on reducing acute-care usage.(45,50,51)

2.8. RPM in COPD – Implementation Opportunities

In short, consensus on RPM's effectiveness and cost-effectiveness is yet to be achieved, but overall results do not show any harm in its adoption with some studies showing slight increases on COPD patients' quality of life.

Additionally, regarding intervention set-up, with intensive investment in remote monitoring systems development, equipment utilised is not limited to multi-device systems utilising pulse oximeters, spirometers, thermometers and/or others, but single data collection devices that monitors multiple clinical parameters have emerged (52), which may prove beneficial for user adoption and accessibility by requiring less input from the user.

Recommended patient clinical data for acute exacerbation assessment was already detailed above, and previous studies have suggested continuous and non-invasive transcutaneous CO_2 measurement as an appropriate alternative to invasive arterial blood gases measurement(53,54) as well as electrocardiogram monitoring(55), further cementing RPM as an appropriate approach for these data parameters collection.

Ultimately, whilst several remote patient monitoring devices have been described for data collection and transmission, one subdivision has been gaining relevance in recent years and presents itself as a possible solution for both single device data collection system development and continuous data parameters assessment, wearable devices.(56)

2.9. Wearable Devices

Despite intensive effort to identify a validated or consensual wearable definition, it couldn't be identified. Hence, for the purpose of this thesis, wearable devices will be identified as autonomous, minimally invasive electronic devices in direct contact with the patient's body or clothing, with minimal hindering of the patient fine and/or gross mobility, thus being hands-free. This definition excludes handheld devices and devices, that, despite being hands-free, limit the full mobility of the patient, as such is the case of finger pulse oximeters. This definition arises from the findings of previous studies which have shown the preference of chronic patients with devices that meet this criteria (57), and allows the identification of current alternatives to finger pulse oximeters, as they have shown limitations.(58,59)

2.10. Wearable Wellness Devices

For the purpose of this thesis, the Food and Drug Administration (FDA) general wellness products definition will be extended to wellness devices.(60) Hence, integrating the definition of wearable, they will be defined as wearable products, usually commercially available, intended to maintain or encourage a general healthy status or activity level or intended to relate this healthy lifestyle with certain chronic diseases impact, if such correlation is well established, as is the case with COPD, where it has been proven that physical activity impairment is strongly correlated with health status impairment and prognosis prediction(3)

2.11. Wearable Clinical Monitoring Devices

On the other hand, for this thesis' purpose, wearable clinical monitoring devices will be defined as wearable products that collect patients' clinical data over a determined period of time by utilising sensing capabilities and transmitting information gathered to healthcare facilities and/or professionals or storing it for delayed assessment.

Wearable clinical monitoring devices are usually comprised of a biosensor that collects pre-established clinical data depending on the condition being assessed, as is the case with chronic diseases, such as wearable electrocardiogram and blood pressure monitors for cardiovascular disease monitoring and blood interstitial glycemia sensors in diabetes monitoring.(56,61)

Concerning COPD, remote monitoring wearable systems are now starting to emerge, but as with non-wearable remote monitoring devices, equipment utilised for data collection and clinical parameters assessed still differ significantly despite continuous research and improvements applied to wearable clinical monitoring devices which hinders regulation attempts by competent organizations such as the FDA.(5)

3. Methodology

A systematic review methodology was followed in order to answer the aforementioned research questions utilising the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 Checklist(62). The systematic review started on 8th January 2023 and its protocol was submitted on the International Prospective Register of Systematic Reviews (PROSPERO) on the 12th of April 2023 under the ID *CRD42023411492*.

3.1. Study Identification

To identify eligible studies for this review, the following databases were searched: PubMed, Scopus, ISI Web of Science, Cochrane Library (Cochrane Central Register of Controlled Trials (CENTRAL)) and IEEE Xplore Digital. A thorough search strategy, compiled in **Appendix 1**, was developed for PubMed, and later applied to the additional databases, guaranteeing a clear comparison of obtained results, and was developed with terms and selection criteria based on the PICO system, **Table 2**. Relevant databases regarding grey literature, i.e., ClinicalTrials.gov, the Australian New Zealand Clinical Trials Registry (ANZCTR) and OAIster, were searched to identify unpublished and ongoing work. Search dates were restricted to studies published in the last 15 years (2008-2023) due to wearable monitoring search results emerging in that year. The references of all eligible studies were reviewed to identify additional possible references and manufacturer's websites were investigated for further study information and device description. No language restrictions were applied, and translations were implemented where necessary. The search was undertaken in January 2023 and updated in April 2023 due to inclusion criteria scoping.

Table 2. PICO System

Population	Adult patients (>18 years of age) diagnosed with COPD OR Healthy adult subjects as pre-test for the development of COPD wearable monitoring OR Synthetic models mimicking COPD patients developed for the intervention
Intervention	Wearable Remote Patient Monitoring
Comparison	No comparison or non-wearable remote monitoring devices and COPD standard monitoring
Outcome(s)	Intervention description; Equipment utilised description; Type of data collected by the wearable device(s)

3.2. Criteria Modulating Study Inclusion

3.2.1. Population Criteria

For study inclusion, one of the following criteria had to be met:

1. Adult (18 years old or over) patients diagnosed with COPD regardless of the presence of other comorbidities
2. Healthy adult subjects as pre-test for the development of COPD wearable monitoring
3. Synthetic models mimicking COPD patients developed for the intervention testing

Additionally, studies with any of the following criteria were excluded:

1. Participants of WRPM interventions not aimed at or including COPD monitoring
2. Concurrent asthma / asthma-COPD overlap (ACO)

3.2.2. Intervention Criteria

For study inclusion, all the following criteria had to be met:

1. Remote Patient Monitoring interventions utilising a wearable device(s) in the form of minimally invasive skin/clothing-attached sensors or hands-free accessories designed for COPD monitoring
2. Description of the equipment and set-up utilised for the patient wearable monitoring
3. Description of the data collected

Additionally, studies with the following criteria were excluded:

1. Remote monitoring interventions utilising only non-wearable devices (e.g., wired devices, smartphone only or computer only), handheld devices (e.g., Finger-tip oximeters, spirometers) or invasive remote monitoring devices, as they represent device classes outside the scope of this review

3.3. Comparators

No comparison or non-wearable remote monitoring devices and current COPD standard monitoring.

3.4. Study Types

Both observational (case reports, case-series, qualitative studies, surveys, cohort studies, case-control studies) and interventional study designs were included. Narrative reviews and

correspondence letters were excluded, but the ones considered relevant were citation searched for additional articles identification.

3.5. Study Selection

Titles and abstracts of the studies generating from search results were uploaded onto an external reference management platform (Rayyan)(63) and were independently assessed against the inclusion criteria by two reviewers, with full text of selected studies being retrieved and assessed for final inclusion eligibility by the same two reviewers, recording the reason for exclusion of all ineligible studies. Disagreements met were resolved by discussion and a third reviewer arbitrated where unresolved discrepancies were met. Duplicate articles were identified and eliminated accordingly. The reviewers also looked for multiple reports of the same study, eliminating it, or, if no population was provided (to avoid data duplication), aggregating the multiple reports for thorough device description. Randomized Control Trials (RCT) registered on grey literature databases with results already identified elsewhere, were counted as duplicated studies, and, as a result, eliminated. To find missing studies or data, authors of the original articles were also contacted for further information. The number of eligible articles were stated for each database and at each screening stage utilising the PRISMA flow diagram(62).

3.6. Data Extraction

Data extraction tables were built using a Microsoft Excel (2302 Version) spreadsheet where data from included articles was individually extracted to, recorded, and organized. For all selected articles, study characteristics collected included: study year, study design and setting, study's population size, age, and severity of COPD level. As for intervention and outcome details, description of the wearable equipment, its technical specifications regarding data collection and assessment and parameters assessed were extracted.

3.7. Data Analysis

A narrative synthesis including descriptive summary tables of all included studies was produced in order to summarize literature regarding the extracted data. For the devices where study publications regarding the device field application weren't yet available, a separate table was constructed regarding found information.

Furthermore, from the preliminary research regarding the topic, it was apparent that 2 major device classes would arise from a systematic literature research: wellness monitoring devices and clinical monitoring devices. Hence, these were addressed as 2 different subgroups.

As such, information on data management and device composition was only collected for clinical monitoring devices, as a recent systematic review already detailed this information on wellness monitoring devices.(64)

3.8. Quality Assessment

Studies eligible for this systematic review were selected independently by two different reviewers, using the Critical Appraisal Skills Programme (CASP) quality assessment tool, where applicable. The following components of each study were appraised: appropriateness of study design, potential for selection bias, measurement of exposures and outcomes, and generalizability of the study findings. For each study, the grading of each individual components and the global study rating were assigned risk of bias categories (low, moderate and high). A global grading was provided by taking an average of all individual components. Some of the studies may associated with a certain degree of observation bias as they come mainly from authors involved in telehealth interventions.

4. Results

The original search identified 966 references in the main databases, with an additional 624 references found through grey literature, citation and devices' website searching, resulting in 1590 initial references. After screening and full text retrieval, 79 finals references were analysed. 65 references regarded published studies and 14 additional references were identified relating to device websites or unpublished interventions. Detailed screening and selection process is summarized on the PRISMA Flow Diagram, **Figure 1**.

Results' analysis was written having the following topics in consideration, resulting from the scrutiny of the eligible references:

1. Intervention and devices identified description
2. Analysis of the data parameters collected by each included device
3. Thorough description of the device composition and respective set-up utilised for data management

4.1. Study Quality Appraisal

Detailed quality appraisal results for each study are presented in **Appendix 2**. Quality assessment was performed for the 19 observational studies (16 prospective cohorts and 3 cross-sectional studies), 14 Randomized Control Trials (RCTs), and 10 qualitative studies identified. Quality appraisal was not conducted on studies with methodology description design (i.e., references detailing device composition or set-up, but lacking field intervention), and on other study designs not referred above, as they lack sufficient interventional or observational components to evaluate.

Regarding appropriateness of study design, all identified studies had low risk of bias. As for potential for selection bias, 27 studies had a low risk (17 in the observational group, 2 in the RCTs group, and 8 in the qualitative group), 13 had a moderate risk of bias (2 in the observational group, 9 in the RCTs group, 2 in the qualitative group), and 3 had a high risk of bias (all in the RCTs group). Relating to the measurement of exposures and outcomes risk of bias, 18 studies had a low risk (6 in the observational group, 3 in the RCTs group, and 9 in the qualitative group), 16 had a moderate risk of bias (13 in the observational group, 2 in the RCTs group, 1 in the qualitative group), and 9 had a high risk of bias (all in the RCTs group). Lastly, concerning generalizability of the study findings risk of bias, 31 studies had a low risk (12 in the observational group, 12 in the RCTs group, and 7 in the qualitative

group), 10 had a moderate risk of bias (5 in the observational group, 2 in the RCTs group, 3 in the qualitative group), and 2 had a high risk of bias (all in the observational group).

4.2. Intervention Characteristics and Devices Identification

Table 3 summarises all the included studies' details regarding study characteristics and devices identified grouped by monitoring class. Regarding population age, the mean COPD population age was 67.9 years (wellness monitoring = 68.2 years; clinical monitoring = 67.2 years) and for the healthy subjects, the mean age was 35.1 years. Concerning COPD severity according to the GOLD stage, for the studies reporting stage demographics, 92 patients were classified as Stage I, 297 as Stage II, 227 as Stage III and 104 as Stage IV. Some studies reported the GOLD staging as group demographics, with 119 patients in GOLD I-II stages, 19 in the GOLD I-III stages, 50 in the GOLD II-III stages, 37 in the GOLD II-IV stages and 51 in the GOLD III-IV stages. The vast majority of COPD staging data derived from wellness monitoring interventions. As for device identification, we registered 48 unique devices (wellness monitoring = 29; clinical monitoring = 19).

Table 4 contains the additional references regarding study protocols and device websites, except for Buekers et al (65), which was included in this separate table as the intervention relates to the validation study of 2 wearable clinical monitoring devices on ambulatory heart rate and oxygen uptake kinetics assessment and not to COPD monitoring in the long term. Regarding devices already included on **Table 3**, we identified the website of 6 clinical monitoring devices and the study protocol of 1 wellness device. As for devices not included on **Table 3**, 3 websites of clinical monitoring devices and 3 intervention protocols, regarding 1 wellness and 2 clinical monitoring devices were identified.

Thus, a total of 56 devices were identified by this review, 30 wellness devices and 26 clinical monitoring devices.

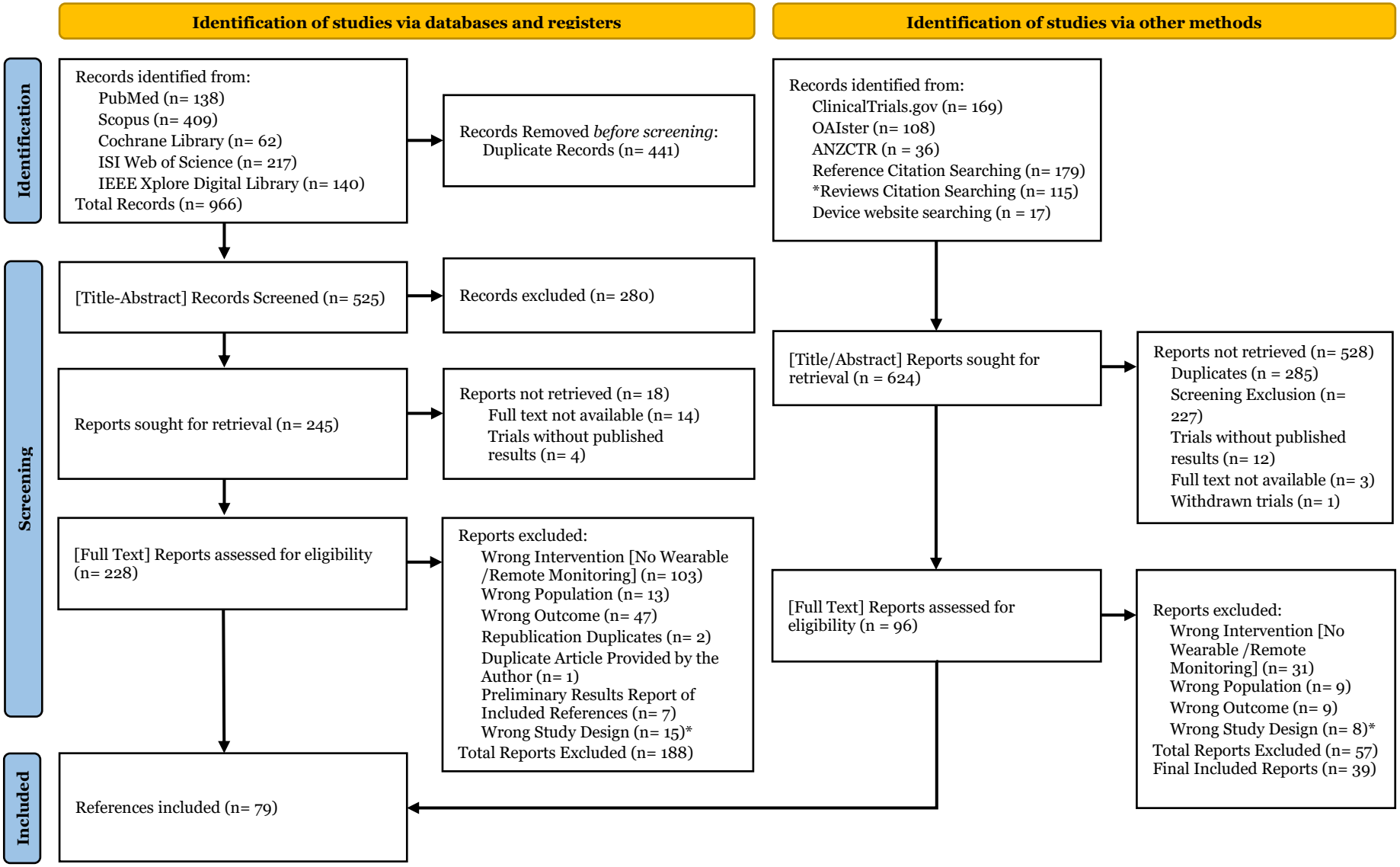


Figure 1. PRISMA Flow Diagram. From (62) *Systematic and narrative reviews assessing similar themes which were citation searched.

Table 3. Device Identification and Study Characteristics. RCT – Randomized Controlled Trial; NA – Not Available; AECOPD – Acute Exacerbations of Chronic Obstructive Pulmonary Disease; USA- United States of America

Reference	Device Name	Design	Country	Sample Size	Mean Age (Years)	COPD Severity (GOLD Stage)
Wellness Devices						
Steele et al (2008) (66)	RT3 Accelerometer	RCT	USA	38 COPD Patients	NA	II – 6 III – 24 IV – 8
Moy et al (2008) (67) (2009) (68)	Actihealth	Cross-Sectional Study (67) Prospective Cohort (68)	USA	46 COPD Patients(67) 10 COPD Patients(68)	71 (67) 70 (68)	I – 2(67) / 1(68) II – 23(67) / 6(68) III – 15(67) / 1(68) IV – 4(67) / 2(68)
Hospes et al (2009) (69) **Altenburg et al** (2015) (70)	Digiwalker SW-2000	RCT	Netherlands	35 COPD Patients(69) 155 COPD Patients(70)	62.2 (69) 62 (70)	I – 5(69) II – 23(69) III – 7(69) I – 32(70) II – 65(70) III – 38(70) IV – 20(70)
Sugino et al (2011) (71)	Actimarker	Validity Study	Japan	24 COPD patients	73	NA
Tabak et al (2012) (72)	MTx-W Sensor	Prospective Cohort	Netherlands	39 COPD Patients	66	II – 13 III – 18 IV – 8
Kawagoshi et al (2013) (73)	A-MES™	Prospective Cohort	Japan	26 COPD Patients	77	I – 4 II – 7 III – 11 IV – 4
Caulfield et al (2014) (74)	Fitbit One	Prospective Case Control	Ireland	10 COPD Patients	61.4	GOLD Stages I-II
McNamara et al (2014) (75)	SenseWear Pro3 Armband	Prospective Cohort	Australia	50 COPD Patients	71.5	II – 33 III – 11 IV – 6
Faria et al (2014) (76)	bioPlux Motion™	Prospective Cohort	Portugal	22 COPD Patients	64.7	NA

Vooijs et al (2014) (77)	Fitbit Ultra **OR** PAM AM300	Mixed Methods (Validity[1] and Usability Study[2])	Netherlands	9 COPD Patients[1] 16 COPD Patients[2]	66.2[1] 63.9[2]	I –1[1] / 2[2] II –4[1] / 9[2] III –3[1] / 4[2] IV - 1[1] / 1[2]
Perriot et al (2014) (78)	ACOR+™ Actimeter	Prospective Cohort	France	22 COPD Patients	65	NA
van der Weegen et al (2015) (79)	PAM AM300	RCT	Netherlands	25 COPD Patients	NA	I – 9 II – 15 III – 1
Kawagoshi et al (2015) (80)	Kens Lifecorder EX **AND** A-MES™	RCT	Japan	19 COPD Patients	74	GOLD Stages I-III
Mendoza et al (2015) (81)	Tanita PD724	RCT	Chile	52 COPD Patients	68.9	I – 13 II – 29 III – 9 IV – 1
Moy et al (2016) (82)	Omron HJ-720 ITC	RCT	USA	238 COPD Patients	66.8	NA
Verwey et al (2016) (83)	MOX Activity Monitor	Mixed Methods (RCT and Cross-sectional Study)	Netherlands	NA	NA	NA
McNamara et al (2016) (84)	SenseWear Pro3 Armband	Usability Study	Australia	252 COPD Patients	71	NA
Lewis et al (2016) (85)	SenseWear Pro3 Armband **AND** Actigraph GT3X+	Cross-Sectional Study	Australia	31 COPD Patients	75	NA
Nolan et al (2017) (86)	Yamax Digi-walker CW700	RCT	United Kingdom	152 COPD Patients	68	NA
Tillis et al (2017) (87)	Link Mobile	Prospective Cohort	USA	28 COPD Patients	72	III – 17 IV – 7
Wu R et al (2018) (88)	LG Watch Urbane W150 **OR** Moto 360 2nd Generation	Prospective Cohort (Feasibility Study)	Canada	28 COPD Patients	68.5	NA
Orme et al (2018) (89)	LUMO **AND** ActiGraph GT3X-BT	RCT (Feasibility Study)	United Kingdom	33 COPD Patients	71	NA

Lin et al (2019) (90)	GeneActiv	Prospective Cohort	Taiwan	16 COPD Patients	NA	NA
Bowler et al (2019) (91)	Actigraph GT9X **OR** Actigraph GT3X-BT	Prospective Cohort	USA	82 COPD Patients	66.5	I – 9 II – 36 III – 24 IV – 13
Buekers et al (2019) (92)	SenseWear Armband	Prospective Cohort	Netherlands	20 COPD Patients	63	GOLD Stages II-IV
Orme et al (2019) (93)	ActiGraph GT3X-BT	Cross-Sectional Study	United Kingdom	109 COPD Patients	65.7	GOLD Stage I-II
Wu CT et al (2021) (94)	Fitbit Versa	Prospective Cohort	Taiwan	67 COPD Patients	66.6	I – 14 II – 24 III – 20 IV – 9
Tiwari et al (2021) (95)	Samsung Galaxy Watch	Prospective Cohort	Canada	35 COPD Patients	69.9	NA
Benzo et al (2022) (96)	Garmin Vivofit	RCT	EUA	188 COPD Patients	69	NA
Clinical Monitoring Devices						
Paradiso et al (2008) (97)	Healthwear System	Methodology Description Study	Greece	NA	NA	NA
Katsaras et al (2011) (98) **Milsis et al** (2012) (99)		RCT	Greece	48 COPD Patients	NA	NA
Rajasekaran et al (2010) (100)	NA	Methodology Description Study	India	NA	NA	NA
Rosso et al (2010) (101)	CHRONIOUS System	Methodology Description Study	Greece	NA	NA	NA
Bellos et al (2011) (102)		Methodology Description Study	Greece	NA	NA	NA
Bellos et al (2012) (103)		Methodology Description Study	Greece	21 COPD Patients	NA	GOLD Stages III-IV

