International Journal of Nursing Studies Advances 7 (2024) 100257

Contents lists available at ScienceDirect

International Journal of Nursing Studies Advances

journal homepage: www.sciencedirect.com/journal/international-journal-of-nursing-studies-advances

Implementation of an algorithm for predicting exacerbations in telemonitoring: A multimethod study of patients' and clinicians' experiences

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ARTICLE INFO

Keywords:
Chronic obstructive pulmonary disease
Disease exacerbation
Physiological monitoring
Clinical decision support systems
Telehealth
Algorithm
Nursing
Qualitative evaluation
Quantitative evaluation

ABSTRACT

Background: Prediction algorithms may improve the ability of telehealth solutions to assess the risk of future exacerbations in patients with chronic obstructive pulmonary disease. Learning from patients' and clinicians' evaluations and experiences about the use of such algorithms is essential to evaluate its potential and examine factors that could potentially influence the implementation and sustained use.
Objective: To investigate the patients' and clinicians' perceptions and satisfaction with an algorithm for predicting exacerbations in patients with chronic obstructive pulmonary disease.
Design: Multimethod study.
Setting: Three community nursing sites in Aalborg Municipality, Denmark.
Participants: One hundred and eleven adults with chronic obstructive pulmonary disease and four clinicians (three nurses and one physiotherapist) specialized in telehealth monitoring of the disease.
Methods: The study was performed from November 2021 to November 2022 alongside a clinical trial in which a prediction algorithm was integrated into an existing telehealth system. The patients' perspectives were investigated using a self-constructed questionnaire. The clinicians' perspective was explored using semistructured individual interviews.
Results: Most patients (84.0 %–90.8 %) were satisfied with the algorithm and the additional measurements required by the algorithm. Approximately 71.7 %–75.9 % found that the algorithm could be a useful tool for disease assessment. Patients elaborated that they could see an exacerbation prevention potential in the algorithm. Patients trusted the algorithm and found an increased sense of security. The clinicians showed a positive response toward the algorithm and its user-friendliness. However, they were concerned that the additional measurements could be too demanding for some patients and questioned the accuracy of the measurements. Some felt that the algorithm could risk being time-consuming and harm the overall assessment of the individual patient. They expressed a need for continuous information about the algorithm to understand its functions and alarms.

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https://doi.org/10.1016/j.ijnsa.2024.100257
Received 25 January 2024; Received in revised form 27 August 2024; Accepted 21 October 2024
Available online 22 October 2024

Conclusions: Optimal use of the algorithm would require that patients perform additional pulse and oxygen saturation measurements. Furthermore, it will require in-depth insight among clinicians regarding the algorithm's functions and alarms.
Registration: The study was performed alongside a clinical trial, which was first registered September 9, 2021, at clinicaltrials.gov (registration number NCT05218525). Date of first recruitment was September 28, 2021.

What is already known

- Telehealth with an integrated prediction algorithm has potential to allow for earlier detection and prevention of exacerbations in patients with chronic obstructive pulmonary disease.
- Evidence on the perspective of patients and clinicians on the use of prediction algorithms in telehealth is limited but highly relevant to examine factors that could potentially influence the implementation and sustained use of the algorithms.

What this paper adds

- The paper provides valuable knowledge about patients and clinicians' responses to and perceptions of prediction algorithms in telehealth.
- The study found that chronic obstructive pulmonary disease patients are predominantly positive towards the use of artificial intelligence and consider the idea advantageous in relation to telehealth.
- The study found that additional oxygen saturation and pulse measurements are not immediately barriers when testing and using algorithms in telehealth even in patients with limited resources.

1. Background

In 2019, the global prevalence of chronic obstructive pulmonary disease was estimated to be approximately 392 million cases, a number that is expected to increase further (Adeloye et al., 2022). Many patients with chronic obstructive pulmonary disease encounter exacerbations, which is an acute worsening of respiratory symptoms that results in additional therapy (Agustí et al., 2019; Lawless et al., 2022; Halpin et al., 2017; Global Initiative for Chronic Obstructive Lung Disease 2023). Frequent exacerbations can lead to a faster decline in lung function, lower quality of life, and increased mortality (Halpin et al., 2017; Seemungal et al., 2009; Spencer et al., 2004; Donaldson et al., 2002; Celli and Barnes, 2007). Furthermore, the economic burden of exacerbations is substantial, i.e., it has been estimated that 3 %–20 % of people with chronic obstructive pulmonary disease require at least one hospitalization per year (Seemungal et al., 2009; Connors et al., 1996; Gunen et al., 2005; Groenewegen and Schols, 2003), and previous hospitalization for acute exacerbation is a strong predictor for future rehospitalization (Kong and Wilkinson, 2020). Consequently, hospitalizations have been shown to account for up to 84 % of total chronic obstructive pulmonary disease expenses (Westbroek et al., 2020). Both the personal consequences and socioeconomic burden following exacerbations highlight the importance of prevention and early detection of exacerbations to facilitate preventive treatment outside the hospital (Wilkinson et al., 2004; Tomasic et al., 2018), and it has been shown that more than 80 % of exacerbations may be managed outside the hospital if early treatment with proper medication is provided (Wilkinson et al., 2004; Gerald and Bailey, 2002).

Current management strategies for the early detection and prevention of exacerbations in chronic obstructive pulmonary disease involve using clinical observations and assessments to monitor clinical symptoms, such as increased coughing, shortness of breath, and sputum production, as well as changes in lung function tests. Factors such as a history of exacerbations, comorbidities, and exposure to environmental triggers are also considered in this process (Global Initiative for Chronic Obstructive Lung Disease 2023; Vestbo et al., 2013). Despite the current management strategies, clinicians may struggle to accurately predict exacerbations due to the variability in symptoms and triggers among patients. Additionally, exacerbations can occur unpredictably and suddenly, making it difficult to intervene early and prevent them from worsening. Furthermore, some patients may ignore or underreport symptoms or fail to seek medical attention until their exacerbation is severe, leading to delays in treatment (Kim and Aaron, 2018; Macleod and Fabbri, 2021). Overall, the effectiveness of current management strategies for early detection and prevention of exacerbations is moderate, highlighting the need for improved strategies that allow for earlier intervention (Wilkinson et al., 2004; Quaderi and Hurst, 2018; Hurst and Wedzicha, 2009; Polisena et al., 2010; Wootton, 2012).

Telehealth, one strategy, has become widespread in the field of chronic obstructive pulmonary disease to monitor and manage symptoms outside the hospital. Although telehealth has shown promising results (Galaznik et al., 2013; Gregersen et al., 2016; Hong and Heui, 2019; McLean et al., 2012; Barbosa et al., 2020; Sul et al., 2020), improvements are needed to identify individual patients at risk of exacerbations (Polisena et al., 2010; Wootton, 2012; Sanchez-morillo et al., 2016). Prediction algorithms (artificial intelligence) have been suggested as a way forward to improve the outcomes of telehealth solutions (Sanchez-morillo et al., 2016; Soiza et al., 2018). Different types of prediction algorithms have been tested in chronic obstructive pulmonary disease to improve outcomes and clinical workflows. These algorithms have been focused on prediction of exacerbations, diagnosis, severity of the disease,

hospitalization, mortality, and costs (Fernández et al., 2022). Considering the use of prediction algorithms to predict exacerbations, these algorithms have been develop to automatically flag the risk of exacerbations in chronic obstructive pulmonary disease by applying selected patient characteristics and physical measurements to support clinicians in their decision-making (Sanchez-morillo et al., 2016; Guerra et al., 2017; Riis et al., 2016; Kronborg et al., 2018). Recent studies have shown that prediction algorithms have the potential to support early detection of exacerbations in chronic obstructive pulmonary disease and generate early warning signs to help clinicians monitor and treat patients more effectively (Fernández et al., 2022; Fernandez-granero et al., 2018; Mekov et al., 2020; Li et al., 2021). Such algorithms have the potential to improve the quality of health care services as well as facilitate clinicians' workflows and to better utilize resources (Amann et al., 2020; Lee and Yoon, 2021).

