Title: Home telemonitoring effectiveness in COPD: a systematic review

Joana Cruz[a] PT MSc, Dina Brooks[b] PT MSc PhD, Alda Marques[c] PT MSc PhD

[a]Department of Health Sciences (SACS), University of Aveiro, Aveiro, Portugal

[b]Graduate Department of Rehabilitation Science, Department of Physical Therapy, University of Toronto, Toronto, Canada

[c]School of Health Sciences, University of Aveiro (ESSUA), Aveiro, Portugal; Unidade de Investigação e Formação sobre Adultos e Idosos (UniFAI), Porto, Portugal

Corresponding author:

Alda Marques

School of Health Sciences of the University of Aveiro (ESSUA),

Campus Universitário do Crasto, Edifício 30, 3810-193 Aveiro, Portugal.

Telephone: 00351 234 372 462

Email: amarques@ua.pt

Disclosures: None

Running head: HOME TELEMONITORING IN COPD

Word count (abstract): 240

Word count (text only): 3280

Tables: 2

Figures: 3

Abstract

Objectives: To provide a systematic review of the effectiveness of home telemonitoring to reduce healthcare utilisation and improve health-related outcomes of patients with COPD.

Methods: An electronic literature search in Medline, Embase, B-on and Web of Science was conducted from June to August 2012 and updated until July 2013, using the following keywords: [tele(-)monitoring or tele(-)health or tele(-)homecare or tele(-)care or tele-home health or home monitoring] and [Chronic Obstructive Pulmonary Disease or COPD]. Randomised and non-randomised controlled trials evaluating home telemonitoring interventions in COPD were included. A meta-analysis using risk ratio (RR) and standardised mean difference (SMD) was conducted for healthcare utilisation (hospitalisations, length of stay, emergency department visits) and associated costs, and health-related outcomes (mortality, exacerbations and health-related quality of life (HRQOL)).

Results: Nine articles were included. Significant differences were found for hospitalisation rates (RR=0.72; 95%CI=0.53-0.98; p=0.034); however, no differences in the other healthcare utilisation outcomes were observed. There was a trend to reduced healthcare costs in the telemonitoring group. In two studies, this intervention was associated with a reduced number of exacerbations (p<0.05) and a significant increase in HRQOL (SMD=-0.53; 95%CI=-0.97--0.09; p=0.019).

Discussion and Conclusions: Home telemonitoring appears to have a positive effect in reducing respiratory exacerbations and hospitalisations and improving quality of life. However, the evidence of its benefits is still limited and further research is needed to assess the effectiveness of home telemonitoring in COPD management, as there are still few studies in this area.

Keywords: COPD; healthcare utilisation; quality of life; telemedicine; telemonitoring.

Review Criteria

Medline, Embase, B-on and Web of Science databases were searched (from June to August 2012, updated up until July 2013) for randomised and non-randomised controlled trials evaluating the impact of home telemonitoring interventions on healthcare utilisation and health-related outcomes of patients with COPD. Meta-analyses were performed, when appropriate.

Message for the Clinic

Home telemonitoring is an innovative approach which enables the management of patients' health condition at home, by exchanging health-related information with healthcare professionals. Studies included in this review provided limited evidence for the effectiveness of home telemonitoring in COPD on healthcare utilisation and health-related outcomes. To advocate the use of home telemonitoring as a patient management approach and to incorporate it into practice, further work needs to be conducted.

Introduction

Chronic obstructive pulmonary disease (COPD) is a progressive disease which accounts for a great economic and social burden [1]. In the United States, COPD was considered the 2nd cause of disability-adjusted life-years (DALYs) and the 5th cause of mortality in 2010 [2]. The disease trajectory is characterised by increasing symptoms (e.g., dyspnoea, fatigue) and a progressive decline in health status, punctuated by acute respiratory exacerbations [3]. Previous studies have shown that COPD exacerbations have a negative impact on patient prognosis [4] and are responsible for the greatest proportion of the total direct costs attributable to COPD [5]. Therefore, interventions to manage exacerbations at an early stage are urgently needed to reduce morbidity and mortality of COPD population, thereby reducing healthcare utilisation and associated costs.

In recent years, researchers and policy makers have been seeking cost-effective strategies for delivering sustainable care in COPD. One promising approach is the use of information and communication technologies to monitor patients' health status while they are at home, also referred to as home telemonitoring [6]. Home telemonitoring allows healthcare providers to review patients' clinical data (e.g., oxygen saturation, heart rate) more regularly and, thus, health deterioration can be quickly detected and addressed. This may lead to improved clinical outcomes, greater patient self-management and less costly interventions [7].

While the interest in telemonitoring interventions to manage patients at home is increasing, the evidence to support its effectiveness is still limited [7]. Previous systematic reviews failed to demonstrate the benefit of home telemonitoring in COPD [6, 8-10]. However, these reviews evaluated studies using home telemonitoring and a different telehealth approach, such as telephone support [9, 10] or teleconsultations with occasional monitoring of patients' clinical data [6, 8, 10], rendering the interpretation of the impact of telemonitoring alone. Therefore, the question of whether home telemonitoring achieves its purpose, i.e., if it reduces healthcare utilisation and costs by effectively detecting and responding to COPD exacerbations in a timely manner, remains unanswered. This systematic review aimed to assess the effectiveness of home telemonitoring to reduce healthcare utilisation and improve health-related outcomes of patients with COPD.