Bellos et al (2013) (104)	CHRONIOUS System	Acceptability Study	Italy	30 COPD Patients	NA	NA
Bellos et al (2014) (105)		Methodology Description Study	Spain and Italy		NA	GOLD Stages III-IV
Colantonio et al (2015) (106)		Methodology Description Study	Spain and Italy	26 COPD Patients	70	III – 15 IV – 11
Xing et al (2012) (107)	HealthWear@AA	Methodology Description Study	Germany	NA	NA	NA
Chau et al (2012) (108)	ASTRI Telecare System	RCT (Feasibility Study)	China	22 COPD Patients	73.5	II – 4 III – 9 IV – 9
Pedone et al (2013) (109)	SweetAge System	RCT	Italy	50 COPD Patients	74	GOLD Stages II-III
Chouvarda et al (2014) (110,111)	WELCOME System	Methodology Description Studies	Greece	NA	NA	NA
Wacker al (2014) (112)		Methodology Description Study	Switzerland	NA	NA	NA
Sobnath et al (2016) (113)		Mixed Methods (Acceptability and Usability Study)	United Kingdom	15 COPD Patients	69	NA
Chetelat et al (2016) (114)		Methodology Description Study	Switzerland	NA	NA	NA
Chouvarda et al (2016) (115)		Methodology Description Study	Greece	NA	NA	NA
Kaimakamis et al (2019) (116)		Methodology Description Study	Greece	17 COPD Patients	68.4	GOLD Stages II-IV
Tey et al (2017) (117)	NA	Methodology Description Study	South Korea	NA	NA	NA
Sharma et al (2018) (118)	S-Mask	Methodology Description Study	India	10 Healthy Subjects	21 (Healthy)	NA

Sarmento et al (2018) (119)	L.I.F.E.'s Medical Compression Garment	Methodology Description Study	Italy	10 COPD Patients **AND** 10 Healthy Subjects	NA	NA
Guber et al (2019) (120)	Oxitone 1000M	Mixed Methods (Methodology Description Study and Usability Study)	Israel	8 COPD Patients **AND** 15 Healthy Patients	60.4 51.5 *(Healthy)*	NA
Moraveji et al (2021) (121)	Spire Health Tag	Adherence Study	USA	94 COPD Patients	64	NA
Polsky et al (2023) (122)		Pre/Post Interventional Study		126 COPD Patients	73.8	
Angelucci et al (2021) (123)	Airgo	Prospective Cohort	Italy	18 Healthy Subjects	43.7 *(Healthy)*	NA
De Fazio et al (2022) (124)	NA	Methodology Description Study	Italy	8 Healthy Subjects	24.3 *(Healthy)*	NA
Emokpae et al (2022) (125)	WearMe System	Methodology Description Study	USA	3 COPD Patients **AND** 35 Healthy Subjects	NA	NA
Arvind et al (2022) (126)	Respeck Monitor	Methodology Description Study	United Kingdom and Netherlands	NA	NA	NA
Martillano et al (2022) (127)	NA	Mixed Methods (Methodology Description, Usability and Acceptability Study)	Philippines	1 COPD Patient **AND** 2 Healthy Subjects	NA	NA
Hawthorne et al (2022) (128,129)	Equivital EQ02 LifeMonitor	Prospective Cohort	United Kingdom	31 COPD Patients 84 COPD Patients	69 67.2	NA
Kuhn et al (2023) (130)	SIVA-P3	Validity Study	Switzerland	4 COPD Patients	50.3	NA

Table 4. Identified Devices Without Interventional Studies Published (exception of **Buekers et al** (65))		
Reference	**Device Name**	**Monitoring Class**
Device's Websites of Studies Included on Table 3		
Device Website (131)	Oxitone 1000M	Clinical Monitoring
Device Website (132)	Spire Health Tag	Clinical Monitoring
Device Website (133)	Airgo	Clinical Monitoring
Device Website (134)	WearMe System	Clinical Monitoring
Device Website (135)	Equivital EQ02 LifeMonitor	Clinical Monitoring
Device Website (136)	SIVA-P3	Clinical Monitoring
Devices Not Included on Table 3		
Randomized Controlled Trial Protocol NCT03857061 (137)	Samsung Gear Smartwatch	Wellness Monitoring
Randomized Controlled Trial Protocol NCT05756075 (138)	Verify Study Watch	Wellness Monitoring
Methodological Validation Study Buekers et al (65)	Polar RS800CX Belt **AND** METAMAX 3B	Clinical Monitoring
Randomized Controlled Trial Protocol NCT05745155 (139)	Senti-Wear	Clinical Monitoring
Study Protocol Brunschwiler et al (140)	Biovotion Everion	Clinical Monitoring
Device Website (141)	Cossinuss OxMotion	Clinical Monitoring
Device Website (142)	Current Health	Clinical Monitoring
Device Website (143)	Adamm RSM	Clinical Monitoring

4.3. Wellness Devices

4.3.1. Device Description

Table 5 describes in detail the 30 unique wellness devices identified in the included references. Regarding the monitoring aim, 22 interventions aimed to monitor the patient's physical activity, 5 utilised wearable devices as a complementary tool for COPD telerehabilitation to assess patient compliance with prescribed activity routines and 4 interventions aimed to predict exacerbation events.

As for the intervention components, 13 required additional data collection devices (3 utilising one wearable with 2 simultaneous sensors, 3 utilising two different wearable devices and 7 utilising non-wearable devices). Additional required non-wearable devices ranged from 1 to 5 gadgets, with the most common one (N=4) utilised being a finger pulse oximeter, followed by handheld spirometers (N= 2). Home activity sensors, a blood pressure cuff, a digital weighing scale, an electronic inhaler with an add-on sensor and a home deployed air quality sensing device were also reported in one intervention each. 12 interventions utilised an external data access device, most commonly a smartphone (N= 9), but with a computer (N= 2) and a tablet (N= 1) also being reported. Thus, regarding data collection, 18 interventions utilised a single device approach.

Regarding unique device types, all corresponded to wearable accessories, the majority (N= 13) corresponded to accelerometers (9 triaxial), followed by pedometers (N= 5), smartwatches and bands (N= 6 each) and 1 inclinometer. The preferred device wearing location was the upper body (N= 15), with 12 interventions adopting a wrist location and 3 opting for the upper arm. As for lower body locations, 4 interventions utilised the device on the waist, 2 on the hip and 1 attached to the shoe. Additionally, 1 intervention utilised a different location during the day (on the hip) and at night (on the chest) and 4 devices utilising multiple locations in simultaneous.

4.3.2. Data Parameters Collected

Wellness devices collected parameter can also be assessed in **Table 5**. In relation to the data parameters collected, the amount of monitored parameters ranged from 1 single parameter to 6 simultaneous measurements. Physical activity (PA) data regarded 13 different parameters. Strict PA parameters included activity duration (N=10), activity intensity (N= 7), activity level (N=5) and 2 had tailored parameters (one assessed the ratio of energy expended in physical activity to resting metabolism and one considered activity quality). Regarding other PA parameters, 19 accounted for steps count, 5 for energy expenditure, 5 for postural changes (with 2 considering time spent in each position), 3 for

Table 5. Wellness Devices Description and Monitoring Parameters. PA – Physical Activity; **PAM Points – PAM-score (ratio PA energy expenditure/resting metabolism); **(Only 154 of the COPD Patients); NA – Not Available; *Subtypes are considered, as all devices belong to the accessory type

Device (Reference)	Monitoring Aim	Devices Overview	Device Subtypes*	Wearing Location	PA and *Other* Parameters
RT3 Accelerometer	Telerehabilitation	Wearable Device	Accelerometer	NA	Activity Level (Daily)
Actihealth	PA Monitoring	Wearable Device	Accelerometer	Shoe-Attached	Steps Count Walking Speed
Digiwalker SW-2000	PA Monitoring	Wearable Device	Pedometer	NA	Steps Count (Daily)
Actimarker	PA Monitoring	Wearable Device	Triaxial Accelerometer	Waist	Activity Intensity Activity Duration
MTx-W Sensor	PA Monitoring	Wearable Device *Data Viewing* Smartphone (App)	Triaxial Accelerometer	Waist	Activity Duration (Hourly/Daily)
A-MES™	PA Monitoring	Wearable Device (2 Simultaneous Sensors)	Triaxial Accelerometer	Hip *(Pocket Sensor)* **AND** Chest *(Pocket Sensor)*	Postural Changes Time in Each Postural Position Activity Duration (Continuous/Total) Walking Speed
Fitbit One	PA Monitoring	Wearable Device *Data Viewing* Computer (Web-based App)	Band	Wrist	Steps Count (Hourly)
SenseWear Pro3 Armband	PA Monitoring	Wearable Device *Non-Wearable Device* Handheld Spirometer	Band	Upper Arm *(Right)*	Steps Count Activity Intensity (Sedentary/Moderate-Vigorous Behaviour) Energy Expenditure Activity Duration
bioPlux Motion™	PA Monitoring	Wearable Device *Non-Wearable Device* Finger Pulse Oximeter *Data Viewing* Smartphone (App)	Accelerometer	Wrist	Activity Level (Daily) *Sleep Pattern*
Fitbit Ultra[1] **OR** PAM AM300[2]	PA Monitoring	Wearable Device (One of the options)	Triaxial Accelerometers	Hip *(Right)*	Energy Expenditure[1] Steps Count[1] Climbed Stairs Count[1] PAM Points**[2]

ACOR+™ Actimeter	PA Monitoring	Wearable Device	Triaxial Accelerometer	*During the Day* Hip *(Belt Clip)* *At night* Over the sternum *(Chesband)*	Steps Count Postural Changes
PAM AM300	PA Monitoring	Wearable Device	Triaxial Accelerometer	Waist	Activity Intensity (Daily) (Light/Moderate/Vigorous Behaviour) Activity Duration (Daily)
Kens Lifecorder EX[1] **AND** A-MES™[2]	Telerehabilitation	2 Wearable Devices (One of which requires 2 simultaneous sensors)	Pedometer[1] **AND** Triaxial Accelerometer[2]	Waist[1] **AND** Hip *(Pocket Sensor)*[2] **AND** Chest *(Pocket Sensor)*[2]	Steps Count[1] Energy Expenditure[1] Postural Changes[2] Time in Each Postural Position[2] Activity Duration (Continuous/Total)[2] Walking Speed[2]
Tanita PD724	Telerehabilitation	Wearable Device	Triaxial Pedometer	NA	Steps Count (Daily)
Omron HJ-720 ITC	Telerehabilitation	Wearable Device *Data Viewing* Computer (Web-based App)**	Pedometer	Waist	Steps Count (Daily)
MOX Activity Monitor	PA Monitoring	Wearable Device (2 Simultaneous Sensors) *Data Viewing* Smartphone (App)	Accelerometer	Hip	Moderate-Intense Walking Duration (Daily)
SenseWear Pro3 Armband	PA Monitoring	Wearable Device	Band	Upper Arm	Activity Level (Daily)
SenseWear Pro3 Armband[1] **AND** Actigraph GT3X+[2]	PA Monitoring	2 Simultaneous Wearable Devices	Armband[1] **AND** Triaxial Accelerometer[2]	Upper Arm (Dominant)[1] **AND** Right Hip (Waistband)[2]	Sedentary Time[1] Steps Count[1, 2] Postural Changes[1] *Sleep Activity*[1]
Yamax Digi-walker CW700	Telerehabilitation	Wearable Device (2 Simultaneous Sensors)	Pedometer	NA	Steps Count (Daily)
Link Mobile	PA Monitoring	Wearable Device *Non-Wearable Devices* Home Activity Sensors Blood Pressure Cuff	Band	Wrist	Physical Activity Level

		Digital Weighing Scale Finger Pulse Oximeter Handheld Spirometer *Data Viewing* Tablet (App)			
LG Watch Urbane W150 **OR** Moto 360 2nd Generation	Exacerbation Prediction	Wearable Device (One of the options) *Data Viewing* Smartphone (App)	Smartwatches	Wrist	Activity Intensity (Sedentary/Moderate-Vigorous Behaviour) Activity Duration *Heart Rate*
LUMO[1] **AND** ActiGraph wGT3X-BT[2]	PA Monitoring	2 Simultaneous Wearable Devices *Data Viewing* Smartphone (App)	Inclinometer **AND** Triaxial Accelerometer	Waist[1] **AND** Hip (Right Anterior)[2]	Steps Count (Daily) Activity Intensity (Sedentary/Moderate-Vigorous Behaviour)
GeneActiv	Exacerbation Prediction	Wearable Device	Accelerometer	Wrist	Quality of Activity Level (Activity Quantity/Activity Regularity) *Sleep Pattern*
Actigraph GT9X **OR** Actigraph wGT3X-BT	PA Monitoring	Wearable Device (One of the options) *Non-Wearable Device* Electronic Inhaler with Add-on Sensor *Data Viewing* Smartphone (App)	Triaxial Accelerometers	Wrist	Steps Count Energy Expenditure Activity Duration
SenseWear Armband	PA Monitoring	Wearable Device *Non-Wearable Device* Finger Pulse Oximeter	Band	Upper Arm (Left)	Activity Intensity (Rest/Light/Moderate/Vigorous Behaviour) Steps Count *Sleep Pattern* *Total Night Sleeping Time* *Wake Time After Sleep Onset* *Sleep Efficiency*
ActiGraph wGT3X-BT	PA Monitoring	Wearable Device	Triaxial Accelerometer	Wrist (Non-Dominant)	Sedentary Time Activity Intensity *Sleep Activity* *Sleep Duration*
Fitbit Versa	Exacerbation Predication	Wearable Device *Non-Wearable Device* Air Quality Sensing Device	Smartwatch	Wrist	Steps Count Climbed Stairs Count Walking Distance Energy Expenditure

		Data Viewing Smartphone (App)			*Heart Rate Variability* *Sleep Pattern*
Garmin Vivofit	PA Monitoring	Wearable Device *Non-Wearable Device* Finger Pulse Oximeter	Band	Wrist	Steps Count (Daily)
Samsung Galaxy Watch	Exacerbation Prediction	Wearable Device *Data Viewing* Smartphone (App)	Smartwatch	Wrist	Steps Count Activity Duration *Heart Rate Variability*
Samsung Gear Smartwatch	PA Monitoring	Wearable Device *Data Viewing* Smartphone (App)	Smartwatch	Wrist	HR Steps Count *Surrounding Audio*
Verily Study Watch	PA Monitoring	Wearable Device	Smartwatch	Wrist	HR Steps Count *(Daily)* *Movement Detection*

walking speed, 2 for stairs climbed, 2 for sedentary time spent, and 1 for walking distance. 10 interventions collected information other than PA activity related data, including sleep pattern and respective characteristics (N= 6), hear rate variability (N= 2), heart rate (N= 1), surrounding audio, and movement detection (N= 1 each).

4.4. Clinical Monitoring Devices

4.4.1. Device Description

Table 6 contains all the assessed clinical monitoring devices, with publicated studies, grouped by development stages identified. In the concept phase, regarding devices still in a theoretical stage, not yet in development, we identified 3 devices; in the healthy subjects testing phase, that is, not yet tested in sufficient COPD patients, we identified 4 devices; in the clinical testing phase, relating to mature COPD testing, we identified the majority (N= 8), of the devices; and the remaining (N= 4) were considered to belong to the certified phase, corresponding to European (CE Mark) or American (FDA Approval) approved devices.

Relating to the monitoring aim, 8 devices were designed for baseline monitoring (i.e., limited to data parameters assessment, not capable of predicting exacerbations through inbuilt algorithms), 7 devices were able to predict exacerbations in advance in addition to baseline monitoring, 2 devices were used exclusively for telerehabilitation sessions patient monitoring, 1 device aimed to assist with outpatient management by allowing early dischargement to diminish hospitalization days, 1 device aimed to conciliate telerehabilitation session monitoring with baseline patient monitoring and 1 device associated earlier hospital dischargement with exacerbation prediction.

As for the device type and composition, the majority (N= 9) were accessories (7 bands, 1 face mask and 1 necklace), 6 belonged to the clothing class as vests, and 4 were attached sensors, 2 to the skin and 2 to the patient's garments. 13 interventions utilised a single device and the remaining required from 1 (N= 3) to 2 (N= 1) additional mandatory non-wearable devices, corresponding to a finger pulse oximeter (N= 3), an environmental sensor or a motion-sensing stereo-camera system (N= 1 each). 2 interventions allowed for optional non-wearable devices connection, 1 allowed to connect a finger pulse oximeter and, the other, 1 portable spirometer and 4 non-wearable devices for comorbidity management.

Regarding wearing location, 7 devices adopted a torso location and 4 a chest location, 2 were placed on the forehead as bands, 2 were wrist accessories, 1 was used on the upper abdomen and 1 covering the mouth and the nose. 2 devices required the usage of 2 simultaneous

Table 6. Clinical Monitoring Devices Description. HR– Heart Rate**;** NA – Not Available

Device	Monitoring Aim	Overview	Device Type	Location	Duration
Concept Phase					
Rajasekaran's Device	Telerehabilitation (+ Baseline Monitoring)	Wearable Device (2 simultaneous sensors)	Skin-Attached Sensors	Armpit (Temperature Sensor) Earlobe/Toe (HR Sensor)	NA
HealthWear@AAL	Exacerbation Prediction	Wearable Device	**Clothing** Vest	Torso	NA
Tey's Device	Telerehabilitation	Wearable Device *Required Non-Wearable Device* Motion-Sensing Stereo-Camera System	**Accessory** Band	Forehead	NA
Healthy Subjects Testing Phase					
S-Mask	Baseline Monitoring	Wearable Device	**Accessory** Band	Forehead	NA
De Fazio's Device	Baseline Monitoring	Wearable Device (2 simultaneous sensors)	**Accessory** Band	Chest and back (1 sensor on each location)	NA
WearMe System	Exacerbation Prediction	Wearable Device (Optionally more than 1 sensor)	Fabric-Attached Sensor *(Designated Shirt / Chestband)*	Chest	NA
Martillano's Device	Exacerbation Prediction	Wearable Device	**Accessory** Face Mask	Over the Mouth and Nose	NA
Clinical Testing Phase					
Healthwear System	Early Discharge Management	Wearable Device *Optional Non-Wearable Device* Finger Pulse Oximeter	**Clothing** Vest	Torso	4 Hours
CHRONIOUS System	Exacerbation Prediction	Wearable Device	**Clothing** Vest	Torso	
ASTRI Telecare System	Baseline Monitoring	Wearable Device *Required Non-Wearable Device* Finger Pulse Oximter	**Accessory** Band	Chest	NA

SweetAge System	Exacerbation Prediction	Wearable Device *Required Non-Wearable Device* Finger Pulse Oximeter	**Accessory** Band	Wrist	NA
WELCOME System	Exacerbation Prediction	Wearable Device *Optional Non-Wearable Device* Portable Spirometer Blood Pressure Cuff Glucometer Digital Thermometer Digital Weighing Scale	**Clothing** Vest	Torso	
L.I.F.E.'s Medical Compression Garment	Baseline Monitoring	Wearable Device	**Clothing** Vest	Torso	NA
Respeck Monitor	Telerehabilitation	Wearable Device	Skin-Attached Sensor	Chest	4-6 Months
SIVA-P3	Baseline Monitoring	Wearable Device	**Accessory** Necklace	Chest (Between 2 clothing layers)	NA
Certified Phase					
Oxitone 1000M *(FDA-Cleared and CE Mark Certified)*	Baseline Monitoring	Wearable Device	**Accessory** Band	Wrist	Up to 24 Hours
Spire Health Tag *(FDA-Cleared)*	Baseline Monitoring	Wearable Device	Fabric-Attached Sensor	Waist *(Underwear – Men/Women)* Chest *(Bra Wing – Women)*	1600 Hours *(per sensor)* 15.8 Months *(pack of 8 sensors)* *Active Use*
Airgo *(CE Class IIa)*	Exacerbation Prediction	Wearable Device *Required Non-Wearable Devices* Finger Pulse Oximeter Environmental Sensor	**Accessory** Band	Upper Abdomen *(Over Clothing)*	3 Weeks
Equivital EQ02 LifeMonitor *(FDA Class II and CE Class IIb)*	Early Discharge Management Exacerbation Prediction	Wearable Device	**Clothing** Vest	Torso	48h

Table 7. Clinical Monitoring Devices Parameters Collected. ECG- Electrocardiogram

Device	Validated Data				Other Data		
	SpO_2	**$SpCO_2$**	**Heart Rate (HR)**	**Respiratory Rate (RR)**	**Clinical**	**Lifestyle**	**Environmental**
Concept Phase							
Rajasekaran's Device	-	-	✓	-	Skin Temperature	Postural Changes	-
HealthWear@AAL	✓	-	✓	✓	Skin Temperature Blood Pressure Body Weight	Movement Physical Activity Level	-
Tey's Device	-	-	✓	✓	-	-	-
Healthy Subjects Testing Phase							
S-Mask	-	-	-	✓	Respiration Details *Respiratory Pattern*	-	-
De Fazio's Device	-	-	-	✓	Respiration Details *Inspiration/Expiration Times* *Inspiration-Expiration Ratio* *Tidal Volume* *Flow Rate*	-	-
WearMe System	-	-	✓	-	Skin Temperature ECG Lung Auscultation Sounds	Physical Activity Level Postural Changes	-
Martillano's Device	-	-	-	✓	Respiration Details *Inspiration-Expiration Ratio*	-	-
Clinical Testing Phase							
Healthwear System	-	-	✓	✓	Skin Temperature 6-Lead ECG	Postural Changes	-
CHRONIOUS System	✓	-	-	✓	Skin Temperature 3-Lead ECG Respiration Details *Inspiration/Expiration Times* *Inspiration/Expiration Volumes* *Respiratory Amplitude*	Steps Count Postural Changes and Duration Fall Count	Environmental Noise Ambient Temperature Ambient Humidity

					Lung Auscultation Sounds Cough and Snoring Events		
ASTRI Telecare System	-	-	-	✓	-	-	-
SweetAge System	-	-	✓	-	Skin Temperature	Physical Activity Level	-
WELCOME System	✓	-	✓	✓	Respiration Details *Tidal Breathing Period* Lung Auscultation Sounds *(Crackles, Rhonchi or Wheezing)* Cough Events Electric Impedance Tomography (EIT)	Postural Changes Physical Activity Level	-
L.I.F.E.'s Medical Compression Garment	-	-	-	✓	12-Lead ECG Respiration Details *Respiratory Waveform* *Tidal Breathing Period*	Postural Changes	-
Respeck Monitor	-	-	-	✓	Respiration Details *Respiratory Effort*	Physical Activity Intensity Exercise Resting Period	-
SIVA-P3	-	-	-	-	Cough Events	-	-
Certified Phase							
Oxitone 1000M	✓	-	✓ (Variability)	*(Future Development)*	Skin Temperature	Steps Count Fall Count *(Future Development)*	-
Spire Health Tag	-	-	✓	✓	Respiration Details *Respiratory Waveform* *Inspiratory/Expiratory Times* *Inspiratory-Expiratory Ratio*	Steps Count Sleep Analysis Calories Burned	-
Airgo	-	-	-	✓	Respiration Details *Tidal Volume* *Minute Ventilation* *Inspiratory/Expiratory Times* *Duty Cycle* *Functional Residual Capacity* *Respiratory Patterns (Cheyne-Stokes, Kussmaul, Apnoea)*	Postural Changes (11 Positions Detection)	-
Equivital EQ02 LifeMonitor	-	-	✓	✓	Skin Temperature ECG	Physical Activity Level Postural Changes	-

sensors, one utilising a chest and back sensors and the other an armpit and an earlobe or toe sensors. Lastly, for device duration, only 6 devices provided information regarding its usage span, ranging from 4h to 4-6 months.