It is well known that the implementation of prediction algorithms in clinical practice requires significant local adaptation to ensure that the algorithm is accepted by end users and fits within local workflows (Kwon et al., 2019; Shortliffe and Sepúlveda, 2018). To successfully integrate and maximize the benefits of algorithms, users should participate in their development, implementation, and evaluation (Kwon et al., 2019). Learning from patients' and clinicians' evaluations and experiences about the use of algorithms is essential to evaluate its potential and examine factors that could potentially influence the implementation and sustained use of the algorithm and other algorithms in telehealth (Gaveikaite et al., 2020). Thus, the aim of this study was to understand the patients' and clinicians' perceptions of an algorithm for predicting exacerbations in patients with chronic obstructive pulmonary disease in an existing telehealth system (Lilholt et al., 2017).

2. Methods

2.1. Clinical implementation of a prediction algorithm for exacerbations

This study was implemented alongside a randomized controlled trial "The CIPA trial" described in detail elsewhere (Secher et al., 2022). The trial was registered at ClinicalTrials.gov (NCT05218525, reg. date: September 9, 2021) before recruitment of the first participant (September 28, 2021). The primary aim of the CIPA trial was to assess the effectiveness of an algorithm used to detect exacerbations in preventing hospitalizations based on selected physiological parameters and patient characteristics. The algorithm was integrated into an existing telehealth system (Lilholt et al., 2017; Heyckendorff et al., 2015) that consisted of a monitoring system used by chronic obstructive pulmonary disease patients to measure oxygen saturation, blood pressure, pulse, and weight along with

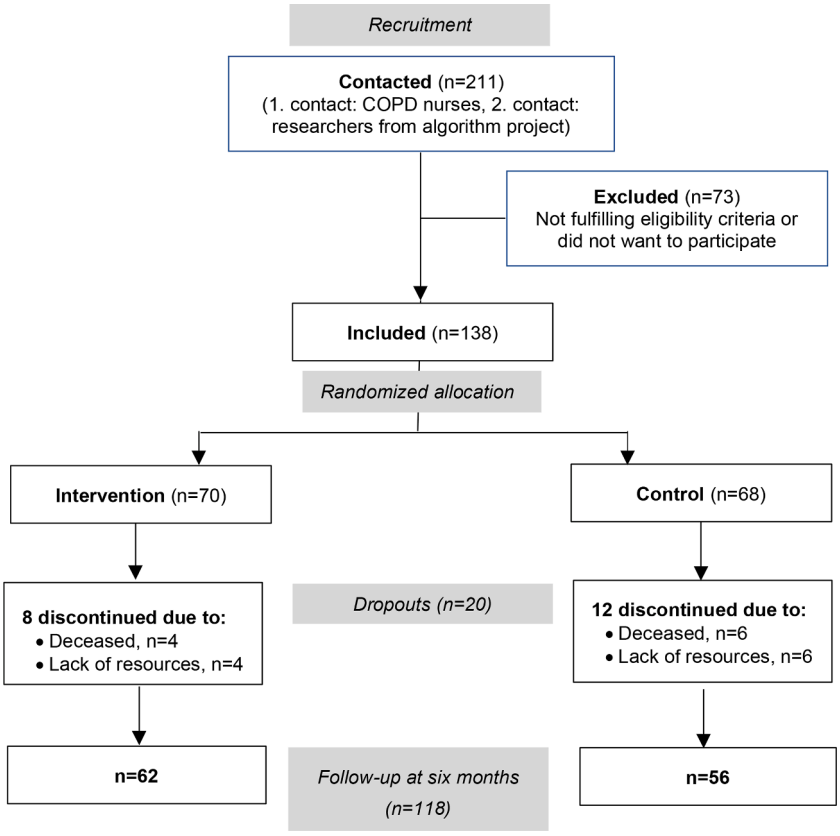

Fig. 1. Flow chart illustrating the progress of the algorithm study from identification and recruitment to outcome assessments at six months. Abbreviations are: COPD, chronic obstructive pulmonary disease.

answering symptom-related questionnaires at home once or twice a week. The measurements were transferred wirelessly to a community nurse (or another clinician) specialized in chronic obstructive pulmonary disease, who provided telephone advice to the patients if needed. During the trial, the algorithm aimed to provide clinicians with additional decision support for managing exacerbations. The trial was carried out in Denmark as a six-month, two-armed randomized controlled trial between November 2021 and November 2022. It was voluntary for the patients to participate in the trial. Inclusion criteria for participating were an age >18 years, a chronic obstructive pulmonary disease diagnosis regardless of severity, and residency in Aalborg Municipality, Denmark. Furthermore, the patient should already use the telehealth system. Exclusion criteria were inability to monitor physiological parameters and/or to complete study questionnaires. A total of 138 participants were included in the trial and randomly assigned to either an intervention or a control group, as illustrated in Fig. 1.

The intervention group (telehealth with algorithm) was asked to measure their oxygen saturation and pulse three times a week, i.e., 1–2 times, in addition to their usual measurements. The algorithm combined the additional measures with the usual measures to predict a potential exacerbation for individual patients. If the algorithm predicted a potential exacerbation, this was automatically flagged in the telehealth system to the clinician specialized in chronic obstructive pulmonary disease, who then had the opportunity to react on the alarm during the usual weekly review of data in the telehealth system. The algorithm alarm was an additional function to the usual alarms in the system. The clinicians were instructed to monitor and guide the patients as usual, and they were made aware

Table 1
Interview guide.

Research question/area of concern	Interview question(s)
Briefing	Thank you for participating in the interview. Purpose, recording, voluntary, anonymity, duration of interview, withdraw their participation.
Introduction	Can you tell me about yourself? • Name, age, education, occupation, years as clinician (nurse or other), time and experience working with COPD patients including field of work, time in TeleCare North and work areas related to this? • Have you worked with other systems or been involved in other projects where you have worked with technology as decision support in addition to TeleCare North? If so, what experiences? What motivated you to participate in the algorithm project?
Overall experiences in relation to using a system with an algorithm as a decision support tool?	How have your experience been using the system with the algorithm as a decision support tool in your patient interactions?How have you found the overall functionality of the system with the algorithm? • Did the features make sense? If no, why not? • Has your experience been that the algorithm in the system was intuitive to use? If no, why not? • Has your participation in the project met your expectations? If no, why not? • Have you experienced any challenges/barriers in relation to using the system with the algorithm? If so, which ones? • Have there been any false alarms? If so – which ones?
How have you handled alarms (algorithm) from the system?	When you received an exacerbation alarm from the system, how did you handle it? • Have you acted the same every time you have received an alarm? What considerations have you made in relation to the individual citizen? • How have you handled if you have had an alarm that did not align with your own assessment? Did you generally experience that there has been an agreement between your own assessment and alarms from the algorithm? • If no, in which cases do you not think there has been agreement? (Both in relation to false alarms and missing alarms) • And how have you acted if you have not experienced an agreement?
How does the use of the algorithm interact with your professionalism as a nurse?	Do you think that the algorithm has had an influence on your assessment in your guidance to the patient with COPD? • If yes, how? • If no, why not? Have you experienced that the algorithm has contributed something relevant to your assessment as a nurse? Has it supported your decisions? • If no, why not? • If yes, how? and in which contexts?
What do you think about the future use of the algorithm in nursing?	What do you think about the future use of the algorithm in nursing? Would you like the algorithm to become part of the system in the future?If yes, why? How do you think it will contribute to you and/or to the patient with COPD?If no, why?Do you think that the algorithm has sufficient and relevant functions at the current time? If no, what do you think could be changed or supplemented? • Do you get sufficient information from the algorithm, or do you need more in relation to assessing the values and guiding the patient? • Is there anything that you think should look different or appear in a different way?
Debriefing and ending the interview	Do you have anything you would like to add or discuss? Thank you very much for your time. Iteration of anonymity and information about what is done with the recording, including how it is handled and when it is deleted. Thank you for your time!

that they could choose whether they wanted to respond to the alarm or not. Thus, the decision regarding whether to act on the alarm or not remained to be the clinicians. The clinicians received very limited information about the underlying mechanisms of the algorithm. However, they were informed about the predictive parameters included in the algorithm.

