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Feature Article

The effect of smart homes on older adults with chronic conditions: A systematic review and meta-analysis

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ABSTRACTS

As populations continue to age, the prevalence of multiple chronic conditions in older adults grows. The purpose of this study was to evaluate the effect of smart homes on older patients with chronic conditions. A review and meta-analysis were conducted after searching both English and Chinese databases. Fifteen RCTs were included in the review, with six studies qualifying for the meta-analysis. The meta-analysis revealed no significant effects on measures of hospital admissions (RR =0.90, 95% CI (0.57, 6.34), $P = 0.65$) or emergency department admissions (RR =0.99, 95% CI (0.34, 2.91), $P = 0.98$). Likewise, no effects were observed for tele-monitoring on days spent in the hospital (MD =-0.90, 95% CI (-3.34, 1.55), $P = 0.47$) or quality of life. However, almost all participants were satisfied with the smart homes. The effect of tele-exercise on cognitive functioning was unclear. However, the smart homes did have an effect on physical functioning and depression in older adults with chronic conditions. Future studies should focus on the economic effectiveness, security, accessibility and practicality of smart homes on older adults with chronic conditions.

Introduction

Aging populations have become a global social phenomenon and have placed heavy medical and economic burdens on societies. As the physical functioning of the elderly gradually weakens and the structure of the population tends towards aging, the incidence of chronic condition increases accordingly. Providing long-term health management is a challenge for the rapidly growing number of patients with chronic condition. Because of the long course of illness, poor compliance and complicated conditions, patients with chronic condition need long-term professional supervision and care. These challenges may increase as the population ages and the complexity of chronic condition treatments increases.[1] Older adults tend to stay at home when they need professional care rather than entering a medical institution.[2] Furthermore, changes in the family structure have added to the heavy burden of care on government, while family dynamics can make changes difficult to implement. In addition, personal home care exacerbates the shortage of nursing personnel and aggravates the nursing workload.[3] Therefore, alternatives are needed for home care, health monitoring, health management and rehabilitation of the home-dwelling elderly with chronic condition. With the contribution of subjective factors (older adults' expectancies) and objective factors (the complex needs of chronic conditions), the field of gerontechnology has emerged as an important tool for chronic condition management in the elderly.

Smart homes are one form of gerontechnological innovation.[4] The smart home refers to a distinctive home or residence augmented with sensors and devices/actuators that are integrated into the infrastructure of the residence. These sensors and devices are intended to observe the environment, monitor the context of the inhabitant and provide proactive services with the goal to improve the elder's experiences.[5,6] The smart home system is composed of three primary technological sections: physical components (sensors, actuators) sensing the data, the control system receiving data from the physical components making decisions, and the communication system (wired/wireless network) connecting the physical components and the control system.[7] With information collected from the physical components, the control system conducts simple task automation, an analysis or prediction of the location of the resident and their behavior, or recognition of the health status of an occupant living at the home.[5] Smart homes may provide greater comfort by automating assistance rather than disrupting the usual life of older adults.

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One of the functions of a smart home is real-time monitoring of older adults' daily life, which has significant consequences for health-related issues. In addition to predicting older adults' health conditions and the detection of anomalous events, they are helpful in ascertaining medical emergencies requiring the deployment of medical professionals. Therefore, continuous monitoring can improve safety and enhance quality of life.[7] Another function of smart homes is to improve the physical functioning of the elderly. Previous studies[8–10] have shown that smart homes have enabled older adults who need healthcare assistance but were unwilling to approach healthcare facilities for frequent health-related check-ups, to continue living independently. They also ease the burden on informal or formal caregivers and allow them to better care for older adults.

Currently, smart homes are just at the exploratory stage. The aim of this research was to explore whether the use of smart homes by older patients with complex chronic conditions has had an impact on their health outcomes, as well as the feasibility of smart home use in this population.

Method

Search strategy

This study was conducted in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis.[11] Two authors conducted a comprehensive literature search. Six English databases were searched including Scope, PubMed, Web of Science, Embase, CENTRAL and the IEEE Digital Library, as well as three Chinese databases: Wan Fang Data, China National Knowledge Infrastructure (CNKI) and Weipu (VIP). All of the databases were searched from each database's inception to July 2018. The following mesh-terms or keywords were applied when searching: ("smart home" OR "gerontechnology" OR "tele-monitoring" OR "wearable sensors" OR "tele-health" OR "tele-surveillance") AND ("aged" OR "elder" OR "senior citizen" OR "old people" OR "aging") AND (randomized controlled trial). We also searched the reference lists of relevant studies and reviews to identify any potentially eligible trials. The full electronic strategy used for the individual databases was provided in Appendix 1.

Eligibility criteria

Only articles that were approved by the peer-review process were included. The inclusion criteria the studies had to meet was as follows:

(1) Randomized controlled trails (RCTs) published in English or Chinese.
(2) Involved older patients (≥60 years old) with chronic conditions. Chronic conditions were defined as human health conditions or diseases that are persistent or otherwise long-lasting in their effects, or they were defined as diseases that occur over time.
(3) Intervention studies that used technologies related to smart home systems to monitor older adults at home. The smart home system had to consist of the three sections of technology: the physical components, the control system and the communication system. According to the pre-retrieval process, we included articles related to tele-monitoring and tele-exercise. Studies that did not provide enough descriptive information about technology readiness were excluded.
(4) Reported health-related outcomes as the primary or secondary outcome.