Methods

Information sources and search strategy

An electronic literature search was performed from June to August of 2012 in Medline, Embase, B-on Online Knowledge Library and Web of Knowledge databases. Search terms were based on a combination of the following keywords: [tele(-)monitoring or tele(-)health or tele(-)homecare or tele(-)care or tele-home health or home monitoring] and [Chronic Obstructive Pulmonary Disease or COPD]. Additional studies were searched within the reference list of the included articles, review articles on the topic [6, 8-12] and weekly automatic updates retrieved from the databases until July 2013.

Eligibility criteria and study selection

This systematic review was reported according to preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines [13]. Eligible studies were randomised (RCT) and non-randomised controlled trials (NRCT) involving patients with COPD and comparing a home telemonitoring intervention (experimental group – HTMG) to usual care (control group - CG). Patients in the HTMG had to periodically record clinical data (e.g., oxygen saturation, heart rate, symptoms) in their homes and transmit the data on a regular basis (i.e., ≥5days/week) using information and communication technologies, for further assessment by a healthcare team. The outcomes of interest were healthcare utilisation (i.e., hospitalisations, length of hospital stay, emergency department visits) and associated costs, mortality rates, respiratory exacerbations and health-related quality of life (HRQOL), collected during or immediately after the intervention.

Studies were excluded if they: i) included patients with diseases other than COPD; ii) included only regular telephone calls, video-consultation or teleconference interventions with infrequent transmission of clinical data; iii) involved downloading the data during healthcare visits or just at the end of the study; iv) provided telemonitoring in other places than patients' home; v) did not include a group without home telemonitoring (i.e., a CG); vi) did not collect the outcomes of interest during or immediately after the intervention. Studies with a different design (e.g., one group pretest-posttest, observational or case studies), review papers, abstracts, papers on conference proceedings, editorials, commentaries to articles and study protocols were excluded. Papers without abstracts or written in languages other than English, Portuguese and Spanish were also excluded.

Initial screening of articles was based on type of publication and relevance for the scope of the review, according to their title and abstract. Then, the full-text of potentially relevant articles was screened for content to decide its inclusion. Studies with multiple publications were identified to avoid duplicate reports.

Data collection

One reviewer (JC) extracted the data from the included studies and a second reviewer (AM) checked the extracted data. Disagreements were resolved by consensus. If consensus could not be reached, a third reviewer (DB) was consulted. A structured data extraction was performed, focusing on: study design, country where the study was conducted, sample size, type of intervention (HTMG) and comparator (CG), telemonitoring duration, outcome measures and results.

Quality assessment

The quality of the studies was independently assessed by two raters (JC and AM) using a modified version of the scoring system developed to evaluate telemedicine research by Hailey and co-workers [14], summarised in Polisena et al. [10]. It consists of 5 levels, from A (high quality) to E (poor quality), based on study design and performance. Inter-rater agreement was assessed using Cohen's kappa coefficient, considering the cut-off points [15]: slight agreement (≤0.20), fair agreement (0.21–0.40), moderate agreement (0.41–0.60), substantial agreement (0.61–0.80) and almost perfect agreement (≥0.81). Disagreements between raters were resolved by consensus.

Synthesis of results

Meta-analyses were conducted to evaluate the effects of home telemonitoring in healthcare utilisation and associated costs, mortality rates, respiratory exacerbations and HRQOL. In case of missing data, the corresponding authors were contacted via e-mail to provide more information. Five authors [16-20] were contacted; however, only one replied. Effect sizes were calculated with the risk ratio (RR) for dichotomous variables and the standardised mean difference (SMD) for continuous variables. The 95% confidence intervals (95%CI) and significance tests were also computed (statistical significance: $p<0.05$). Effect size data were synthesised into forest plots and a fixed-models effect was used in the absence of substantial heterogeneity across studies. Heterogeneity was measured using the I^2 test, which represents the percentage of the variation in effect sizes that is due to heterogeneity rather than sampling error [21]. When substantial heterogeneity was found ($I^2 \geq 50\%$) [22], a random-effects model was applied. If appropriate, subgroup analyses for study design, COPD severity and telemonitoring duration were also conducted to explore reasons for heterogeneity. Publication bias was assessed by visual inspection of funnel plots and Egger's regression intercept test if more than 5 studies were included in the meta-analysis [23]. Quantitative analyses were performed using Comprehensive Meta-Analysis software v2.0 (Biostat, Englewood, New Jersey).

Results

Study selection

The literature search identified 455 records. After duplicates removed, 130 records were screened for content through title and abstract. From these, 114 were excluded. The full-text of 16 articles was then assessed for eligibility and 11 articles were excluded (Figure 1). Five articles were identified as relevant from the automatic updates of the databases and the reference lists and were included in the review. One study had 2 publications reporting healthcare utilisation [18] and health-related outcomes [24], thus both articles were considered. In total, 10 articles on 9 studies were included, all published in English: 7 RCTs [16-18, 20, 24-27] and 2 NRCTs [19, 28].

(Insert Figure 1)

Quality assessment

Two articles were rated as A (high quality) [18, 26], 7 as B (good quality) [17, 19, 20, 24, 25, 27, 28] and 1 as C (fair to good quality) [16]. Two articles rated as good quality were in the borderline to be considered as high quality [24, 25]. Cohen's kappa coefficient revealed substantial agreement between raters (κ=0.63; p=0.036).