The control participants (telehealth without algorithm) were also asked to perform the additional weekly pulse and oxygen saturation measurements to blind the process. Otherwise, the control group continued usual telehealth care. However, the clinicians could access and use the additional measurements in both groups. This approach was chosen to ensure that the difference between the groups was the integration of the algorithm and not the additional measurements.

The clinicians were not blinded during the trial as they would have to see the algorithm alarms for the individual patients in the intervention group.

2.2. Study design

This multimethod study was performed from November 2021 to November 2022 and evaluated two exploratory outcomes of the CIPA trial (Secher et al., 2022), which were the clinicians' experiences with and attitudes toward the algorithm as well as the patients' satisfaction with and perceptions of having the algorithm as part of the telehealth intervention. Individual face-to-face qualitative interviews were conducted to evaluate the clinicians' experiences and satisfaction with the algorithm (Brinkmann and Kvale, 2015), whereas a self-constructed oral questionnaire was used to measure the participants' perception of and their personal satisfaction with the prediction algorithm as part of the telehealth solution.

2.3. Interview study: clinicians' experiences and attitudes

2.3.1. Data collection approach

As the purpose of the interview was to investigate the informants' experiences of and attitudes towards the use of the algorithm, a phenomenological approach was chosen. Furthermore, a semistructured approach was adopted, as it allowed for flexibility during the interviews (Brinkmann and Kvale, 2015). The interview guide was formulated on the basis of the methodological literature (Brinkmann and Kvale, 2015; Dejonckheere and Vaughn, 2019; Kallio et al., 2016) and consisted of both closed- and open-ended questions to vary the level of reflection (Brinkmann and Kvale, 2015). The preliminary interview guide was pilot tested and adjusted accordingly to ensure credibility. This included internal testing, i.e., evaluation of the interview guide in collaboration with the investigators on the research team. This technique produced critical information about and relevant adjustments to the interview guide to avoid ambiguities and inappropriate leading questions (Kallio et al., 2016). This approach was chosen because the investigators in the research group possessed broad knowledge and experience within chronic obstructive pulmonary disease, nursing, telehealth, and interview design. Table 1 presents the final interview guide after adjustments.

The interviews were conducted between October 4, 2022, and November 9, 2022, by three authors (SHL, JE, and LH). The three authors were all females with clinical experience. SHL (PhD) and LH (PhD) were employed as postdocs during the project, whereas JE (MSc) was employed as a research assistant. All had experience with health technology and qualitative interviewing. The authors had met briefly online with the informants during project meetings. Thus, there had been limited interaction before the interview. The informants were informed in writing and orally about the reason for the interview beforehand.

Each interview was audiotaped and lasted between 20 and 40 minutes and was carried out in an office without disturbances at the informant's workplace based on each of the informant's preferences (Brinkmann and Kvale, 2015). The transcript of the interview recording was sent to the informant before further analysis was performed. This was done from an ethical viewpoint and to ensure credibility (Rowlands, 2021).

2.3.2. Participants

The informants included four clinicians specialized in telehealth monitoring: three nurses and one physiotherapist. The four clinicians were responsible for monitoring patients with chronic obstructive pulmonary disease at three different locations. The informants consisted of four of a total of eight clinicians who were responsible for telehealth monitoring in the CIPA trial. The remaining four clinicians declined to participate in the interview study due to lack of time or limited experience with the telehealth system.

2.3.3. Data analysis

The interview data were analyzed by SHL and LH using the thematic analysis approach developed by Braun et al. (2019,2021). This included a six-phase reflexive nonlinear iterative process using an inductive approach.

During the initial stage, SHL and LH familiarized themselves with the interview data by transcribing, reading, re-reading, and noting interesting concepts as they transcribed and reviewed the data. In the second phase, the researchers systematically coded the entire dataset both individually and collaboratively. During the third step, the two researchers organized the compiled codes to identify potential themes in alignment with the specific study objective. Subsequently, in the fourth step, they reviewed the themes to ensure alignment with the coded extracts and the dataset as a whole. Step five involved further specification and refinement of the themes before finalizing and reporting them in step six.

The NVivo qualitative data analysis software program QSR International Pty Ltd. (2020) Nvivo (released in March 2020), structured and assisted the analytical process. SHL and LH coded the data.

2.3.4. Rigor and reflexivity

Several measures were taken to ensure the rigor of the study. The authors aimed to maintain clarity and transparency in the method section to facilitate replication of the study design and methods. Additionally, to promote transparency, the interview guide (Table 1) was included as a table.

To enhance the truth value of the research data and aim for credibility, all interviews were audio recorded, and the interviewer provided follow-up statements to confirm understanding during the interviews. To enhance the quality and credibility of the data analysis, two researchers (SHL and LH) independently and collectively analyzed the data, engaging in discussions until reaching a consensus on quotations and themes. Moreover, verbatim quotes from the transcripts were inserted in relation to each theme to further establish trustworthiness and ensure that all informants' voices were represented in the findings.

2.4. Questionnaire study: patient satisfaction

2.4.1. Data collection approach and measurements

Data were gathered through a questionnaire developed by the authors, as there were no existing validated questionnaires that met the requirements of the study. However, the questionnaire was developed with inspiration from the Patient Reported Experience Measures (PREM) approach, defined as "a measure of a patient's perception of their personal experience of the health care they have received" (Male et al., 2017). Some of the questions differentiated to some extent between the control group and intervention group participants. Hence, the control questions were solely centered on the participants' perception of the prediction algorithm as part of the telehealth solution, whereas the intervention questions were centered both on the participants' perception and on their personal satisfaction with the prediction algorithm as part of the telehealth solution. Due to the deviation between questions, the intervention group participants were asked to answer four specific questions, while the control group participants were asked to answer five specific questions. The questions for each group are presented in Box 1. All questions were answered on a 5-point Likert scale, and the participants were informed of their allocation (control or intervention) prior to completing the questionnaire due to the nature of the questions. Furthermore, the participants were reminded of the intention of the algorithm (i.e. to predict exacerbations) before they answered the questionnaire in order for this, as opposed to a more general attitude towards the use of algorithms, to be the basis for their answers to the questions.

When asked about advantages and disadvantages in relation to the clinician using an algorithm to assess their disease, the participants were encouraged to elaborate on their thoughts.

The questionnaires were not validated but pilot tested using the same procedure as in the interview study (Kallio et al., 2016).

The following demographic data was extracted and used to characterize the participants: gender, age, civil status, geographical distribution, employment status, highest educational level, years since chronic obstructive pulmonary disease diagnosis, whether they smoked within the last 6 months (yes or no), and number of comorbidities (considering the following: none, diabetes type 1, diabetes type 2, cardiovascular disease, disease of muscles, bones or joints, or cancer).

