The effectiveness of electronic health interventions on blood pressure control, self-care behavioural outcomes and psychosocial well-being in patients with hypertension: A systematic review and meta-analysis

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A R T I C L E   I N F O

A B S T R A C T

Objectives: Hypertension is a global health issue. Electronic health (eHealth) is a potential alternative for managing hypertension and modifying hypertension-related self-care set of behaviour. This review aims to identify the delivery mode and strategies used by current eHealth interventions and examine the effectiveness of eHealth on blood pressure control, self-care behavioural outcomes and psychosocial well-being.

Design: Systematic review and meta-analysis.

Data source: Ten English databases (Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Embase, Joanna Briggs Institute EBP Database, MEDLINE, CINAHL Plus, PsycINFO, SCOPUS, Web of Science and INSPEC) and two Chinese databases (China Journal Net and WanFang Data) were searched from January 2000 to November 2017.

Review methods: This review was conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement. Two reviewers independently selected potential articles and extracted the details of each eligible article. The Randomized Controlled Trial Checklist of Joanna Briggs Institute was used to assess the methodological quality of the included articles. Meta-analysis was conducted using Review Manager 5.3 for at least two studies reporting the same outcome. Otherwise, narrative synthesis was performed.

Results: Fifteen articles from fourteen studies satisfied the inclusion criteria. The pooled result of 13 studies reported that eHealth intervention significantly affected the reduction of systolic blood pressure (mean difference [MD]: −5.96 mmHg, 95% confidence interval [CI]: −9.21 to −2.70, p < .001) and diastolic blood pressure (MD: −3.35 mmHg, 95% CI: −6.36 to −0.35, p < .05). eHealth interventions significantly decreased the proportion of patients with inadequate blood pressure control (risk ratio: 0.69, 95% CI: 0.57–0.84, p < .001) and their body weight (MD: −1.08 kg, 95% CI: −2.04 to −0.13, p < .05). Regarding self-care behavioural outcomes, the pooled results show that eHealth interventions significantly reduced the sodium intake.

Conclusions: This study reported that eHealth interventions positively affect blood pressure control and thus could be a promising alternative in the management of hypertension. However, their effectiveness on self-care behavioural change and psychosocial well-being is insufficient. Therefore, additional eHealth interventions with rigorous experimental design on hypertension self-care are needed to provide a robust evidence for a wide population and to address the increasing health care needs of patients with hypertension.

What is already known about the topic?

- Hypertension is a critical public health issue worldwide, and its control is highly dependent on pharmacological therapy and lifestyle modification, in which patient self-care plays an important role.

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- Electronic health is a potential alternative for addressing the increasing health needs by providing remote support for self-care, flexible and convenient access and individualised advice and feedback.

What this paper adds

- This review identified two delivery modes adopted in current eHealth interventions: 'system generating feedback by using automated email reminders' mode and 'health care providers supporting individualised goal-directed feedback through multiple media.'
- This report indicated that eHealth enhanced the reduction of blood pressure, body weight and sodium intake. For psychosocial well-being and other self-care behaviour outcomes, the results from current eHealth studies were suboptimal. Additional eHealth studies with a rigorous experimental design on hypertension self-care are needed to provide a robust evidence for a wide population and to address the increasing health care needs of patients with hypertension.

1. Introduction

Hypertension is a condition in which the blood persistently exerts increased pressure against the blood vessels (World Health Organization [WHO], 2013). This illness has become a global public health crisis because of its consistently high incidence and prevalence rates (Olsen et al., 2016). Hypertension is a leading contributor to the burden of cardiovascular, cerebrovascular and kidney diseases (James et al., 2014), which could deteriorate patients' quality of life and increase health care utilisation and cost (Trevisol et al., 2011). Blood pressure control is highly dependent on pharmacological therapy and lifestyle modification, in which patient self-care plays an important role (Whelton et al., 2017; Lee et al., 2010). Stress and depression management also complements self-care (Cuevas et al., 2017). Self-care is the ability to take care of oneself and conduct a series of necessary activities to achieve, maintain and/or promote optimal health condition (Richard and Shea, 2011). Weight loss, healthy diet, sodium reduction, increased physical activity and reduced alcohol consumption are effective and highly recommended self-care activities to control blood pressure (Whelton et al., 2017).

However, patients often fail to control their blood pressure consistently because of the encountered difficulties in adhering to self-care activities (Lee et al., 2010). Patients become dissatisfied and less motivated to maintain self-care activities when their experiences do not match their expectations of a new lifestyle, particularly in environments that could not support health-related decision making (Whelton et al., 2017). Individualised factors such as age, sex, baseline health status and comorbid conditions could also negatively affect adherence to lifestyle modification (Whelton et al., 2017). Young patients are on the rise and exhibit poor blood pressure control, and interventions to facilitate their adherence to self-care activities are needed (Gooding et al., 2014). Thus, exploring optimal individualised interventions to improve the motivation of performing hypertension self-care activities remains a challenge for health care providers and researchers (Khan et al., 2017).

The interest in the application of technology to develop individualised self-care interventions for patients with hypertension is growing. McLean conducted a systematic review to explore the effectiveness of interactive digital technology on hypertension self-management, reporting significant positive effect on blood pressure control (McLean et al., 2016). Considering the rapid growth of technology, the telephone calls used in two included studies (Piette et al., 2012; Friedman et al., 1996) of this review were viewed as a traditional intervention delivery format.

The proliferation of the internet from 2000 (Eland-de Kok et al., 2011) provided many convenient devices for chronic disease management, such as smartphone application and website, featuring interactive wireless communication capability, operating web-based applications and high portability (Stellefson et al., 2013). Many organisations and researchers have focused on the combination of these devices and hypertension control. Electronic health (eHealth) defined as 'the electronic application to utilise information communication technologies to support health and health-related activities' (WHO, 2016) that could address the increasing health needs by providing remote support, flexible and convenient access and individualised advice and feedback (Band et al., 2017). Sizable studies used eHealth for promoting health, making it a potential alternative for managing hypertension and modifying hypertension self-care set of behaviour (Kim et al., 2016; Lee et al., 2016; Moore et al., 2014; Bove et al., 2013; Margolis et al., 2013; McKinstry et al., 2013; Rifkin et al., 2013; Bennett et al., 2012; Magid et al., 2013; Nolan et al., 2012; Durrani et al., 2012; Yoo et al., 2009; Green et al., 2008; Madsen et al., 2008; Xu et al., 2017). eHealth provides individualised intervention for hypertension self-care to motivate patients to maintain their self-care behaviour without time and space limitation (Poon et al., 2006), particularly for young patients who are unlikely to receive lifestyle modification counselling (Gooding et al., 2014).