Study characteristics

Five studies were published from 2011 to the present [16, 20, 25-27]. Table 1 provides an overview of the characteristics of each study.

(Insert Table 1)

COPD severity was an inclusion criterion in all studies. Patients had to present moderate to severe COPD (n=4) [18, 20, 24-26], severe COPD (n=2) [19], severe to very severe COPD (n=5) [17, 27, 28] and/or receive oxygen therapy (n=1) [16, 27]. Samples included varied from 30 [19] to 165 [28], mostly older people (mean age≥65 years old). Telemonitoring data were generally transmitted to a monitoring centre on a daily basis, during 2 [26] to 12 [25] months. Patients' compliance with data transmission was assessed in 5 studies [18, 20, 25-27] and ranged from 40% [25] to 98% [26], depending on the clinical measurement. In all studies, patient's readings outside pre-determined values triggered an immediate action from the healthcare team monitoring the data. Usual care included the same healthcare component provided to the HTMG, but without telemonitoring (Table 1).

Synthesis of results

An overview of the outcomes assessed in each study is provided in Table 2.

(Insert Table 2)

Hospitalisation rates

Six RCTs [16, 17, 20, 24, 26, 27] and 2 NRCTs [19, 28] including 486 patients reported hospitalisation rates in both groups. Patients receiving home telemonitoring had a significantly lower risk of hospitalisation than those receiving usual care (RR=0.72; 95%CI=0.53-0.98; Z=-2.12; p=0.034; Figure 2; I^2=4.73%). Publication bias was not evident either from visual inspection of the funnel plot (data not shown) and the Egger's regression intercept test (intercept=-0.21; 95%CI=-2.46-2.03; p=0.824).

(Insert Figure 2)

Mean number of hospitalisations

Seven studies reported the mean number of hospitalisations per patient [16, 17, 19, 24, 25, 27, 28]. Three studies were excluded from quantitative analysis due to missing data [16, 17, 19]. Therefore, 4 studies including 244 patients with COPD were included [24, 25, 27, 28]. There were no significant differences between groups (SMD=-0.06; 95%CI=-0.32-0.19; Z=-0.50; p=0.617; I^2=16.42%).

Length of hospital stay

Eight studies providing information about hospitalisations also reported the mean length of hospital stay (in days) [16, 18-20, 25-28]. Four studies were excluded from the quantitative analysis due to missing or non-comparable data [16, 18-20]. Four studies with 244 patients with COPD were included [25-28]. The length of hospital stay was not different between groups (SMD=0.06; 95%CI=-0.19-0.31; Z=0.48; p=0.635; I^2=0%).

Emergency department visit rates

Only 4 studies with 194 patients, all RCTs, reported emergency department visit rates [16, 17, 26, 27]. There was no evidence of a significant effect of home telemonitoring on emergency department visit rates (RR=0.68; 95%CI=0.38-1.18; Z=-1.34; p=0.179; I^2=22.53%).

Mean number of emergency department visits

Five studies reported the mean number of emergency department visits [16-18, 27, 28]. Three studies were excluded from the quantitative analysis due to non-comparable data [16-18]. Two studies, 1 RCT [27] and 1 NRCT [28], comparing home telemonitoring to usual care for 4-6 months in 160 patients with severe to very severe COPD were included. The number of emergency department visits was not significantly different between groups (SMD=0.20; 95%CI=-0.49-0.88; Z=0.56; p=0.576). There was substantial heterogeneity across studies (I^2=74.81%) [22], therefore, a random-effects model was applied and a subgroup analysis of study designs was conducted.

The NRCT [28] reported a significantly lower mean number of emergency department visits in the HTMG (SMD=0.51; 95%CI=0.14-0.88; Z=2.70; p=0.007). This positive trend was not observed in the RCT [27] (SMD=-0.19; 95%CI=-0.78-0.39; Z=-0.65; p=0.515).

Healthcare-related costs

Three studies assessed the costs related to healthcare services [16, 17, 19]. De San Miguel et al. [16] reported total cost savings of 112,439US dollars (USD) in the HTMG. Koff et al. [17] suggested that home telemonitoring reduced healthcare-related costs (mean change=-1,401USD; 95%CI=-6,566-3,764USD) when compared to usual care (mean change=1,709USD; 95%CI=-4,349-7,768USD); however, the difference was not significant (p=0.21). Paré et al. [19] found that telemonitoring yielded a reduction in hospitalisation costs (29,686USD) and a total cost reduction of 6,750USD when compared to usual care, including the costs associated with the implementation of each intervention (e.g., home visits or technology).

Mortality rates

Four studies with 294 patients presented mortality rates [18, 25, 27, 28]. Two of them reported non-COPD related reasons for death [18, 25]. Mortality rates were not different between groups (RR=1.43; 95%CI=0.40-5.03; Z=0.55; p=0.582; I^2=0%).

Respiratory exacerbations

One RCT [20] and 1 NRCT [28] including 214 patients assessed the number of respiratory exacerbations during the intervention in both groups. These studies found that the CG had a higher incidence of respiratory events (HTMG:9/50; CG:15/49; p=0.152) [20] and mean number of exacerbations (HTMG=0.65±1.4; CG=1.01±1.4; p=0.004) [28]. Two studies reported the number of exacerbations detected by the telemonitoring system in the HTMG [17, 27]. In Jódar-Sánchez et al. [27] the device provided 40 alerts and in Koff et al. [17] it detected 9 exacerbations. A worsening of peripheral oxygen saturation was the most frequent altered clinical finding in the detection of a respiratory exacerbation [17, 20].