2.4.2. Setting

The participants answered the questionnaire as part of a follow-up visit by one of the researchers after the CIPA trial period. To avoid recall bias, efforts were made to ensure that the participants answered the questionnaire no later than one month after finalizing the trial. The questionnaire was completed in the participant's home in collaboration with the researcher to ensure that the patient understood the questions as intended; the researcher recorded the patient's statements if necessary. No one else was in the room when the questionnaire was answered.

2.4.3. Participants

All participants included in the CIPA trial were considered suitable for inclusion in the questionnaire study.

Using a convenience sampling technique, those participants of the 138 CIPA participants who were willing to participate answered the questionnaire (Etikan et al., 2016). However, following Roscoe's rule of thumb (Roscoe, 1975), a minimum sample size of 30 participants from each group (control and intervention) was deemed sufficient. Additionally, by assigning distinct sets of questions to the control and intervention groups, the sampling method partially adhered to a purposive sampling technique (Etikan et al., 2016).

2.4.4. Data analysis

Data from the questionnaire, except from the data collected in the open-ended section, were analyzed descriptively using the "Data Exports, Reports, and Stats" function in REDCap and SPSS, version 29.0 (Microsoft 365, 2021, (16.0.13801.21072)). Tools in SPSS were also utilized to descriptively summarize participant characteristics and to test for statistically significant differences in these characteristics between the intervention and control groups. This analysis was conducted for all participants ($n = 111$) as well as separately for the 78 participants who provided detailed responses regarding the advantages and disadvantages in the questionnaire. Independent t-tests were employed for continuous variables, while chi-square tests were applied to categorical variables. The significance level was set to 0.05 (2-sided).

The data collected in the in-depth section of the questionnaire, regarding advantages and disadvantages, was meticulously analyzed by two researchers (SHL and LH) using a systematic approach to make sense of the responses and extract meaningful insights. With inspiration from the thematic analysis method developed by Braun et al. (2019, 2021), the analysis followed the following steps. First, the responses were transcribed and organized for easy comparison and analysis. This was followed by coding of the responses based on common themes or topics to help categorize the responses and identify patterns. In the third step themes were identified from

patterns in the responses related to common experiences, opinions, or suggestions. After identifying key themes, the findings were interpreted to draw insights and conclusions. Finally, the results of the analysis were presented in a clear and concise manner using quotes or examples from the responses to support the findings and provide context.

2.5. Ethical considerations

The North Denmark Regional Committee on Health Research Ethics approved the CIPA trial (N-20200076), including the explorative outcomes. Furthermore, the present study followed written regulatory requirements in relation to data responsibility and was in accordance with the General Data Protection Regulation (GDPR) (EUR, 2022). The study followed the Declaration of Helsinki (World Medical Association 2013) and the principles from the UN Declaration of Human Rights (World Medical Association 1948).

All participants gave verbal consent and signed a written formal consent form after receiving written and verbal information about the study. The participants were assured of anonymity, confidentiality, and voluntary participation throughout the process and that they could withdraw at any time.

Table 2
Baseline characteristics of participants in the questionnaire study.

	Participants who answered the questionnaire (n = 111)				Participants who elaborated on the section about advantages and disadvantages (n = 78)			
	All participants (n = 111)	Intervention (n = 58)	Control (n = 53)	P	All participants (n = 78)	Intervention (n = 41)	Control (n = 37)	P
Gender								
Male	43 (38.7)	25 (43.1)	18 (34.0)	0.323	28 (35.9)	15 (36.6)	13 (35.1)	0.894
Female	68 (61.3)	33 (56.9)	35 (66.0)		50 (64.1)	26 (63.4)	24 (64.9)	
Age	69.6 ± 7.3	69.3 ± 7.0	69.9 ± 7.7	0.652	69.3 ± 6.9	68.7 ± 7.0	70.0 ± 6.8	0.401
Civil status								
Married/domestic	60 (54.1)	32 (55.2)	28 (52.8)	0.522	47 (60.3)	26 (63.4)	21 (56.8)	0.731
partnership	35 (31.5)	16 (27.6)	19 (35.8)		18 (23.1)	8 (19.5)	10 (27.0)	
Single	16 (14.4)	10 (17.2)	6 (11.3)		13 (16.7)	7 (17.1)	6 (16.2)	
Widow/widower								
Geographical								
distribution	36 (32.4)	19 (32.8)	17 (32.1)	0.433	20 (25.6)	12 (29.3)	8 (21.6)	0.461
Major city (≥100,000	16 (14.4)	11 (19.0)	5 (9.4)		5 (6.4)	1 (2.4)	4 (10.8)	
citizens)	44 (39.6)	22 (37.9)	22 (41.5)		40 (51.3)	21 (51.2)	19 (51.4)	
City with 10,000 to	15 (13.5)	6 (10.3)	9 (17.0)		13 (16.7)	7 (17.1)	6 (16.2)	
99,999 citizens								
City with 2000 to 9999								
citizens								
Smaller city (<2000								
citizens)								
Employment status								
Employed full time	2 (1.8)	0 (0.0)	2 (3.8)	0.199	2 (2.6)	1 (2.5)	1 (2.7)	0.932
Employed part time	7 (6.4)	5 (8.8)	2 (3.8)		5 (6.5)	3 (7.5)	2 (5.4)	
Unemployed	101 (91.8)	52 (91.2)	49 (92.5)		70 (90.9)	36 (90.0)	34 (91.9)	
Highest educational								
level	39 (35.8)	22 (39.3)	17 (32.1)	0.169	27 (35.5)	16 (41.0)	11 (29.7)	0.361
Primary school	2 (1.8)	1 (1.8)	1 (1.9)		1 (1.3)	1 (2.6)	0 (0.0)	
High school	17 (15.6)	12 (21.4)	5 (9.4)		12 (15.8)	7 (17.9)	5 (13.5)	
Higher education	51 (46.8)	21 (37.5)	30 (56.6)		36 (47.4)	15 (38.5)	21 (56.8)	
Craftsman education/								
skilled worker								
Years since COPD	13.4 ± 6.9	12.5 ± 5.3	14.3 ± 8.4	0.179	13.7 ± 7.6	13.0 ± 5.5	14.5 ± 9.4	0.398
diagnosis								
Smoked within the last								
6 months	23 (20.7)	12 (20.7)	11 (20.8)	0.993	13 (16.7)	6 (14.6)	7 (18.9)	0.612
Yes	88 (79.3)	46 (79.3)	42 (79.2)		65 (83.3)	35 (85.4)	30 (81.1)	
No								
Number of								
comorbidities	22 (19.8)	12 (20.7)	10 (18.9)	0.889	15 (19.2)	9 (22.0)	6 (16.2)	0.297
0	72 (64.9)	37 (63.8)	35 (66.0)		51 (65.4)	27 (65.9)	24 (64.9)	
1	14 (12.6)	8 (13.8)	6 (11.3)		9 (11.5)	5 (12.2)	4 (10.8)	
2	3 (2.7)	1 (1.7)	2 (3.8)		3 (3.8)	0 (0.0)	3 (8.1)	
3								

Data are mean (standard deviation) or number of participants (proportion %). P-values were determined using independent t-test (continuous variables) or chi-square test (categorical variables).