Study selection and data extraction

The screening process was independently conducted by two researchers. They read and assessed the eligibility of the title and abstract of retrieved articles, while a third reviewer adjudicated discrepancies. Full texts of the remaining articles were downloaded and assessed according to the inclusion criteria. The third reviewer resolved discrepancies and made the final decision for inclusion. Two reviewers used a consolidation data extraction form to extract the following information: author and year, study design, population (including sample size, age and characteristics), intervention (tele-monitoring, tele-exercise, etc.), control group details and results (Table 1). A narrative synthesis was conducted if the data could not be pooled.

Quality assessment

The methodological quality of the included RCTs was evaluated using Cochrane Collaboration's tool for assessing the risk of bias, which included six criteria: selection bias, performance bias, detection bias, attrition bias, reporting bias and other bias. The risk of each item was evaluated as low, high and unclear. Two reviewers independently conducted the quality assessment of the extracted articles.

Statistical analysis

Review Manager (version 5.3) was used to perform the statistical analyses. The use of a random-effects model or fixed model on estimates to generate summary values depended on a test of heterogeneity. Both continuous and dichotomous outcomes were reported in the studies that were included for meta-analysis. A standardized mean difference (SMD) was calculated when there was variation in the measurement used by the studies. Otherwise, weighted mean differences (WMD) were used. Adjusted relative risks (RRs) with 95% confidence intervals were applied to the dichotomous data. A value of $P < 0.05$ was considered to be significant. The heterogeneity of outcomes was quantified by the I^2 value. Heterogeneity was considered significant when $I^2 > 50\%$. A subgroup analysis was not conducted due to the lack of original studies.

Results

The initial database search retrieved 10,757 articles from nine databases. Additionally, two studies were identified by searching the references of the relevant articles. After removing duplications, 8466 articles were identified for title and abstract screening. Forty-two full text articles remained to be assessed according to the pre-specified eligibility criteria. Finally, we obtained 14 studies to be qualitatively summarized, and 9 articles were selected for meta-analysis. (Fig. 1)

Study characteristics

The characteristics of the included studies were summarized in Table 1. The eligible RCTs investigated a total of 1604 participants. These studies were conducted in the United States[10,12–19] ($n = 9$), Korea[20,21] ($n = 2$), Australia[22] ($n = 1$), Italy[23] ($n = 1$) and Denmark[24] ($n = 1$). Eight studies[12,16–19,21–23] evaluated older patients with chronic heart failure or COPD, two studies[13,15] reported on frail older adults, while the other studies examined older patients with multiple medical conditions,[14] chronic dizziness,[24] sarcopenia[20] or amnestic MCI.[10] The types of interventions included home-based exercise and home tele-monitoring. Four studies[10,13,20,24] conducted home-based exercise regimes in older patients, with the training programs varying from 1 month[10] to 24 months.[13] The results regarding home-based exercise were based on physical and cognitive functioning. Ten studies[12,14–19,21-23] used home monitoring technology, with the total monitoring duration varying from 2 months[12,15,21] to 12 months.[14,22] The results regarding home tele-monitoring were categorized into three domains: ① Hospital utilization: Seven studies[12,15,18,19,21–23]

Table 1
Characteristics of the included studies.

		Study population				Intervention		
Author, year (country)	Study Design	N	Characteristics	Age Year	Type	Intervention group Number/length/details	Control group	Results
Antoniades et al., 2012 (Australia)	RCT	36	COPD	≥60	Tele-monitoring	16; 12 months; SBP(standard best practice care) + RM(involved daily recording of physiological variables, symptoms, and medication usage)	20; usual care	1. No differences in the number of total admissions and total lengths of stay between the two groups 2. No significant improvement in the quality of life in the intervention group
Chau et al., 2012 (Korea)	RCT	40	COPD	≥60	The ASTRL tele-care system(ATS)	22; 2 months; monitor oxygen saturation, pulse rate and respiration rate 3 times a day and transmit the data to the platform.	18; usual care	1. Intervention participants are satisfied with the tele-care service. 2. No significant differences are found between the two time points with regard to health-related quality of life. 3. No significant differences in the number of emergency department visits and hospital re-admissions between the study groups are found.
Finkelstein et al., 2011 (USA)		84	Frail/Chronic disease	≥60	A web portal allowed videoconference	40; 2 months; a VALUE workstation	44; usual care	1. All 68 subjects were satisfied with the tele-health technology and it met their expectations. 2. Intervention subjects made fewer emergency department visits than control subjects. 3. However, no significant differences were found in hospital admissions between groups.
Gellis et al., 2014 (USA)		94	Chronic illness(heart failure or COPD)/ depression	≥65	Tele-health intervention(integrated tele-health education and activation of mood (I-TEAM)	48; 3 months; daily tele-health; sessions of problem-solving treatment for depression; providing communication with participants' primary care physicians	46; usual care	1. T-test analyses revealed no significant differences between groups in satisfaction scores, with all participants reporting general satisfaction with their care. 2. No significant between group differences were found in SF-12 scores. 3. The I-TEAM group had significantly fewer ED visits but did not have significantly fewer in-hospital days.
Gellis et al., 2012 (USA)		102	Chronic illness (heart failure or COPD)	≥65	Tele-health intervention/" Home Med " Health Monitoring System	51; 3 months; tele-HEART intervention	51; usual care	1. The intervention group had significantly fewer ED visits but did not have significantly fewer in-hospital days. 2. The intervention group experienced significantly greater increases in two of the three SF-36 scales. 3. All participants were satisfied with the tele-HEART intervention.
Hong et al., 2016 (Korea)	RCT	23	Sarcopenia	≥60	SkypeTM	11; 3 months; supervised resistance exercise 20–40 min a day, three times per week	12; usual care	Significant improvements in body composition and functional fitness compared to the control group
Madigan et al., 2013 (USA)	RCT	99	Heart failure	≥60	Tele-monitoring	54; 2 months; home tele-monitoring	45; usual care	1. No statistically significant group differences in hospital admissions, hospital days and ED visits 2. Improvement occurred in quality of life in the intervention group
Michael et al., 2016 (Denmark)	RCT	57	Chronic dizziness	≥65	"Move It To Improve It" (Mitii)	28; 3 months; computer-assisted home exercise program	29; usual care	No significant difference in functional levels between groups