Therefore, the effectiveness of existing eHealth interventions, particularly internet-based new technology (e.g. smartphone application), on hypertension self-care needs to be explored. This review aims to 1) identify the delivery mode and strategies of current eHealth interventions and 2) examine the effectiveness of eHealth interventions on blood pressure control, self-care behavioural outcomes and psychosocial well-being of patients with hypertension.

2. Methods

This review was developed and conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement (Moher et al., 2009).

2.1. Eligibility criteria

Eligible studies should meet the following criteria:

2.1.1. Population
The population must include patients with clinical diagnosis of hypertension, with or without adequate blood pressure control (adequate blood pressure control operational defined as blood pressure low than 140/90 mmHg).

2.1.2. Intervention
Eligible eHealth interventions include: (i) interventions that use devices featuring interactive wireless communication capability, operating web-based applications and with high portability (such as smartphone, computer and personal digital assistance tools) (Stellefson et al., 2013); and (ii) interventions comprising self-care, self-management, self-care behavioural change or education dissemination. The exclusion criteria include: (i) electronic devices used for follow-up or information display only; and (ii) eHealth interventions that mostly benefit health care providers.

2.1.3. Comparison
The comparison group could be standard care, usual care or attention control.

2.1.4. Outcomes

a Physical outcomes, including systolic blood pressure (SBP), diastolic blood pressure (DBP), blood pressure control, body mass index, body weight and cholesterol;

b Self-care behavioural outcomes, including medication adherence, sodium intake, healthy diet, physical activity and smoking and alcohol consumption (Whelton et al., 2017);

c Psychosocial well-being, including anxiety, stress, depression and quality of life.

2.1.5. Types of studies

Randomised controlled trials published in English and Chinese.

2.2. Search strategy

Major English and Chinese electronic databases were searched from January 2000 to November 2017, including Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Embase, Joanna Briggs Institute EBP Database, Ovid MEDLINE(R), CINAHL Plus, PsycINFO, SCOPUS, Web of Science, INSPEC, China Journal Net and WanFang Data. Keywords with the combination of 'AND' and 'OR' and medical subject heading terms were used for searching, including hypertension, electronic health, web, internet, blood pressure, medication adherence, lifestyle, quality of life and randomised controlled trial.

2.3. Study selection

Basing on the inclusion criteria, two reviewers (MY and CL) independently selected potential articles by screening and reviewing their titles and abstracts and further assessing their full texts. Any discrepancies or disagreements regarding the inclusion were resolved by discussion. Divergences were settled by the senior reviewer through a discussion. The reference lists of eligible articles were reviewed to identify additional potential eligible studies.

2.4. Data extraction and risk of bias appraisal

Two reviewers (MY and CL) independently extracted the details of each eligible articles by using standardised data extraction forms. The study design (setting, sample size and drop-out rate), characteristics of participants (age, gender and education level) and characteristics of eHealth interventions (device type, method, dosage and duration) were extracted to identify the delivery mode and strategies. The data of outcomes were extracted for meta-analysis to examine the effectiveness of eHealth interventions. For the randomised controlled trial with three arms to evaluate two different eHealth interventions against the control group, such as 'system generating feedback by using automated email reminders' and 'health care providers supporting individualised goal-directed feedback through multiple media' modes (Green et al., 2008), separate data extraction and analysis were conducted. Any disagreement between the two reviewers was resolved by discussion; otherwise, the senior reviewer was consulted. Data from different articles covering the same study were extracted simultaneously to provide comprehensive information. The Randomized Controlled Trial Checklist of Joanna Briggs Institute was used to assess the methodological quality of the randomised controlled trial (Tufanaru et al., 2017). The risk of bias of the randomised controlled trial was assessed according to the Cochrane Handbook for Systematic Reviews of Interventions (Higgins and Green, 2011).

2.5. Data synthesis

Meta-analysis was conducted for 'health care providers supporting individualized goal-directed feedback through multiple media' mode by using Review Manager 5.3. For continuous variables assessed by the same instruments, the mean difference (MD) with a 95% confidence interval (CI) was used for the pooled effects, and the standardised mean difference (SMD) was calculated for the continuous variable assessed by various instruments. SMD of less than 0.2 was a small effect size, 0.5 was a medium effect size, whilst 0.8 was a large effect (Faraone, 2008). If $I^2 \leq 50\%$, then the fixed-effect model was used; otherwise, the random-effect model was used. The calculator in Review Manager 5.3 was used to calculate the standard deviation using 95% CI or standard error if the studies provided the data of 95% CI or standard error (Lee et al., 2016; Margolis et al., 2013; Bennett et al., 2012; Nolan et al., 2012; Green et al., 2008). Narrative synthesis was performed as an addition. Subgroup analysis was conducted to explore the effect of these two delivery modes on blood pressure reduction.

3. Results

3.1. Search results

An initial pool of 13,404 articles was identified from 12 databases. After removing 4390 duplicated articles, 9014 articles were screened for titles and abstracts, whereas 8754 inadequate articles were excluded. A total of 260 articles were screened for full-text versions through manual searching. Finally, 15 articles of 14 randomised controlled trials satisfied the inclusion criteria (Fig. 1).