3. Results

3.1. Participant characteristics – interview study

The four clinicians who participated in the interview study were all females with a median age of 50.5 years (49 to 64 years). The informants had between 12 and 39 years (median 25 years) of experience in their occupational field, i.e., within nursing ($n = 3$) or physiotherapy ($n = 1$). Furthermore, all informants had ten years of experience in telehealth monitoring as chronic obstructive pulmonary disease specialists. Individual details about the informants will not be elaborated to aim for anonymity.

3.2. Participant characteristics – questionnaire study

Of the 118 participants who completed the CIPA trial, a total of 111 participants (intervention 58 and control 53) answered the questionnaire. All 111 participants answered the closed-ended questions in the questionnaire, while 78 (intervention 41, control 37) of the 111 participants also elaborated on the in-depth part of the questionnaire. Table 2 outlines the participant characteristics at baseline. The average age was approximately 69 years regardless of whether the participants answered the in-depth part of the questionnaire and whether they were in the intervention or control group. The average time since the diagnosis of chronic obstructive pulmonary disease was 13.4 ± 6.9 years, which was comparable between the intervention and control participants. More women than men answered the questionnaire; the women's answers constituted 61.3 % ($n = 111$) and 64.1 % ($n = 78$) of the answers, respectively.

Table 3
Themes, subthemes, and examples of quotes identified from the analysis of the qualitative interviews.

Theme (s)	Subtheme(s)	Example quotes
Theme 1: The significance of patients' resources and motivation	The algorithm might only be advantageous for some patients	"*We must be mindful not to burden the patients excessively (…). Therefore, it will be for the chosen ones. Whoever that might be? Maybe those who are new or more resourceful*". (Clinician 1) "*It is highly likely that this algorithm is suitable for new patients, rather than for patients we are already familiar with*". (Clinician 3).
	Additional measurements of oxygen saturation	*"They actually became fatigued from making these additional measurements. They felt it was a prolonged process and had difficulty remembering to check in twice a week. Consequently, I think that many people may choose not to do this)"*. (Clinician 4)
Theme 2: The clinician's concerns about the use of the algorithm	Invalid data behind the algorithm	"*I'm wondering if the measurements are accurate. Whether they were taken correctly, at the right time, or on cold or warm hands, and other related factors, one might consider*". (Clinician 3) "*I believe that when you sit down and perform multiple routine measurements, you tend to be more relaxed. For instance, when measuring blood pressure, you typically sit for 5 min, which can result in a slightly lower heart rate compared to when you're busy with daily tasks and suddenly decide to take an extra measurement. In those situations, you might be more active and less calm. In addition, I suspect, but I do not know for sure, that we got some false alarms because of a high heart rate*". (Clinician 2)
	Discrepancy between the algorithm and the clinician's assessment	*"After taking some extra time to wonder, you may ask yourself, 'Is there something I have missed?' However, I have never found it to be logical*". (Clinician 4) *"There have been instances where the system didn't alert me, but various other indicators did. It wasn't limited to just pulse and saturation; there were numerous indicators, and it was quite remarkable"*. (Clinician 2)
Theme 3: The user-friendliness of the algorithm	The algorithm has been easy to use	*"I think it has been reasonably easy to implement and fairly quickly to deal with the additional measurements"*. (Clinician 1) *"It has essentially only required one or two extra mouse clicks, but otherwise, it has been easy to use*". (Clinician 4)
	Resource consumption when using the algorithm	"*Therefore, I can confidently state that it hasn't been more time-consuming for me (…). I found it reasonably easy to implement and manage the additional measurements*". (Clinician 1) *"I'm unable to keep track of all the measurements, answer all the questions, and simultaneously call all the patients. It's simply not feasible, especially given the limited resources in our nursing home. We face a shortage of nurses, which is why it's crucial to allocate our time to more complex tasks than an algorithm*". (Clinician 3)
Theme 4: The applicability of the algorithm	The algorithm is part of an overall assessment	*"…then you take a second look at it, because it is both an assessment of a patient who we have known for years, so it is not just the measurements as such - it is not black and white"*. (Clinician 2) *"We are constantly considering other factors that play a role. While the algorithm can be a part of an assessment, it is not sufficient alone"*. (Clinician 3)
	The potential value of the algorithm	*"During one Monday measurement, everything appeared peaceful, but the following Monday, I encounter a serious exacerbation. Moreover, exacerbations do not occur overnight but develop slowly. Hence, it makes a lot of sense to take additional measures"*. (Clinician 2)
	The clinician needs to understand the algorithm	*"…Does it go back five measurements and then alerts on the fourth measurement, or? (…) It would be nice to just to have some background information"*. (Clinician 4) *"However, I'm a bit uncertain about when I should call the patient. Is it now that I must call (…)?* (Clinician 3)

Approximately half (54.1 %) of the participants were married or in a domestic relationship, and the majority lived in a major city with≥100,000 citizens (32.4 %) or in a city with 2000–9999 citizens (39.6 %). Most participants (91.8 %) were unemployed, and 82.6 % reported having a lower level of education, with 35.8 % and 46.8 % indicating that their highest level of education was primary school or craftsman education/skilled worker, respectively. Furthermore, approximately one-fifth of the participants reported having smoked within the last six months, and the majority (80.2 %) indicated that they had one or more comorbidities. This prevalence was comparable between the intervention and control groups. No statistically significant differences were found between control and intervention participants or regarding the participant characteristics (all p-values > 0.05).

3.3. Interview findings

Table 3 presents the themes and subthemes identified from the thematic analysis.

Theme 1: The significance of patients' resources and motivation

All informants expressed that the algorithm might only be advantageous for some patients:

> *"We must be mindful not to burden the patients excessively (…). Therefore, it will be for the chosen ones. Whoever that might be? Maybe those who are new or more resourceful". (Clinician 1)*

This informant indicates that the use of the algorithm must not impose too many tasks on the patients, as some of the patients may lack the resources to handle the increased frequency of home pulse and oxygen saturation measurements. She therefore suggests that the algorithm may only be advantageous for patients who have the resources to manage any additional tasks. The informant also mentions that the algorithm could be relevant for new telehealth patients. This is also mentioned by another informant: "*It is likely, very likely, that it is this type of patient (new patient) that is suitable for this (algorithm) and not perhaps patients we already know*". (Clinician 3). This informant indicates that the algorithm may be less advantageous in patients known to the clinician. This is interpreted as the informant having less need for decision support to assess the patient's condition if it is a known patient. This is supported by the following statement: "*Most of them (the patients). They are quite stable. Therefore, I know when they fluctuate in their measurements. I know something is up. It's not that complex*". (Clinician 3)

There were divided opinions as to whether the additional pulse and oxygen saturation measurements are a significant burden for the patients. One informant states that the algorithm is only advantageous for some patients, as some will think that it will be too much if the use of the algorithm requires additional measurements: "*Because some patients think that there are already many measurements in the original setup (…) some patients will think that it will be too much*". (Clinician 1) Another informant pointed out that some patients found it difficult to remember to perform the additional measurements.

A third informant was of a different opinion considering the additional oxygen measurements: *"…as a patient, it is more manageable (…) because it does not take too long if it is just an oxygen measurement. (…) and it can't take that many minutes*". (Clinician 2) According to this informant, the additional pulse and oxygen saturation measurements are not a considerable burden for the patients.

Theme 2: The clinicians' concerns about the use of the algorithm

Two informants expressed concerns that there may be bias when using the algorithm. The informants indicated that the patients may perform incorrect measurements, which will impact the outcome of the algorithm:

> "*I'm wondering if the measurements are accurate. Whether they were taken correctly, at the right time, or on cold or warm hands, and other related factors, one might consider*". (Clinician 3)

This informant stated the problem that different factors might provide invalid data, resulting in unreliable alarms from the algorithm.