4.4.2. Data Parameters Collected

Table 7 indicates the data parameters collected by each device which were grouped by GOLD validated data utilised for COPD exacerbation assessment and other data collected. The most commonly validated assessed vital was respiratory rate (RR), with all but 5 devices measuring it (of which one is aiming to introduce as a feature), followed by heart rate (HR), assessed by 10 devices (one measuring its variability), whilst only 4 devices measured the peripheral oxygen saturation (SpO_2) in a non-disruptive manner. No device assessed the peripheral carbon dioxide saturation ($SpCO_2$).

Regarding other types of data collected, 35 different features were reported (22 clinical, 10 lifestyle and 3 environmental parameters). Additional clinical data collected ranged from none to 8 concurrent vitals. Respiration details, encompassing 13 different measurements, were the most commonly evaluated (N= 9), followed by skin temperature (N= 8), ECG (N= 5), ranging from 3 to 12 leads (2 didn't report how many leads were assessed), lung auscultation sounds (N = 3), cough events count (N= 3), and blood pressure, body weight, falls and snoring events count, and electrical impedance tomography (N= 1 each). Lifestyle data included postural changes (N= 8) and duration of each posture (N= 1), physical activity related measurements (N= 6), steps count (N= 3), and movement detection, resting period, sleep analysis and calories burned (N= 1 each). Only 1 device registered environmental data.

4.4.3. Data Management: Technical Considerations

Table 8 details all the components of each device in addition to an extensive technical and clinical overview of collected data, healthcare professionals (HCPs) and patient management.

Concerning the technical aspects of each device, only 5 devices detailed information on all parameters assessed (data collection, processing, transmission, and analysis).

Data collection procedure was reported by 15 devices, with 12 providing information on parameters assessment rate: 5 claimed continuous data collection and 4 an intermittent collection approach (ranging from every 12 seconds to 3 times per weekday and no reporting on the weekend), 1 referred a continuous or intermittent collection rate, without further detailing the preferred modality, 1 required the patient's manual input through a companion

smartphone application to assess his vitals and 1 adopting a continuous assessment rate during exercise and an intermittent rate when at rest.

Regarding data processing, all the 13 devices reporting its procedure used a local processing unit (i.e., processing before data transmission elsewhere).

As for data transmission, all but 2 devices reported details on its realization. Only 5 devices had a direct connection with a central server, whilst 9 devices required an intermediate device to further transmit the collected data. Additionally, 3 devices only mentioned data transfer to a local interface, without detailing further transmission details. 14 devices further indicated their communication protocol: of the direct communication devices, 2 utilised Wi-Fi and 2 utilised General Packet Radio Service (GPRS), and in the intermediate device group, for the first stage communication, 5 utilised Bluetooth transmission (Bluetooth Low Energy (BLE) = 1 and Class 1 Bluetooth = 1) and 1 short- range wi-fi, and for the second stage transmission, internet connection was the preferred method (N= 7), of which 1 utilised a 5Ghz connection and the remaining opted for older generations Wi-Fi or mobile connections.

Lastly, regarding data analysis, 5 devices didn't report how data was assessed for vitals monitoring. As for the remaining devices, 10 utilised automation tools for data analysis through inbuilt algorithms and 4 required manual analysis by respiratory care professionals or intermediate call centres that further communicated any vital deviations to the healthcare professionals.

4.4.4. Data Management: Clinical Considerations

In relation to healthcare professionals' notification and data access and patient management, 14 devices described both in conjunction and 2 devices only reported one of either. Automatic HCP alert receival was mentioned by 8 devices with the others requiring data analysis by the HCP through graphical display access. As for patient management, 13 interventions provided direct access to collected data and 2 interventions only prompted the patient for eventual abnormalities. Most interventions provided additional features regarding patient and HCP management, as thoroughly described on table 7.

Table 8. Clinical Monitoring Devices Set-Up Description. COPD- Chronic Obstructive Pulmonary Disease; CAT - COPD Assessment Test; FSS- Fatigue Severity Scale; MMRC dyspnoea scale- Modified Medical Research Council Dyspnea Scale; EHR- Electronic Health Record; HCP- Health Care Professional; NA – Not Available; DSS– Decision Support System; PPG– Photoplethysmogram; BLE- Bluetooth Low Energy**;** IMUs- Inertial Measurement Units; RR– Respiratory Rate; SNR– Signal-to-Noise Ratio**;** ECG– Electrocardiogram; PPU– Portable Patient Unit; PDA– Personal Digit Assistant; GPRS- General Packet Radio Service; ADSL- Asymmetric Digital Subscriber Line**;** HPMU**-** Hybrid Power Management Units; RMS- Remote Monitoring System**;** EIT- Electrical Impedance Tomography; SpO2- Oxygen saturation; PA- Physical Activity**;** HR– Heart Rate**;** GOLD– Global Initiative for Chronic Obstructive Lung Disease; ID- Identification

Device	Components	Technical Overview	Clinical Overview
		Concept Phase	
Rajasekaran's Device	***Data Collection and Management*** 1. Sensing Module a. Heart Rate Sensor b. Temperature Sensor c. Inbuilt biaxial accelerometer d. Amplifier box e. Ear clip 2. Patient Station 3. Central Cloud Server ***Data Access*** PDA/Mobile Phone (Web-based Portal)	***Data Processing*** *First Stage (Preprocessing)* – Sensing Module *Second Stage* – Patient Station Collected data integration via an aggregation node; redundant data removal through an inbuilt software ***Data Transmission*** *Connection* – Wi-Fi (2.4GHz) (From the Patient Station to the Central Cloud Server) Processed critical vitals deviations data sending for further cloud server storage ***Data Analysis*** *Component – Patient Station* *Threshold-based algorithm* –Critical vitals' abnormalities identification based on time-series analysis *Inactivity detection algorithm* –Patient movement analysis Upon critical event algorithm identification, HCP alert generation	***HCPs Management*** *Interface* – PDA/Mobile Phone (Web-based Portal) *Rate* – Real time access to data collected *Features* – Graphical data view (historical view); Information sharing between multiple parties; vitals deviation alert receival **Patient Management** NA
HealthWear@AAL	***Data Collection and Management*** 1. Sensing Module (Fabric-Embedded Sensors) 2. Control and Computing Unit ***Data Access*** Control and Computing Unit	***Data Collection*** *Rate* – Continuous OR Intermittent ***Data Processing*** *Component* – Control and Computing Unit ***Data Analysis*** *Component* – Control and Computing Unit Collected data and individualised DSS data (containing patient's health characteristics, a Medical Knowledge Base containing patient medical background and COPD guidelines) integration; vitals' deviation analysis in real time using stored sensor data as a baseline; event severity assessment as critical or uncritical	***HCPs Management*** *Interface* – NA *Rate* – Real time access to data collected *Features* – Continuously update the Medical Knowledge Base; Improve the DSS event recognition through feedback provision; alarm notification receival via SMS ***Patient Management*** *Interface* – Control and Computing Unit *Features* – Graphical data view (historical view); symptom, medication, and overall health status questionnaires filling; alarm receival
Tey's Device	***Data Collection and Management*** 1. Sensing Module a. Pulse Oximetry Sensor b. Microprocessor c. Bluetooth Transmitter	***Data Collection*** *Component* – Pulse oximeter Collects the Photoplethysmogram (PPG) signal ***Data Transmission*** *Connection* – Bluetooth (From the Bluetooth Transmitter to the	***HCPs Management*** *Interface* – Computer (Web-based App) *Rate* – Real time access to data collected *Features* – Graphical data view of both collected data and pulmonary rehabilitation exercise programs; exercise program creation

	Data Access Computer (Web-based Portal)	patient's computer) NA (From the patient's computer to the HCPs' computer) ***Data Analysis*** *Preprocessing* –Received PPG signal noise reduction filtering and peak detection algorithm appliance *Second Stage* – Waveform peak-to-peak analysis	***Patient Management*** *Interface* – Computer (Web-based Portal) *Features* – Rehabilitation exercises prescription and results access; collected data display
		Healthy Subjects Testing Phase	
S-Mask	***Data Collection and Management*** 1. Sensing Module (Face Mask adapted from a nebulization mask with its inlet removed) a. Piezoelectric sensor (parallel to the inlet opening close to the nostrils) 2. Signal Conditioning Unit 3. Microcontroller Transceiver Unit	***Data Processing*** *Component* – Signal Conditioning Unit Amplifier appliance and low-pass filtering provides gain and filters out surrounding noise *Component* – Microcontroller Transceiver Unit Filtered signal digitization by an analog-to-digital converter ***Data Transmission*** *Rate* – Continuous *Connection* – NA (From the Microcontroller Transceiver Unit to the desired interface)	NA
De Fazio's Device	***Data Collection and Management*** 1. Sensing Module (elastic band with 2 custom-made housing units) a. 2 Inertial Measurement Units a1. Triaxial accelerometer a2. Triaxial gyroscope a3. Digital Motion Processor b. Electronic Processing Module b1. Microcontroller Board b2. Microcontroller b3. Bluetooth Low Energy (BLE) Module c. Single-Cell Lithium Battery 2. Electrical cable connecting back and chest IMUs ***Data Access*** Smartphone (App)	***Data Processing*** *Component* – Electronic Processing Module *Completion Time* – 30 s *Preprocessing* – Respiratory waveform isolation via differential acceleration between the 2 IMUs collected data *Processing* – Residual motion artifacts elimination by low-pass filtering; RR determination via a peak detection algorithm *Tidal Volume Calculation* – Using user's height and ideal body weight *Flow Rate Calculation* – Using the ratio of the air volume during each respiratory cycle to the inhalation time ***Data Transmission*** *Connection* – BLE (From the device to the Smartphone) Upon data transfer, stored data is cleared and a new time window is started	NA
WearMe System	***Data Collection and Management*** 1. Sensing Module a. Digital Stethoscope b. ECG Monitor c. Temperature Sensor d. Goniometer ***Data Access*** Smartphone (App)	***Data Collection*** Signal-to-Noise Ratio (SNR) (combination of surrounding noise and airflow obstruction noise) collection via the stethoscope acoustic sensors ***Data Processing*** *Component* – Sensing Module SNR processing for breathing intensity assessment	***HCPs Management*** NA ***Patient Management*** *Interface* – Smartphone (App) *Features* – Multiple sensors configuration; collected data display; exercise tracking; direct communication with HCPs

Martillano's Device	***Data Collection and Management*** 1. Sensing Module a. Oxygen-based Wearable Mask b. Temperature Sensor (tubing area) c. Microcontroller (Dedicated IoT WIFI device) d. Powerbank 2. Central Cloud Server (Web API) ***Data Access*** Smartphone (x-Hale Mobile App)	***Data Collection*** Exhaled air and ambient temperatures collection; data collection is manual, requiring the patient's manual input using the app (1min25s for complete collection) ***Data Processing*** *Component* – Microcontroller Inhalation and exhalation periods identification by a breathing pattern recognition algorithm (one breath count for each temperature change) ***Data Transmission*** *Connection* – Wi-Fi (HTTP) (From the device to the Cloud Server) The Web API controls data traffic by providing a response for each HTTP request and storing the data	***HCPs Management*** *Interface* – Smartphone (x-Hale Mobile App) *Features* – Patient listing; patient health records; feedback provision option for breathing analysis; notification automation management ***Patient Management*** *Interface* – Smartphone (x-Hale Mobile App) *Features* – Graphical data view (historical view); HCPs analysis receival; notification management Upon manual data collection, a pop-up displays a general breathing analysis, later evaluated by the HCP
		Clinical Testing Phase	
Healthwear System	***Data Collection and Management*** 1. Sensing Module (Sensor Embedded Vest) a. 6 ECG hydro gel membrane electrodes b. 1-4 I2C skin temperature sensors c. 3D Accelerometer d. 4 Piezo-Resistive Strain Sensors 2. Patient Unit a. 2 LEDs and 1 buzzer b. External port for optional non-wearable connection 3. Remote Monitoring Centre ***Data Access*** a. Mobile Phone (App) b. Computer (Web-based Portal) c. Personal Digit Assistant (PDA)	***Data Collection*** *Rate* – Continuous (ECG signal – 250Hz Sampling Rate) ***Data Processing*** *Component* –Patient Unit Highest sampling rate parameters extraction by an inbuilt algorithm ***Data Transmission*** *Connection* – GPRS (From the Patient Unit to the Remote Monitoring Centre) Only one ECG lead is transmitted at a time ***Data Analysis*** *Component* – Remote Monitoring Centre Generated alerts analysis using patient's past medical data, adjudicating the alerts as true or false; if deviation detection, HCPs contacting via phone calls/online alerts**;** Transmitted ECG lead selection; Data storage in individualised electronical health records	***HCPs Management*** *Interface* – Personal/Hospital Computer / PDA (Web-based Portal) *Features* – Graphical data view; critical health alerts receival ***Patient Management*** *Interface* – Patient Unit Critical health alerts receival visually or in an audio manner through the LED's/buzzer; HCP alert upon sudden health deterioration or to initiate a signal transmission
CHRONIOUS System	***Data Collection and Management*** 1a. Sensing Module a. Wearable vest a1. 4 Dry ECG electrodes a2. Pulse oximeter a3. 1 Internal Temperature sensor a4. 1 External Temperature and Humidity Sensor a5. Context-Audio Microphone Sensor a6. 2 Respiration bands (1 thoracic, 1 abdominal) a7. 1 Accelerometer 2. Data Handler (on the vest's side	***Data Processing*** *Component* – Data Handler *Real-time Preprocessing* – Signal denoising; cough and motion events identification; feature extraction *Processing* – Wearable and non-wearable collected data integration; redundant data removal and missing values replacement algorithms ***Data Transmission*** *Connection* – Bluetooth (From the Data Handler to the PDA) Home ADSL connection (From the PDA to the Central Server)* Forced synchronization – Upon vitals abnormalities or threshold surpassing identification by the DSS Regular transmission – If no abnormalities are identified, processed data and the DSS output are stored at the Central Server	***HCPs Management*** *Interface* – Computer (Web-based App) *Features* – Graphical data display (historical view); Alarm receival; Action recommendation receival; Central and PDA DSSs' knowledge database update capability; access to patients' nutritional planners, medication intake management ***Patient Management*** *Interface* – HPMU (Larger display of PDA data) *Features* – Daily vitals measurements and activities schedule display; Food and medication

	cradle) 1b. *Non-Wearable Devices* (Portable Spirometer, Home environmental sensor, Digital Scale, Blood Pressure Cuff, Glucometer) 4. PDA 5. Central Server ***Data Access*** 1. Computer (Web-based App) 2. Home Patient Monitoring Unit (HPMU) 3. PDA	***Data Analysis*** *Component* – PDA (Local DSS) Collected and stored data integration; Exacerbation recognition according to predefined critical vitals thresholds; Event severity assessment via HCP defined threshold vitals values and respective weight of deviation; Alert generation and transmission upon threshold surpassing *Component* – Central Server (Central DSS) Transmitted and patient's historical health data integration with disease guidelines and past HCPs' input; an e-diary card maps deviated values, comparing its sum with individualised baseline values; for lower increases, a recommended action is provided to the patient; for higher increases, additional HCP alert generation occurs; alerts follow a traffic light system according to the severity	intake, lifestyle habits and mental status questionnaire filling
ASTRI Telecare System	***Data Collection and Management*** 1. Sensing Module 2. Central Cloud Server 3. Remote Monitoring Centre ***Data Access*** 1. Mobile Phone 2. Computer (Web-based App)	***Data Collection*** *Rate* – 3 Times a Day (Monday-Friday) ***Data Transmission*** *Rate* – 3 Times a Day (Monday-Friday) *Connection* – GPRS (From the mobile phone to the remote monitoring centre) ***Data Analysis*** *Components* – Remote Monitoring Centre Vitals monitoring by community nursers	***HCPs Management*** *Interface* – Web-based app *Features* – Data display via individualised health databases ***Patient Management*** *Interface* – Mobile Phone *Features* – Data display (historical view); emergency contact services through a designated phone button
SweetAge System	***Data Collection and Management*** 1. Sensing Module a. Bluetooth Transmitter b. Commercial Finger Pulse Oximeter 2. Remote Monitoring Centre ***Data Access*** 1. Mobile Phone (App) 2. Computer (Web-based App)	***Data Collection*** *Rate* – 5 Measurements every 3 Hours ***Data Transmission*** *Connection* – Bluetooth (From the device to the Mobile Phone) NA (From the Mobile Phone to the RMS) ***Data Analysis*** Daily evaluation by a respiratory care HCP Alert generation upon individualised vitals threshold exceeding	***HCPs Management*** *Interface* – Computer (Web-based App) *Features* – Generated alerts receival; data view (historical view); individualised thresholds customisation ***Patient Management*** *Interface* – Mobile Phone (App) *Features* – Data access in real time Upon alert generation, contacted by the HCP to check for new/worsening symptoms and therapy adherence
WELCOME System	***Data Collection and Management*** 1a. Sensing Module a1. 25 signal emitting sensors (type I) a2. 25 ECG measuring sensors (type V) a3. Reference sensor 1b. *Optional Non-wearable Devices* b1. Glucometer b2. Digital Weighing Scale b3. Blood Pressure Cuff b4. Electronic Inhaler (with an add-on	***Data Collection*** *Type I sensors* – Baseline current injection at a different frequency for each signal *Type V sensors* –ECG, EIT and chest sounds signals (voltages) measurement ***Data Processing*** Reference sensor –SpO_2 and physical activity measurement; type I and type V sensors synchronisation; received signals digitisation and time synchronisation; measured voltages storage or transmission; HR and RR extraction	***HCPs Management*** *Interface* – Computer (Web-based Portal) *Features* – Graphical data display (historical view); alarms receival; vitals trend plotting; direct and continuous imaging of the chest; Patient Hub App update options ***Patient Management*** *Interface* – Tablet (Android App) *Features* – Single Page Application layout; Data display; Lifestyle, physical and mental well-being, and weather forecast modules; CAT, FSS

	audio sensor) 2. Central Cloud Server ***Data Access*** 1. Tablet (Android App – Patient Hub) 2. Computer (Web-based Portal)	Data anonymization and compression before transmission via a secure network to the Central Cloud Server ***Data Transmission*** *Rate* – Every 5 Minutes *Connection* – Short-range Wi-Fi (From the wearable to the Patient Hub) When recharging, the vest transmits the largest signals missing Wi-Fi (From the Patient Hub to the central cloud server) An orchestrator software coordinates communication between the system's components ***Data Analysis*** *Component* – Cloud Server Further data processing and feature extraction; DSS uses raw data, or cloud calculated features for comparison with stored individualised average values; integration with medication history, patient existing comorbidities, COPD guidelines, individualised GOLD stage and group class and patient questionnaires data for disease progression assessment; depending on the result, alarms, warnings or simple estimations regarding health status are generated and transmitted *Storage* – Collected vitals, historical patient clinical data, HCPs patient evaluation data and HCPs and patients app inputs	and mMRC questionnaire filling; alarms, recommendations and motivational cues receival; diary and medication schedule access
L.I.F.E.'s Medical Compression Garment	***Data Collection and Management*** 1. Sensing Module a. 12 ECG Ink-based dry electrodes (layer of electrodes with ink conductive particles connected to the processing module via a stitched connector) b. 5 respiratory strain sensors c. Accelerometer 2. Recording and Processing Module ***Data Access*** 1. Computer (Web-based Portal)	***Data Collection*** *Rate* – Continuous (50 Hz Sampling Rate) Respiratory sensors provide electrical resistance variations ***Data Processing*** *Component* – Recording and Processing Module Raw ECG and respiratory data extraction from a secure digital card ***Data Transmission*** *Connection* – NA (From the Processing Module to the Computer) ***Data Analysis*** Computer stored data manual analysis by two experts in cardiology and respiratory physiology	NA
Respeck Monitor	***Data Collection and Management*** 1. Sensor Module a. Triaxial Accelerometer b. Processor c. Bluetooth 4.0 Transmitter d. Battery 2. Central Cloud Server ***Data Access*** 1. Smartphone (Android Rehab App) 2. Computer (Web-based Portal)	***Data Collection*** *Rate* – Continuous RR elevation at each exercise's end and its rest recovery value detection through quiet breathing extraction ***Data Processing*** *Component* – Local Processor Quiet breathing of each exercise averaging for the entire PR session ***Data Transmission*** *Connection* – NA (From the device to the Smartphone) Wi-Fi/Mobile Connection (From the Smartphone to the central server) The wearable device is paired with the App via an unique personal ID	***HCPs Management*** *Interface* – Password-protected Web-based app *Rate* – Delayed manner *Features* – Data display of patient performance status (historical view) ***Patient Management*** *Interface* – Smartphone App *Features* – Exercise routine display access with visual animations and voice instructions; exercise validation and feedback receival; virtual pet aiming to ensure patient compliance as a

		ensuring anonymised sent data is tagged with the patient's ID during data transfer, storage and analysis ***Data Analysis*** Raw accelerometer data is analysed using machine learning techniques to recognise and validate the exercise prescription and execution for consecutive session evolution assessment	game-like feature with in-game currency obtained through exercise execution
SIVA-P3	***Data Collection and Management*** 1. Sensing Module 2. Central Cloud Server ***Data Access*** 1. Computer (Web-based Portal) 2. Smartphone (App)	***Data Collection*** *Rate* – Continuous Collection continues during nighttime, if kept by the bed's side ***Data Processing*** *Component* – Sensing Module *Preprocessing* – Via a cough detection algorithm (Only sound segments exceeding a specific loudness are stored as time-stamped cough events) ***Data Transmission*** *Rate* – Continuous *Connection* – NA (From the device to the cloud server) **Certified Phase**	***HCPs Management*** *Interface* – Web-based Portal *Features* – 1h segments graphical view of collected ***Patient Management*** *Interface* – Smartphone App *Features* – Cough events display; prompt receival to indicate daily meal timing (once in the evening)
Oxitone 1000M	***Data Collection and Management*** 1. Sensing Module 2. Cloud central server ***Data Access*** 1. Smartphone (App) 2. Computer (Web-based Portal)	***Data Collection*** *Rate* – Every 12 s ***Data Transmission*** *Connection* – BLE (From the device to the Smartphone) NA (From the smartphone's app to the cloud server) ***Data Analysis*** Data synchronization according to the Smartphone's clock providing 5 paired data points per minute	***HCPs Management*** *Interface* – Computer (Web-based App) *Rate* – Real time access to collected data *Features* – Graphical data display; AI enabled ***Patient Management*** *Interface* – Smartphone (App) *Features* – Data display
Spire Health Tag	***Data Collection and Management*** 1. Sensing Module a. Semi-Flexible Casing Module a1. Skin-facing hypoallergenic microfiber a2. Purpose-built force sensor a3. Microcontroller a4. 225mAh Lithium Battery a5. Adhesive b. PPG sensor b1. Triaxial Accelerometer b2. Force Sensor 2. Cloud Central Server ***Data Access*** 1. Computer (Web-based Portal) 2. Cellular-based home hub	***Data Collection*** *Rate* – Every 5 minutes (at rest) Continuous (during sustained PA) Continues night collection if a sensor is adhered to the sleep undergarment ***Data Transmission*** *Connection* – Bluetooth (From the wearable to the home hub) Mobile Connection (From the home hub the cloud server) An unique software-associated ID allows successive sensor automatic pairing with the app after the first sensor is connected. ***Data Analysis*** A notification algorithm detects sustained elevation of RR and HR or pre-defined threshold surpassing Low quality data is automatically excluded	***HCPs Management*** *Interface* – Computer (Web-based Portal) *Features* – Graphical data display; notifications receival; individualised thresholds management ***Patient Management*** *Interface* – Wearable device *Features* – (Optional) Vibration prompts for behavioural, breathing or technical abnormalities or positive feedback notification