(*continued*)

Table 1 (*Continued*)

Author, year (country)	Study Design	Study population N	Characteristics	Age Year	Type	Intervention Intervention group Number/length/details	Control group	Results
Pecina et al., 2013 (USA)	RCT	166	Multiple medical conditions	≥60	Intel Health Guide® (home tele-monitoring)	77; 12 months; daily home tele-monitoring	89; usual care	Significant difference in the baseline to 12-month change of SF-12 between groups
Pedone et al., 2013 (Italy)	RCT	99	COPD	≥65	SweetAge tele-monitoring system	50; 9 months; a noninvasive system able to tele-monitor vital signs	49; usual care	1. Compared to standard care, a multiparametric remote monitoring system reduced COPD exacerbation rates and COPD-related hospitalizations.
Schwenk et al., 2016 (USA)	RCT	20	Amnestic MCI	≥60	Sensor-based balance training program	11; 4 weeks; sensor-based balance training included weight shifting and virtual obstacles	9; usual care	No significant difference in gait speed and cognitive performance between groups
Tomita et al., 2007a (USA)	RCT	78	Frail elders	≥60	Internet access and X10-based Smart Home Technology	34; 2 years; smart home based technology to computer training	44; usual care	1. Cognitive level increased significantly in the intervention group. 2. Physical level maintained in the intervention group, while the control group decreased significantly
Tompkins et al., 2010 (USA)	RCT	390	Heart failure	≥65	The Honeywell HomMed Sentry and Genesis monitors	195; 6 months; tele-monitoring care	195; usual care	1. No significant group differences in hospital utilizations were found.
Wade et al., 2011 (USA)	RCT	316	Heart failure	≥60	The Intel HGS	164; 6 months; tele-health system with case management (THCM)	152; usual care	1. The results found no difference between groups in clinical outcomes including hospital admissions, ED visits and hospital days or quality of life among HF patients. 2. More than 93% of THCM members expressed satisfaction with the equipment

COPD: chronic obstructive pulmonary disease; ED: Emergency Department; MCI: Mild cognition impairment; HF: heart failure.

reported outcomes regarding hospital admissions, seven studies[12,15–19,21] evaluated emergency department visits (ED visits) and six studies[16-19,21,22] assessed days in the hospital. ② Quality of life: There were six studies[12,14,16–18,22] evaluating quality of life using the measurements SF-12, SF-36 and the Quality of Life-index. ③ Satisfaction: There were six studies[15-18,21,22] reporting participants' satisfaction with smart home technology.

Methodological quality

The risk of bias in the included RCTs assessed by Cochrane Collaboration's tool was presented in Fig. 2. Almost all of the included studies tried to randomize participants into two groups; only four articles did not report the method of random sequence generation. Allocation concealment was unclear in most studies. Blinding participants to the type of intervention was impossible, as they were always involved in the intervention. The blinding of assessors was only conducted in six articles. With regard to incomplete outcome data, 12 of the 15 articles used intention-to-treat analysis.

Analysis of outcomes

Tele-monitoring

Hospital utilization. Four studies[15,18,21,23] reported hospital admissions as discontinuous data, calculated using Rate Ratios with 95% CIs. The meta-analysis revealed that tele-monitoring did not have a significant effect on hospital admissions (RR =0.90, 95% CI (0.57, 1.42), $P = 0.65$; I^2=38%). (Fig. 3) Only one study[22] reported hospital admissions as continuous data, and the results indicated that remote in-home monitoring did not reduce hospital admissions in patients with chronic obstructive pulmonary disease.