One of the informants had experienced that the algorithm did not alarm her even though she would have expected it to: "*There have been instances where the system didn't alert me, but various other indicators did. It wasn't limited to just pulse and saturation; there were numerous indicators, and it was quite remarkable"*. (Clinician 2). This quote indicates that the informant experienced discrepancy between her own assessment and that of the algorithm. She expressed that it was a surprise that the algorithm did not alert her.

Another informant had experienced alarms that she agreed with but mostly alarms that were inconsistent with her own assessment. This challenged her professional opinion:

> *"After taking some extra time to wonder, you may ask yourself, 'Is there something I have missed?' However, I have never found it to be logical*". (Clinician 4)

This informant considered why her own assessment was different from that of the algorithm and she was confused as to whether her own assessment or that of the algorithm was the right one.

Theme 3: The user friendliness of the algorithm

All informants agreed that the algorithm was easy to use and implement: "*I think it has been reasonably easy to implement and fairly quickly to deal with the additional measurements*". (Clinician 1) This informant expressed that the algorithm and the additional pulse and oxygen saturation measurements had no major impact on her work and that it was simply a matter of turning to a new routine.

The informants somewhat disagreed about how time- and resource-consuming the use of the algorithm and the additional measurements was. One informant expressed:

> "*Therefore, I can confidently state that it hasn't been more time-consuming for me (…). I found it reasonably easy to implement and manage the additional measurements*". (Clinician 1)

According to this informant, the time used on the additional measurements has not deviated much from the time she usually spends on the patients. This is inconsistent with the statement from another informant:

> "*I'm unable to keep track of all the measurements, answer all the questions, and simultaneously call all the patients. It's simply not feasible, especially given the limited resources in our nursing home. We face a shortage of nurses, which is why it's crucial to allocate our time to more complex tasks than an algorithm*". (Clinician 3)

This informant sees the additional measurements and the time spent on the algorithm as time that could be better spent on other caring tasks, as time is already scarce. Thus, she is concerned that the algorithm will lead to more time spent on measurements and more calls to patients.

Theme 4: The algorithm's applicability

The informants were overall positive about the concept of the algorithm, but a general opinion was that it is important that their assessment is not solely based on the algorithm but from an overall picture of the individual patient: "*…then you take a second look at it, because it is both an assessment of a patient who we have known for years, so it is not just the measurements as such - it is not black and white*". (Clinician 2) This informant stated that she does not blindly trust the measurements and alarms that come from the algorithm in the system but uses it in an overall assessment of the patient, where her knowledge of the patient plays a key role.

Some of the informants indicated that the algorithm had supported their assessment in some situations. This is evident from the following quotation:

> *"…but the fact that there has been an exacerbation (from the algorithm), it has made me think, well, okay, that is truly what I'm assessing myself. Therefore, I want to call and check up on the patient*". (Clinician 4)

From this quote, it is evident that the algorithm has supported the specialist's assessment and thereby how she has managed the situation with the patient.

Even though some of the informants thought that the algorithm supported their assessment, they are not all convinced that the algorithm should become a permanent part of the system: "*I do not feel sufficiently helped by this (the algorithm) to think that this is just what we must do in the future. I must be honest*". (Clinician 4) This statement deviates from that of one of the other informants: "*Yes, I would like that (the algorithm to become part of the system in the future), but on the condition that I also know slightly more about what it is set up to react to (…)*". (Clinician 2) This quote indicates that the informant was positive toward the idea about the algorithm but needs to be more informed about how it works to benefit from it. The need for more in-depth information was also pointed out by two other informants: "*…Does it go back five measurements and then alerts on the fourth measurement, or? (…) It would be nice to have some*

Table 4
Reported experiences in the intervention and control group, respectively, at follow-up. The values are n (%). Abbreviations: COPD, chronic obstructive pulmonary disease.

Intervention group						
	Follow-up					
	Very satisfied	*Partly satisfied*	*Neither satisfied nor dissatisfied*	*Partially dissatisfied*	*Very unsatisfied*	
How satisfied are you that an algorithm has been used by the COPD nurse to assess your COPD during the project? ($n = 57$)	44 (77.2)	4 (7.0)	9 (15.8)	0 (0.0)	0 (0.0)	
How satisfied have you been with the requirement to conduct two additional pulse and oxygen saturation measurements each week during the project period? ($n = 58$)	42(72.4)	8 (13.8)	6 (10.3)	2 (3.4)	0 (0.0)	
	Extremely useful	*Very useful*	*Fairly useful*	*Not very useful*	*Not useful at all*	*Do not know*
How useful do you think an algorithm is as a tool for the COPD nurse to assess your COPD? ($n = 58$)	28 (48.3)	16 (27.6)	6 (10.3)	1 (1.7)	0 (0.0)	7 (12.1)
Control group						
	Follow-up					
	Highly agree	*Agree*	*Neither agree nor disagree*	*Disagree*	*Highly disagree*	
I would have preferred that the COPD nurse used an algorithm for assessing my COPD during the project. ($n = 53$)	11 (20.8)	10 (18.9)	24 (45.3)	4 (7.5)	4 (7.5)	
	Very satisfied	*Partly satisfied*	*Neither satisfied nor dissatisfied*	*Partially dissatisfied*	*Very unsatisfied*	
How satisfied have you been with having to perform two additional pulse and oxygen measurements each week during the project period? ($n = 53$)	41 (71.9)	10 (18.9)	2 (3.8)	0 (0.0)	0 (0.0)	
How satisfied are you that the COPD nurse gets more pulse and oxygen saturation measurements sent than usual when she uses the algorithm? ($n = 52$)	49 (94.2)	0 (0.0)	3 (5.8)	0 (0.0)	0 (0.0)	
	Extremely useful	*Very useful*	*Fairly useful*	*Not very useful*	*Not useful at all*	*Do not know*
How useful do you think an algorithm is as a tool for the COPD nurse to assess your COPD? ($n = 53$)	21 (39.6)	17 (32.1)	9 (17.0)	3 (5.7)	1 (1.9)	2 (3.8)

background information". (Clinician 4). This informant expressed that she wanted to have more insight into what caused the alarm.

3.4. Questionnaire results

Tables 4 presents the answers to the Likert scale questions for the intervention and control groups. Overall, the intervention participants were satisfied that the algorithm had been used by the clinician during the trial; 84 % answered either 'Very satisfied'

Table 5
Themes, subthemes, and examples of answers identified from the analysis of the in-depth questionnaire section. The percentage for each theme indicates the proportion ($n = 78$) of the participants' answers that falls within this specific theme.