3.2. Risk of bias and quality assessment

Table 1 summarises the methodological quality assessment, and Fig. 2 presents the risk of bias. Nine studies provided detailed information about random sequence generation (Lee et al., 2016; Margolis et al., 2013; McKinstery et al., 2013; Rifkin et al., 2013; Bennett et al., 2012; Magid et al., 2013; Nolan et al., 2012; Durrani et al., 2012; Green et al., 2008; Madsen et al., 2008), and six studies reported detailed information about allocation concealment (McKinstry et al., 2013; Rifkin et al., 2013; Magid et al., 2013; Nolan et al., 2012; Durrani et al., 2012; Green et al., 2008; Madsen et al., 2008). The lack of information on randomisation and allocation concealment could increase the risk of selection bias. Two studies demonstrated the participants were blinded to the treatment assignment (Kim et al., 2016; Margolis et al., 2013), and a study revealed that the staff who delivering treatment was blinded (Mckinstry et al., 2013). However, blinding the participants and individuals who deliver treatment interventions was not feasible because they could easily know the treatment assignment when they underwent eHealth interventions, thus resulting in performance bias. Ten studies did not clearly report the blinding of the outcome assessors (Kim et al., 2016; Lee et al., 2016; Moore et al., 2014; Bove et al., 2013; Margolis et al., 2013; Rifkin et al., 2013; Bennett et al., 2012; Yoo et al., 2009; Madsen et al., 2008; Xu et al., 2017), which increase the concern of detection bias. Eleven studies reported two groups were similar at the baseline. The majority of the studies used intention-to-treat analysis, reliable measurements and appropriate statistical analysis. The drop-out rate of the included studies ranged from 0.67% (Xu et al., 2017) to 20.67% (Nolan et al., 2012; Durrani et al., 2012), which influenced the attrition bias. The drop-out rate among the nine included studies was below 10% (Lee et al., 2016; Moore et al., 2014; McKinstry et al., 2013; Rifkin et al., 2013; Magid et al., 2013; Yoo et al., 2009; Green
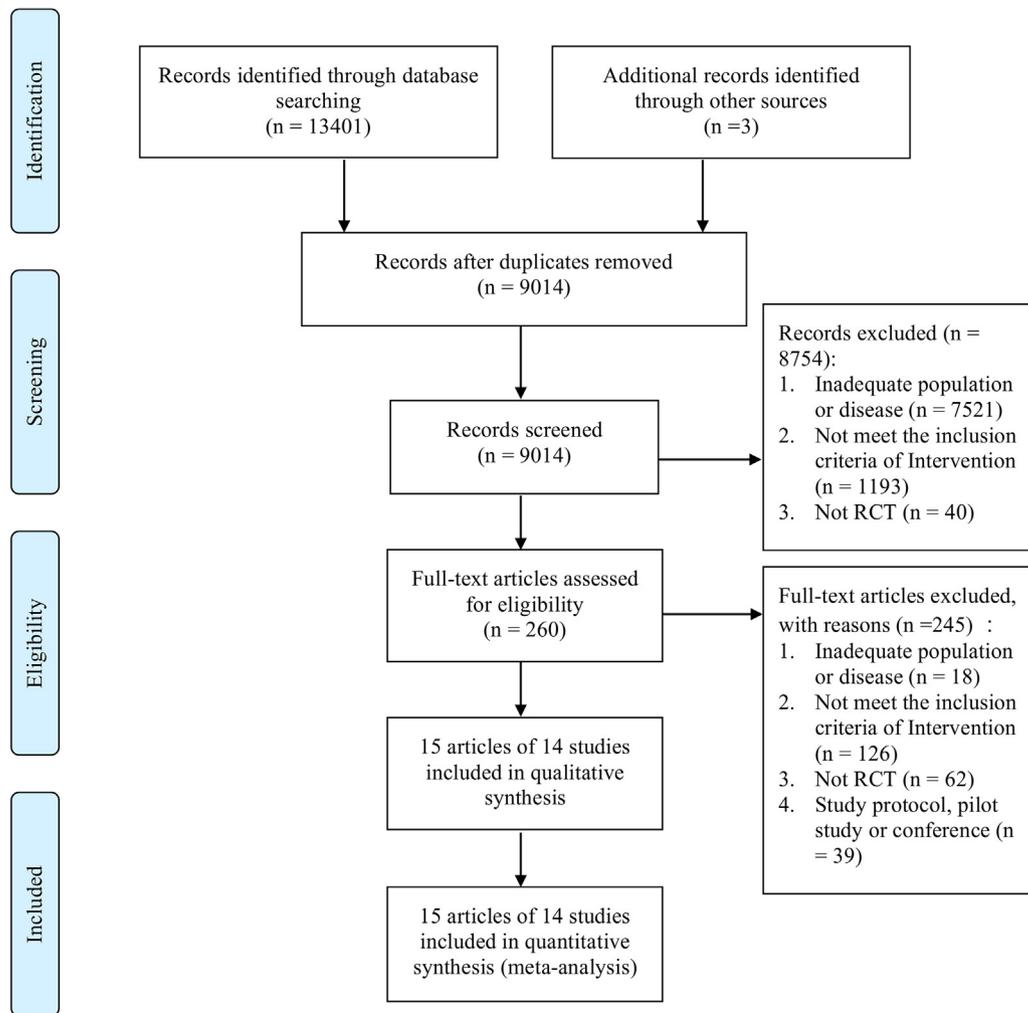
Fig. 1. Flow diagram of study retrieval and selection progress.

et al., 2008; Madsen et al., 2008; Xu et al., 2017). Five studies reported medication adjustment during the study period (Lee et al., 2016; Magid et al., 2013; Margolis et al., 2013; Moore et al., 2014; Rifkin et al., 2013), which may influence the patient outcomes.

3.3. Characteristics of study and participants

Fifteen articles were published from 2008 to 2016, majority of which were conducted in western countries (Kim et al., 2016; Bove et al., 2013; Margolis et al., 2013; Rifkin et al., 2013; Magid et al., 2013; Green et al., 2008; Moore et al., 2014; McKinstry et al., 2013; Bennett et al., 2012; Nolan et al., 2012; Durrani et al., 2012; Madsen et al., 2008). Three studies were conducted in mainland China (Xu et al., 2017), Taiwan (Lee et al., 2016) and South Korea (Yoo et al., 2009).

Fourteen studies included 3998 participants with 44 to 778 participants per study. The mean age of participants ranged from 50 (Moore et al., 2014) to 68 (Rifkin et al., 2013). Eight studies involved male participants at above 50% (Moore et al., 2014; Margolis et al., 2013; McKinstry et al., 2013; Rifkin et al., 2013; Magid et al., 2013; Yoo et al., 2009; Madsen et al., 2008; Xu et al., 2017).

Six studies recruited patients having hypertension with or without adequate blood pressure control (Kim et al., 2016; Lee et al., 2016; Bove et al., 2013; Xu et al., 2017; Bennett et al., 2012;

Yoo et al., 2009). Eight studies recruited patients with inadequate blood pressure control (Moore et al., 2014; Margolis et al., 2013; Magid et al., 2013; Green et al., 2008; Madsen et al., 2008; McKinstry et al., 2013; Nolan et al., 2012; Durrani et al., 2012; Rifkin et al., 2013). Furthermore, among the 14 included studies, three studies indicate recruited population with uncontrolled hypertension with chronic kidney disease (Rifkin et al., 2013), obesity (Bennett et al., 2012) and type 2 diabetes (Yoo et al., 2009).

3.4. Characteristics of intervention

3.4.1. Delivery mode

Delivery modes were divided based on whether health care providers participate during eHealth intervention delivery through multiple media, including 'system generating feedback by using automated email reminders' mode and 'health care providers supporting individualised goal-directed feedback through multiple media (SMS, email and telephone call)' mode.