The meta-analysis for outcomes related to ED visits, presented as discontinuous data,[15,18,21] indicated that no statistically significant difference (RR =0.99, 95% CI (0.34, 2.91), $P = 0.98$; I^2=80%) was found (Fig. 4). However, Gelliset al.[16,17] reported that ED visits, presented as continuous data, could be reduced by integrated tele-health care.

Hospital days were treated as continuous variables in five articles.[16–18,21,22] The results of the meta-analysis indicated that no significant effect of tele-monitoring on hospital days (MD =−0.90, 95% CI (−3.34, 1.55), $P = 0.47$; I^2=65%) was found (Fig. 5).

Two studies[12,19] did not report complete data and were not included in the quantitative synthesis. They were qualitatively described. One study[12] measured the ability of tele-monitoring in reducing hospital utilization. After a six-month intervention, tele-monitoring was related to lower hospital admissions, hospital days and ED visits, but there were no statistically significant differences between the two groups. The other study[19] investigated the effectiveness of tele-monitoring on older patients with heart failure. However, the finding did not support a superior potential of tele-monitoring in reducing hospitalizations.

Quality of life. Five studies reported detailed data on quality of life measures, with three studies[14,16,18] using SF-12 and two studies[17,22] using SF-36. The pooled results demonstrated that the tele-monitoring group did not have a statistically significant effect on quality of life, either in the SF-12 variable [MD = −1.03, 95% CI (−4.30, 2.24), $P = 0.54$; I^2=70%] or in the SF-36 variable [MD = 1.75, 95% CI (−6.54, 10.04), $P = 0.68$; I^2=44%] (Fig. 6a, 6b). The study by Madigan et al.[12] did not report detailed data, but it did indicate that

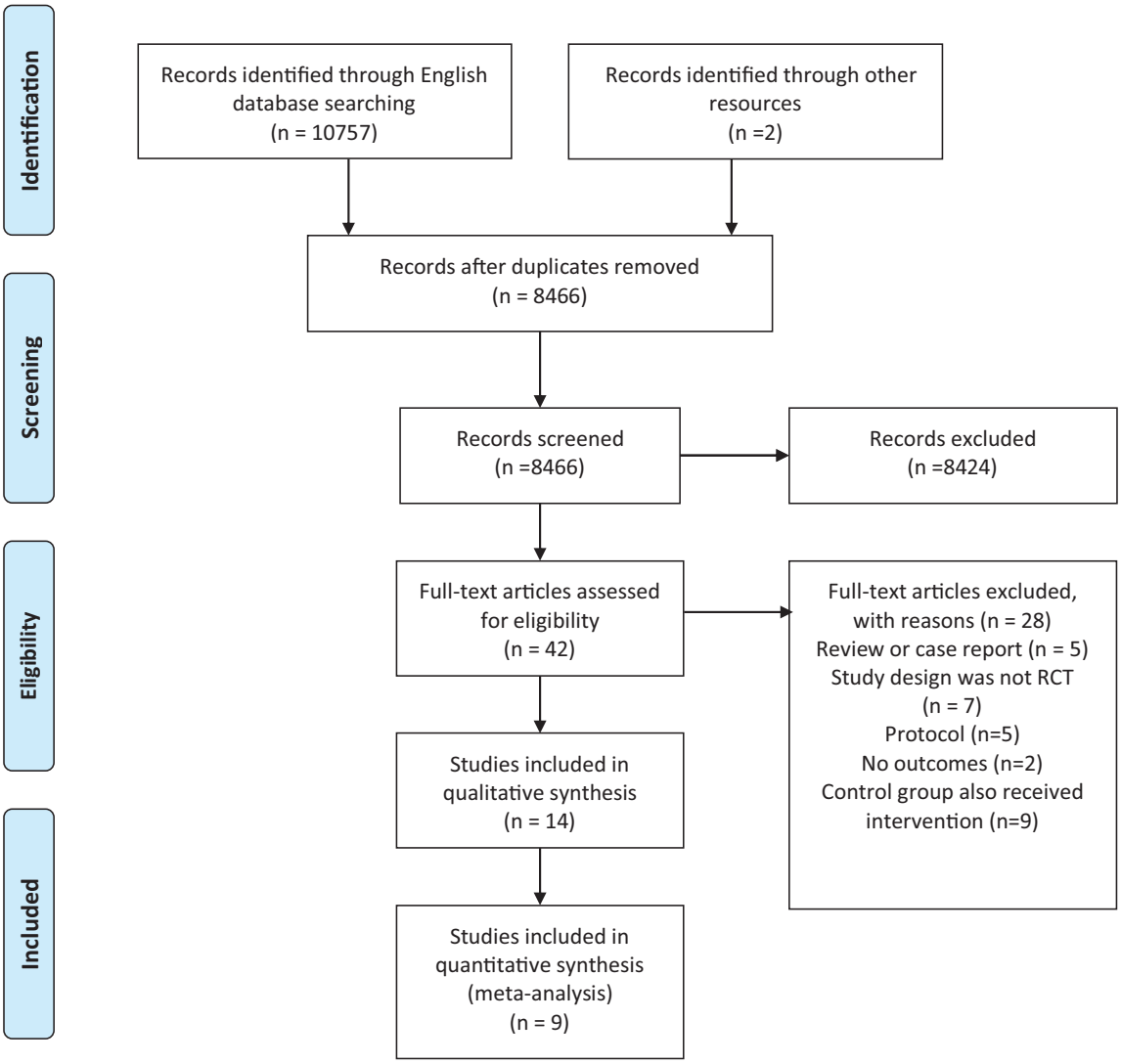

Fig. 1. Study selectionflow chart.

tele-monitoring had a positive, but not statistically significant, effect on quality of life.