	Theme(s)	Subtheme(s)	Example answers
Advantageous	Theme 1: Direct and indirect benefits in relation to disease development and management (71.8 %)	Has the potential to prevent worsening of the condition and hospitalizations	• A good idea if it can lead to more monitoring and that action can be taken before it gets too bad. • Intervention can be taken more quickly if there is a deterioration in the condition. • You may feel well, and the measurements may look reasonable. In these situations, the algorithm may be able to catch problems before it gets too serious.
		Development in the disease can perhaps be caught	• I think they will be able to see more about how it (the disease) changes over time. • You may better follow the development of the disease.
		Valuable tool for the COPD nurse	• It will be easier for the nurse to see (whether action needs to be taken) and the nurse can react more quickly. • The nurse may learn something more about illness and can be more prepared.
	Theme 2: Confidence in the algorithm (11.5 %)		• The nurse must have better control of it when she receives a message from the algorithm. • You might be listened to more if an algorithm is used. • The more "eyes" that evaluate the measurements, the better. I have nothing to hide.
	Theme 3: It can provide security (19.2 %)	The algorithm can provide security	• It is a security with additional monitoring. • It would be nice if there could be a faster response. It is reassuring.
		The additional pulse and oxygen saturation measurements can provide security	• The nurse has additional measurements she can keep an eye on. • It is reassuring to have additional measurements
	Theme 4: Especially advantageous for selected patients (2.6 %)		• Sees it as an advantage for those who are somewhat troubled and for their relatives. • If you are not so good at noticing whether a deterioration is on the way, I think the algorithm can be of help.
Disadvantageous	Theme 1: The significance of the severity of the illness and the patient's resources (10.3 %)	The algorithm might only be advantageous for some patients	• It is a minor advantage for those who are not so ill. • It is important to look at the individual patient and not solely rely on the mathematics, as there will be individual differences in relation to whether the algorithm makes sense.
		Additional pulse and oxygen saturation measurements and calls can become a burden	• It is a disadvantage if it requires more than two measurements. Measurement number three became a bit of a burden and you easily forgot about it. • If there is a need for additional measurements with the algorithm, there may be periods where you have less surplus energy to perform additional measurements. • You may be called extra (by the COPD specialist) - perhaps someone sees this as a problem. However, I do not.
	Theme 2: There may be a vulnerability associated with the algorithm (6.4 %)		• The measurements may be misleading if it is a snapshot (of the person's condition). Therefore, I think there will be uncertainty as to whether the measurements provide a true picture. • It is a problem if the nurse relies too much on the algorithm. It is important that the nurse uses both her professional judgment and the algorithm.
	Theme 3: The algorithm becomes abstract for the patient (2.6 %)		• It is difficult to assess in terms of advantages and disadvantages, as it is a bit difficult to understand (the thing with the algorithm)
	Theme 4: Risk that the algorithm may cause anxiety and dependence (2.6 %)		• Anxious people may become nervous if the algorithm requires more measurements (as there is a greater risk of abnormal measurements and the person can see changes). This may be important for those who may have difficulty assessing whether something is serious. • The nurse may be too dependent on the algorithm.

(77.2 %) or 'Partly satisfied' (7.0 %). No one chose the options 'Partly unsatisfied' or 'Very unsatisfied'. Most participants in both groups were also satisfied overall with having to perform two additional pulse and oxygen saturation measurements each week during the trial. Hence, a total of 86.2 % in the intervention group and 90.8 % in the control group answered either 'Very satisfied' or 'Partly satisfied'. Only two from the intervention group answered 'Partly unsatisfied'. No one chose the option 'Very unsatisfied'.

The majority of participants agreed that the algorithm constituted a useful tool for the clinician to assess their chronic obstructive pulmonary disease; 75.9 % in the intervention group and 71.7 % in the control group chose the options 'Extremely useful' or 'Very useful'. When controls were asked about if they would have liked that an algorithm had been used by the clinician to assess their chronic obstructive pulmonary disease during the trial, the answers were more spread; most participants (45.5 %) answered 'Neither agree nor disagree'.

Of the 78 participants who elaborated on the in-depth section of the questionnaire, 15 (intervention 9 and control 6) indicated both advantages and disadvantages, 58 (intervention 28 and control 30) indicated advantages only, and 5 (intervention 4 and control 1) indicated disadvantages only. Based on the thematic analysis, a total of eight themes emerged, four relating to advantageous and four relating to disadvantageous. The four themes under advantageous were identified as: Direct and indirect benefits in relation to disease development and management (with three subthemes: Has the potential to prevent worsening of the condition and hospitalizations, Development in the disease can perhaps be caught, and Valuable tool for the COPD nurse), Confidence in the algorithm, It can provide security (with two subthemes: The algorithm can provide security, and The additional pulse and oxygen saturation measurements can provide security), and Especially advantageous for selected patients. The four themes under disadvantageous were identified as: The significance of the severity of the illness and the patient's resources (with two subthemes: The algorithm might only be advantageous for some patients, and Additional pulse and oxygen saturation measurements and calls can become a burden), There may be a vulnerability associated with the algorithm, The algorithm becomes abstract for the patient, and Risk that the algorithm may cause anxiety and dependence. The themes and subthemes are presented in Table 5 with some representative examples of answers. Some of the answers were placed under different themes. The theme *Direct and indirect benefits in relation to disease development and management* that lay within advantageous covered most of the answers. Thus, 55 answers (intervention 30 and control 25) were placed under this theme. In general, the responses linked to this theme included positive attitudes that the algorithm could potentially be a relevant tool to prevent and detect exacerbations and make it possible to act quickly in the event of a deterioration. An example of an answer was "*You may feel well, and the measurements may look reasonable. In these situations, the algorithm may be able to catch problems before they get too serious*". This participant sees the potential in that the algorithm detects something that she or the nurse could not detect.

The theme that covered the second most responses (11 answers; intervention 8 and control 3) was *It can provide security*. This theme also lies within the advantageous section and includes responses about the algorithm and the additional measurements providing security for the patients. One participant answered, "*It is a security with additional monitoring*". 'This participant states that she appreciates the increased monitoring of her disease.

The theme that covered the third most responses (9 answers; intervention 5 and control 4) was *Confidence in the algorithm*. This theme related to participants trusting the algorithm. One participant's response was as follows: "*The more "eyes" that evaluate the measurements, the better. I have nothing to hide*". This participant has faith that the algorithm is an extra set of eyes that can help the nurse assess her condition.

The theme *The significance of the severity of the illness and the patient's resources* that lay within disadvantageous covered the fourth most responses (8 answers; intervention 6 and controls 2). This theme covered thoughts that not all could benefit from the algorithm and that the algorithm and additional pulse and oxygen saturation measurements could become a burden for some patients. Most responses were about the additional measurements. One example is "*If there is a need for additional measurements with the algorithm, there may be periods where you have less surplus energy to perform additional measurements*". This indicates that there may be periods where the use of the algorithm will be less relevant in some patients if it continues to require additional pulse and oxygen saturation measurements.

4. Discussion

The aim of the present study was to understand the patients' and clinicians' perceptions of an algorithm for predicting

Box 1
. Questionnaire.

Intervention questions
- How satisfied are you that an algorithm has been used by the telemonitoring nurse to assess your chronic obstructive pulmonary disease during the project?
- How satisfied have you been with the requirement to conduct two additional pulse and oxygen saturation measurements each week during the project period?
- How useful do you think an algorithm is as a tool for the telemonitoring nurse to assess your chronic obstructive pulmonary disease?
- What advantages and disadvantages do you think there might be in the telemonitoring nurse using an algorithm to assess your chronic obstructive pulmonary disease?

Control questions
- I would have preferred that the telemonitoring nurse used an algorithm for assessing my chronic obstructive pulmonary disease during the project.
- How satisfied have you been with having to perform two additional oxygen measurements each week during the project period?
- How useful do you think an algorithm is as a tool for the telemonitoring nurse to assess your chronic obstructive pulmonary disease?
- How satisfied are you that the telemonitoring nurse gets more pulse and oxygen saturation measurements sent than usual when she uses the algorithm?
- What advantages and disadvantages do you think there might be in the telemonitoring nurse using an algorithm to assess your chronic obstructive pulmonary disease?

exacerbations in patients with chronic obstructive pulmonary disease in an existing telehealth system. The patients had a predominantly positive response toward the prediction algorithm. The algorithm concept was considered useful, as it was assessed as having the potential to catch impending exacerbations and provide security among users. From an ethical viewpoint, it is essential that the patients are receptive to the algorithm considering the autonomy principle (Behura, 2022). Thus, the patients have the right to disenroll from the telehealth intervention if they feel uncomfortable with the algorithm being used by their clinician.