Airgo	***Data Collection and Management*** 1. Sensing Module (AirGo Band) (electrically-conductive, elastomeric knitted matrix of nylon and spandex with a knitted-in silver coated yarn) a. Built-in microprocessor b. Triaxial accelerometer) 2. 5G Central Server ***Data Access*** 1. Tablet (iPad iOS App) 2. Computer (Web-based App)	***Data Collection*** *Rate* – Continuous (10Hz Sampling Rate) *Measurement* – Thoracic circumference as relative resistance changes ***Data Processing*** *Component* – Microprocessor An analog-to-digital converter converts the spontaneous resistance changes and integrates movement and postural orientation, from the accelerometer, augmenting breathing information ***Data Transmission*** *Outside* – Recorded and stored on the device *At home* – Bluetooth (From the device to the iPad) 5G Wi-Fi (From the iPad to the Central Server) ***Data Analysis*** Algorithm differentiates static and dynamic activities, and a threshold-based model is applied Collected data is integrated with the offline saved data for a more complete posterior analysis	***HCPs Management*** *Interface* – Computer (Web-based Portal) *Rate* – Real time access to collected data *Features* – Central server stored data view; vitals trend analytics; alert receival and AI aided diagnostic reports ***Patient Management*** *Interface* – Tablet (App) *Features* – Graphical data display
Equivital EQ02 LifeMonitor	***Data Collection and Management*** 1. Sensor Module (Biocompatible fabric sensor embedded vest) a. Inbuilt triaxial accelerometer b. Inbuilt ECG electrodes c. Inbuilt expansion belt d. Inbuilt infrared thermometer 2. Sensor Electronic Module (SEM) (On a vest side cradle) a. LEDs b. Lithium Polymer Battery c. 8 GB Memory Card ***Data Access*** 1. Smartphone (eqView Android App) 2. Computer (eqView Professional App)	***Data Collection*** *Rate* – Every 15 s ***Data Processing*** *Component* – Sensor Electronic Module Automatically time synchronisation and storage on the SEM ***Data Transmission*** *Rate* – Real time *Connection* – Class 1 Bluetooth (From SEM to the Smartphone) Wi-Fi (From the Smartphone to the Computer) ***Data Analysis*** *(a posteriori analysis)* Time series plots analysis to identify pre-exacerbation vitals' changes (at 3, 2 and 1 day prior the exacerbation) by calculating the percentage change to the first day of an exacerbation	***HCPs Management*** *Interface* – Computer (eqView Professional App*)* *Clinical Management* – Graphical data display ***Patient Management*** *Interface* – Smartphone (eqView Android App*)* *Features* – Real time data display (if SEM Bluetooth connection available)

4.5. Additional Clinical Monitoring Devices Identified

Table 9 includes the 6 additional clinical monitoring devices lacking sufficient information to include in the main clinical monitoring devices comparative table (except for Buekers et al, as addressed in **Section 4.2.**). All but 1, which aimed to predict exacerbations, monitored the patient baseline symptoms. 3 were accessories (1 used on the upper arm, 1 on the wrist and 1 used a dual device setup: one band and one face mask), 1 a vest and were 2 skin-attached sensors (1 used on the upper torso, and 1 as an in-ear sensor). Only 2 were currently certified.

Regarding data management, all but 1, detailed the set-up description from a technical standpoint, where only 1 device mentioned continuous collection of data parameters and 2 referred an intermittent collection, 1 every 5 seconds and the other ranging from twice per day to once every 2 days, and of the 2 devices describing their transmission set-up, 1 required an intermediate device (using Bluetooth for the first stage communication and Wi-Fi for the second stage) and 1 had direct communication with the central server (using Global System for Mobile Communication (GSM) connection). Regarding patient and HCP management, 3 devices alerted HCPs for abnormal readings, whilst the remaining 3 didn't describe HCP notification, 3 devices provided patients with data access, whilst 2 devices only notified regarding acute events.

Table 9. Additional Clinical Monitoring Devices Identified. NA – Not Available; PA – Physical Activity; SpO2– Oxygen Saturation; RR – Respiratory Rate; HR– Heart Rate; HCP – Healthcare Professional; VO2 – Oxygen Consumption

Device (Reference)	Monitoring Aim	Device Class	Device Location	Data Parameters Collected	Set-Up Description
Clinical Monitoring					
CurrentHealth Wearable *(FDA Class II)*	Baseline Monitoring	**Accessory** Band (attached sensor)	Upper Arm	**Clinical Data** SpO2 RR HR Skin Temperature **Lifestyle Data** Steps Count	*Optional Non-wearable Device* Portable Spirometer **HCP Management** *Interface* – Web-based CurrentHealth App *Rate* - Real time access to data collected *Features* – Data sorting by risk-stratification; Threshold customisation; Patient notifications, check-ins and educational content management; Chat and video options for real-time or asynchronous communication **Patient Management** *Interface* – Smartphone/Tablet App *Features* – Direct communication with the HCP; Symptom, medication and activity questionnaires filling
Adamm RSM	Baseline Monitoring	Skin-Attached Sensor	Upper Torso	**Clinical Data** RR HR Skin Temperature Cough Events Respiratory Sounds *(Wheezing)* **Lifestyle Data** Physical Activity Level	*Optional Non-wearable Device* Electronic inhaler ***Data Collection*** Nighttime cough events monitoring if placed by bed side ***Data Processing*** *Component* – Sensor ***Data Transmission*** *Connection* – Bluetooth (From the device to the smartphone) Wi-Fi (From the device/smartphone to the central server) **HCP Management** *Interface* – Web-based App *Rate* – Real time access to data collected *Clinical Management* – Vitals tracking (historical view); Vitals deviation notification receival **Patient Management** *Interface* – Smartphone/Tablet App (Optional) *Features* – Direct communication with the HCP; Symptom, medication and activity questionnaires filling; 24 hours historical data display; Notification receival *Interface* – Sensor *Features* – Device vibration upon vitals threshold deviation; Voice recording for subjective data entries

Senti-Wear(139)	Baseline Monitoring	**Clothing** Vest	Torso	**Clinical Data** Chest bioacoustic and biokinetic signals **Lifestyle Data** Surrounding Audio Steps Count	***Data Collection*** *Rate* – Twice per day to Once every two days ***Data Analysis*** Performed by proprietary machine learning models ***HCP Management*** *Interface* – Web Portal *Features* – Alert receival and management ***Patient Management*** *Interface* – Mobile Phone *Features* – Notification (Phone Call/SMS) receival upon vitals threshold deviation
Cossinuss OxMotion	Exacerbation Prediction	Skin-Attached Sensor	In-ear	**Clinical Data** SpO2 HR (Variability) RR Skin Temperature **Lifestyle Data** Steps Count Steps Pattern Walking Distance Head Movement	**Data Collection** *Rate* – Continuous ***Data Transmission*** *Connection* – NA (From the device to a Smartphone) ***Data Analysis*** *Component* – Cloud Server Artificial Intelligence analyses and interprets collected data, adjusts individual training plans and recognises early warning signs for possible disease condition's future decline ***Patient Management*** *Interface* – Smartphone App *Features* – Data display; Alarms and motivational cues receival; Social circle connection; Data sharing with HCPs option
Biovotion Everion (140) *(FDA Class IIa)*	Baseline Monitoring	**Accessory** Band	Wrist	**Clinical Data** SpO2 RR HR Heart Rate Variability Skin Temperature **Lifestyle Data** Steps Count Energy Expenditure	***Data Transmission*** *Connection* – Global System for Mobile Communication (From a Smartphone to a Cloud server) ***Patient Management*** *Interface* – Smartphone (App) *Features* – direct communication with the HCP; questionnaire filling; alert receival; motivational cues, medication and disease information notifications receival
Polar RS800CX[1] **AND** METAMAX 3B[2]	Baseline Monitoring	**Accessories** a. Band b. Face mask (with a wearable gas exchange analysis system)	Chest Over the mouth and nose	**Clinical Data** HR VO2	***Data Collection*** *Rate* –Every 5 s ***Data Processing*** HR and VO2 time-series resampling to 1 second and smoothing using an integrated algorithm; deviating values removal; fixed time window extraction of HR and VO2 following physical activity transitions; magnitude of HR and VO2 responses calculation

5. Discussion

This thesis utilised a systematic review design to attempt to identify all wearable devices utilised in remote COPD patient monitoring, independent of the intervention utilising a wearable device alone or requiring additional non-wearables for data collection, in order to solidify the current panorama of wearable remote COPD monitoring.

5.1. Summary of Main Findings

80 references were included in this review, of which 66 were study publications and 14 were device related websites or trial protocols. A total of 56 wearable remote patient monitoring devices were identified, 30 wellness devices and 26 clinical monitoring devices.

Overall results regarding methodology design, device description, set-up management and data parameters collected were heterogeneous.

5.1.1. Population Characteristics

Considering the mean population's age, COPD patients and healthy subjects demonstrated a substantial difference with the healthy subjects being considerably younger. Regarding COPD patients staging, several studies lacked stratified GOLD stage information. Of the ones providing this information, there was a slight preference showed for mild to moderate severity patients inclusion.

5.1.2. Quality Appraisal

Overall study risk of bias regarding appropriateness of study design was low. Relating to potential for selection bias, overall risk was low to moderate, but when analysing RCT interventions, they mostly displayed a moderate to high risk of bias, resulting from the lack of blinding in these interventions. Regarding measurement of exposures and outcomes risk of bias, higher disparity was identified, with overall risk being low to moderate, but 9 studies presenting a high risk of bias, again verified in the RCT study design. Lastly, concerning generalizability of the study findings, in general, risk of bias was moderate to low.

5.1.3. Device Description – Regarding Research Question (RSQ) 1

Firstly, regarding the number of devices utilised in each intervention, the majority (N= 36, 64%) utilised a single device approach, of which only a small number (N= 5, 14%) allowed for optional devices connection. As for multidevice interventions (N= 20, 36%), reporting of mixed interventions (i.e., simultaneous wearable and non-wearable devices) was on par with wearable only interventions. In addition, the majority of the interventions allowed data access through an external device, most commonly a smartphone.

In relation to the monitoring aim, 5 different aims were identified (physical activity monitoring, baseline monitoring, exacerbation prediction, early discharge management, and telerehabilitation). The most commonly reported aim was physical activity monitoring, exclusively verified in the wellness devices class and the least common was early discharge management.

Concerning the device type, 4 different types (accessories, clothing, skin-attached sensors, and fabric-attached sensors) and 8 subsequent different subtypes (bands, accelerometers, vests, smartwatches, pedometers, face masks, inclinometers, and necklaces) were identified. The majority (77%) of the devices were accessories.

Lastly, 12 different wearing locations (wrist, waist, shoe, chest, hip, upper arm, torso, forehead, back, over the mouth and nose, upper abdomen, in-ear) were reported with upper body locations prevailing. Additionally, the preferred wearing location was the wrist.

The interclass trend for single device interventions, physical activity monitoring and wrist wearing location preference classes extends to the wellness devices assessed. Only a few devices reported telerehabilitation support and exacerbation prediction and none aimed to assist in early discharge management.

On the other hand, contrary to the interclass trend, wellness devices displayed no device type disparity as the totality of the devices identified were wearable accessories but displayed the highest heterogeneity of subtype and wearing locations.

Regarding identified development stages, only a minority of clinical monitoring devices are certified for market use, whilst the major group is still in clinical COPD patient testing.

Contrary to the global trend, clinical monitoring devices most commonly limit their aim to patient baseline data parameters monitoring, but close to half have introduced an exacerbation prediction of some kind, whether through automated algorithms or manual analysis through intermediate agents. Current devices provide scarce information regarding their duration, with the few reporting it displaying both rechargeable batteries or working as disposable sensors that need to be replaced.

5.1.4. Parameters Assessed – Regarding RSQ 2

Concerning wellness devices, physical activity data corresponded to 13 different parameters regarding strict and other PA activity data. The most commonly assessed parameter was steps count. Additional non-physical activity related parameters were reported by a minority of the interventions and mostly included sleep related data and heart rate.

As for clinical monitoring devices, regarding validated vitals in exacerbation assessment, respiratory rate was the most commonly reported, closely followed by heart rate. Contrastingly, $SpCO_2$ was not assessed by any device and SpO_2 was scarcely reported. Additional clinical data measured included 22 different parameters, of which the most reported were respiration details, skin temperature and ECG.

Lifestyle data was additionally reported by the majority of studies. Only one study reported environmental data.

5.1.5. Technical Set-Up Overview – Regarding RSQ3

Only a quarter of the clinical monitoring devices simultaneously reported information on the four set-up components analysed. Although, when individually assessed, each of the 4 components was reported by a similar number of devices.

Regarding data collection rate, for the devices providing information on its modality, all but one had an automated collection process. Devices using continuous and intermittent modalities were on par. As for the timeframe between data collection, a sizeable difference was assessed.

In relation to the devices detailing data processing, all utilised a local processing unit before initiating data transmission.

Concerning data transmission, only a quarter of the devices communicated directly with a central storage and analysis server, and half required an intermediate transmission device. Regarding transmission communication protocol, GPRS and Wi-Fi were shared modalities between the direct communication devices, and Bluetooth was the preferred first stage transmission protocol, compared to internet connection in the second stage, in the intermediate device group.

Lastly, with respect to data analysis, most of the devices reporting its process, utilised automation tools to enhance the procedure and a minority required manual data revision through intermediate call centres that further communicated vitals deviations to the healthcare professionals.

5.1.6. Clinical Set-Up Overview – Regarding RSQ3

Most devices reported simultaneous patient and healthcare professionals' management. Of these, the majority had an automated notification system to alert the HCP, with the remaining requiring manual analysis through graphical data display. Patient management also verified a positive trend of data access, with the majority of devices allowing the patient

to visualise his/her data in real time. In addition, virtually all devices tackling patient and healthcare professionals' management provided additional features regarding clinical management beyond mere data access, including individualised care with past electronic health records data and comorbidities management.

5.2. Comparison with Prior Work

5.2.1. Quality Appraisal

Most identified references, regarding clinical monitoring devices, were mere methodology description studies, lacking solid intervention device testing, apart from small sample sized patient or healthy groups testing which may result from a still premature development stage of overall clinical monitoring devices, considering the minority were certified devices.

The scarcity of identified RCT design studies is in line with previous findings (144). When considering the higher risk of bias identified in this study design, it recalls the judgment of a previous review, claiming that randomized controlled trials are probably no longer the better suited design to evaluate digital health solutions(145). In addition, it is comprehensible that clinical monitoring devices have fewer published RCTs and have a higher potential for selection bias, considering the difficulty to blind patients and clinicians regarding the usage of an electronic clinical assisting device. A strategy to overcome the blinding difficulty may be the use of placebo/sham devices in the control groups.(56)

5.2.2. Methodology Standpoint

Contrary to previous publications on similar topics (8,41,146,147), addressing the paucity of devices utilised in RPM interventions, we identified and included a greater number of references, resulting in a greater number of devices identified as well, despite excluding non-wearable devices, clinical facilities interventions and interventions using exclusively fine or gross mobility impairment devices (i.e., portable spirometers and finger pulse oximeters). This may be due to the inclusion of references utilising both wearable and non-wearable devices or, most likely, to a broader spectrum of databases and external references and research methods adoption, considering half of the included references derived from the "Identification of studies via other methods" PRISMA Flow Diagram branch, which might be explained by the relative novelty of wearable devices already addressed, resulting in less indexed publications results. Furthermore, we looked to aggregate studies referring to the same device, if they contained additional information on the device description, to obtain the most up to date information on the device.

5.2.3. Device Trends – Regarding RSQ 1

The higher number of wellness devices identified may be due to the easier market introduction of wellness devices when compared to clinical devices, resulting from less strict regulation. Another explanation, on par with the previous, is that manufacturers often elect to enter the industry through the introduction of low-risk general wellness products and, once further refinement is reached or higher investment is obtained, they market the devices as clinical devices, a technique called "skating the line".(148)

Concerning the reported number of single device interventions, it caters to patient's preference over the simplicity of interventions that do not rely on the memorization of the function of each device (149). Data access being provided by the majority of the interventions, most commonly through a smartphone interface, is also in line with previous findings.(150) As for multidevice interventions, independent of wearable only or mixed interventions adoption, similar to what occurs with single vs combination drugs, where pharmacological interactions must be assessed to infer downsides, it is mandatory to understand if multidevice and single interventions are similarly effective, considering previously reported challenges concerning manufacturers' device-binding compatibility as well as multidevice interventions still identified as in an immature state.(150)

Lastly, still concerning intervention components, the propensity to utilise additional non-wearable only devices in the wellness devices class may result from the wide availability of wellness devices that are an increasingly used tool for physical monitoring resulting in increased interventions adopting these devices for the evaluation of physical activity in multicomponent assessments.

Regarding intraclass trend analysis in the 2 major classes considered, substantial heterogeneity regarding the structural composition (i.e., adopted device type and subtypes) and wearing location was identified. Despite this heterogeneity and continuous updates in the wearable field regarding the introduction of biosensors (151), this device type was not reported by either device class, but most importantly, by the clinical monitoring class, in this thesis.

Most devices were accessories, more noticeable in the wellness device class, where it was the only reported type. This finding may relate to improved usability that accessories provide as they assimilate the disseminated usage of daily gadgets in the modern world, thus not requiring additional intellectual burden from their users to recall instructions on device wearing.

Concluding, considering the loose regulation regarding wellness devices, the lack of standardization and the relative novelty of wearable devices, the identified heterogeneity in device types, components and monitoring aim is in line with previous reviews' findings (152), and hence results from a multifactorial aetiology. In addition, the lack of standardization may be explained by remote monitoring being a relatively recent innovation, as assessed in the previously mentioned WHO's global survey in 2015, where only close to 50% of responding countries reported a RPM programme of which only 22% reported a mature one according to the survey's established criteria, with over 50% still reporting a pilot remote monitoring project.(38)

This heterogeneity isn't inherently a challenge, as it provides diversity of solutions, such as the emergence of wearable devices aiming to not only monitor COPD patients, but also providing remote management, whether by integrating additional non-wearable devices in the intervention, providing companion data access devices for further patient input or by utilising the wearable alone for distant patient notification of clinical and/or technical abnormalities, contrary to the findings of Zheng et al (56) in 2014, showing the market evolution of wearable technology.

Contrastingly, the disparity of wearing locations regarding devices of the same type and the multitude of subtypes identified, highlights the need to conduct a validity review to assess the ones with least measurement disparity, which, when paired to patient satisfaction analysis regarding this matter, will help tailor future devices development that provide the most up to date clinically validated benefits and satisfy the intended consumer needs.

5.2.4. Collected and Validated Parameters – Regarding RSQ 2

Considering each of the monitoring aims:

5.2.4.1. Physical Activity Monitoring

PA monitoring, as a monitoring aim, was solely reported by wellness devices and encompassed an assortment of parameters assessed, of which steps count prevailed along with activity details, namely activity duration and assessment. This finding may arise from the strong correlation between physical activity impairment and COPD health status impairment and prognosis prediction (3) which makes wearable devices valuable tools as remote assessment technologies that allow to infer daily and hourly activity patterns and have a more continuous view of individual and population variability. This has the therapeutical benefit of helping to individualise physical activity programs for COPD patients, and the prognostic benefit of assessing the self-paced walking distance for longer periods of time and in different walking courses, when we factor in daily activities such as

climbing stairs and walking up and down hills, compared to the 6-minute walking test performed in controlled environments, which is currently utilised.(3)

5.2.4.2. Baseline Monitoring

In the clinical monitoring devices class, baseline monitoring was the preferred aim, likely because exacerbation prediction algorithms are not yet widely disseminated nor validated.

A vast number of distinct clinical parameters was reported in this review. Of particular relevance, the multitude of respiration details assessed by the clinical monitoring devices provides significant clinical value, considering the importance of routine spirometry assessment to estimate lung function declining(3), which is therefore assessed in a non-disruptive manner, barely requiring patient collaboration, and in a continuous manner, further allowing evaluation of lung function variations during daily activities.