Satisfaction. Six studies assessed participants' satisfaction with the use of tele-health.[15–18,21,22] They focused on five categories: privacy protection, nursing service, the tele-monitoring device, availability and timely care provision. All participants indicated they would recommend tele-health to others. In one article, almost 100% of the participants were satisfied with the support, and 83% reported that the explanations were easy to understand and follow.[21]

Tele-exercise

Physical functioning. The results were not pooled due to the heterogeneity of the method and outcome measures. Four articles reported the results of physical functioning.[10,13,20,24] In the study by Hong et al.,[20] the tele-exercise group showed significant improvements in body composition and functional fitness, including lower muscle mass, appendicular lean soft tissue and total muscle mass when compared to the control group. In a study conducted by Tomita et al.,[13] the physical level achieved in the intervention group was maintained after a 2-year intervention, while the control group's level decreased significantly. While in the study conducted by Smaerup et al.,[24] no statistically significant difference in physical functioning levels was found between groups. In the study by Schwenk et al.,[10] tele-exercise showed a significantly positive effect on balance, but not on walking speed.

Cognitive function. Only two included articles[10,13] provided detailed data on cognitive functioning. In one article, the results revealed that the treatment group showed significant improvements when compared to the control group.[13] While the study conducted by Schwenk et al.[10] did not report a significant effect due to the short training period.

Discussion

The effects of smart homes and an interpretation of results

Tele-monitoring

We conducted a systematic review and meta-analysis to provide evidence of an effect of smart homes on older adults with chronic conditions. In contrast with previous reviews,[25,26] we calculated an estimate of the size of this effect on hospital utilization and quality of life. The result of the meta-analysis was not significant, indicating that smart homes probably result in little to no difference on health

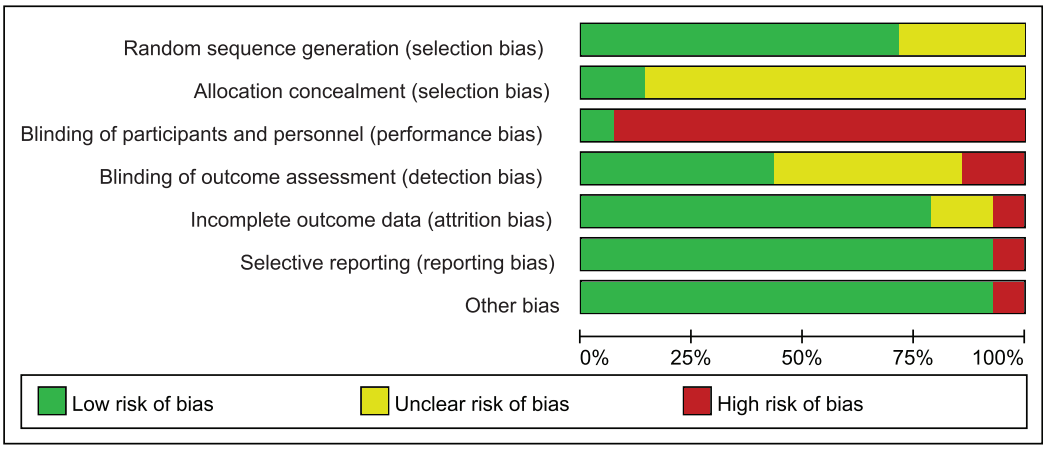

Fig. 2. Risk of bias across studies included in the meta-analysis.

Study or Subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Risk Ratio M-H, Random, 95% CI
Finkelstein 2011	7	40	15	44	22.0%	0.51 [0.23, 1.13]
Pedone 2013	6	50	9	49	16.9%	0.65 [0.25, 1.70]
Wade 2011	57	164	49	152	49.3%	1.08 [0.79, 1.47]
Chau 2012	7	22	3	18	11.8%	1.91 [0.57, 6.34]
Total (95% CI)		**276**		**263**	**100.0%**	**0.90 [0.57, 1.42]**
Total events	77		76			

Heterogeneity: Tau² = 0.08; Chi² = 4.84, df = 3 (P = 0.18); I² = 38%
Test for overall effect: Z = 0.45 (P = 0.65)

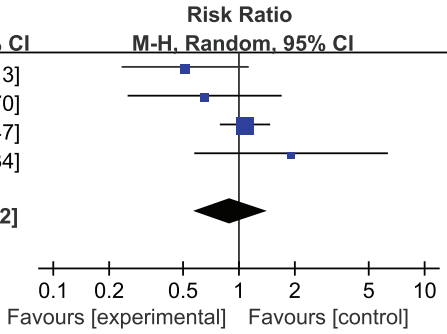

Fig. 3. Forest plot of all studies reporting hospital admissions.