A study that published two articles (Nolan et al., 2012; Durrani et al., 2012) employed 'system generating feedback by using automated email reminders' delivery mode for patient–device interaction based on the Prochaska's trans-theoretical model (Prochaska et al., 1994) to develop eHealth intervention on a website system. Patients set their prioritised behavioural change goals on the device. Feedback was generated through eight automated emails for 4 months.

Table 1
Methodological quality assessment of 14 studies according to the Randomised Controlled Trial Checklist of Joanna Briggs Institute ("√" = "Yes"; "×" = "No"; "?" = "Unclear").

Items	Kim et al. (2016)	Lee et al. (2016)	Moore et al. (2014)	Bove et al. (2013)	Margolis et al. (2013)	Mckinstry et al. (2013)	Rifkin et al. (2013)
1. Was true randomization used for assignment of participants to treatment groups?	?	√	?	?	√	√	√
2. Was allocation to treatment groups concealed?	?	?	?	?	?	√	√
3. Were treatment groups similar at the baseline?	×	√	√	√	√	√	√
4. Were participants blind to treatment assignment?	√	×	?	?	√	×	×
5. Were those delivering treatment blind to treatment assignment?	×	×	?	?	√	×	?
6. Were outcomes assessors blind to treatment assignment?	?	?	?	?	×	√	?
7. Were treatment groups treated identically other than the intervention of interest?	√	√	√	√	√	√	√
8. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	×	×	×	×	×	√	×
9. Were participants analyzed in the groups to which they were randomized?	×	×	√	×	×	√	×
10. Were outcomes measured in the same way for treatment groups?	√	√	√	√	√	√	√
11. Were outcomes measured in a reliable way?	√	√	√	√	√	√	√
12. Was appropriate statistical analysis used?	√	√	√	√	√	√	√
13. Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	√	√	?	√	√	√	√
Overall appraisal:	Include	Include	Include	Include	Include	Include	Include

Items	Bennett et al. (2012)	Magid et al. (2013)	Nolan and Durrani	Yoo et al. (2009)	Green et al. (2008)	Madsen et al. (2008)	Xu et al., (2017)
1. Was true randomization used for assignment of participants to treatment groups?	√	√	√	?	√	√	?
2. Was allocation to treatment groups concealed?	?	√	√	?	√	√	?
3. Were treatment groups similar at the baseline?	×	√	×	√	√	√	√
4. Were participants blind to treatment assignment?	×	?	×	×	?	×	?
5. Were those delivering treatment blind to treatment assignment?	?	?	×	×	?	×	?
6. Were outcomes assessors blind to treatment assignment?	?	√	√	×	√	×	?
7. Were treatment groups treated identically other than the intervention of interest?	√	√	√	√	√	√	√
8. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	√	√	×	×	×	√	×
9. Were participants analyzed in the groups to which they were randomized?	√	√	√	√	√	√	?
10. Were outcomes measured in the same way for treatment groups?	√	√	√	√	√	√	√
11. Were outcomes measured in a reliable way?	√	√	√	√	√	√	?
12. Was appropriate statistical analysis used?	√	√	√	√	√	√	√
13. Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	√	√	√	√	√	√	√
Overall appraisal:	Include	Include	Include	Include	Include	Include	Include

The remaining studies combined health care providers and patient-device interaction through individualised goal-directed feedback obtained through the use of smartphone application, website, personal digital assistant and tablet application (Kim et al., 2016; Moore et al., 2014; McKinstry et al., 2013; Bove et al., 2013; Margolis et al., 2013; Magid et al., 2013; Rifkin et al., 2013; Lee et al., 2016; Yoo et al., 2009; Madsen et al., 2008; Bennett et al., 2012; Xu et al., 2017). Health care providers, such as nurses, pharmacists and physicians, participated in the studies, and their inputs were delivered through website, mobile applications, telephone call, SMS or email (Table 2). Their inputs for eHealth interventions are summarised as follows: 1) health care providers track the performance of patients; 2) based on the patients' performance, health care providers supply individualised reminder, feedback and recommendations to help patients with disease management and lifestyle modification and promote patients' maintenance on intervention; 3) health care providers supply communication and consultation with patients to promote their motivation and knowledge; and 4) health care providers educate patients. The organisation of these inputs from two studies was based on the theory: the model for incorporating social context in health behavioural interventions (Bennett et al., 2012) and the chronic care model (Green et al., 2008).

3.4.2. Frequency

Only four studies required patients to use the device in the stated frequency and employed different dosages. Three health care providers supporting patient–device interaction interventions encouraged patients to use the device thrice (Kim et al., 2016; Bennett et al., 2010) or twice a week (Bove et al., 2013). Nolan, Durrani and their colleagues used a full-automated system for patient–device interaction intervention, setting the receipt of at least 8 programmed emails as the therapeutic dosage (Nolan et al., 2012; Durrani et al., 2012).

3.4.3. Strategies

Goal-setting, provision of feedback, self-monitoring and motivational interviewing strategies are recommended to achieve a healthy lifestyle for patients with hypertension (Whelton et al., 2017). This review extracted information from the included studies and summarised the current eHealth interventions strategies including, blood pressure monitoring, lifestyle modification techniques (goal-setting and decision-making), motivation and maintenance (Table 2).

3.4.3.1. Blood pressure monitoring.
Eleven studies regarded regular blood pressure monitoring by patients as an important intervention characteristic (Kim et al., 2016; Lee et al., 2016; Moore et al., 2014; Bove et al., 2013; Margolis et al., 2013; McKinstry et al., 2013; Rifkin et al., 2013; Bennett et al., 2012; Magid et al., 2013; Yoo et al., 2009; Madsen et al., 2008). The majority of the studies used wireless upload through internet or bluetooth transfer of data from the blood pressure measurement device to the eHealth device. The required frequency of blood

Fig. 2. Risk of bias of 14 studies according to the Cochrane Handbook for Systematic Reviews of Interventions ("+" means low risk; "-" means high risk; "?" means unclear risk).

pressure measurement varied. The eHealth device can store blood pressure reading, where patients tracked and assessed their blood pressure levels by reviewing the records. Health care providers could access patients' blood pressure readings, evaluate their condition and provide individualised feedback.