Additionally, cough events assessment may help tailoring symptom relieving medication regimens, as chronic cough is one of the main COPD symptoms and is often underestimated by the patients.(153) Additionally, snoring events evaluation poses additional value for comorbidity assessment, as it may be an indicator of obstructive sleep apnoea-COPD overlap syndrome.(154)

Regarding novel parameters assessed, Electrical Impedance Tomography (EIT) providing real time lung ventilation distribution assessment could deliver great clinical value(155), as lung imageology provides crucial insight in COPD, allowing emphysema area identification, mainly through Computed Tomography(3), which, in the case of EIT would have the added benefit of lacking eventually harmful radiation. The same principle extends to lung auscultation sounds assessment, providing healthcare professionals with remote access to real time adventitious sounds identification or allowing pulmonary sounds database creations.

5.2.4.3. Exacerbation Prediction and Early Discharge Management

From an exacerbation management standpoint, all devices included in this review (aiming to predict exacerbations or to monitor early discharged patients) were assessed as lacking compliance with current guidelines(3), regarding recommended clinical data assessment and the 4 vital parameters established (SpO_2, $SpCO_2$, HR, RR) (discussed in **Section 2.3.**).

On the one hand, 4 wellness devices aimed to assess lifestyle data patterns prior to disease exacerbation events to establish prediction trends, dismissing clinical data entirely, likely due to the association between COPD exacerbation likelihood increase and physical inactivity.(156)

On the other hand, no clinical monitoring device included $SpCO_2$ assessment despite its comparable effectiveness to $PaCO_2$, which evaluation is recommended by current guidelines (see **Section 2.8.**), as hypercapnia is of crucial importance in acute exacerbations management. Similarly, SpO_2 monitoring utilising a non-wearable device was reported only by a minority of the studies, with multiple studies still utilising finger pulse oximeters, despite its previously mentioned limitations (see **Section 2.9.**).

Contrastingly, in the clinical monitoring devices class, respiratory rate was the most reported clinical data parameter assessed, in line with the current trend regarding increasing respiratory rate monitoring devices development(157), followed by heart rate, with the majority of the devices reporting either.

Despite not being related to the 4 vital signals assessed, no device assessed biomarkers or biofluids, which may be a shortcoming considering the current guidelines recommendation to assess both $PaCO_2$ and CRP blood level to distinguish between moderate and severe COPD exacerbations.(3)

5.2.4.4. Telerehabilitation

Regarding the small number of devices utilised for telerehabilitation, wellness devices mostly aimed to increase patient physical activity through steps counts, and clinical monitoring devices looked to mostly assess respiratory rate and were paired with additional devices to assess the patient pulmonary capacity in a remote manner. Physical activity importance in COPD patients was already assessed in **Section 5.2.4.1.**, although, regarding telerehabilitation, these interventions may provide valuable information regarding the effectiveness of pulmonary rehabilitation, using physical activity evaluation (3), in a more repeated manner compared to scheduled presential appointments. Regarding the telerehabilitation clinical monitoring devices, the ability to detect respiratory rate in real time during rehabilitation exercise training allows to understand the variations of this parameter between patients and better cater exercise routines to each patient in order to provide increased benefit.

5.2.5. Technical Set-Up Overview – Regarding RSQ3

The lack of transparency regarding data management has been a repeated theme in remote monitoring technologies, and this review further cements this idea with only a minority of the interventions and/or devices reporting the dataflow in its entirety. This category recalls the lack of standardization involved in clinical monitoring wearable devices, namely regarding frequency of collection and transmission of data, which is of the utmost importance to address as it may be the deciding survival factor during acute disease events

where time is of the essence and the data may have not been transmitted as the device was not yet in its next transmission phase.

Contrastingly, the automated data collection process trend identified is of substantial value considering the limitation of user error that might derive from having the patients interacting with the sensing modules to perform repeated measurements. The same positive note was verified in data processing reporting, where a local processing unit dealt with the data flow before transmission, which improves data packaging and further facilitates its transmission instead of raw data bundle transmission.

Data transmission had the highest heterogeneity of results, with only a quarter of the devices reporting direct communication with a cloud storage server where data was further analysed by automated algorithms or manually analysed by healthcare professionals when accessed through the desired interface. This finding recalls previous recommendations of appropriate data management infrastructures creation to ensure better dataflow.(147) Furthermore, regarding communication networks, the majority of the devices reported older generation modalities, with only a few reporting more recent innovations, such as BLE and 5G integration for transmission, which when combined with the use of an intermediate device for further transmission to the final intended destination, warrants the urgency of updating older devices, namely GSM and GPRS, as newer networks are considerably more efficient and reliable.(158)

As for data analysis, with most devices reporting automation tools to evaluate vitals' trends, and some aiming to integrate the patient's electronic health record, wearable collected and individualised situations data, such as disease states that could hinder both automated analysis of the patient's baseline and healthcare professionals delayed analysis of patient reported data, that many times do not recall exact situations, continuous improvement of machine learning algorithms and better comprehension of individualised patient baselines may be attained. The interface utilised to display patient data to the HCP was mostly reported as designated web-based portals, thus not integrated with the patient health record as has been previously recommended.(147)

5.2.6. Clinical Set-Up Overview – Regarding RSQ3

Concerning healthcare professionals' management, most of the reported devices had an automated notification system identifying event abnormalities, not limited to clinical events, but also concerning technical issues on the patient's end, allowing for a better control over the patient's health status by having access to disease deteriorations in real time, assisting in timely intervention regarding eventual life-threatening events. In

addition, with some of the algorithms identifying events other than exacerbations, such as cough events, there are now tools to minimise the healthcare professionals' clinical burden, allowing better allocation of resources, otherwise spent in the heavily time-consuming analysis of graphical trends. This trend extends to the identified devices, that despite not being as evolved as the ones containing machine learning algorithms, allocate the vitals analysis' burden to intermediate facilities.

Regarding patient management, patient's access to their own data was a verified trend, which is consistent with patient reported preferences (159), who claim it gives them a sense of knowledge and control over their disease. On the other hand, some interventions alternatively notified patients utilising the wearable device alone, through vibration or visual prompts, which is an overcome attempt to literature identified challenges, concerning patients lacking smartphones and general preference of simple prompt notification (149) or individual preference of not needing to check their smartphone (159). In addition, regarding telerehabilitation, whose benefits in COPD patients can't be overstated (3), the direct communication with healthcare professionals, reported by the clinical monitoring devices identified, in a remote manner, allows the patients to maintain a personal interaction with practitioners, and also provides access to collected parameters in real time, which have been identified as positive additions to remote technologies in a previous review.(160)

5.3. Study Limitations and Future Developments

Considering the vast parameters aimed to assess and the limited timeframe to conduct the systematic review, effectiveness analysis of the included reviews was not conducted; instead, a thorough exploration of each of the proposed components was conducted. Hence, with the considerable pool of devices identified in mind, effectiveness analysis as well as economical evaluations of each device, and interclass analysis should be conducted to further assess the validity of each solution. The same limitation extends to patient usability evaluation of the identified devices, which appeals for future investigation, considering the importance of integrating the patient input in the device development and regulatory processes.(161)

A systematic review design was utilised aiming to identify as many devices as possible, although, only wearable remote monitoring devices were included, leaving wearable devices utilised for clinical facility and ward monitoring out of the scope of the review and which may perhaps be adapted for long range remote monitoring, warranting future research interest.

Additionally, some risk of bias may arise from missing study information regarding each parameter analysed which was preemptively addressed with author contacting to derive relevant information.

These limitations shouldn't take away from the rich wearable device market availability and clinical interest, contrarywise they should elicit further investigation to the bridge the current literature gaps by providing investigation opportunities.

5.3.1. Academic Statement

Due to time constraints concerning the extensive procedure, typical of systematic review's design, and the monetary constraints regarding indexed journals' publishing, only the review's protocol upload on PROSPERO was achieved. Future dissemination plans include publishing the systematic review's main findings, regarding the devices for which publications were identified, on a major indexed pulmonary medicine journal. In addition, considering the extensive scope of the thesis, further articles on journals with slighter journal impact factor are planned, one considering the technical set-up findings on a digital health journal, and one considering the clinical findings, regarding both devices with published studies' results and novel devices identified, on a pneumology journal.

6. Conclusion and Recommendations

In this thesis, an overview of wearable devices, encompassing wellness and clinical monitoring, and respective set-up utilised for data, healthcare professionals and patient management in COPD remote monitoring interventions utilising a comprehensive systematic review design is provided. The aim was to contribute meaningful insight through extensive wearable COPD monitoring description to healthcare professionals, stakeholders and manufacturers to tailor future device development and technical regulations.

Concerning the thesis methodology, regarding the systematic review's reference screening, of the 1590 initial references, 79 were included in the final analysis. 65 published studies and 14 references identified through extensive additional screening.

Regarding RSQ1 (Device description):

- Wellness devices make up only the slight majority of the wearable solutions in remote COPD monitoring, showing clinical monitoring devices are starting to catch up;
- The majority of the interventions utilised a single device approach and allowed the patients to assess their own data through an external device;
- 5 different monitoring aims were identified, most comprising physical activity monitoring or baseline monitoring, in the wellness and clinical monitoring devices, respectively.

Regarding RSQ 2 (Data parameters):

- In the wellness devices subgroup, 13 different physical activity parameters were identified, with the most prominent being steps count;
- In the clinical monitoring devices subgroup, of the 4 validated vitals assessed, respiratory rate was the most frequent. Additional clinical data included 22 different measurements and lifestyle data was additionally reported by most studies. Contrastingly, environmental data was reported by a single study.

Regarding RSQ3 (Data set-up; clinical monitoring devices only):

- Only a quarter simultaneously reported information on the four set-up components. Data collection was mostly automated with sizeable differences in collection rate identified. All devices utilised a local processing unit. As for transmission, only a quarter had direct connection with a central server and a need for communication networks update was assessed. Data analysis utilised automation tools for them most part;

- Most devices reported patient and healthcare professionals' management simultaneously through automated notification systems. Features other than data access, namely access to comorbidities management.

Concluding, an extensive heterogeneity regarding all the referred themes was identified, alerting for the need to formalize guidelines regarding wearable remote COPD monitoring intervention reporting and device construction. As such, below some recommendations for academics, developers, and clinicians are presented.

6.1. Academic Recommendations

Academics looking to review the technological solutions in the telehealth field should:

- Aim to search for references outside the mainstream databases, as several other mediums provide additional information and device identification, namely device websites and grey literature databases;
- Adopt additional strategies for thorough relevant publications inclusion, namely citation searching of both identified references and relevant reviews on the same topic.

Researchers looking to conduct investigations on this subject should consider:

- When performing experimental studies, if the selected design is a Randomized Controlled Trial, adopt a placebo device that mimics the experimental device, from an aesthetical perspective, to reduce the observer bias where blinding is expected not to be feasible;
- Regarding the device development testing interventions, assure a similar demographic, such as age, between the healthy subjects and the intended target population.

6.2. Manufacturers and Policy Makers Recommendations

From a policy making perspective, regulation concerning devices set-up for the 4 assessed parameters: data collection, data processing, data transmission, and data analysis, should aim to address the heterogeneity regarding the frequency of occurrence of each parameter to ensure standardization of data workflow.

Manufacturers should aim to:

- Utilise pillars like continuous data collection, local data processing, short intervals between data transmissions, and data analysis outsource from healthcare professionals to tailor future device development;

- Provide transparency regarding device components and data workflow and make it easily available for both researchers and patients, even with commercially sensitive details factored in, and independent of the device having been developed for market introduction or experimental research only;
- Produce more field application investigations and attain to publish them, to assist with device validation.

Policy makers should attempt to:

- Reenforce policies regarding data privacy and storage
- Ensure nomenclatures are sufficiently precise and well-established in order to better regulate the wearable device market

6.3. Clinical Recommendations

Concluding, this review paves the way for a better understanding of available wearable technologies in COPD Remote Patient Monitoring, but further investigation is required to properly evaluate the solutions on the market, as such, future reviews may:

- Evaluate the effectiveness of identified, and released in the meantime, wearable devices, establishing comparisons between single and multidevice interventions, wearable only and mixed devices interventions, wellness and clinical monitoring devices, and intraclass comparison;
- Evaluate the clinical efficacy of each data parameter identified to assess which monitoring aims benefit the most with each;
- Conduct economic evaluation and patient usability analyses regarding the identified devices.

In addition, if we consider remote patient monitoring a subgroup of patient monitoring, the same research suggestions above, and a similar study to the one conducted here, should extend to presential (i.e., non-remote) patient monitoring, regarding wearable devices utilised in hospital care or other medical facilities which may benefit COPD patients during their severe exacerbation events hospitalisation.

7. References

1. Soriano JB, Kendrick PJ, Paulson KR, Gupta V, Abrams EM, Adedoyin RA, et al. Prevalence and attributable health burden of chronic respiratory diseases, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet Respir Med. 2020 Jun 1;8(6):585–96.

2. Adeloye D, Song P, Zhu Y, Campbell H, Sheikh A, Rudan I. Global, regional, and national prevalence of, and risk factors for, chronic obstructive pulmonary disease (COPD) in 2019: a systematic review and modelling analysis. Lancet Respir Med. 2022 May 1;10(5):447–58.

3. Global Strategy for the Diagnosis M and P of COPD. Global Initiative for Chronic Obstructive Lung Disease (GOLD) 2023 Report. 2022.

4. Lu L, Zhang J, Xie Y, Gao F, Xu S, Wu X, et al. Wearable Health Devices in Health Care: Narrative Systematic Review. JMIR Mhealth Uhealth. 2020 Nov 9;8(11):e18907.

5. El-Rashidy N, El-Sappagh S, Riazul Islam SM, El-Bakry HM, Abdelrazek S. Mobile Health in Remote Patient Monitoring for Chronic Diseases: Principles, Trends, and Challenges. Diagnostics. 2021 Apr 1;11(4):1–32.

6. Nagase FI, Stafinski T, Avdagovska M, Stickland MK, Etruw EM, Menon D. Effectiveness of remote home monitoring for patients with Chronic Obstructive Pulmonary Disease (COPD): systematic review. BMC Health Serv Res. 2022 Dec 1;22(1):1–25.

7. Al Rajeh A, Steiner MC, Aldabayan Y, Aldhahir A, Pickett E, Quaderi S, et al. Use, utility and methods of telehealth for patients with COPD in England and Wales: a healthcare provider survey. BMJ Open Respir Res. 2019 Feb 1;6(1):1–6.

8. Fan KG, Mandel J, Agnihotri P, Tai-Seale M. Remote Patient Monitoring Technologies for Predicting Chronic Obstructive Pulmonary Disease Exacerbations: Review and Comparison. JMIR Mhealth Uhealth. 2020 May 21;8(5):1–6.

9. Celli B, Fabbri L, Criner G, Martinez FJ, Mannino D, Vogelmeier C, et al. Definition and Nomenclature of Chronic Obstructive Pulmonary Disease: Time for Its Revision. Am J Respir Crit Care Med. 2022 Dec 1;206(11):1317–25.

10. Agustí A, Melén E, DeMeo DL, Breyer-Kohansal R, Faner R. Pathogenesis of chronic obstructive pulmonary disease: understanding the contributions of gene-environment interactions across the lifespan. Lancet Respir Med. 2022 May 1;10(5):512–24.

11. Forey BA, Thornton AJ, Lee PN. Systematic review with meta-analysis of the epidemiological evidence relating smoking to COPD, chronic bronchitis and emphysema. BMC Pulm Med. 2011 Jun 14;11:1–61.

12. Kohansal R, Martinez-Camblor P, Agustí A, Sonia Buist A, Mannino DM, Soriano JB. The Natural History of Chronic Airflow Obstruction Revisited. Am J Respir Crit Care Med. 2012 Dec 20;180(1):3–10.

13. Miravitlles M, Soler-Cataluña JJ, Soriano JB, García-Río F, de Lucas P, Alfageme I, et al. Respiratory symptoms and their determinants in the general Spanish population: changes over 20 years. ERJ Open Res. 2022 Oct 1;8(4):1–11.

14. Darawshy F, Abu Rmeileh A, Kuint R, Berkman N. Waterpipe smoking: a review of pulmonary and health effects. European Respiratory Review. 2021 Jun 30;30(160):1–9.

15. Wills TA, Soneji SS, Choi K, Jaspers I, Tam EK. E-cigarette use and respiratory disorders: an integrative review of converging evidence from epidemiological and laboratory studies. Eur Respir J. 2021 Jan 1;57(1):1–16.

16. Tehrani H, Rajabi A, Ghelichi- Ghojogh M, Nejatian M, Jafari A. The prevalence of electronic cigarettes vaping globally: a systematic review and meta-analysis. Archives of public health . 2022 Dec 1;80(1):1–15.

17. Ministério da Saúde. Telemonitorização DPOC [Internet]. 2019 [cited 2023 Feb 16]. Available from: www.dgs.pt

18. Levine S, Marciniuk D, Aglan A, Celedón JC, Fong K, Horsburgh R, et al. The Global Impact of Respiratory Disease. 2021:1-52.

19. Zafari Z, Li S, Eakin MN, Bellanger M, Reed RM. Projecting Long-term Health and Economic Burden of COPD in the United States. Chest. 2021 Apr 1;159(4):1400–10.

20. Toy EL, Gallagher KF, Stanley EL, Swensen AR, Duh MS. The economic impact of exacerbations of chronic obstructive pulmonary disease and exacerbation

definition: a review. COPD: Journal of Chronic Obstructive Pulmonary Disease. 2010;7(3):214–28.

21. Yawn BP, Thomashow B. Management of patients during and after exacerbations of chronic obstructive pulmonary disease: the role of primary care physicians. Int J Gen Med. 2011 Sep;4:665–76.

22. Fundação Portuguesa do Pulmão. Observatório Nacional Doenças Respiratórias. 2022.

23. Fundação Portuguesa do Pulmão. Estimativa da Prevalência de Tratamento da DPOC em Portugal. 2020.

24. Fundação Portuguesa do Pulmão. Observatório Nacional Doenças Respiratórias. 2020.

25. Patel AR, Patel AR, Singh S, Singh S, Khawaja I. Global Initiative for Chronic Obstructive Lung Disease: The Changes Made. Cureus. 2019 Jun 24;11(6):1–7.

26. Walters JA, Smith S, Poole P, Granger RH, Wood-Baker R. Injectable vaccines for preventing pneumococcal infection in patients with chronic obstructive pulmonary disease. Cochrane Database Syst Rev. 2010 Nov 10;(11):1–48.

27. Poole P, Chacko EE, Wood-Baker R, Cates CJ. Influenza vaccine for patients with chronic obstructive pulmonary disease. Cochrane Database of Systematic Reviews. 2009;(4):1–58.

28. Wongsurakiat P, Maranetra KN, Wasi C, Kositanont U, Dejsomritrutai W, Charoenratanakul S. Acute respiratory illness in patients with COPD and the effectiveness of influenza vaccination: a randomized controlled study. Chest. 2004;125(6):2011–20.

29. Jefferson T, Rivetti D, Rivetti A, Rudin M, Di Pietrantonj C, Demicheli V. Efficacy and effectiveness of influenza vaccines in elderly people: a systematic review. Lancet . 2005 Oct 1;366(9492):1165–74.

30. Raveling T, Vonk J, Struik FM, Goldstein R, Kerstjens HAM, Wijkstra PJ, et al. Chronic non-invasive ventilation for chronic obstructive pulmonary disease. Cochrane Database Syst Rev. 2021 Aug 9;8(8):1–105.

31. Hurst JR. GOLD and COPD- Exacerbations What is (and what is not) a COPD exacerbation: thoughts from the new GOLD guidelines. 2007. p. 198–9.

32. Soler-Cataluña JJ, Martínez-García MÁ, Román Sánchez P, Salcedo E, Navarro M, Ochando R. Severe acute exacerbations and mortality in patients with chronic obstructive pulmonary disease. Thorax. 2005 Nov;60(11):925–31.

33. Celli BR, Fabbri LM, Aaron SD, Agusti A, Brook R, Criner GJ, et al. An updated definition and severity classification of chronic obstructive pulmonary disease exacerbations: The rome proposal. Am J Respir Crit Care Med. 2021 Dec 1;204(11):1251–8.

34. Aksu F, Capan N, Aksu K, Ofluoğlu R, Canbakan S, Yavuz B, et al. C-reactive protein levels are raised in stable Chronic obstructive pulmonary disease patients independent of smoking behavior and biomass exposure. J Thorac Dis. 2013 Aug;5(4):414–21.

35. Medline Plus. Vital signs [Internet]. 2023 [cited 2023 Jun 27]. Available from: https://medlineplus.gov/ency/article/002341.htm

36. Janjua S, Carter D, Threapleton CJD, Prigmore S, Disler RT. Telehealth interventions: remote monitoring and consultations for people with chronic obstructive pulmonary disease (COPD). Cochrane Database Syst Rev. 2021 Jul 20;2021(7):1–157.

37. World Health Organization. Consolidated Telemedicine Implementation Guide. Geneva; 2022 Nov.

38. WHO. Global Diffusion of eHealth: Making universal health coverage achievable:report of the third global survey on eHealth. 2016:1-160.

39. Omboni S, Padwal RS, Alessa T, Benczúr B, Green BB, Hubbard I, et al. The worldwide impact of telemedicine during COVID-19: current evidence and recommendations for the future. Connected Health. 2022;1–40.

40. Oracle. What Is the Internet of Things (IoT)? | Oracle Portugal [Internet]. [cited 2023 Feb 27]. Available from: https://www.oracle.com/pt/internet-of-things/what-is-iot/

41. Peyroteo M, Ferreira IA, Elvas LB, Ferreira JC, Lapão LV. Remote Monitoring Systems for Patients With Chronic Diseases in Primary Health Care: Systematic Review. JMIR Mhealth Uhealth. 2021 Dec 1;9(12):1–11.

42. Chang A. The Role of Artificial Intelligence in Digital Health. In: Digital Health Entrepreneurship. Springer, Cham; 2020. p. 71–81.

43. Global Smart Healthcare Market Size, Share Report, 2030. 2021:1-110.

44. Taylor ML, Thomas EE, Snoswell CL, Smith AC, Caffery LJ. Does remote patient monitoring reduce acute care use? A systematic review. BMJ Open. 2021 Mar 2;11(3):1–9.

45. De Guzman KR, Snoswell CL, Taylor ML, Gray LC, Caffery LJ. Economic Evaluations of Remote Patient Monitoring for Chronic Disease: A Systematic Review. Value Health. 2022 Jun 1;25(6):897–913.