Study or Subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Risk Ratio M-H, Random, 95% CI
Chau 2012	7	22	3	18	28.0%	1.91 [0.57, 6.34]
Finkelstein 2011	5	40	17	44	33.0%	0.32 [0.13, 0.80]
Wade 2011	34	164	20	152	39.1%	1.58 [0.95, 2.61]
Total (95% CI)		**226**		**214**	**100.0%**	**0.99 [0.34, 2.91]**
Total events	46		40			

Heterogeneity: Tau² = 0.71; Chi² = 9.84, df = 2 (P = 0.007); I² = 80%
Test for overall effect: Z = 0.02 (P = 0.98)

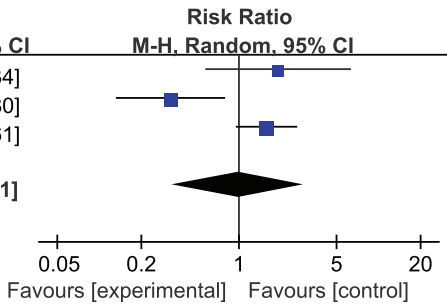

Fig. 4. Forest plot of all studies reporting ED visits.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Antoniades 2012	21.6	30.4	22	22.1	29.9	22	1.8%	-0.50 [-18.32, 17.32]
Chau 2012	2.16	4.69	22	0.78	1.93	18	33.3%	1.38 [-0.77, 3.53]
Gellis 2012, 2014	7.5	4.3	57	10.5	6.5	58	34.4%	-3.00 [-5.01, -0.99]
Wade 2011	5.41	11.33	164	6.44	11.33	152	30.5%	-1.03 [-3.53, 1.47]
Total (95% CI)			**265**			**250**	**100.0%**	**-0.90 [-3.34, 1.55]**

Heterogeneity: Tau² = 3.46; Chi² = 8.50, df = 3 (P = 0.04); I² = 65%
Test for overall effect: Z = 0.72 (P = 0.47)

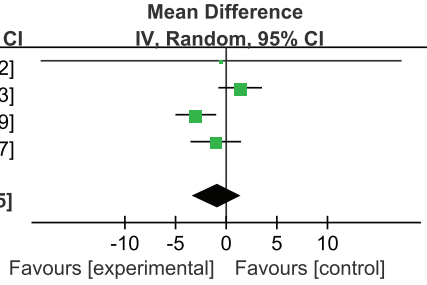

Fig. 5. Forest plot of all studies reporting hospital days.

care utilization. Studies regarding tele-exercise did, however, report that smart homes improved physical functioning.

Our findings that tele-monitoring did not have a statistically significant effect on hospital admissions, ED visits or hospital days were roughly consistent with previous reviews.[9,27] Tele-monitoring was still promising, as it tended to be effective on all of the three outcomes. There are a number of possible explanations for these findings. First, the sample sizes may not have been large enough. Tompkins et al.[19] reported that in a study examining the efficacy of tele-monitoring on tele-health in patients with heart failure, the

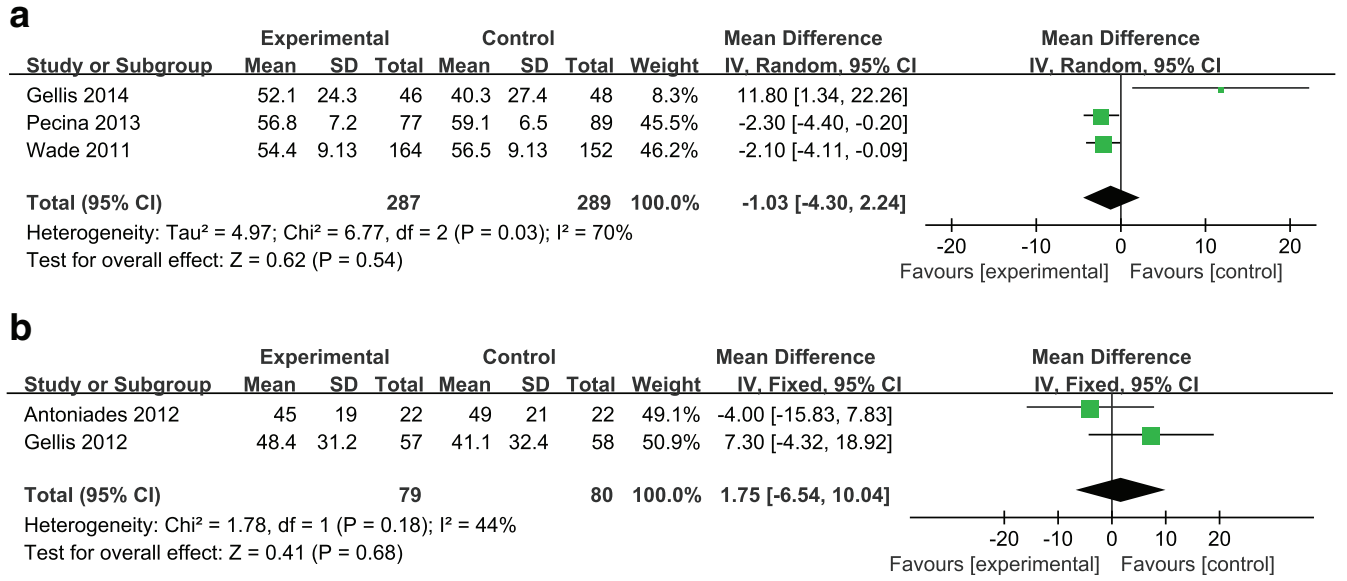

Fig. 6. a): Forest plot of all studies reporting SF-12. b): Forest plot of all studies reporting SF-36.