3.4.3.2. Lifestyle modification techniques. Goal-setting (Bennett et al., 2012; Nolan et al., 2012; Durrani et al., 2012) and decision-making (Moore et al., 2014) were employed to support patients' lifestyle modification, which could change their self-care behavioural outcomes. Moore's team developed electronic health charts to support patients and nurses in making decision about medication adherence, diet, exercise and stress management (Moore et al., 2014). Two studies used goal-setting to facilitate patients to select their medication adherence goals and priority of

modified behaviour on the eHealth device (Bennett et al., 2012). Nolan, Durrani and their colleagues recommended the use of goal-setting on diet, exercise and smoking by self-directing. The website system promoted patients' motivation and knowledge by providing programmed feedback (Nolan et al., 2012; Durrani et al., 2012).

3.4.3.3. Motivation and maintenance. Usage training, personal account, individualised reminders and interactive communication could improve the motivation and maintenance on intervention of patients. Eight studies conducted usage training (Kim et al., 2016; Moore et al., 2014; Bove et al., 2013; Margolis et al., 2013; McKinstry et al., 2013; Rifkin et al., 2013; Magid et al., 2013; Green et al., 2008), two of which were conducted by face-to-face (Margolis et al., 2013; McKinstry et al., 2013). Five studies stated

Table 2
Characteristics of the included studies.

Study (Country/region, study setting, duration/theory)	Participants	Intervention		Main outcomes
		Intervention group	Control group	
Kim et al. (2016) USA Scripps facility 6-month No information	Hypertensive patient 1. Mean age: 57.6 ± 8.6 2. Female 68% 3. Caucasian 80% 4. Education: ≥college 82% 5. Income: income ≥ 50,000 89% generally in the middle-income bracket 6. SBP: IG 136.1 ± 15.2 mmHg; CG 145.9 ± 19.5 7. DBP: IG 86.3 ± 12.8; CG 93.1 ± 14.1	All participant in both group enrolled in the disease management program, nurse could reach out to all participant for the purpose of relaying medical education and wellness information with regard to disease prevention and chronic disease management. N = 52 Drop-out rate: no information from this article and the article of original study [secondary analysis of original study] Device: mobile application & website 1. Usage training 2. Personal account 2. self-monitoring BP 3. upload BP reading wirelessly 4. Self-tracking 5. Automatically reminders for monitoring, information about the disease condition, and general health behavior recommendations. 6. Educational materials online 7. Communication with families, caregivers, and health care professionals via an online dashboard 8. Frequency: encourage to use the device 3 times a week, taking 2 measurements per day, with the first in the morning. 9. nurse would send reminders via email on website: if patients monitoring frequency <3/week for 2 consecutive weeks)	N = 43 Drop-out rate: no information from this article and the article of original study Bloss et al. (2016)* [secondary analysis of original study] * Bloss et al. (2016). A prospective randomized trial examining health care utilization in individuals using multiple smartphone-enabled biosensors. Peerj, 4, e1554. doi: https://doi.org/10.7717/peerj.1554	1. alcohol usage frequency: one question 2. smoking usage frequency: one question 3. exercise frequency: Godin Leisure-Time Exercise Questionnaire 4. Medication adherence: 8-item Morisky Medication Adherence Scale 5. BP 6. BP control: based on recommendations from the Eighth Joint National Committee (JNC 8) 7. patient activation: 13-item Patient Activation Measure
Lee et al. (2016) Taiwan Hospital 6-month No information	Hypertensive patients 1. Mean age: 58.18 ± 10.83 2. Female 50.3% 3. BMI 25.55 Overweight 45.0% Obese 11.3% 4. LEFT: mean sitting SBP 137.03 ± 15.92 Mean sitting DBP 83.33 ± 10.75 RIGHT: mean sitting SBP 137.67 ± 16.45 Mean sitting DBP 83.77 ± 10.78	All patients were requested to self-monitor their own BP at home and received information based on literatures/guidelines produced by the European Society of Hypertension (ESH).They were instructed to monitor their own BP four times a day (twice in the morning when they awoke and twice in the evening before they went to bed). The frequency was once a week and seven consecutive days the week before their follow-up visit. The BP capture rates were calculated based on this rule. N = 170 Drop-out n = 8 Device: Internet-based system via computer, smartphone, tablet. Patients 1. self-monitor BP: 4/d (2-monrning; 2-before sleep), 1/week & seven consecutive days the week before their follow-up visit 2. upload BP reading wirelessly via GPRS 3. self-tracking 4. weekly text message reminder 5. Automatic reminder: missed BP checking. If the message was ignored, the system would re-send once and only once. Physicians: tracking	N = 212 Drop-out n = 7 1. keep BP records on paper and bring paper-based records when they met their cardiologist	1. BP measurement compliance: the proportion of patients who regularly reported their BP at baseline, 2mon, 4-mon and 6-mon. 2. BP control: <140/90 mmHg 3. BP 4. number of antihypertensive medication
Moore et al. (2014) UK Hospital 3-month No information	Uncontrolled essential hypertensive patients 1. Mean age 50.0 ± 12.8 2. Male 59.5% 3. weight 207.3 ± 47.6 lbs 4. SBP 147.6 ± 9.4 mmHg DBP 87.2 ± 9.9 mmHg	The nurse health coach conducted an introductory visit with each subject including motivational interviewing to assess their health values and to discuss hypertension management goals. The subject and coach made shared decisions about diet, exercise, stress management, and medication. N = 21 Drop-out n = 1 Device: tablet application 1. usage training 2. Self-monitor BP 3. upload BP reading & medication adherence 4. self-tracking by visualized daily clock 5. health charts support decision making on medication [If the last medication change is greater than 14 days in the past, the average SBP for the past 3 days is greater than or	N = 23 Drop-out n = 1 Nurse Standard hypertension care: Check BP 3-5 times a week. Communication through office visit, phone calls, email.	1. BP 2. medication load 3. weight 4. hypertension knowledge: self-designed questionnaire 5. cost 6. medical usage

Table 2 (Continued)