The clinicians were also predominantly positive about the algorithm. However, they had some different concerns relating to its sustained use and implementation as a permanent part of the system. For instance, a general concern was that the algorithm could lead to a neglect of the overall assessment of the individual patient. This reserved attitude toward the algorithm is appropriate since studies have shown that some people tend to rely too much on artificial intelligence, which may lead to addiction and improper use of the algorithm (Branley-Bell et al., 2020; Magrabi et al., 2019) —issues in line with concerns expressed by some of the patients in the questionnaire. The unreflective use of artificial intelligence could cause certain adverse events and thus pose a risk to patients (Magrabi et al., 2019). Conversely, a certain level of trust could be necessary to take advantage of opportunities using artificial intelligence (Branley-Bell et al., 2020). Hence, it is relevant to clarify to clinicians that the algorithm is intended to support their assessment and that it should not overrule their professional assessment. The clinicians are thus charged with substantial decision-making competence in relation to assessing when they should trust the algorithm. This will immediately require that they are aware of what to act on considering the algorithm alarms. Such a responsibility requires in-depth and continuous insight into how the algorithm works and how it can support the clinician's assessment (Adadi and Berrada, 2018). The importance of in-depth knowledge about the algorithm also emerged from the interview findings, as the clinicians wanted to be more informed about the algorithm functions and the reasons behind the alarms. Lack of explanation for and understanding of algorithm functions and alarms is problematic because it has a negative impact on the decision support that can be provided, and moreover, it can create mistrust among the users (Adadi and Berrada, 2018; Arrieta et al., 2020).

There were also consistent views among the clinicians that the algorithm might only be relevant for some patients, as patients who are lacking resources will not always have the surplus energy to perform additional tasks. This finding was consistent with some of the patients' answers. This may limit the potential use of the algorithm since the individuals who are expected to benefit the most from advances in telehealth are extremely ill and elderly individuals (Kuziemsky et al., 2019; Ohno-Machado, 2017). However, the results from the questionnaire showed that most patients regardless of group were positive toward taking the additional pulse and oxygen saturation measurements. That questions whether additional measurements will become a problem for the patient group or whether it is an incorrect or partly incorrect perception by the clinicians.

Some of the patients and clinicians were concerned about how the patients executed the measurements considering the performance of the algorithm. This issue was also pointed out in a systematic review in 2016 (Sanchez-morillo et al., 2016). Wade et al. concluded that the perceived ease of use of home telehealth devices is a significant predictor of usage compliance (Wade et al., 2012). Hence, it is crucial that the telehealth monitoring device is user-friendly and that the patients are sufficiently trained in using the device for timely reporting of accurate data. It should be noted that the telehealth solution used in the CIPA trial was evaluated to be very user-friendly for patients with diverse literacy and communication skills (Heyckendorff et al., 2015; Lilholt et al., 2016).

There were discrepancies between the clinicians regarding whether the algorithm was time-consuming. In a study by Sangers et al., clinicians found it time-consuming and challenging to implement an algorithm (Sangers et al., 2023). The results from the present study indicate that time issues may especially be a problem in the preliminary phase, where clinicians must spend time learning the algorithm. However, this is a perspective that is central to consider before implementing algorithms, as the potential of artificial intelligence should preferably help make better use of resources and ease clinicians' workflows and thus prevent provider burnout (Amann et al., 2020; Lee and Yoon, 2021; Kuziemsky et al., 2019).

4.1. Strength and limitations of the work

The present study was undertaken by a research team with extensive experience within telehealth and predictive analytics. Furthermore, the study aimed to capture both the patients' and clinicians' views on algorithm use in telehealth using a multimethod approach. Despite this, the present work has limitations. One limitation was that the interview findings could have been return to the informants for feedback. Moreover, it was not possible to reach theoretical data saturation in the interview study, as it was only possible to include four informants. As a result, the interview findings may lack diversity and fail to capture the full spectrum of perspectives on the topic, potentially impacting the validity of the study (Brinkmann and Kvale, 2015; Rowlands et al., 2016). The use of convenience sampling may also have introduced bias, as it may not accurately represent the entire population of interest. Another limitation was the use of an unvalidated questionnaire, which may have led to incorrect conclusions based on the data and undermined the credibility of the results. Additionally, the questionnaire was not anonymous and was filled out in collaboration with the researcher who in some cases recorded the patient's statements; both perspectives could produce some information bias attributed to a Hawthorne effect (Etikan et al., 2016). Moreover, supplementing the internal pilot testing of the questionnaire and the interview guide with field testing may have made the questions more comprehensible and relevant for the target group (Kallio et al., 2016). Finally, there have been doubts as to whether all patients understood the concept of the algorithm, which may have produced some incorrect answers. Moreover, it must be added that the patients' positive attitude toward carrying out the additional measurements was solely assessed based on their satisfaction with this during the CIPA trial. Therefore, there could have been a different response if patients had been asked whether they could continue with the additional measurements beyond the trial.

4.2. Recommendations for further research

The development of technological solutions that contains artificial intelligence is rapidly progressing in the healthcare field. This requires a continued focus on patients and clinicians' perspectives to ensure the usefulness and acceptance of the artificial intelligence technologies in the context in which they are intended. The findings from the present study provide valuable insights into the perceptions and experiences of clinicians and patients regarding the use of the algorithm for assessing chronic obstructive pulmonary disease. The patients were predominantly positive toward the use of artificial intelligence and considered the idea advantageous in relation to telehealth. However, future research could focus on identifying patients who are most likely to benefit from algorithm-based interventions based on their resources and motivation levels. Furthermore, the concerns expressed by clinicians about potential biases in the algorithm's outcomes suggest the need for further research on the accuracy and reliability of the measurements used in the algorithm to ensure that clinicians trust the algorithm's recommendations.

Furthermore, in addition to the analyzes that are underway in relation to assessing the effect and economic value of the algorithm (Secher et al., 2022), it is highly relevant to explore further on the ethical complexity of such algorithm solutions and to assess the clinicians' attitude towards such algorithms in chronic obstructive pulmonary disease as well as other chronic diseases.

5. Conclusions

In conclusion, most patients and clinicians were receptive toward using a prediction algorithm in a telehealth solution. However, some patients may not benefit from the solution if additional pulse and oxygen saturation measurements are needed. Moreover, it is important to investigate how the patients perform the measurements to make adjustments that could limit the extent of measurement errors and thus ensure reliable algorithm alarms. Additionally, it is essential that clinicians are sufficiently informed and trained to make clinical decisions based on algorithm alarms. Overall, the present study may support clinicians and other stakeholders involved in algorithm and telehealth development and implementation.

Data sharing statement

The data is not publicly available due to ethical and privacy considerations of the participants and informants.

CRediT authorship contribution statement

Sisse Heiden Laursen: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lisa Korsbakke Emtekær Hæsum:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Julie Egmose:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Thomas Kronborg:** Writing – review & editing, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Flemming Witt Udsen:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ole Kristian Hejlesen:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Stine Hangaard:** Writing – review & editing, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding sources

The CIPA trial was funded by the Danish Agency for Digitization, Copenhagen K, Denmark. The Danish Agency for Digitization launched 15 signature projects in Denmark aimed at investigating different perspectives of artificial intelligence. The funder did not influence on the conception, analysis, or results of the study.

Acknowledgments

We greatly appreciate the participants' effort in making additional measurements during the trial period and thank the clinicians for monitoring more frequently. Furthermore, we would like to thank OpenTeleHealth, the TeleCare North administration office, and Danish Agency for Digitization (funding) for making this study possible.

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