estimated sample size was 350 subjects in each group, which was far more than the sample sizes in the included studies. Second, the compliance of the participants may have been poor. Two studies[21,23] reported that only 60% of patients transmitted data at least three times a day. Third, the intervention periods may have been too short. The studies for two months[15,21] and six months[12,18,19] had inconsistent results, while the studies for nine months[23] and twelve months[16,22] were all more likely to be effective. One possible reason may be that in the beginning, patients were likely to be nervous when out-of-normal-range data was detected by the tele-monitoring device, therefore more health utilization may have resulted. As time went on, they would have been able to handle small problems by themselves, and the health utilization would decrease.

Our meta-analysis showed that tele-monitoring had no significant improvements on quality of life in older adults with chronic conditions. However, the results of the six studies[12,14,16–18,22] that we included are controversial. Madigan et al.[12] and Gellis et al.[16,17] reported a significant effect of tele-monitoring on the quality of life in older adults with chronic conditions compared with participants in control group. This positive effect was in accordance with findings from earlier studies.[28,29] One possible explanation for participants with chronic condition experiencing an increased quality of life is that daily tele-monitoring with enhanced surveillance may help older adults feel less worried about their health status. With tele-monitoring, a nurse will give advice and guidance in a timely manner when the data being measured fall out of the normal range. In three other studies,[14,18,22] there were no significant effects of tele-monitoring on the quality of life in older adults with chronic conditions when compared with the effects of usual care. In other words, the effect of tele-monitoring on the quality of life of older adults with chronic conditions remains unclear. The inconsistency in these results may be due to subjective factors having to do with the assessor, the different sample sizes, or the different types of chronic conditions.

Six studies[15–18,21,22] investigating satisfaction with the tele-monitoring interventions were present in all of the included studies. Satisfaction assessments focused on five categories: privacy protection, nursing service, the tele-monitoring device, availability to use the device and timely care provision. In Chau's study,[21] almost 100% of participants commented that they were satisfied with the tele-monitoring service, 86.3% indicated that the explanations for using the tele-monitoring equipment was adequate and easy to understand, and 54.5% thought the tele-monitoring service was useful in helping to manage their disease at home. In Antoniades's study,[22] the overall satisfaction rate of participants was 88%. All of the users felt that the technical support they received was good, 94% of users found the tele-monitoring system easy to use and 82% of users believed the system helped them better manage their disease symptoms. Similar results were found in four other included studies[15–18] and two later studies.[30,31] Overall, the level of satisfaction with the five categories was found to be high in six of the included studies, suggesting that user satisfaction with tele-monitoring interventions was high. However, a small number of participants experienced problems when using tele-monitoring equipment to measure physiological indicators.[21] For example, some users worried that they would not be able to finish the measurement without help from a caregiver, and some users thought it was difficult for them to place the sensing device in the correct position. In addition, with regard to the sensor devices, the participants needed to recharge the batteries every other day. This procedure was a complicated process that involved different electrical wires and adaptors. Therefore, tele-monitoring should be personalized to the needs of the older adults who use them in order to maximize their satisfaction with the experience.

Tele-exercise

In terms of physical functioning, 80% of the studies included in the present systematic review demonstrated that an intelligent exercise intervention greatly improves one's health. One study[10] suggested that sensor-based balance training is beneficial for promoting postural control in patients with mild cognitive impairment. Moreover, walking speeds of older adults was improved and the improvement could be maintained over time after using a motion capture system.[32] It is understood that the safety, availability, acceptability, and technical simplicity of exercise should be key considerations. One advantage of home health monitoring technologies is increasing the precision of sports training, which may be related to the technology of intelligent monitoring and feedback. Therefore, elderly people suffering from chronic conditions may obtain high-quality exercise through smart home technologies without professional guidance. In addition, compared to traditional training, some settings such as games and virtual reality make exercise more attractive and motivate patients to be more engaged in the exercise.[33] Notably, there are almost no adverse events reported for

tele-exercise. This indicates the potential of intelligent monitoring technology in physical functioning. However, there are only a small number of studies that illustrate the benefits of home health technologies. A previous review[5] had indicated that the current level of health-monitoring technologies is still low. Therefore, more high-quality research is needed to further the discussion on the effectiveness of home health technologies.