46. Cordova FC, Ciccolella D, Grabianowski C, Gaughan J, Brennan K, Goldstein F, et al. A Telemedicine-Based Intervention Reduces the Frequency and Severity of COPD Exacerbation Symptoms: A Randomized, Controlled Trial. Telemedicine Journal and e-Health. 2016 Feb 2;22(2):114–22.

47. Hong Y, Lee SH. Effectiveness of tele-monitoring by patient severity and intervention type in chronic obstructive pulmonary disease patients: A systematic review and meta-analysis. Int J Nurs Stud. 2019 Apr 1;92:1–15.

48. Udsen FW, Hejlesen O, Ehlers LH. A systematic review of the cost and cost-effectiveness of telehealth for patients suffering from chronic obstructive pulmonary disease. J Telemed Telecare. 2014;20(4):212–20.

49. McLean S, Nurmatov U, Liu JLY, Pagliari C, Car J, Sheikh A. Telehealthcare for chronic obstructive pulmonary disease. Cochrane Database Syst Rev. 2011 Jul 6;2011(7):739–49.

50. McDowell JE, McClean S, FitzGibbon F, Tate S. A randomised clinical trial of the effectiveness of home-based health care with telemonitoring in patients with COPD. J Telemed Telecare. 2015 Mar 15;21(2):80–7.

51. Taylor ML, Thomas EE, Snoswell CL, Smith AC, Caffery LJ. Does remote patient monitoring reduce acute care use? A systematic review. BMJ Open. 2021 Mar 2;11(3):1–9.

52. Kim Y, Mahmood M, Lee Y, Kim NK, Kwon S, Herbert R, et al. All-in-One, Wireless, Stretchable Hybrid Electronics for Smart, Connected, and Ambulatory Physiological Monitoring. Advanced Science. 2019 Sep 24;6(17):1–14.

53. Storre JH, Magnet FS, Dreher M, Windisch W. Transcutaneous monitoring as a replacement for arterial PCO(2) monitoring during nocturnal non-invasive ventilation. Respir Med. 2011 Jan;105(1):143–50.

54. Janssens JP, Perrin E, Bennani I, De Muralt B, Titelion V, Picaud C. Is continuous transcutaneous monitoring of PCO2 (TcPCO2) over 8 h reliable in adults? Respir Med. 2001;95(5):331–5.

55. Tomasic I, Tomasic N, Trobec R, Krpan M, Kelava T. Continuous remote monitoring of COPD patients—justification and explanation of the requirements and a survey of the available technologies. Med Biol Eng Comput. 2018 Apr 1;56(4):547–69.

56. Zheng YL, Ding XR, Poon CCY, Lo BPL, Zhang H, Zhou XL, et al. Unobtrusive Sensing and Wearable Devices for Health Informatics. IEEE Trans Biomed Eng. 2014;61(5):1538–54.

57. Areia C, Young L, Vollam S, Ede J, Santos M, Tarassenko L, et al. Wearability Testing of Ambulatory Vital Sign Monitoring Devices: Prospective Observational Cohort Study. JMIR Mhealth Uhealth. 2020 Dec 16;8(12):1–3.

58. Chesley CF, Lane-Fall MB, Panchanadam V, Harhay MO, Wani AA, Mikkelsen ME, et al. Racial Disparities in Occult Hypoxemia and Clinically Based Mitigation Strategies to Apply in Advance of Technological Advancements. Respir Care. 2022 Dec 1;67(12):1499–507.

59. Henry NR, Hanson AC, Schulte PJ, Warner NS, Manento MN, Weister TJ, et al. Disparities in Hypoxemia Detection by Pulse Oximetry Across Self-Identified Racial Groups and Associations With Clinical Outcomes. Crit Care Med. 2022 Feb 1;50(2):204–11.

60. Food and Drug Administration. General Wellness: Policy for Low Risk Devices - Guidance for Industry and Food and Drug Administration Staff [Internet]. USA; Sep 27, 2017. Available from: https://www.fda.gov/media/90652/download

61. Alex DelVecchio. What is remote patient monitoring (RPM)? | Definition from TechTarget [Internet]. 2019 [cited 2023 Feb 27]. Available from: https://www.techtarget.com/searchhealthit/definition/remote-patient-monitoring-RPM

62. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021 Mar 29;1–9.

63. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. Syst Rev. 2016 Dec 5;5(1):1–10.

64. Burge AT, Cox NS, Abramson MJ, Holland AE. Interventions for promoting physical activity in people with chronic obstructive pulmonary disease (COPD). Cochrane Database . 2020 Apr 16;(4):1–520.

65. Buekers J, Arbillaga-Etxarri A, Gimeno-Santos E, Donaire-Gonzalez D, Chevance G, Aerts JM, et al. Heart rate and oxygen uptake kinetics obtained from continuous measurements with wearable devices during outdoor walks of patients with COPD. Digit Health. 2023 Jan 14;9:1–13.

66. Steele BG, Belza B, Cain KC, Coppersmith J, Lakshminarayan S, Howard J, et al. A Randomized Clinical Trial of an Activity and Exercise Adherence Intervention in Chronic Pulmonary Disease. Arch Phys Med Rehabil. 2008 Mar;89(3):404–12.

67. Moy ML. Accuracy of uniaxial accelerometer in chronic obstructive pulmonary disease. The Journal of Rehabilitation Research and Development. 2008 Dec 1;45(4):611–8.

68. Moy ML, Matthess K, Stolzmann K, Reilly J, Garshick E. Free-Living Physical Activity in COPD: Assessment with Accelerometer and Activity Checklist. The Journal of Rehabilitation Research and Development. 2009;46(2):1–16.

69. Hospes G, Bossenbroek L, ten Hacken NHT, van Hengel P, de Greef MHG. Enhancement of daily physical activity increases physical fitness of outclinic COPD patients: Results of an exercise counseling program. Patient Educ Couns. 2009 May;75(2):274–8.

70. Altenburg WA, ten Hacken NHT, Bossenbroek L, Kerstjens HAM, de Greef MHG, Wempe JB. Short- and long-term effects of a physical activity counselling

programme in COPD: A randomized controlled trial. Respir Med. 2015 Jan;109(1):112–21.

71. Sugino A, Minakata Y, Kanda M, Akamatsu K, Koarai A, Hirano T, et al. Validation of a Compact Motion Sensor for the Measurement of Physical Activity in Patients with Chronic Obstructive Pulmonary Disease. Respiration. 2012;83(4):300–7.

72. Tabak M, Vollenbroek-Hutten MMR, van der Valk PDLPM, van der Palen J, Tönis TM, Hermens HJ. Telemonitoring of Daily Activity and Symptom Behavior in Patients with COPD. Int J Telemed Appl. 2012;2012:1–8.

73. Kawagoshi A, Kiyokawa N, Sugawara K, Takahashi H, Sakata S, Miura S, et al. Quantitative assessment of walking time and postural change in patients with COPD using a new triaxial accelerometer system. Int J Chron Obstruct Pulmon Dis. 2013 Sep;397–404.

74. Caulfield B, Kaljo I, Donnelly S. Use of a consumer market activity monitoring and feedback device improves exercise capacity and activity levels in COPD. In: 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE; 2014. p. 1765–8.

75. McNamara RJ, McKeough ZJ, McKenzie DK, Alison JA. Physical comorbidities affect physical activity in chronic obstructive pulmonary disease: A prospective cohort study. Respirology. 2014 Aug;19(6):866–72.

76. Faria I, Gaspar C, Zamith M, Matias I, César das Neves R, Rodrigues F, et al. TELEMOLD Project: Oximetry and Exercise Telemonitoring to Improve Long-Term Oxygen Therapy. Telemedicine and e-Health. 2014 Jul;20(7):626–32.

77. Vooijs M, Alpay LL, Snoeck-Stroband JB, Beerthuizen T, Siemonsma PC, Abbink JJ, et al. Validity and Usability of Low-Cost Accelerometers for Internet-Based Self-Monitoring of Physical Activity in Patients With Chronic Obstructive Pulmonary Disease. Interact J Med Res. 2014 Oct 27;3(4):1–10.

78. Perriot B, Argod J, Pepin JL, Noury N. Characterization of Physical Activity in COPD Patients: Validation of a Robust Algorithm for Actigraphic Measurements in Living Situations. IEEE J Biomed Health Inform. 2014 Jul;18(4):1225–31.

79. van der Weegen S, Verwey R, Spreeuwenberg M, Tange H, van der Weijden T, de Witte L. It's LiFe! Mobile and Web-Based Monitoring and Feedback Tool

Embedded in Primary Care Increases Physical Activity: A Cluster Randomized Controlled Trial. J Med Internet Res. 2015 Jul 24;17(7):1–14.

80. Kawagoshi A, Kiyokawa N, Sugawara K, Takahashi H, Sakata S, Satake M, et al. Effects of low-intensity exercise and home-based pulmonary rehabilitation with pedometer feedback on physical activity in elderly patients with chronic obstructive pulmonary disease. Respir Med. 2015 Mar;109(3):364–71.

81. Mendoza L, Horta P, Espinoza J, Aguilera M, Balmaceda N, Castro A, et al. Pedometers to enhance physical activity in COPD: a randomised controlled trial. European Respiratory Journal. 2015 Feb;45(2):347–54.

82. Moy ML, Martinez CH, Kadri R, Roman P, Holleman RG, Kim HM, et al. Long-Term Effects of an Internet-Mediated Pedometer-Based Walking Program for Chronic Obstructive Pulmonary Disease: Randomized Controlled Trial. J Med Internet Res. 2016 Aug 8;18(8):1–14.

83. Verwey R, van der Weegen S, Spreeuwenberg M, Tange H, van der Weijden T, de Witte L. Process evaluation of physical activity counselling with and without the use of mobile technology: A mixed methods study. Int J Nurs Stud. 2016 Jan;53:3–16.

84. McNamara RJ, Tsai LLY, Wootton SL, Ng LWC, Dale MT, McKeough ZJ, et al. Measurement of daily physical activity using the SenseWear Armband. Chron Respir Dis. 2016 May 15;13(2):144–54.

85. K. Lewis L, Hunt T, T. Williams M, English C, S. Olds T. Sedentary Behavior in People with and without a Chronic Health Condition: How Much, What and When? AIMS Public Health. 2016;3(3):503–19.

86. Nolan CM, Maddocks M, Canavan JL, Jones SE, Delogu V, Kaliaraju D, et al. Pedometer Step Count Targets during Pulmonary Rehabilitation in Chronic Obstructive Pulmonary Disease. A Randomized Controlled Trial. Am J Respir Crit Care Med. 2017 May 15;195(10):1344–52.

87. Tillis W, Bond WF, Svendsen J, Guither S. Implementation of Activity Sensor Equipment in the Homes of Chronic Obstructive Pulmonary Disease Patients. Telemedicine and e-Health. 2017 Nov;23(11):920–9.

88. Wu R, Liaqat D, de Lara E, Son T, Rudzicz F, Alshaer H, et al. Feasibility of Using a Smartwatch to Intensively Monitor Patients With Chronic Obstructive Pulmonary Disease: Prospective Cohort Study. JMIR Mhealth Uhealth. 2018 Jun 14;6(6):1–8.

89. Orme MW, Weedon AE, Saukko PM, Esliger DW, Morgan MD, Steiner MC, et al. Findings of the Chronic Obstructive Pulmonary Disease-Sitting and Exacerbations Trial (COPD-SEAT) in Reducing Sedentary Time Using Wearable and Mobile Technologies With Educational Support: Randomized Controlled Feasibility Trial. JMIR Mhealth Uhealth. 2018 Apr 11;6(4):1–15.

90. Lin WY, Verma VK, Lee MY, Lin HC, Lai CS. Prediction of 30-Day Readmission for COPD Patients Using Accelerometer-Based Activity Monitoring. Sensors. 2019 Dec 30;20(1):1–12.

91. Bowler R, Allinder M, Jacobson S, Miller A, Miller B, Tal-Singer R, et al. Real-world use of rescue inhaler sensors, electronic symptom questionnaires and physical activity monitors in COPD. BMJ Open Respir Res. 2019 Feb 18;6(1):1–10.

92. Buekers J, Theunis J, De Boever P, Vaes AW, Koopman M, Janssen EV, et al. Wearable Finger Pulse Oximetry for Continuous Oxygen Saturation Measurements During Daily Home Routines of Patients With Chronic Obstructive Pulmonary Disease (COPD) Over One Week: Observational Study. JMIR Mhealth Uhealth. 2019 Jun 6;7(6):1–15.

93. Orme MW, Steiner MC, Morgan MD, Kingsnorth AP, Esliger DW, Singh SJ, et al. 24-hour accelerometry in COPD: Exploring physical activity, sedentary behavior, sleep and clinical characteristics. Int J Chron Obstruct Pulmon Dis. 2019 Feb;14:419–30.

94. Wu CT, Li GH, Huang CT, Cheng YC, Chen CH, Chien JY, et al. Acute Exacerbation of a Chronic Obstructive Pulmonary Disease Prediction System Using Wearable Device Data, Machine Learning, and Deep Learning: Development and Cohort Study. JMIR Mhealth Uhealth. 2021 May 6;9(5):1–17.

95. Tiwari A, Liaqat S, Liaqat D, Gabel M, de Lara E, Falk TH. Remote COPD Severity and Exacerbation Detection Using Heart Rate and Activity Data Measured from a Wearable Device. In: 2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC). IEEE; 2021. p. 7450–4.

96. Benzo R, Hoult J, McEvoy C, Clark M, Benzo M, Johnson M, et al. Promoting Chronic Obstructive Pulmonary Disease Wellness through Remote Monitoring and Health Coaching: A Clinical Trial. Ann Am Thorac Soc. 2022 Aug 1;19(11):1808–17.

97. Paradiso R, Alonso A, Cianflone D, Milsis A, Vavouras T, Malliopoulos C. Remote health monitoring with wearable non-invasive mobile system: The Healthwear project. In: 2008 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE; 2008. p. 1699–702.

98. Katsaras Th, Milsis A, Rizikari M, Saoulis N, Varoutaki E, Vontetsianos A. The use of the "Healthwear" wearable system in chronic patients' early hospital discharge: Control randomized clinical trial. In: 5th International Symposium on Medical Information and Communication Technology. IEEE; 2011. p. 143–6.

99. Milsis A, Katsaras T, Saoulis N, Varoutaki E, Vontetsianos A. Clinical Effectiveness of the "Healthwear" Wearable System in the Reduction of COPD Patients' Hospitalization. In: International Conference on Wireless Mobile Communication and Healthcare. 2012. p. 54–60.

100. Rajasekaran MP, Radhakrishnan S, Subbaraj P. Ambulatory monitoring of free living patients affected by Chronic Obstructive Pulmonary Disease (COPD) and Parkinson's Disease (PD) using Wireless Sensor Networks. Int J Biomed Eng Technol. 2010;4(2):111–22.

101. Rosso R, Munaro G, Salvetti O, Colantonio S, Ciancitto F. CHRONIOUS: An open, ubiquitous and adaptive chronic disease management platform for Chronic Obstructive Pulmonary Disease (COPD), Chronic Kidney Disease (CKD) and renal insufficiency. In: 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology. IEEE; 2010. p. 6850–3.

102. Bellos C, Papadopoulos A, Rosso R, Fotiadis DI. CHRONIOUS: A wearable platform for monitoring and management of patients with chronic disease. In: Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE; 2011. p. 864–7.

103. Bellos C, Papadopoulos A, Rosso R, Fotiadis DI. Categorization of COPD patient's health level through the use of the CHRONIOUS wearable platform. In: 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE; 2012. p. 61–4.

104. Bellos C, Papadopoulos A, Rosso R, Fotiadis DI. Clinical validation of the CHRONIOUS wearable system in patients with chronic disease. In: 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE; 2013. p. 7084–7.

105. Bellos CC, Papadopoulos A, Rosso R, Fotiadis DI. Identification of COPD Patients' Health Status Using an Intelligent System in the CHRONIOUS Wearable Platform. IEEE J Biomed Health Inform. 2014 May;18(3):731–8.

106. Colantonio S, Govoni L, Dellacà RL, Martinelli M, Salvetti O, Vitacca M. Decision Making Concepts for the Remote, Personalized Evaluation of COPD Patients' Health Status. Methods Inf Med. 2015 Jan 22;54(03):240–7.

107. Xin Xing, Herzog O. Towards Adaptive Decision Support for Individual Persons Suffering from Chronic Diseases. In: IEEE/ACIS 11th International Conference on Computer and Information Science. IEEE; 2012. p. 225–9.

108. Chau JPC, Lee DTF, Yu DSF, Chow AYM, Yu WC, Chair SY, et al. A feasibility study to investigate the acceptability and potential effectiveness of a telecare service for older people with chronic obstructive pulmonary disease. Int J Med Inform. 2012 Oct;81(10):674–82.

109. Pedone C, Chiurco D, Scarlata S, Incalzi RA. Efficacy of multiparametric telemonitoring on respiratory outcomes in elderly people with COPD: a randomized controlled trial. BMC Health Serv Res. 2013 Dec 6;13(1):1–7.

110. Chouvarda I, Philip NY, Natsiavas P, Kilintzis V, Sobnath D, Kayyali R, et al. WELCOME – innovative integrated care platform using wearable sensing and smart cloud computing for COPD patients with comorbidities. In: 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE; 2014. p. 3180–3.

111. Raptopoulos A, Chouvarda I, Kilintzis V, Perantoni E, Kaimakamis V, Maglaveras N, et al. Combining Pervasive Technologies and Cloud Computing for COPD and Comorbidities Management. In: 4th International Conference on Wireless Mobile Communication and Healthcare. Athens, Greece: Institute for Computer Sciences, Social Informatics and Telecommunications Engineering (ICST); 2014. p. 1–5.

112. Wacker J, Chételat O, Rapin M, Meier C, Porchet JA, Chang Y, et al. Electrical and Mechanical Design of a Vest Measuring a Large Set of Physiological Signals. In:

Proceedings of the 4th International Conference on Wireless Mobile Communication and Healthcare - "Transforming healthcare through innovations in mobile and wireless technologies." ICST; 2014. p. 1–4.

113. Sobnath D, Philip N, Kayyali R, Nabhani-Gebara S, Pierscionek B, Raptopoulos A. Mobile self-management application for COPD patients with comorbidities: A usability study. In: IEEE 18th International Conference on e-Health Networking, Applications and Services (Healthcom). IEEE; 2016. p. 1–6.

114. Chetelat O, Wacker J, Rapin M, Porchet JA, Meier C, Fahli A, et al. New biosensors and wearables for cardiorespiratory telemonitoring. In: IEEE-EMBS International Conference on Biomedical and Health Informatics (BHI). IEEE; 2016. p. 481–4.

115. Chouvarda I, Kilintzis V, Beredimas N, Natsiavas P, Perantoni E, Vogiatzis I, et al. Clinical flows and decision support systems for co-ordinated and integrated care in COPD. In: IEEE-EMBS International Conference on Biomedical and Health Informatics (BHI). IEEE; 2016. p. 477–80.

116. Kaimakamis E, Perantoni E, Serasli E, Kilintzis V, Chouvarda I, Cheimariotis GA, et al. Applying translational medicine by Using the WELCOME Remote Monitoring System on Patients with COPD and Comorbidities. In: IEEE EMBS International Conference on Biomedical & Health Informatics (BHI). IEEE; 2019. p. 1–4.

117. Tey CK, An J, Chung WY. A Novel Remote Rehabilitation System with the Fusion of Noninvasive Wearable Device and Motion Sensing for Pulmonary Patients. Comput Math Methods Med. 2017;2017:1–8.

118. Sharma S, Mishra RK. Device to monitor quiet breath of CRD patients. In: EEE 20th International Conference on e-Health Networking, Applications and Services (Healthcom). IEEE; 2018. p. 1–6.

119. Sarmento A, Vignati C, Paolillo S, Lombardi C, Scoccia A, Nicoli F, et al. Qualitative and quantitative evaluation of a new wearable device for ECG and respiratory Holter monitoring. Int J Cardiol. 2018 Dec;272:231–7.

120. Guber A, Epstein Shochet G, Kohn S, Shitrit D. Wrist-Sensor Pulse Oximeter Enables Prolonged Patient Monitoring in Chronic Lung Diseases. J Med Syst. 2019 Jul 14;43(7):1–7.

121. Moraveji N, Holt M, Hollenbach J, Murray R, White H, Crocker M. Adherence to a garment-adhered respiratory force monitor in patients with advanced COPD. In: IEEE 17th International Conference on Wearable and Implantable Body Sensor Networks (BSN). IEEE; 2021. p. 1–4.

122. Polsky M, Moraveji N, Hendricks A, Teresi RK, Murray R, Maselli DJ. Use of Remote Cardiorespiratory Monitoring is Associated with a Reduction in Hospitalizations for Subjects with COPD. Int J Chron Obstruct Pulmon Dis. 2023 Mar;Volume 18:219–29.

123. Angelucci A, Kuller D, Aliverti A. A Home Telemedicine System for Continuous Respiratory Monitoring. IEEE J Biomed Health Inform. 2021 Apr;25(4):1247–56.

124. De Fazio R, Greco MR, De Vittorio M, Visconti P. A Differential Inertial Wearable Device for Breathing Parameter Detection: Hardware and Firmware Development, Experimental Characterization. Sensors. 2022 Dec 16;22(24):1–29.

125. Emokpae LE, Emokpae RN, Bowry E, Bin Saif J, Mahmud M, Lalouani W, et al. A wearable multi-modal acoustic system for breathing analysis. J Acoust Soc Am. 2022 Feb;151(2):1033–8.

126. Arvind DK, Georgescu T, Bao W, Bates CA. A virtual/digital pet Point-of-Care system for self-management of COPD patients. In: IEEE Healthcare Innovations and Point of Care Technologies (HI-POCT). IEEE; 2022. p. 14–7.

127. Martillano D. Wearable Tool for Breathing Pattern Recognition and Exacerbation Monitoring for COPD Patients via a Device-to-Cloud Communication Model. Journal of Communications. 2022;16(6):423–33.

128. Hawthorne G, Richardson M, Greening NJ, Esliger D, Briggs-Price S, Chaplin EJ, et al. A proof of concept for continuous, non-invasive, free-living vital signs monitoring to predict readmission following an acute exacerbation of COPD: a prospective cohort study. Respir Res. 2022 Dec 26;23(1):1–10.

129. Hawthorne G, Greening N, Esliger D, Briggs-Price S, Richardson M, Chaplin E, et al. Usability of Wearable Multiparameter Technology to Continuously Monitor Free-Living Vital Signs in People Living With Chronic Obstructive Pulmonary Disease: Prospective Observational Study. JMIR Hum Factors. 2022 Feb 16;9(1):1–12.