Study (Country/region, study setting, duration/theory)	Participants	Intervention		Main outcomes
		Intervention group	Control group	
		equal to 130, and the patient's medication adherence has been perfect, it suggests that an increase in medication can be considered. If the average SBP is less than 130, a decrease in medication can be considered. It simply visualizes the options in order to support effective human decision-making.] 6. communication with by instant messaging: real-time messaging server		
Bove et al. (2013) USA Medical center and care center 6-month No information	Hypertension SBP of 140 mm Hg or above and no overt CVD. 14.5% 1. mean age: IG 61.0 ± 13.6; CG 58.2 ± 13.5 2. Female 65% 3. African American: 80.9% 4. education ≥ college: 17.4% 5. Income <25,000$: IG 55%; CG 50% [more than 50% had family incomes at or near the poverty level] 6. BMI: IG 33.7 ± 7.8; CG 33.7 ± 7.5 7. SBP: IG 154.4 ± 16.3; CG 155.9 ± 13.7 8. DBP: IG 87.6 ± 10.9; CG 88.9 ± 11.2	N = 120 Drop-out n = 21 Device: website/optional telephone communication system 1. usage training 2. personal account and password for website; personal identification number and a toll-free telephone number for telephone system 3. upload BP, pulse, weight, steps per day through web or telephone [frequency: At least twice a w0eek] 4. reminder: automatically generated e-mail or telephone call from the database program as a reminder to report 5. After 2 weeks of absent reports, the study nurse call the patient by telephone to provide motivation. 6. Education through the Internet or via voice messages on the telephone. 7. If SBP < 140 mm Hg, the telemedicine system00 automatically sent a short messa0ge to the patient stating that the measures were acceptable, a short message on health care, and instructions to continue with the scheduled transmission of data. Nurse Based on device: 1. tracking 2. reminder: call the patient by telephone to provide motivation if patients absent after 2 weeks Physicians 1. a monthly 0report via fax on the patient's BP status and a reminder of BP goals	N = 121 Drop-out n = 14 Control subjects were provided with the data from their initial assessment and instructed to contact their primary care provider for further care. No further intervention was provided to the control subjects.	1. The proportion who reach BP goal 2. BP 3. Blood lipid 4. Blood glucose 5. BMI 6. number of medication 7. medication adherence: a medication adherence self-efficacy scale
Margolis et al. (2013) USA Primary care clinics 12-month intervention and 6-month post-intervention follow-up No information	Uncontrolled hypertensive patients (≥140/90 mm Hg or ≥130/80 mm Hg if diabetes or chronic kidney disease was present) 1. mean age: 61.1 ± 12.0 2. Female 44.7% 3. Caucasian 81.8% 4. education ≥ college: 47.9% 5. BMI: overweight 30.9% Obese 54.3% 6. SBP 147.9 ± 13.0 7. DBP 84.7 ± 11.6	N = 228 Drop-out n = 34 Device: website 1. Pharmacists met with patients for a 1-hour, in-person visit, during which they reviewed the patient's relevant history, covered general teaching points about hypertension, instructed the patients on using the home BP tele monitoring system, and provided patients with an individualized home BP goal 5 mm Hg lower than their clinic BP goal. 2. Patients upload at least 6 BP measurements weekly (3 in the morning and 3 in the evening). 3. During the first 6 months of the intervention, patients and pharmacists met every 2 weeks via telephone until BP control was sustained for 6 weeks, and then frequency was reduced to monthly. 4. During intervention months 7 through 12, telephone visits occurred	N = 222 Drop-out n = 36 Usual care This could include referral to a medication therapy management pharmacist for consultation (1-2 visits without telephone follow-up or prolonged monitoring) and conventional home BP measurement.	1. the proportion of patients with controlled BP (ie, <140/90 mm Hg or <130/80 mm Hg if diabetes or chronic kidney disease was present) at both the 6- and 12- month clinic visits. 2. BP 3. patient satisfaction with care: 6-item selected from the Consumer Assessment of Healthcare Providers and Systems adult survey (version 4) 4. BP control 5. number and type of medication 6. medication adherence: 4-item Morisky adherence scale 7. quality of life: SF-12v2 8. self-efficacy: 13-item subset of questions assessing perceived self-efficacy

Table 2 (*Continued*)

Study (Country/region, study setting, duration/theory)	Participants	Intervention		Main outcomes
		Intervention group	Control group	
		every 2 months. 5. During telephone visits, pharmacists emphasized lifestyle changes and medication adherence. They assessed and adjusted antihypertensive drug therapy based on an algorithm using the percentage of home BP readings0 meeting goal.		
McKinstry et al. (2013) UK Primary care practices 6-month No information	Uncontrolled hypertensive patients (SBP > 145 mmHg or DBP > 85 mm Hg) 1. Mean age: IG 60.5 ± 11.8; CG60.8 ± 10.7 2. Men: IG 59%; CG 60% 3. BMI: IG 30.1 ± 5.7; CG: 30.2 ± 6.2 4. mean surgery measured SBP: IG 152.9 ± 15.1; CG 152.4 ± 14.3 mean surgery measured DBP: IG 92.1 ± 11.5; CG 89.9 ± 11.3 5. mean daytime ambulatory SBP: IG 146.2 ± 10.6; CG 146.2 ± 10.5 mean daytime ambulatory DBP: IG 87.1 ± 10.0; CG85.4 ± 9.6	N = 200 Drop-out n = 5 Device: mobile phone transmit the data to website 1. Nurse conducted a 20-min usage training. 2. BP measurement frequency: twice each morning and twice each evening for the first week and then at least weekly thereafter or as often as they wished. 3. personal account 4. self-tracking 5. automatic SMS or email for feedback on BP control 6. contact with clinicians if they were concerned about their BP control 7. education leaflets on hypertension management and lifestyle modification Clinicians 1. tracking based on device 2. contact with patients if nee0ded to arrange modification0 of therapy	N = 201 Drop-out n = 16 1. education leaflets on hypertension management and lifestyle modification 2. Participants allocated to the usual care group were advised that they should see their doctor or practice nurse for further management. Subsequently they received standard care for hypertension from their doctor or nurse who were asked to aim for a target surgery blood pressure of <140/90 mm Hg.	1. daytime systolic ambulatory blood pressure 2. daytime diastolic ambulatory blood pressure 3. number of mediation 4. resource use
Rifkin et al. (2013) USA Clinic 6-month No information	With stage 3 or greater chronic kidney disease and uncontrolled hypertension [SBP > 140 or DBP > 90 in-clinic or on reported home readings] 1. Mean age: 68 2. Male: IG 93%; CG100% 3. African-American: IG 25%; CG27% 4. completed college: IG 28%; CG 13.3% 5. SBP: IG 149 ± 16.2; CG 147 ± 8.6 6. DBP: IG 78 ± 12.4; CG 81 ± 11.2 7.BMI: IG 30.1; CG 29.2	N = 30 Drop-out n = 2 Device: **home health cuff** which could automatically transmit the BP readings to a secure **Website**. 1. usage training 2. BP measurement: no frequency 3. personal account and password 4. upload and store the data (BP, pulse) 5. self-tracking 6. Study physician and pharmacist review and check BP on weekly basis, and could contact patients by telephone if their BP was out of range, and would not contact if BP was at goal.	N = 17 Drop-out n = 2 1. measure BP 2. study personnel would be checking in with them at the end of 6 months for an end-of-study visit	1. BP 2. number of BP medication 3. medication adherence: 8-item Morisky Medication Adherence Scale
Bennett et al., (2012) UK Community health centers 24-month Model for incorporating social context in health behavior interventions	Obese hypertensive patients 1. Mean age 54.5 2. Female 68.5% 3. African American 71.2% 4. Education completed college 13.7% [Education level between two groups have significant difference] 5. SBP: IG 128.50 ± 19.73; CG 130.20 ± 18.89 6. DBP: IG 77.45 ± 13.77; CG 79.34 ± 12.73 7. weight (kg): IG 100.60 ± 18.67; CG 99.70 ± 16.29 8. BMI: IG 36.99 ± 5.24; CG 37.03 ± 4.96	N = 180 Drop-out n = 32 Device: Website/interactive voice response system 1. Goal setting: 3 tailored goals to modify routine obesogenic lifestyle behaviors which are easily self-monitored. New goals were selected at subsequent 13-week intervals. Medication adherence goal were maintained for the duration of study. 2. Patients self- monitor their progress via website or an interactive voice response system with automatic real-time tailored feedback. 3. Community health educ0ator delivered counseling calls monthly during the first 12 months and bimonthly during the second year (18 scheduled calls). counseling calls: 15 to 20 min. calls covering self-monitoring data, problem solving, and behavior skills training 4. 12 optional monthly group sessions	N = 185 Drop-out n = 19 Usual care: provided "Aim for a Healthy Weight" self-help booklet	1. Weight 2. SBP 3. Hypertension self-management behaviors: The Hill-Bone Compliance to Hypertension Therapy Scale