Health-related quality of life

Seven studies evaluated patients' HRQOL before/after the intervention, using either disease-specific (Chronic Respiratory Disease Questionnaire [25], Chronic Respiratory Questionnaire [16, 26], St. George's Respiratory Questionnaire (SGRQ) [17, 24, 27], Clinical COPD Questionnaire [28]) or general (EURO-QOL-5D Questionnaire [24, 27], Medical Outcome Study Short-Form 36 Questionnaire[25]) quality of life measurement instruments. Overall, no significant differences were found between groups. Pooling was not appropriate because the instruments measure different domains of HRQOL [29]. Only two RCTs presenting the mean change (i.e., posttest-pretest) of total and sub-dimension scores of the SGRQ were pooled [17, 27]. In SGRQ, lower scores represent better quality of life [30]. A statistically significant change was found in the SGRQ total score (SMD=-0.53; 95%CI=-0.97- -0.09; Z=-2.35; p=0.019; I^2=17.74%) suggesting that patients receiving home telemonitoring had a greater HRQOL after the intervention (Figure 3). This trend was not confirmed for SGRQ sub-dimensions (p>0.05; I^2=0.00%).

In terms of clinical significance (i.e., mean change≥4units) [30], both groups exhibited a clinically important change in SGRQ total score in Jódar-Sánchez et al. [27] (HTMG=10.9; CG=4.5); however, only the HTMG achieved this clinical change in Koff et al. [17].

(Insert Figure 3)

Discussion

This systematic review assessed the effectiveness of home telemonitoring in COPD. Nine studies were included, five of them published from 2011 to the present which emphasises the novelty of this type of intervention. Most studies were RCTs of good quality; however, some of them had relatively small samples. Findings suggest that, although home telemonitoring appears to have a positive effect in detecting and reducing respiratory exacerbations and improving HRQOL, there is still no clear indication that it reduces healthcare utilisation and associated costs as only hospitalisation risk was reduced in the HTMG. One NRCT [28] also showed a significantly lower number of emergency department visits in the HTMG. However, this result should be interpreted with caution because of the inherent risk of bias associated with this study design. Furthermore, this positive trend was not observed in a RCT with a similar target-population and telemonitoring duration [27].

Healthcare utilisation was similar in both groups, with the exception of hospitalisation rates. Some reasons may have contributed to these findings. Firstly, it was not always clear whether healthcare utilisation reported in some studies was related to respiratory exacerbations [19, 27, 28, 31]. Therefore, it is unclear if COPD-related healthcare utilisation was actually reduced. Secondly, the levels of patients' compliance with telemonitoring may also explain some of the results. As reported earlier, compliance with data transmission ranged from 40% [25] to 98% [26]. This lower compliance found in some studies might have contributed to the failure in detecting health deterioration. Hence, the purpose of home telemonitoring, i.e., the continuous monitoring of patients' clinical data to early detect and address health deterioration, may not have been reached due to a lack of patients' compliance.

The two studies reporting the occurrence of respiratory exacerbations in both groups found that the CG had a higher number of exacerbations during the intervention, when compared to the HTMG [20, 28]. Two additional studies reported that the telemonitoring system was able to detect respiratory exacerbations [17, 27]. These findings support the hypothesis that telemonitoring can be a potential way of detecting and managing COPD exacerbations in a timely manner. Advancements in physiological sensors and in information and communication technologies may, therefore, offer opportunities for providing healthcare management tools, enabling extended independent living at home for individuals with COPD. However, there is still a lack of clarity about which parameters should be used to detect exacerbations [7]. The worsening of peripheral oxygen saturation was the most frequent altered clinical finding in the detection of respiratory exacerbations [17, 20]. A previous exploratory research supports these results [32]. According to Hurst and co-workers [32], a composite measure that combines oxygen saturation and heart rate may be useful to identify an exacerbation onset. In this review, only four of the eight studies collected both measurements [18, 20, 24, 26, 27].

Studies reporting healthcare-related costs revealed a positive trend towards telemonitoring interventions, suggesting that home telemonitoring may, therefore, have the ability to produce savings in COPD management [11]. This trend may be in part related to the decreased hospitalisation rates found in the present study. According to previous research, hospitalisations represent more than one-half of the total direct costs attributable to COPD [33], mostly due to respiratory exacerbations [34]. However, the small number of studies providing healthcare-related cost information and the differences in the estimation of this outcome (e.g., in the study of De San Miguel et al. [16], hospital visit costs were based on length of stay rather than number of hospitalisations) limit the interpretation of the findings. Further work still needs to be conducted on this topic to draw final conclusions.

Findings on patients' HRQOL were inconsistent. In most studies, no significant changes after the intervention were found. Nevertheless, they used different measurement instruments which made difficult to perform comparisons. When two studies using the same questionnaire were pooled [17, 27], significant changes were found in favour of the HTMG. These studies also demonstrated a clinically important change in the HTMG and one found a clinical change also in the CG [27]. Hence, the ability of home telemonitoring to demonstrate an improvement in HRQOL beyond to that achieved with usual care remains a challenge.