130. Kuhn M, Nalbant E, Kohlbrenner D, Alge M, Kuett L, Arvaji A, et al. Validation of a Small Cough Detector. ERJ Open Res. 2023 Jan;9(1):1–27.

131. Oxitone. Oxitone 1000M Home Page [Internet]. [cited 2023 Jun 20]. Available from: https://www.oxitone.com/oxitone-1000m/

132. Spire Health. Spire Health Home Page [Internet]. [cited 2023 Jun 19]. Available from: https://www.spirehealth.com/

133. AirGo. Airgo Home Page. [cited 2023 Jun 19]; Available from: https://www.myairgo.com/

134. Kickstarter. WearME | 4-in-1 Wearable to improve your health and fitness. [cited 2023 Jun 19]; Available from: https://www.kickstarter.com/projects/1288458422/wearme-your-advanced-wearable-companion

135. equivital. eq lifemonitor. [cited 2023 Jun 19]; Available from: https://equivital.com/products/eq02-lifemonitor

136. Siva Health. SIVA Home Page. [cited 2023 Jun 19]; Available from: https://www.siva-health.com/

137. Wu R. A Wearable and a Self-management Application for Chronic Obstructive Pulmonary Disease (COPD) Patients at Home (COPDwear). 2023 May. Report No.: NCT03857061.

138. de Graaf D. The ADAPT-study: Measuring Physical Performance Using Wearable Sensors in Parkinson's Disease and COPD (ADAPT) (ADAPT). 2023 Mar. Report No.: NCT05756075.

139. Kaul S. REMAP-WEST-FLARE - FLAg for Review Efficacy Investigation (REMAPWESTFLARE). 2023 Feb. Report No.: NCT05745155.

140. Brunschwiler T, Straessle R, Weiss J, Michel B, Van Kessel T, Ko BJ, et al. CAir: Mobile-health intervention for COPD patients. In: 2017 IEEE 19th International Conference on e-Health Networking, Applications and Services (Healthcom). IEEE; 2017. p. 1–3.

141. cossinuss. OxMotion - Motivation and guidance for COPD affected people through safe exercise [Internet]. [cited 2023 Jun 19]. Available from: https://www.cosinuss.com/en/use-cases/copd/

142. Current Health. Current Health Web Page [Internet]. [cited 2023 Jun 19]. Available from: https://www.currenthealth.com/

143. Health Care Originals. ADAMM-RSM-TM: For Telemedicine [Internet]. [cited 2023 Jun 19]. Available from: https://healthcareoriginals.com/professional/telemed/

144. Pericleous P, Van Staa TP. The use of wearable technology to monitor physical activity in patients with COPD: a literature review. Int J Chron Obstruct Pulmon Dis. 2019 Jun;Volume 14:1317–22.

145. Pépin JL, Degano B, Tamisier R, Viglino D. Remote Monitoring for Prediction and Management of Acute Exacerbations in Chronic Obstructive Pulmonary Disease (AECOPD). Life. 2022 Mar 29;12(4):1–9.

146. Vegesna A, Tran M, Angelaccio M, Arcona S. Remote Patient Monitoring via Non-Invasive Digital Technologies: A Systematic Review. Telemedicine and e-Health. 2017 Jan;23(1):3–17.

147. Davis MM, Freeman M, Kaye J, Vuckovic N, Buckley DI. A Systematic Review of Clinician and Staff Views on the Acceptability of Incorporating Remote Monitoring Technology into Primary Care. Telemedicine and e-Health. 2014 May;20(5):428–38.

148. Simon DA, Shachar C, Cohen IG. Skating the line between general wellness products and regulated devices: strategies and implications. J Law Biosci. 2022 Jul 1;9(2):1–22.

149. Tase A, Vadhwana B, Buckle P, Hanna GB. Usability challenges in the use of medical devices in the home environment: A systematic review of literature. Appl Ergon. 2022 Sep;103:1–8.

150. Grubert J, Kranz M, Quigley A. Challenges in mobile multi-device ecosystems. mUX: The Journal of Mobile User Experience. 2016 Dec 26;5(1):1–22.

151. Sharma A, Badea M, Tiwari S, Marty JL. Wearable Biosensors: An Alternative and Practical Approach in Healthcare and Disease Monitoring. Molecules. 2021 Feb 1;26(3):1–32.

152. Cruz J, Brooks D, Marques A. Home telemonitoring in COPD: a systematic review of methodologies and patients' adherence. Int J Med Inform. 2014 Apr;83(4):249–63.

153. Avdeev SN, Vizel AA, Abrosimov VN, Zaicev AA, Ignatova GL, Khamitov RF, et al. Management of Cough in Patients with Chronic Obstructive Pulmonary Disease: Results of the Multicenter Randomized Placebo-Controlled Clinical Trial. Int J Chron Obstruct Pulmon Dis. 2021 May;Volume 16:1243–53.

154. Adler D, Bailly S, Benmerad M, Joyeux-Faure M, Jullian-Desayes I, Soccal PM, et al. Clinical presentation and comorbidities of obstructive sleep apnea-COPD overlap syndrome. PLoS One. 2020 Jul 9;15(7):1–14.

155. Mansouri S, Alharbi Y, Haddad F, Chabcoub S, Alshrouf A, Abd-Elghany AA. Electrical Impedance tomography – recent applications and developments. J Electr Bioimpedance. 2021 Jan 1;12(1):50–62.

156. Garcia-Rio F, Rojo B, Casitas R, Lores V, Madero R, Romero D, et al. Prognostic Value of the Objective Measurement of Daily Physical Activity in Patients With COPD. Chest. 2012 Aug;142(2):338–46.

157. De Fazio R, Stabile M, De Vittorio M, Velázquez R, Visconti P. An Overview of Wearable Piezoresistive and Inertial Sensors for Respiration Rate Monitoring. Electronics (Basel). 2021 Sep 6;10(17):1–35.

158. Dangi R, Lalwani P, Choudhary G, You I, Pau G. Study and Investigation on 5G Technology: A Systematic Review. Sensors. 2021 Dec 22;22(1):1–32.

159. Wu RC, Ginsburg S, Son T, Gershon AS. Using wearables and self-management apps in patients with COPD: a qualitative study. ERJ Open Res. 2019 Jul 10;5(3):1–9.

160. Inskip JA, Lauscher HN, Li LC, Dumont GA, Garde A, Ho K, et al. Patient and health care professional perspectives on using telehealth to deliver pulmonary rehabilitation. Chron Respir Dis. 2018 Feb;15(1):71–80.

161. Benz HL, Saha A, Tarver ME. Integrating the Voice of the Patient Into the Medical Device Regulatory Process Using Patient Preference Information. Value in Health. 2020 Mar;23(3):294–7.

8. Appendix 1 – Search Strategy

PubMed

1	COPD[MeSH Terms] OR COPD[Title/Abstract]
2	chronic obstructive pulmonary disease[MeSH Terms] OR "chronic obstructive pulmonary disease"[Title/Abstract]
3	Chronic Obstructive Lung Disease[MeSH Terms] OR “chronic obstructive lung disease”[Title/Abstract]
4	bronchitis[MeSH Terms] OR bronchitis[Title/Abstract]
5	emphysema[MeSH Terms] OR emphysema[Title/Abstract]
6	"Acute exacerbation of COPD"[Title/Abstract]
7	"Acute exacerbation of Chronic Obstructive Pulmonary Disease"[Title/Abstract]
8	AECOPD[Title/Abstract]
9	#1 or #2 or #3 or #4 or #5 or #6 or #7 or #8
10	wearable medical devices[MeSH Terms] OR wearab*[Title/Abstract]
11	wireless[Title/Abstract]
12	Hands-free[Title/Abstract] OR "hands free"[Title/Abstract]
13	Contactless[Title/Abstract]
14	sensor[Title/Abstract]
15	sensing[Title/Abstract]
16	Biosens*[Title/Abstract] OR biosensor[MeSH Terms]
17	sensor-based[Title/Abstract] OR "sensor based"[Title/Abstract] OR sensor-enabled[Title/Abstract] OR "sensor enabled"[Title/Abstract]
18	"Minimally-invasive"[Title/Abstract] OR "Minimal* Invasive"[Title/Abstract]
19	Non-invasive[Title/Abstract] OR "Non invasive"[Title/Abstract] OR "no* invasive"[Title/Abstract]
20	"skin attached"[Title/Abstract] OR skin-attached[Title/Abstract]
21	“Clothes-attached”[Title/Abstract] OR “Clothing-attached”[Title/Abstract] OR “Clothes attached”[Title/Abstract] OR “Clothing attached”[Title/Abstract] OR “Garment-attached”[Title/Abstract] OR “Garment attached”[Title/Abstract] OR “Fabric attached”[Title/Abstract] OR “Fabric-attached”[Title/Abstract]
22	#10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 or #20 or #21
23	ambulatory monitoring[MeSH Terms]
24	telemonitor*[Title/Abstract]
25	telemanag*[Title/Abstract]
26	teleassess*[Title/Abstract]
27	telehealth[Title/Abstract] OR telehealth[MeSH Terms]
28	telemedicine[MeSH Terms] OR telemedicine[Title/Abstract]
29	e-health[Title/Abstract] OR ehealth[Title/Abstract]
30	m-health[Title/Abstract] OR mhealth[Title/Abstract]
31	“digital Health”[Title/Abstract]
32	"home monitor*"[Title/Abstract] OR "Home monitoring"[Title/Abstract:~2]
33	"home manag*"[Title/Abstract] OR "Home management"[Title/Abstract:~2]
34	"home assess*"[Title/Abstract] OR "Home assessment"[Title/Abstract:~2]
35	"remote monitor*"[Title/Abstract] OR "Remote monitoring"[Title/Abstract:~2]
36	"remote manag*"[Title/Abstract] OR "Remote management"[Title/Abstract:~2]
37	"Remote assessment"[Title/Abstract:~2] OR "remote assess*"[Title/Abstract]
38	"mobile monitoring"[Title/Abstract:~2] OR "mobile monitor*"[Title/Abstract]
39	"mobile assessment"[Title/Abstract:~2] OR "mobile assess*"[Title/Abstract]
40	"mobile management"[Title/Abstract:~2] OR "mobile manag*"[Title/Abstract]
41	"continuous monitoring"[Title/Abstract:~2] OR "continuous monitor*"[Title/Abstract]
42	"continuous management"[Title/Abstract:~2] OR "continuous manag*"[Title/Abstract]
43	"continuous assessment"[Title/Abstract:~2] OR "continuous assess*"[Title/Abstract]
44	"distant monitoring"[Title/Abstract:~2] OR "distant monitor*"[Title/Abstract]
45	"distant management"[Title/Abstract:~2] OR "distant manag*"[Title/Abstract]
46	"distant assessment"[Title/Abstract:~2] OR "distant assess*"[Title/Abstract]
47	"ambulatory monitoring"[Title/Abstract:~2] OR "ambulatory monitor*"[Title/Abstract]
48	"ambulatory management"[Title/Abstract:~2] OR "ambulatory manag*"[Title/Abstract]
49	"ambulatory assessment"[Title/Abstract:~2] OR "ambulatory assess*"[Title/Abstract]
50	#23 or #24 or #25 or #26 or #27 or #28 or #29 or #30 or #31 or #32 or #33 or #34 or #35 or #36 or #37 or #38 or #39 or #40 or #41 or #42 or #43 or #44 or #45 or #46 or #47 or #48 or #49
51	#9 and #22 and #50

Cochrane Library (Cochrane Central Register of Controlled Trials (CENTRAL))

1	MeSH descriptor: [Pulmonary Disease, Chronic Obstructive] explode all trees
2	(COPD):ti,ab,kw
3	(“chronic obstructive pulmonary disease”):ti,ab,kw
4	(“chronic obstructive lung disease”):ti,ab,kw
5	(bronchitis):ti,ab,kw
6	(emphysema):ti,ab,kw
7	(“Acute exacerbation of COPD”):ti,ab,kw
8	(“Acute exacerbation of Chronic Obstructive Pulmonary Disease”):ti,ab,kw

9	(AECOPD):ti,ab,kw
10	#1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9
11	MeSH descriptor: [Wearable Electronic Devices] explode all trees
12	(wearab*):ti,ab,kw
13	(wireless):ti,ab,kw
14	(Hands-free):ti,ab,kw OR (“hands free”):ti,ab,kw
15	(Contactless):ti,ab,kw
16	(sensor):ti,ab,kw
17	(sensing):ti,ab,kw
18	(Biosens*):ti,ab,kw
19	(“sensor based”):ti,ab,kw OR (sensor-based):ti,ab,kw OR (sensor-enabled):ti,ab,kw OR (“sensor enabled”):ti,ab,kw
20	(Minimally-invasive):ti,ab,kw OR ("Minimal* Invasive"):ti,ab,kw
21	(Non-invasive):ti,ab,kw OR (“Non invasive”):ti,ab,kw OR (“no* invasive”):ti,ab,kw
22	(“skin attached”):ti,ab,kw OR (skin-attached):ti,ab,kw
23	(clothing-attached):ti,ab,kw OR (clothes-attached):ti,ab,kw OR (garment-attached):ti,ab,kw OR (“garment attached”):ti,ab,kw or (fabric-attached):ti,ab,kw or (“fabric attached”):ti,ab,kw
24	#11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 or #20 or #21 or #22 or #23
25	MeSH descriptor: [Telemetry] explode all trees
26	(telemonitor*):ti,ab,kw
27	(telemanag*):ti,ab,kw
28	(teleassess*):ti,ab,kw
29	(telehealth):ti,ab,kw
30	(telemedicine):ti,ab,kw OR MeSH descriptor: [Telemedicine] explode all trees
31	(e-health):ti,ab,kw OR (ehealth):ti,ab,kw
32	(m-health):ti,ab,kw OR (mhealth):ti,ab,kw
33	(“digital health”):ti,ab,kw
34	(home NEAR/2 monitor*):ti,ab,kw
35	(home NEAR/2 manag*):ti,ab,kw
36	(home NEAR/2 assess*):ti,ab,kw
37	(remote NEAR/2 monitor*):ti,ab,kw
38	(remote NEAR/2 manag*):ti,ab,kw
39	(remote NEAR/2 assess*):ti,ab,kw
40	(mobile NEAR/2 monitor*):ti,ab,kw
41	(mobile NEAR/2 assess*):ti,ab,kw
42	(mobile NEAR/2 manag*):ti,ab,kw
43	(continuous NEAR/2 monitor*):ti,ab,kw
44	(continuous NEAR/2 manag*):ti,ab,kw
45	(continuous NEAR/2 assess*):ti,ab,kw
46	(distant NEAR/2 monitor*):ti,ab,kw
47	(distant NEAR/2 manag*):ti,ab,kw
48	(distant NEAR/2 assess*):ti,ab,kw
49	(ambulatory NEAR/2 monitor*):ti,ab,kw
50	(ambulatory NEAR/2 manag*):ti,ab,kw
51	(ambulatory NEAR/2 assess*):ti,ab,kw
52	25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49 or 50 or 51
53	10 and 24 and 52

ISI Web of Science

1	TS=(COPD)
2	TS=("Chronic Obstructive Pulmonary Disease")
3	TS=("Chronic Obstructive Lung Disease")
4	TS=(bronchitis)
5	TS=(emphysema)
6	TS=(“Acute exacerbation of COPD”)
7	TS=(“Acute exacerbation of Chronic Obstructive Pulmonary Disease”)
8	TS=(AECOPD)
9	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8
10	TS=(Wearab*)
11	TS=(“Wireless Sens*”)
12	TS=(Contactless)
13	TS=(Sensor)
14	TS=(Sensing)
15	TS=(Biosens*)
16	TS=(Hands-free) OR TS=(“Hands free”)
17	TS=(Sensor-Based) OR TS=(“Sensor Based”) OR TS=(Sensor-Enabled) OR TS=(“Sensor Enabled”)
18	TS=(“Minimal* Invasive”) OR TS=(Minimally-invasive)
19	TS=(Non-Invasive) OR TS=(“Non Invasive”) OR TS=(“No* Invasive”)
20	TS=(Skin-attached) OR TS=(“Skin attached”)
21	TS=(Clothes-attached) OR TS=(Clothing-attached) OR TS=(“Clothes attached”) OR TS=(“Clothing attached”) OR TS=(Garment-attached) OR TS=(“Garment attached”) OR TS=(“Fabric attached”) OR TS=(Fabric-attached)

22	10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21
23	TS=(Telemonitor*)
24	TS=(Telemanag*)
25	TS=(Teleassess*)
26	TS=(Telemetry)
27	TS=(Telehealth)
28	TS=(Telemedicine)
29	TS=(e-health) OR TS=(ehealth)
30	TS=(m-health) OR TS=(mhealth)
31	TS=("Digital health")
32	TS=(Home NEAR/2 monitor*)
33	TS=(Home NEAR/2 manag*)
34	TS=(Home NEAR/2 assess*)
35	TS=(Remote NEAR/2 monitor*)
36	TS=(Remote NEAR/2 assess*)
37	TS=(Remote NEAR/2 manag*)
38	TS=(Mobile NEAR/2 monitor*)
39	TS=(Mobile NEAR/2 manag*)
40	TS=(Mobile NEAR/2 Assess*)
41	TS=(Continuous NEAR/2 monitor*)
42	TS=(Continuous NEAR/2 assess*)
43	TS=(Continuous NEAR/2 manag*)
44	TS=(Distant NEAR/2 monitor*)
45	TS=(Distant NEAR/2 assess*)
46	TS=(Distant NEAR/2 manag*)
47	TS=(Ambulatory NEAR/2 monitor*)
48	TS=(Ambulatory NEAR/2 assess*)
49	TS=(Ambulatory NEAR/2 manag*)
50	23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49
51	9 and 22 and 50

Scopus

1	TITLE-ABS-KEY (COPD)
2	TITLE-ABS-KEY({chronic obstructive pulmonary disease})
3	TITLE-ABS-KEY({Chronic Obstructive Lung Disease})
4	TITLE-ABS-KEY(bronchitis)
5	TITLE-ABS-KEY(emphysema)
6	TITLE-ABS-KEY({Acute exacerbation of COPD})
7	TITLE-ABS-KEY({Acute exacerbation of Chronic Obstructive Pulmonary Disease})
8	TITLE-ABS-KEY(AECOPD)
9	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8
10	TITLE-ABS-KEY(wearab*)
11	TITLE-ABS-KEY(wireless)
12	TITLE-ABS-KEY(Hands-free) OR TITLE-ABS-KEY({hands free})
13	TITLE-ABS-KEY(Contactless)
14	TITLE-ABS-KEY(sensor)
15	TITLE-ABS-KEY(sensing)
16	TITLE-ABS-KEY(Biosens*)
17	TITLE-ABS-KEY({sensor based}) OR TITLE-ABS-KEY(sensor-based) OR TITLE-ABS-KEY(sensor-enabled) OR TITLE-ABS-KEY({sensor enabled})
18	TITLE-ABS-KEY(Minimally-invasive) OR TITLE-ABS-KEY({Minimal* Invasive})
19	TITLE-ABS-KEY(Non-invasive) OR TITLE-ABS-KEY({Non invasive}) OR TITLE-ABS-KEY({no* invasive})
20	TITLE-ABS-KEY({skin attached}) OR TITLE-ABS-KEY(skin-attached)
21	TITLE-ABS-KEY(clothing-attached) OR TITLE-ABS-KEY(clothes-attached) OR TITLE-ABS-KEY(garment-attached) OR TITLE-ABS-KEY({garment attached}) OR TITLE-ABS-KEY(fabric-attached) OR TITLE-ABS-KEY({fabric attached})
22	10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21
23	TITLE-ABS-KEY(telemonitor*)
24	TITLE-ABS-KEY(telemanag*)
25	TITLE-ABS-KEY(teleassess*)
26	TITLE-ABS-KEY(telehealth)
27	TITLE-ABS-KEY(telemedicine)
28	TITLE-ABS-KEY(e-health) OR TITLE-ABS-KEY(ehealth)
29	TITLE-ABS-KEY(m-health) OR TITLE-ABS-KEY(mhealth)
30	TITLE-ABS-KEY({digital health})
31	TITLE-ABS-KEY(home W/2 monitor*)
32	TITLE-ABS-KEY(home W/2 manag*)
33	TITLE-ABS-KEY(home W/2 assess*)
34	TITLE-ABS-KEY(remote W/2 monitor*)
35	TITLE-ABS-KEY(remote W/2 manag*)
36	TITLE-ABS-KEY(remote W/2 assess*)

37	TITLE-ABS-KEY(mobile W/2 monitor*)
38	TITLE-ABS-KEY(mobile W/2 assess*)
39	TITLE-ABS-KEY(mobile W/2 manag*)
40	TITLE-ABS-KEY(continuous W/2 monitor*)
41	TITLE-ABS-KEY(continuous W/2 manag*)
42	TITLE-ABS-KEY(continuous W/2 assess*)
43	TITLE-ABS-KEY(distant W/2 monitor*)
44	TITLE-ABS-KEY(distant W/2 manag*)
45	TITLE-ABS-KEY(distant W/2 assess*)
46	TITLE-ABS-KEY(ambulatory W/2 monitor*)
47	TITLE-ABS-KEY(ambulatory W/2 manag*)
48	TITLE-ABS-KEY(ambulatory W/2 assess*)
49	23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48
50	9 and 22 and 49