In terms of the impact of tele-exercise on cognition, the findings are conflicting. A two-year intervention[13] showed that smart home technology can alleviate the progression of cognitive impairment in older adults, which was consistent with the results of a previous study.[34] However, a different, short-term intervention was ineffective. Hence, the results of this review suggest that cognitive function may only benefit from long-term tele-exercising. However, people with cognitive impairment may have difficulty performing complex exercises correctly.[35] Nevertheless, the application of an interactive virtual reality device is safe and may reduce participants' fear of falling, as well as convince them to make bolder attempts to better training effects.

Issues that require attention and directions for future research

At present, smart home technology still needs to be improved, and there are several issues that need to be considered.

(1) Privacy. Concern over privacy violations may result from home-based monitoring. Thus, applying these technologies in such a manner as to reduce the exposure of patients' privacy is of great significance to usability.
(2) Safety. Future studies should focus on reducing the occurrence of errors and increasing monitoring sensitivity. The effectiveness of the monitoring determines the degree of application and the dependence of patients and healthcare professionals on smart homes.
(3) Risk prediction: Big data may be used to analyze and predict the risk of adverse events in the elderly by monitoring the behavior (such as gait and response rate) of older people.
(4) Personalized service: More attention needs to be paid to the different types of chronic conditions that can be addressed by this technology so the elderly can be provided with exercise methods and monitoring indicators that are suitable for their disease. This can provide a more personalized service for different elderly people, promote their health and improve user satisfaction.

Limitations

Our review has a number of limitations. First, due to limited resources, only English and Chinese databases were searched. We only included studies that had been published through the peer-review process. As such, gray literature such as unpublished documents and reports were not identified. The included studies were mainly in North America, Asia and Europe. Second, most of the included studies did not report allocation concealment, and blinding of participants and personnel in most of the studies were at a high risk of bias. This is because participants were always involved in the interventions. Finally, a small number of studies were included in the Meta-analyze; more well-designed and high-quality studies are required.

Conclusion

Smart homes appear to have an effect on physical functioning and depression in older adults with chronic conditions. Most of the participants included in the studies are satisfied with tele-monitoring and tele-exercises that are a part of smart homes. However, the impact of tele-monitoring on hospital utilization is unclear. Future studies should focus on the economic effectiveness, security, accessibility and practicality of this technology for older adults with chronic conditions.

Appendix 1. Search strategy

Source	Literature search
PubMed	(((((((smart home) OR Telemedicine [MeSH Terms]) OR gerontechnology) OR wearable sensors) OR Telehealth) OR assisted living)) AND ((((((aged [MeSH Terms]) OR elderly) OR senior citizen) OR old people) OR elder*) OR aging) Sort by: Best Match Filters: Clinical Trial; Randomized Controlled Trial
CENTRAL	"smart home":ti,ab,kw OR gerontechnology: ti,ab,kw OR telemonitoring: ti,ab,kw OR wearable sensors: ti,ab,kw OR Telehealth: ti,ab,kw OR assisted living:ti,ab,kw MeSH descriptor: [aged] explode all trees OR aged:ti,ab, kw OR aging: ti,ab,kw OR senior citizen:ti,ab,kw OR old people:ti,ab,kw OR elder*:ti,ab,kw
Web of Science	TS= (smart home OR Telemedicine OR gerontechnology OR wearable sensors OR Telehealth OR assisted living) TS= (aged OR elderly OR senior citizen OR old people OR elder* OR aging) TS= (randomized controlled trials OR randomized controlled study OR randomized controlled studies)
EMBase	('smart home' OR sensors OR gerontechnology OR 'assisted living' OR tech OR monitoring OR telesurvelillance OR telemonitoring) AND (((aged OR elder OR senior) AND citizen OR older) AND people OR aging) AND ([*chinese*]/lim OR [english]/lim) AND ([*aged*]/lim OR [very elderly]/lim) AND [article]/lim AND ([*controlled clinical trial*]/lim OR [randomized controlled trial]/lim)
IEEE	((((((("Abstract": smart home) OR "Abstract": gerontechnology) OR "Abstract": telemonitoring) OR "Abstract": wearable sensors) OR "Abstract": Telehealth) OR "Abstract": assisted living) AND ((((("Abstract": elderly) OR "Abstract": senior citizen) OR "Abstract": old people) OR "Abstract": aging) AND ("Abstract": trial)
Scope	("smart home" OR sensors OR gerontechnology OR "assisted living" OR tech OR monitoring OR telesurvelillance OR telemonitoring) AND (aged OR elder OR "senior citizen" OR "older people" OR aging) AND ("Randomized Controlled Study") AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (EXACTKEYWORD, "Aged") OR LIMIT-TO (EXACTKEYWORD, "Controlled Study")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j"))
Wan Fang Data	TS= (smart home OR Telemedicine OR gerontechnology OR wearable sensors OR Telehealth OR assisted living) TS= (aged OR old people OR aging) TS= (randomized controlled trial OR random)
CNKI	TS= (smart home OR Telemedicine OR gerontechnology OR wearable sensors OR Telehealth OR assisted living) TS= (aged OR old people OR aging) TS= (randomized controlled trial OR random)
VIP	TS= (smart home OR Telemedicine OR gerontechnology OR wearable sensors OR Telehealth OR assisted living) TS= (aged OR old people OR aging)

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.gerinurse.2019.03.016.

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