Table 2 (Continued)

Study (Country/region, study setting, duration/theory)	Participants	Intervention		Main outcomes
		Intervention group	Control group	
		5. Tailored behavioral skill training materials and tailored informatio0n on community resource. 0		
Magid et al. (2013) USA primary care clinics 6-month No information	Uncontrolled hypertensive patients (SBP ≥ 140 mmHg or DBP ≥ 90 mmHg or, for those with DM or CKD, SBP ≥ 130 mmHg or DBP ≥80 6.3% 1. Mean age: IG 59.1 ± 10.9 CG 60.0 ± 11.3 2. Male: IG 59.0%; CG 61.7% 3.Caucasia 83% 4. SBP: IG 145.5 ± 14.5; CG 148.8 ± 16.2 5. DBP: IG 88.0 ± 9.9; CG 89.6 ± 10.2	N = 175 Drop-out n = 13 Device: website 1. Same educational materials as control group. 2. Usage training of home BP monitor and device. 3. personal account 4. frequency: measure BP at least 3/ week and upload BP reading weekly 5. Met with clinical pharmacist specialist who reviewed their0 current BP medication regimen, provided counseling on lifestyle changes, and adjusted or changed antihypertensive medications as needed. 6. From the patients' account, BPs were automatically uploaded nightly and organized into BP summary reports that were viewed by the clinical pharmacy specialists managing the0ir care. The reports summarized0 weekly BP averages and flagged patients with averages above their goal. 7. The clinical pharmacy specialist reviewed the home BP measurements and adherence to antihypertensive medications of the patients, made medication adjustments as needed, and communicated with patients via telephone or secure e-mail. 8. Patients wh0o neglected to upload their BP readings as instructed received up to 3 reminder phone calls through an automated interactive voice response system. If a patient still failed to upload readings, he or she received a call from a clinic staff member.	N = 173 Drop-out n = 9 1. Received written educational materials on managing high BP, diet, and physical activity. 2. Were instructed to follow up with their primary care physician.	1. the proportion of patients who attained BP goal (<140/ 90 mmHg; DM/CKD: <130/ 80 mmHg) 2. BP 3. change in antihypertensive medication intensity 4. antihypertensive medication adherence: a medication possession ratio 5. satisfaction 6. medical service usage
Nolan et al. (2012) Durrani et al., 2012 Canada clinic 4-month Prochaska's Transtheoetical Model (Precontemplation, Contemplation, Preparation, Action, and Maintenance).	Hypertensive patients 1. diagnosed with stage 1 or 2 hypertension: SBP/DBP, 140-159/ 90-99 mmHg, or 160-180/ 100-110 mmHg, respectively 20.7% 1. Mean age: 56 2. Female 59% 3. 72% taking ≥1 antihypertensive drug 4. 41% obesity 1. Mean SBP:140mmHg 2. Mean DBP: 80 mmHg	N = 193 Drop-out n = 45 Device: website 1. 8 programmed feedback on "change goa0ls" according to motivation0al interviewing sent from e-platform: Weekly e-mails in month one, bi-weekly e-mails in month two, and monthly e-mails in months three and four. 2. This program initially guided patients self-rated their stage of motivational "readiness" to follow the guideline for diet, exercise, and smoke-free living. 3. Self-direct goal: patients were promoted to actively choose their priority for lifestyle change. 4. The program provided key messages to promote motivation, and numerous menus that were linked to educational material and self-help tips for lifestyle change.	N = 194 Drop-out n = 35 Received e-newsletters that contained general information and advice for heart-healthy living.	Study defined: 1. ≥ 8 emails = therapeutic dosage 2. 1-7 emails = sub-therapeutic dosage 3. 0 emails = control Outcomes: 1. BP 2. Total cholesterol 3. Pulse pressure 1. readiness level: Exercise and Diet (The Health Promotion Lifestyle Profile) 2. Depression: the Beck Depression Inventory-II (BDI-II). 3. Psychological stress : the Perceived Stress Scale (PSS)
Yoo et al. (2009) South Korea Hospital & community health center 3-month No information	The patients with both type 2 diabetes and hypertension blood pressure > 130 / 80 mmHg; 9.8% 1. Mean age: IG 57.0 ± 9.1 ; CG 59.4 ± 8.4	N = 62 Drop-out n = 5 Device: mobile phone application & website 1. automatic measurement reminder0 Measurement frequency: BP & blood	N = 61 Drop-out n = 7 Patients in the control group visited their clinic according to their routine schedule and received the usual out-patient treatment from their physicians during the study period.	BP Weight BMI Waist circumference Total cholesterol HDL-cholesterol LDL-cholesterol

Table 2 (Continued)