Limitations

One limitation of this review concerns the exclusion of six studies written in languages other than English, Portuguese and Spanish, since they could be relevant for the scope of the review. The fact that some studies could not be integrated in the quantitative analysis due to missing or non-comparable data is another limitation. Thus, it is unknown if any of these studies could have influenced the outcomes in the telemonitoring group. Lastly, in most cases, the number of studies included in the meta-analysis was insufficient (n<5) [23] to measure the potential of publication bias.

Implications for research and practice

The value of home telemonitoring to reduce healthcare utilisation and improve health-related outcomes is not yet well defined. Therefore, to advocate the use of this intervention as a patient management approach and to incorporate it into practice, further work needs to be conducted. In addition, variations in compliance rates suggest that telemonitoring regimens may not be appropriate for all patients. Further research is needed to identify the types of patients most likely to benefit from these interventions. Future studies should also consider: i) including a composite measure of oxygen saturation and heart rate to early detect exacerbations; ii) using similar HRQOL measurement instruments to enable comparisons across studies; iii) reporting healthcare utilisation data in a format that can be further pooled into meta-analysis.

Conclusion

The findings provide limited evidence of the effectiveness of home telemonitoring to reduce healthcare utilisation and improve health-related outcomes in patients with COPD. Although this intervention appears to have a positive effect in reducing respiratory exacerbations and hospitalisations and improving HRQOL, there is still no clear indication that it reduces healthcare utilisation and associated costs. Further research is needed to assess the effectiveness of home telemonitoring in COPD management, as there are still few studies in this area.

Authors' contributions

All authors contributed in different processes of the systematic review. JC and AM worked on the definition of appropriate search terms, quality assessment, data extraction and analysis. JC performed the search in the electronic databases and provided a draft of the manuscript, which was critically revised by all authors. All authors read and approved the final manuscript.

Funding and Acknowledgements

Support for this study was provided by Fundação para a Ciência e Tecnologia (Ref. SFRH/BD/81328/2011), Portugal.

References

1. World Health Organization. The global burden of disease: 2004 update. WHO Library Cataloguing-in-Publication Data, 2008.
2. Murray CJL, Lopez AD. Measuring the Global Burden of Disease. *N Engl J Med*. 2013; **369:** 448-57.
3. Global Strategy for the Diagnosis Management and Prevention of COPD. Global Initiative for Chronic Obstructive Lung Disease (GOLD) 2013. Available from: http://www.goldcopd.org/. Date last accessed: February 11, 2013.
4. 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; **60:** 925-31.
5. O'Reilly JF, Williams AE, Rice L. Health status impairment and costs associated with COPD exacerbation managed in hospital. *Int J Clin Pract*. 2007; **61:** 1112-20.
6. Bolton CE, Waters CS, Peirce S, Elwyn G. Insufficient evidence of benefit: a systematic review of home telemonitoring for COPD. *J Eval Clin Pract*. 2010; **17:** 1216-22.
7. McKinstry B. The use of remote monitoring technologies in managing chronic obstructive pulmonary disease. *QJM*. 2013. doi: 10.1093/qjmed/hct068. Epub ahead of print: April 5, 2013.
8. Kamei T, Yamamoto Y, Kajii F, Nakayama Y, Kawakami C. Systematic review and meta-analysis of studies involving telehome monitoring-based telenursing for patients with chronic obstructive pulmonary disease. *Jpn J Nurs Sci*. 2012. doi: 10.1111/j.1742-7924.2012.00228.x. Epub ahead of print: October 1, 2013.
9. McLean S, Nurmatov U, Liu JL, Pagliari C, Car J, Sheikh A. Telehealthcare for chronic obstructive pulmonary disease. *Cochrane DB Syst Rev*. 2011**:** CD007718.

10. Polisena J, Tran K, Cimon K, Hutton B, McGill S, Palmer K, et al. Home telehealth for chronic obstructive pulmonary disease: a systematic review and meta-analysis. *J Telemed Telecare*. 2010; **16:** 120-7.

11. Jaana M, Pare G, Sicotte C. Home telemonitoring for respiratory conditions: a systematic review. *Am J Manag Care*. 2009; **15:** 313-20.

12. Paré G, Jaana M, Sicotte C. Systematic review of home telemonitoring for chronic diseases: the evidence base. *J Am Med Inform Assoc*. 2007; **14:** 269-77.

13. Moher D, Liberati A, Tetzlaff J, Altman DG, The PG. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med*. 2009; **6:** e1000097.

14. Hailey D, Roine R, Ohinmaa A, Dennett L. Evidence of benefit from telerehabilitation in routine care: a systematic review. *J Telemed Telecare*. 2011; **17:** 281-7.

15. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977; **33:** 159-74.

16. De San Miguel K, Smith J, Lewin G. Telehealth Remote Monitoring for Community-Dwelling Older Adults with Chronic Obstructive Pulmonary Disease. *Telemed J E Health*. 2013; **19:** 652-7.

17. Koff PB, Jones RH, Cashman JM, Voelkel NF, Vandivier RW. Proactive integrated care improves quality of life in patients with COPD. *Eur Respir J*. 2009; **33:** 1031-8.

18. Lewis KE, Annandale JA, Warm DL, Rees SE, Hurlin C, Blyth H, et al. Does Home Telemonitoring after Pulmonary Rehabilitation Reduce Healthcare Use in Optimized COPD? A Pilot Randomized Trial. *COPD*. 2010; **7:** 44-50.

19. Paré G, Sicotte C, St.-Jules D, Gauthier R. Cost-Minimization Analysis of a Telehomecare Program for Patients with Chronic Obstructive Pulmonary Disease. *Telemed J E Health*. 2006; **12:** 114-21.