IEEE Xplore Digital

1	All Metadata:COPD
2	All Metadata:“chronic obstructive pulmonary disease”
3	All Metadata:“chronic obstructive lung disease”
4	All Metadata:bronchitis
5	All Metadata:emphysema
6	All Metadata:“Acute exacerbation of COPD”
7	All Metadata:“Acute exacerbation of Chronic Obstructive Pulmonary Disease”
8	All Metadata:AECOPD
9	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8
10	All Metadata:wearab*
11	All Metadata:wireless
12	All Metadata:Hands-free OR All Metadata:“hands free”
13	All Metadata:Contactless
14	All Metadata:sensor
15	All Metadata:sensing
16	All Metadata:Biosens*
17	All Metadata:“sensor based” OR All Metadata:sensor-based OR All Metadata:sensor-enabled OR All Metadata:“sensor enabled”
18	All Metadata:Minimally-invasive OR All Metadata:"Minimal* Invasive"
19	All Metadata:Non-invasive OR All Metadata:“Non invasive” OR All Metadata:“no* invasive”
20	All Metadata:“skin attached” OR All Metadata:skin-attached
21	All Metadata:clothing-attached OR All Metadata:clothes-attached OR All Metadata:“clothing attached” OR All Metadata:“clothes attached” OR All Metadata:garment-attached OR All Metadata:“garment attached” OR All Metadata:fabric-attached OR All Metadata:“fabric attached”
22	10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21
23	All Metadata:telemonitor*
24	All Metadata:telemanag*
25	All Metadata:teleassess*
26	All Metadata:telehealth
27	All Metadata:telemedicine
28	All Metadata:e-health OR All Metadata:ehealth
29	All Metadata:m-health OR All Metadata:mhealth
30	All Metadata:“digital health”
31	All Metadata:home NEAR/2 monitor*
32	All Metadata:home NEAR/2 manag*
33	All Metadata:home NEAR/2 assess*
34	All Metadata:remote NEAR/2 monitor*
35	All Metadata:remote NEAR/2 manag*
36	All Metadata:remote NEAR/2 assess*
37	All Metadata:mobile NEAR/2 monitor*
38	All Metadata:mobile NEAR/2 assess*
39	All Metadata:mobile NEAR/2 manag*
40	All Metadata:continuous NEAR/2 monitor*
41	All Metadata:continuous NEAR/2 manag*
42	All Metadata:continuous NEAR/2 assess*
43	All Metadata:distant NEAR/2 monitor*
44	All Metadata:distant NEAR/2 manag*
45	All Metadata:distant NEAR/2 assess*
46	All Metadata:ambulatory NEAR/2 monitor*
47	All Metadata:ambulatory NEAR/2 manag*
48	All Metadata:ambulatory NEAR/2 assess*
49	23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48
50	9 and 22 and 49

ClinicalTrials.gov

1	Condition or Disease: COPD
2	Condition or Disease: “chronic obstructive pulmonary disease”
3	Condition or Disease: “chronic obstructive lung disease”
4	Condition or Disease: bronchitis
5	Condition or Disease: emphysema
6	Condition or Disease: “Acute exacerbation of COPD”
7	Condition or Disease: “Acute exacerbation of Chronic Obstructive Pulmonary Disease”
8	Condition or Disease: AECOPD
9	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8
10	Other terms: wearable
11	Other terms: wireless
12	Other terms: Hands-free OR Other terms: “hands free”
13	Other terms: Contactless
14	Other terms: sensor
15	Other terms: sensing
16	Other terms: Biosensor OR Other terms: Biosensing
17	Other terms: “sensor based” OR Other terms: sensor-based OROther terms: sensor-enabled OR Other terms: “sensor enabled”
18	Other terms: Minimally-invasive OR Other terms: "Minimally Invasive"
19	Other terms: Non-invasive OR Other terms: “Non invasive”
20	Other terms:“skin attached” OR Other terms: skin-attached
21	Other terms: clothing-attached OR Other terms: clothes-attached OR Other terms: garment-attached OROther terms: “garment attached” OR Other terms: “fabric attached” OR Other terms: fabric-attached
22	10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21
23	Intervention/Treatment: telemonitor*
24	Intervention/Treatment: telemanag*
25	Intervention/Treatment: teleassess*
26	Intervention/Treatment: telehealth
27	Intervention/Treatment: telemedicine
28	Intervention/Treatment: e-health OR Intervention/Treatment: ehealth
29	Intervention/Treatment: m-health OR Intervention/Treatment: mhealth
30	Intervention/Treatment: “digital Health”
31	Intervention/Treatment: “home monitoring”
32	Intervention/Treatment: “home management”
33	Intervention/Treatment: “home assessment”
34	Intervention/Treatment: “remote monitoring”
35	Intervention/Treatment: “remote management”
36	Intervention/Treatment: “remote assessment”
37	Intervention/Treatment: “mobile monitoring”
38	Intervention/Treatment: “mobile assessment”
39	Intervention/Treatment: “mobile management”
40	Intervention/Treatment: “continuous monitoring”
41	Intervention/Treatment: “continuous management”
42	Intervention/Treatment: “continuous assessment”
43	Intervention/Treatment: “distant monitoring”
44	Intervention/Treatment: “distant management”
45	Intervention/Treatment: “distant assessment”
46	Intervention/Treatment: “ambulatory monitoring”
47	Intervention/Treatment: “ambulatory management”
48	Intervention/Treatment: “ambulatory assessment”
49	23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48
50	9 and 22 and 49

OAIster

1	kw:COPD
2	kw:“chronic obstructive pulmonary disease”
3	kw:“chronic obstructive lung disease”
4	kw:bronchitis
5	kw:emphysema
6	kw:“Acute exacerbation of COPD”
7	kw:“Acute exacerbation of Chronic Obstructive Pulmonary Disease”
8	kw:AECOPD
9	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8
10	ti:wearable
11	ti:wireless
12	ti:hands-free OR ti:”hands free”
13	ti:contactless
14	ti:sensor
15	ti:sensing

16	ti:biosensor or kw:biosensing
17	ti:”sensor based” OR ti:sensor-based OR ti:sensor-enabled OR ti:“sensor enabled”
18	ti:Minimally-invasive OR ti:"Minimally Invasive"
19	ti:Non-invasive OR ti:“Non invasive”
20	ti:“skin attached” OR ti:skin-attached
21	ti:clothing-attached OR ti:clothes-attached OR ti:”clothing attached” OR ti:”clothes attached” OR ti:garment-attached OR ti:“garment attached” OR ti:fabric-attached OR ti:”fabric attached”
22	10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21
23	ti:telemonitoring
24	ti:telemanagement
25	ti:teleassessment
26	ti:telehealth
27	ti:telemedicine
28	ti:e-health OR kw:ehealth
29	ti:m-health OR kw:mhealth
30	ti:“digital Health”
31	ti:“home monitoring”
32	ti:“home management”
33	ti:“home assessment”
34	ti:“remote monitoring”
35	ti:“remote management”
36	ti:“remote assessment”
37	ti:“mobile monitoring”
38	ti:“mobile assessment”
39	ti:“mobile management”
40	ti:“continuous monitoring”
41	ti:“continuous management”
42	ti:“continuous assessment”
43	ti:“distant monitoring”
44	ti:“distant management”
45	ti:“distant assessment”
46	ti:“ambulatory monitoring”
47	ti:“ambulatory management”
48	ti:“ambulatory assessment”
49	23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48
50	9 and 22 and 49

ANZCTR

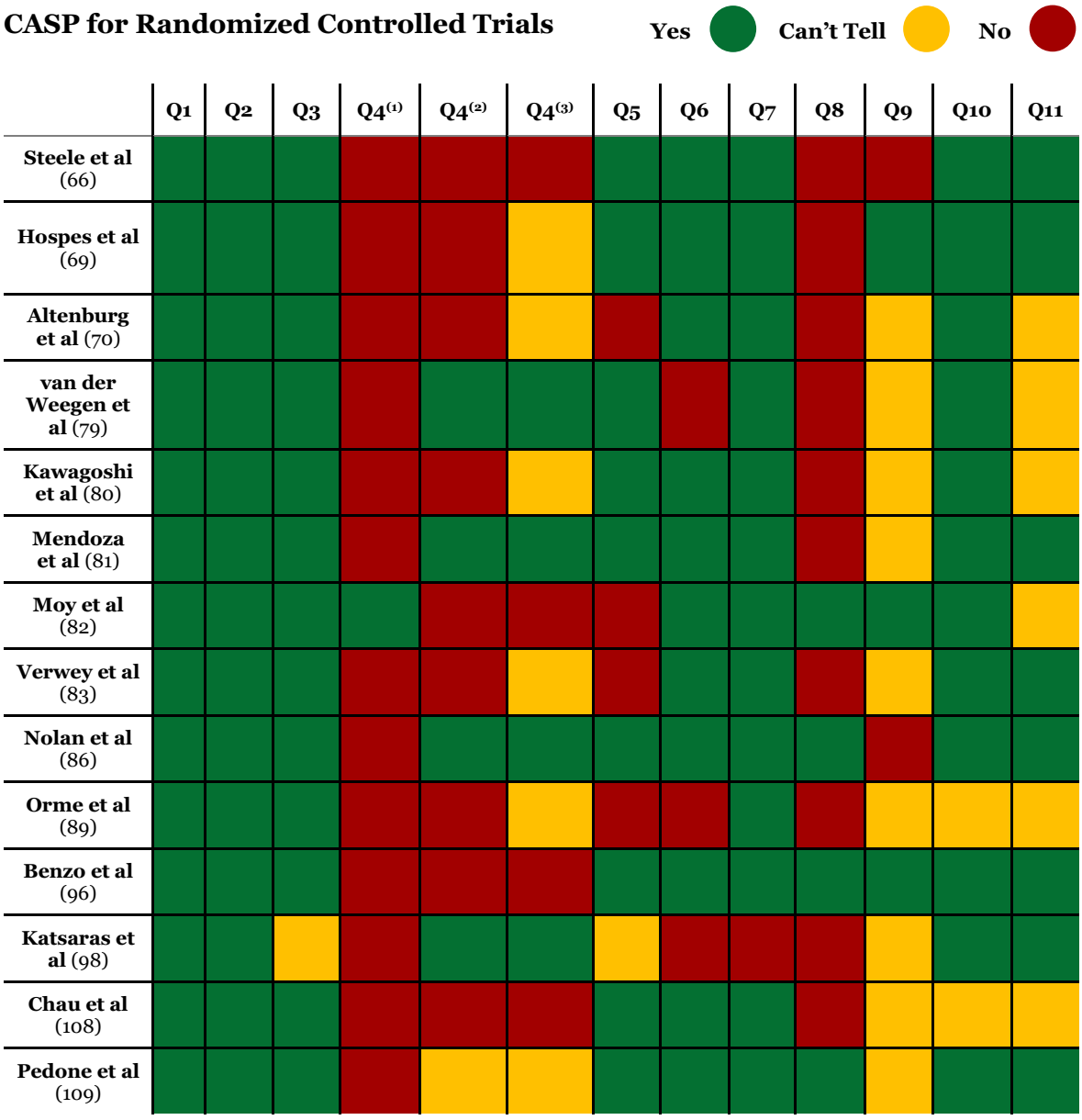
1	COPD AND wearab*
2	COPD AND wireless
3	COPD AND (Hands-free OR “hands free”)
4	COPD AND Contactless
5	COPD AND sensor
6	COPD AND sensing
7	COPD AND Biosens*
8	COPD AND (”sensor based” OR sensor-based OR sensor-enabled OR “sensor enabled”)
9	COPD AND (Minimally-invasive OR "Minimal* Invasive")
10	COPD AND (Non-invasive OR “Non invasive” OR “no* invasive”)
11	COPD AND (“skin attached” OR skin-attached)
12	COPD AND (clothing-attached OR clothes-attached OR ”clothing attached” OR ”clothes attached” OR garment-attached OR “garment attached” OR fabric-attached OR ”fabric attached”)
13	“chronic obstructive pulmonary disease” AND wearab*
14	“chronic obstructive pulmonary disease” AND wireless
15	“chronic obstructive pulmonary disease” AND (Hands-free OR “hands free”)
16	“chronic obstructive pulmonary disease” AND Contactless
17	“chronic obstructive pulmonary disease” AND sensor
18	“chronic obstructive pulmonary disease” AND sensing
19	“chronic obstructive pulmonary disease” AND Biosens*
20	“chronic obstructive pulmonary disease” AND (”sensor based” OR sensor-based OR sensor-enabled OR “sensor enabled”)
21	“chronic obstructive pulmonary disease” AND (Minimally-invasive OR "Minimal* Invasive")
22	“chronic obstructive pulmonary disease” AND (Non-invasive OR “Non invasive” OR “no* invasive”)
23	“chronic obstructive pulmonary disease” AND (“skin attached” OR skin-attached)
24	“chronic obstructive pulmonary disease” AND (clothing-attached OR clothes-attached OR ”clothing attached” OR ”clothes attached” OR garment-attached OR “garment attached” OR fabric-attached OR ”fabric attached”)
25	“Chronic Obstructive Lung Disease” AND wearab*
26	“Chronic Obstructive Lung Disease” AND wireless
27	“Chronic Obstructive Lung Disease” AND (Hands-free OR “hands free”)
28	“Chronic Obstructive Lung Disease” AND Contactless
29	“Chronic Obstructive Lung Disease” AND sensor
30	“Chronic Obstructive Lung Disease” AND sensing

31	“Chronic Obstructive Lung Disease” AND Biosens*
32	“Chronic Obstructive Lung Disease” AND (”sensor based” OR sensor-based OR sensor-enabled OR “sensor enabled”)
33	“Chronic Obstructive Lung Disease” AND (Minimally-invasive OR "Minimal* Invasive")
34	“Chronic Obstructive Lung Disease” AND (Non-invasive OR “Non invasive” OR “no* invasive”)
35	“Chronic Obstructive Lung Disease” AND (“skin attached” OR skin-attached)
36	“Chronic Obstructive Lung Disease” AND (clothing-attached OR clothes-attached OR ”clothing attached” OR ”clothes attached” OR garment-attached OR “garment attached” OR fabric-attached OR ”fabric attached”)
37	bronchitis AND wearab*
38	bronchitis AND wireless
39	bronchitis AND (Hands-free OR “hands free”)
40	bronchitis AND Contactless
41	bronchitis AND sensor
42	bronchitis AND sensing
43	bronchitis AND Biosens*
44	bronchitis AND (”sensor based” OR sensor-based OR sensor-enabled OR “sensor enabled”)
45	bronchitis AND (Minimally-invasive OR "Minimal* Invasive")
46	bronchitis AND (Non-invasive OR “Non invasive” OR “no* invasive”)
47	bronchitis AND (“skin attached” OR skin-attached)
48	bronchitis AND (clothing-attached OR clothes-attached OR ”clothing attached” OR ”clothes attached” OR garment-attached OR “garment attached” OR fabric-attached OR ”fabric attached”)
49	emphysema AND wearab*
50	emphysema AND wireless
51	emphysema AND (Hands-free OR “hands free”)
52	emphysema AND Contactless
53	emphysema AND sensor
54	emphysema AND sensing
55	emphysema AND Biosens*
56	emphysema AND (”sensor based” OR sensor-based OR sensor-enabled OR “sensor enabled”)
57	emphysema AND (Minimally-invasive OR "Minimal* Invasive")
58	emphysema AND (Non-invasive OR “Non invasive” OR “no* invasive”)
59	emphysema AND (“skin attached” OR skin-attached)
60	emphysema AND (clothing-attached OR clothes-attached OR ”clothing attached” OR ”clothes attached” OR garment-attached OR “garment attached” OR fabric-attached OR ”fabric attached”)
61	“Acute exacerbation of COPD” AND wearab*
62	“Acute exacerbation of COPD” AND wireless
63	“Acute exacerbation of COPD” AND (Hands-free OR “hands free”)
64	“Acute exacerbation of COPD” AND Contactless
65	“Acute exacerbation of COPD” AND sensor
66	“Acute exacerbation of COPD” AND sensing
67	“Acute exacerbation of COPD” AND Biosens*
68	“Acute exacerbation of COPD” AND (”sensor based” OR sensor-based OR sensor-enabled OR “sensor enabled”)
69	“Acute exacerbation of COPD” AND (Minimally-invasive OR "Minimal* Invasive")
70	“Acute exacerbation of COPD” AND (Non-invasive OR “Non invasive” OR “no* invasive”)
71	“Acute exacerbation of COPD” AND (“skin attached” OR skin-attached)
72	“Acute exacerbation of COPD” AND (clothing-attached OR clothes-attached OR ”clothing attached” OR ”clothes attached” OR garment-attached OR “garment attached” OR fabric-attached OR ”fabric attached”)
73	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND wearab*
74	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND wireless
75	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND (Hands-free OR “hands free”)
76	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND Contactless
77	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND sensor
78	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND sensing
79	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND Biosens*
80	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND (”sensor based” OR sensor-based OR sensor-enabled OR “sensor enabled”)
81	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND (Minimally-invasive OR "Minimal* Invasive")
82	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND (Non-invasive OR “Non invasive” OR “no* invasive”)
83	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND (“skin attached” OR skin-attached)
84	“Acute exacerbation of Chronic Obstructive Pulmonary Disease” AND (clothing-attached OR clothes-attached OR ”clothing attached” OR ”clothes attached” OR garment-attached OR “garment attached” OR fabric-attached OR ”fabric attached”)
85	AECOPD AND wearab*
86	AECOPD AND wireless
87	AECOPD AND (Hands-free OR “hands free”)
88	AECOPD AND Contactless
89	AECOPD AND sensor
90	AECOPD AND sensing
91	AECOPD AND Biosens*
92	AECOPD AND (”sensor based” OR sensor-based OR sensor-enabled OR “sensor enabled”)
93	AECOPD AND (Minimally-invasive OR "Minimal* Invasive")

94	AECOPD AND (Non-invasive OR “Non invasive” OR “no* invasive”)
95	AECOPD AND (“skin attached” OR skin-attached)
96	AECOPD AND (clothing-attached OR clothes-attached OR “clothing attached” OR “clothes attached” OR garment-attached OR “garment attached” OR fabric-attached OR “fabric attached”)

9. Appendix 2 – Studies Quality Appraisal

CASP for Randomized Controlled Trials



A. Appropriateness of Study Design

Q1 – Did the study address a clearly focused research question?

Q2 – Was the assignment of participants to interventions randomised?

Q3 – Were all participants who entered the study accounted for at its conclusion?

B. Potential for Selection Bias

Q4(1) – Were the participants 'blind' to intervention they were given?

Q4(2) – Were the investigators 'blind' to the intervention they were giving to participants?

Q4(3) – Were the people assessing/analysing outcome/s "blinded"?

Q5 – Were the study groups similar at the start of the randomised controlled trial?

Q6 – Apart from the experimental intervention, did each study group receive the same level of care?

C. Measurement of Exposures and Outcomes

Q7 – Were the effects of intervention reported comprehensively?

Q8 – Was the precision of the estimate of the intervention or treatment effect reported?

Q9 – Do the benefits of the experimental intervention outweigh the harms and costs?

D. Generalizability of the Study Findings

Q10 – Can the results be applied to your local population/in your context?

Q11 – Would the experimental intervention provide greater value to the people in your care than any of the existing interventions?

CASP for Cohort and Observational Studies

	Q1	Q2	Q3	Q4	Q5(1)	Q5(2)	Q6(1)	Q6(2)	Q7	Q8	Q9	Q10	Q11	Q12
Moy et al (67)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	No
Moy et al (68)	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tabak et al (72)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Kawagoshi et al (73)	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
McNamara et al (75)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes
Faria et al (76)	Yes	Can't Tell	Yes	Yes	Can't Tell	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Perriot et al (78)	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Lewis et al (85)	Yes	Yes	Yes	Yes	Yes	Yes	Can't Tell	Can't Tell	Yes	No	Yes	Yes	Yes	Yes
Tillis et al (87)	Yes	Yes	Yes	Yes	Yes	No	Can't Tell	Yes	Yes	No	Yes	Yes	Yes	Can't Tell
Wu R et al (88)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Lin et al (90)	Yes	Yes	Yes	Yes	Yes	Yes	Can't Tell	Can't Tell	Yes	No	Yes	Yes	Can't Tell	No
Bowler et al (91)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Can't Tell	Yes	No
Buekers et al (92)	Yes	Yes	Yes	Yes	Can't Tell	Can't Tell	Yes	Yes	Yes	No	Yes	Can't Tell	Can't Tell	No
Orme et al (93)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Can't Tell	Can't Tell	Can't Tell
Wu CT et al (94)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Tiwari et al (95)	Yes	Yes	Can't Tell	Yes	No	Can't Tell	No	Yes	Yes	No	Yes	Can't Tell	Yes	Can't Tell
Angelucci et al (123)	Yes	Yes	Yes	Yes	Can't Tell	Yes	Can't Tell	Can't Tell	Yes	No	Yes	No	Yes	No
Hawthorne et al (128)	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

A. Appropriateness of Study Design

Q1 – Did the study address a clearly focused issue?

Q2 – Was the cohort recruited in an acceptable way?

B. Potential for Selection Bias

Q3 – Was the exposure accurately measured to minimise bias?

Q4– Was the outcome accurately measured to minimise bias?

Q5(1) – Have the authors identified all important confounding factors?

Q5(2) – Have they taken account of the confounding factors in the design and/or analysis?

Q6(1) – Was the follow up of subjects long enough?

Q6(2) – Have they taken account of the confounding factors in the design and/or analysis?

C. Measurement of Exposures and Outcomes

Q7 – What are the results of this study?

Q8 – How precise are the results?

Q9 – Do you believe the results?

D. Generalizability of the Study Findings

Q10 – Can the results be applied to the local population?

Q11 – Do the results of this study fit with other available evidence?

Q12 – What are the implication of this study for practice?

CASP for Qualitative Studies

Yes **Can't Tell** **No**

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Sugino et al (71)	Yes	Yes	Yes	Can't Tell	Yes	Can't Tell	Yes	Can't Tell	Yes	Can't Tell
Vooijs et al (77)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Can't Tell	Yes	Yes	Can't Tell
Verwey et al (83)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes
McNamara et al (84)	Yes	Yes	Can't Tell	Yes	Yes	Can't Tell	Yes	Yes	Yes	Yes
Bellos et al (104)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Can't Tell	Yes	Yes
Guber et al (120)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Yes
Moraveji et al (121)	Yes	Yes	No	Yes	Yes	Can't Tell	Can't Tell	Yes	Yes	Can't Tell
Polsky et al (122)	Yes	Yes	Yes	Yes	Yes	Can't Tell	Yes	Yes	Yes	Yes
Martillano et al (127)	Yes	Yes	No	No	Yes	Can't Tell	Can't Tell	Can't Tell	Yes	Yes
Kuhn et al (130)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

A. Appropriateness of Study Design

Q1 – Was there a clear statement of the aims of the research?

Q2 – Is a qualitative methodology appropriate?

Q3 – Was the research design appropriate to address the aims of the research?

B. Potential for Selection Bias

Q4 – Was the recruitment strategy appropriate to the aims of the research?

Q5 – Was the data collected in a way that addressed the research issue?

Q6 – Has the relationship between researcher and participants been adequately considered?

C. Measurement of Exposures and Outcomes

Q7 – Have ethical issues been taken into consideration?

Q8 – Was the data analysis sufficiently rigorous?

Q9 – Is there a clear statement of findings?

D. Generalizability of the Study Findings

Q10 – How valuable is the research?