20. Pedone C, Chiurco D, Scarlata S, Antonelli Incalzi R. Efficacy of multiparametric telemonitoring on respiratory outcomes in elderly people with COPD: a randomized controlled trial. *BMC Health Serv Res*. 2013; **13:** 82.

21. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003; **327:** 557-60.

22. Deeks JJ, Higgins JP, Altman DG, on behalf of the Cochrane Statistical Methods Group. Analysing data and undertaking meta-analyses In: Higgins JP, Green S, editors. Cochrane Handbook for Systematic Reviews of Interventions - Cochrane Book Series. Chichester, UK: John Wiley & Sons; 2008.

23. Sterne JAC, Becker BJ, Egger M. The funnel plot. In: Rothstein H, Sutton A, Borenstein M, editors. Publication bias in meta-analysis : prevention, assessment and adjustments. West Sussex: John Wiley & Sons; 2005. p. 75-98.

24. Lewis KE, Annandale JA, Warm DL, Hurlin C, Lewis MJ, Lewis L. Home telemonitoring and quality of life in stable, optimised chronic obstructive pulmonary disease. *J Telemed Telecare*. 2010; **16:** 253-9.

25. Antoniades NC, Rochford PD, Pretto JJ, Pierce RJ, Gogler J, Steinkrug J, et al. Pilot study of remote telemonitoring in COPD. *Telemed J E Health*. 2012; **18:** 634-40.

26. Chau JP-C, Lee DT-F, Yu DS-F, Chow AY-M, Yu W-C, Chair S-Y, 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 Inf*. 2012; **81:** 674-82.

27. Jódar-Sánchez F, Ortega F, Calderon CP, Gomez-Suarez C, Jordan A, Perez P, et al. Implementation of a telehealth programme for patients with severe chronic obstructive pulmonary disease treated with long-term oxygen therapy. *J Telemed Telecare*. 2013; **19:** 11-7.

28. Trappenburg JCA, Niesink A, de Weert-van Oene GH, van der Zeijden H, van Snippenburg R, Peters A, et al. Effects of Telemonitoring in Patients with Chronic Obstructive Pulmonary Disease. *Telemed J E Health*. 2008; **14:** 138-46.

29. Glaab T, Vogelmeier C, Buhl R. Outcome measures in chronic obstructive pulmonary disease (COPD): strengths and limitations. *Respir Res*. 2010; **11:** 79.

30. Jones PW. St. George's Respiratory Questionnaire: MCID. *COPD*. 2005; **2:** 75-9.

31. Dinesen B, Haesum LK, Soerensen N, Nielsen C, Grann O, Hejlesen O, et al. Using preventive home monitoring to reduce hospital admission rates and reduce costs: a case study of telehealth among chronic obstructive pulmonary disease patients. *J Telemed Telecare*. 2012; **18:** 221-5.

32. Hurst J, Donaldson G, Quint J, Goldring J, Patel A, Wedzicha J. Domiciliary pulse-oximetry at exacerbation of chronic obstructive pulmonary disease: prospective pilot study. *BMC Pulm Med*. 2010; **10:** 52.

33. Miller JD, Foster T, Boulanger L, Chace M, Russell MW, Marton JP, et al. Direct costs of COPD in the U.S.: an analysis of Medical Expenditure Panel Survey (MEPS) data. *COPD*. 2005; **2:** 311-8.

34. 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*. 2010; **7:** 214-28.

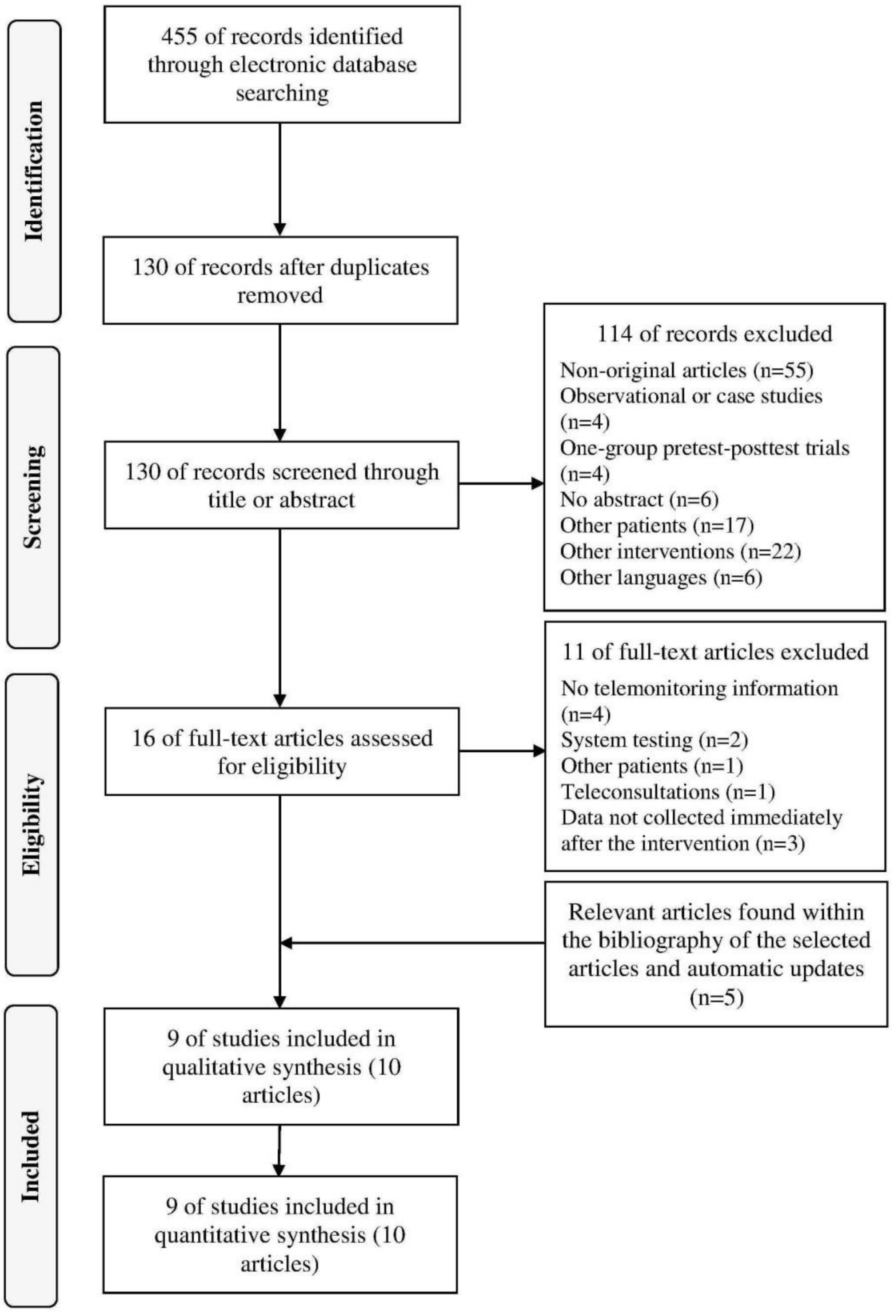

Figure 1 – Flow diagram for study selection.

Study name	Risk ratio	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Chau, 2012	1.91	0.57	6.34	1.06	0.29	6.66
De San Miguel, 2013	0.46	0.23	0.92	-2.19	0.03	19.60
Jódar-Sánchez, 2013	1.46	0.40	5.38	0.57	0.57	5.63
Koff, 2009	0.33	0.04	2.93	-0.99	0.32	2.03
Lewis, 2010b	0.57	0.20	1.65	-1.03	0.30	8.53
Paré, 2006	0.33	0.08	1.45	-1.47	0.14	4.45
Pedone, 2013	0.65	0.25	1.70	-0.87	0.38	10.52
Trappenburg, 2008	0.83	0.51	1.33	-0.79	0.43	42.58
	0.72	0.53	0.98	-2.12	0.03	

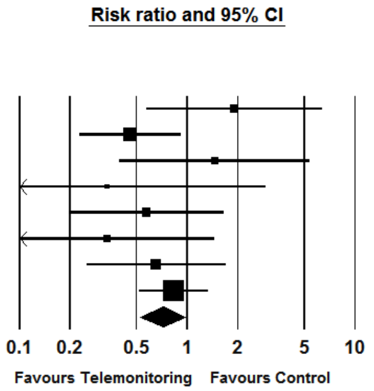

Figure 2 – Risk ratio of hospitalisation in the home telemonitoring and control groups (fixed-effects model).

Study name	Score	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Relative weight
Jódar-Sánchez, 2013	Activity	-0.36	0.30	0.09	-0.95	0.23	-1.19	0.24	54.38
Koff, 2009	Activity	-0.47	0.33	0.11	-1.11	0.18	-1.42	0.16	45.62
		-0.41	0.22	0.05	-0.84	0.03	-1.83	0.07	
Jódar-Sánchez, 2013	Impact	-0.28	0.30	0.09	-0.87	0.31	-0.93	0.35	54.42
Koff, 2009	Impact	-0.42	0.33	0.11	-1.07	0.22	-1.29	0.20	45.58
		-0.34	0.22	0.05	-0.78	0.09	-1.56	0.12	
Jódar-Sánchez, 2013	Symptoms	-0.33	0.30	0.09	-0.92	0.26	-1.11	0.27	54.17
Koff, 2009	Symptoms	-0.36	0.33	0.11	-1.00	0.28	-1.11	0.27	45.83
		-0.35	0.22	0.05	-0.78	0.09	-1.57	0.12	
Jódar-Sánchez, 2013	Total	-0.31	0.30	0.09	-0.90	0.28	-1.02	0.31	55.74
Koff, 2009	Total	-0.80	0.34	0.11	-1.47	-0.14	-2.38	0.02	44.26
		-0.53	0.22	0.05	-0.97	-0.09	-2.35	0.02	

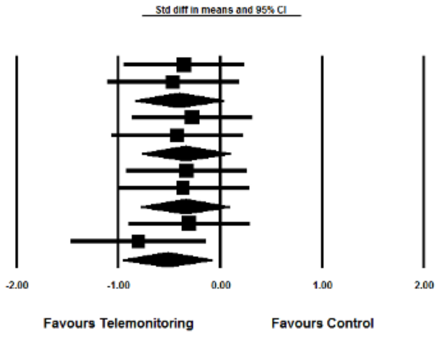

Figure 3 – Mean change in quality of life of the experimental and control groups using the St. George's Respiratory Questionnaire total and sub-dimension (activity, impact and symptoms) scores (fixed-effects model). Std diff in means: standardised mean difference.

Table 1 - Main characteristics of the studies.

First author (year)	Study design	Country	Participants	Telemonitoring duration	Home telemonitoring (experimental group)	Usual care (experimental and control groups)
Antoniades (2012) [25]	RCT	Australia	44 patients with moderate to severe COPD and with ≥1 hospitalisations/year: HTMG (n=22) and CG (n=22).	12 months	Transmission of data about spirometry parameters, weight, temperature, blood pressure, oxygen saturation, electrocardiogram, sputum colour and volume, symptoms and medication usage, on a daily basis (on weekdays).	Clinical management according to Australian and New Zealand guidelines with provision of outreach nursing, a written action plan and availability of pulmonary rehabilitation (chronic disease management programme).
Chau (2012) [26]	RCT	Hong Kong	53 older people with moderate to severe COPD and with ≥1 hospitalisations/year: HTMG (n=30) and CG (n=23).	2 months (mean duration 54.36 days)	Measurements of oxygen saturation, heart rate and respiration rate 3 times a day (on weekdays). The technology	In-home nurse visits to offer education on self-care and symptom management techniques.

					provided patients with a medication and pursed-lips breathing reminder with a feedback function.	
Jódar-Sánchez, (2013) [27]	RCT	Spain	45 patients with clinically stable COPD and chronic respiratory failure, receiving long-term oxygen therapy and with ≥1 hospitalisations/year: HTMG (n=24); CG (n=21).	4 months	Daily measurement (on weekdays) of blood pressure, heart rate and oxygen saturation and spirometry 2 days per week, 20 minutes after taking prescribed inhaled therapy, seated and rested, and while on oxygen therapy.	Conventional medical care.
Koff (2009) [17]	RCT	United States of America	40 patients with severe to very severe COPD (GOLD 3 and GOLD 4):[3] HTMG (n=20) and CG (n=20).	3 months	Transmission of data about symptoms, oxygen saturation, spirometry parameters and steps in six-minute walking distance,	Usual access to healthcare providers.

					on a daily basis (on weekdays), plus disease-specific and self-management education and interaction with study coordinators through the telemonitoring system (proactive integrated care programme).	
Lewis (2010a) [24], (2010b) [18]	RCT	United Kingdom	40 patients with moderate to severe COPD after undertaken pulmonary rehabilitation: HTMG (n=20) and CG (n=20).	6 months	Data transmission twice a day regarding the condition of patients' chest over the preceding day/night, oral temperature, heart rate and oxygen saturation.	Standard care.
Paré (2006) [19]	NRCT	Canada	30 patients with severe COPD that required frequent home	6 months	Daily transmission of peak flow rate, symptoms and medication	Traditional system of in-home visits (control group only).

			visits: HTMG (n=20) and CG (n=10).		taken.	
Pedone (2013) [20]	RCT	Italy	99 older people with moderate to severe COPD (GOLD 2 and GOLD 3):[3] HTMG (n=50) and CG (n=49).	9 months	Data transmission 5 times a day, every 3 hours, of oxygen saturation, heart rate, respiratory rate, physical activity and body temperature.	Standard care.
De San Miguel (2013) [16]	RCT	Australia	71 patients with COPD treated with long-term oxygen therapy: HTMG (n=36); CG (n=35).	6 months	Daily transmission of blood pressure, heart rate, oxygen saturation, weight, temperature and of data related to patients' general state of health. Patients also received an educational book about COPD.	Educational book about COPD.
Trappenburg	NRCT	Netherlan	165 patients with severe to very	6 months	Daily transmission of data about	Usual access to healthcare

(2008) [28]	ds	severe COPD (GOLD 3 and GOLD 4)[3] with ≥1 hospitalisations/6 months: HTMG (n=101) and CG (n=64).	symptoms, medication compliance and knowledge, with immediate feedback from the system.	providers.

COPD – chronic obstructive pulmonary disease; CG – control group; HTMG – home telemonitoring group; GOLD - Global Initiative for Chronic Obstructive Lung Disease; NRCT - non-randomised controlled trial; RCT – randomised controlled trial.

Table 2 - Types of outcomes measured in the home telemonitoring and control groups.

	Hospitalisations		**Length of hospital stay**	**Emergency department visits**		**Healthcare costs**	**Mortality**	**Quality of life**	**Respiratory exacerbations**		**Other outcomes***
First author (year)	Rate	Mean	Mean	Rate	Mean	Mean	Rate	Mean	Rate	Mean	
Antoniades (2012) [25]		●	●				●	●			
Chau (2012) [26]	●		●	●				●			●
Jódar-Sánchez, (2013) [27]	●	●	●	●	●		●	●			●
Koff (2009) [17]	●			●		●		●			
Lewis (2010a)	●	●	●		●		●	●			●

[24], (2010b)											
[18]											
Paré (2006) [19]	●	●	●			●					●
Pedone (2013) [20]	●		●						●		
De San Miguel (2013) [16]	●	●	●	●	●	●		●			●
Trappenburg (2008) [28]	●	●	●		●		●	●		●	●

*Other outcomes: forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC) and FEV_1/FVC ratio [26], type and quantity of prescribed medication [28], six-minute walking distance [25], anxiety and depression symptoms [24], primary care contacts (chest and non-chest) [18], specialised consultations [27], healthcare team phone calls and home visits [16-19, 27], mortality [18, 27] and costs related to telemonitoring equipment and healthcare resources [19].