Study (Country/region, study setting, duration/theory)	Participants	Intervention		Main outcomes
		Intervention group	Control group	
	2. Male : IG 52.6% ; CG 64.8% 3. BMI : IG 25.6 ± 3.5; CG 25.5 ± 3.3 4. SBP : IG 140 ± 18 ; CG 138 ± 18 5. DBP : IG 84 ± 10 ; CG 83 ± 10	glucose twice per day (before breakfast and bedtime); body weight once per day (before breakfast). 2. upload data 3. Automatic feedback according to patient's BP value. 4. Automatic record exercise time by SMS (recommendation exercise frequency: 150 min/week, distributed over at least 3 da0ys each week). Patients replied via an automatic answer system whether or not they actually exercised. 5. Education via SMS 3 times per day regarding healthy diet and exercise methods, along with general information about diabetes, hypertension and obesity.0 6. Physician could follow patients' trends in BP, blood glucose and weight change, allowing them to send individualized recommendations to patients when needed.		
Green et al. (2008) USA Clinic 12-month The chronic care model	Uncontrolled essential hypertensive patients 6.2% 1. Mean age: 59.1 ± 8.5 2. Female: 52.2% 3. Caucasian: 82.8% 4. ≥ college: 50.4% 5. BMI: overweight 31.6% Obese 61.1% 6. SBP 151.9 ± 10.3 7. DBP 89.1 ± 8.0	All patients received hypertension pamphlet which describes the definition for BP control, the importance of medication and lifestyle behaviors that influence BP and cardiovascular risk, (i.e., sodium intake, weight, and physical activity) and pamphlet which describes the patient website and utilities available to registered users. **Device: website** (consists of secure e-mail, refilling medications, viewing portions of their medical record, use of the health library, and links to Group Health and community resour0ces for lifestyle and behavioral change) **Only Web group N = 259** Drop-out n = 13 1. Received a home BP monitor and usage training. BP measurement frequency: at least 2 days per week with 2 measurements each time. 2. Patients were told the goal for average home BP (<135/80 mmHg), lower than the goal of clinic meas0urement (<140/90 mmHg). 3. w0ebsite usage training **Web Plus Pharmacist group N = 261** Drop-out n = 24 1. all Only Web group content Pharmacist: 1. send a welcome message to patients via website 2. One planned telephone visit to obtain more patients' information and introduce action plan which consists of 5 components: instructions for ho0me BP monitoring; a list of current medications; at least 1 patient-selected lifestyle goal(s) from the list in the hypertension pamphlet (such as increasing physical activity); recommended medication changes based on the stepped medication protocols; and the follow-up plan. Each patient and his or her physician received an e0lectronic copy of the action plan. 03. Planned communications via website every 2 weeks until BP was controlled. 4. Patients were asked to provide BP measurements, concerns about	N = 258 Drop-out n = 11	1. BP 2. BP control rate [target: <140/90 mmHg] 3. BMI 4. quality of life: SF-12v2 5. satisfaction: the Consumer Assessment of Healthcare Providers and Systems instrument

Table 2 (Continued)

Study (Country/region, study setting, duration/theory)	Participants	Intervention		Main outcomes
		Intervention group	Control group	
		medication, and progress related to their lifestyle goals. Pharmacists responded with specific recommendations (including medication changes) and patients were encouraged to provide feedback and collaboratively change the action plan.		
Madsen et al. (2008) Denmark Primary care setting 6-month No information	Uncontrolled hypertensive patients (>150/95 mmHg or SBP > 150 mmHg and DBP > 90 mmHg) 1. Mean age: IG 55.0 ± 11.7; CG 56.7 ± 11.6 2. Female: 49.6% 3. BMI: IG 28.3 ± 6.7; CG 29.4 ± 12.3 4. daytime ABPM SBP: IG 153.1 ± 13.2 CG 152.2 ± 13.7 5. Daytime ABPM DBP: IG 91.2 ± 8.1; CG 90.5 ± 13.7 6. night-time ABPM SBP: IG 132.0 ± 15.6; CG 133.7 ± 16.6 7. Night-time ABPM DBP: IG 77.6 ± 8.7; CG 77.8 ± 9.5	N = 113 Drop-out: n = 8 Device: home BP monitor connected to a PDA with a software interface website General practitioner – website BP measurements were transferred to a central server by a PDA-embedded mobile phone unit. Patients access to their own BP measurements on website, where they could also communicate with their general practitioner by email. For patients with no Internet access, the PDA could record and send spoken messages to the general practitioners, who could respond by written messages to the PDA. Frequency: BP measure between 9 am and 8 pm, 3 times a week during first 3 months and once a week during last 3 months. Each BP measurement consist of three readings with 1-mon intervals. General practitioner: 1. give instruction in correct BP measurement technique 2. check website on a weekly basis to monitor BP levels of their patients and contact patients if BP measurements were not performed 3. institute or change antihypertensive treatment at their own discretion with the goal to achieve target home BP for each patient	N = 123 Drop-out: n = 5 Patients were instructed to visit their general practitioner as often as needed and to follow the antihypertensive treatment instituted.	1. systolic daytime 24-h ambulatory blood pressure monitoring 2. diastolic daytime 24-h ambulatory blood pressure monitoring 3. systolic and diastolic night-time ABPM 4. BP control rate [target: daytime BP < 130/85 mmHg]
Xu et al. (2017) China Hospital 6-month No information	Hypertensive patients 1. Mean age: 48.0 ± 6.2 2. Male: 60.33% 3. SBP: IG 159 ± 13; CG 158 ± 9 4. DBP: IG 98 ± 9; CG 99 ± 9 5. BMI: IG 23.3 ± 2.6; CG 24.2 ± 1.9	N = 310 Drop-out: n = 4 Device: WeChat (mobile application) Patients: 1. Self-monitor and upload BP to WeChat every Monday and Thursday. 2. Communication and sharing between group members. 3. attend a quiz about hypertensive knowledge monthly Physician: upload education material and give comments and guidance according to blood pressure value.	N = 290 Drop-out: n = 0 1. General hypertensive education at first face to face visit. 2. Monthly blood pressure follow-up via face to face. 3. Other time: usual care.	1. 24-h ambulatory blood pressure 2. lifestyle modification: 4 questions about smoking, alcohol, exercise, salt intake 3. medication adherence: MMAS-4 4. blood pressure control rate [target: < 130/80 mmHg]

that patients in the intervention group had their personal accounts and passwords (Kim et al., 2016; Bove et al., 2013; McKinstry et al., 2013; Rifkin et al., 2013; Magid et al., 2013). The patients received reminders from device and/or from health care providers including recommendations/reports on health condition and reminders when blood pressure measurement and upload were ignored (Kim et al., 2016; Lee et al., 2016; Bove et al., 2013; McKinstry et al., 2013; Magid et al., 2013; Yoo et al., 2009). Some reminders and recommendations from health care providers were included in the communication and consultation through telephone call, fax or email. The frequency and delivery format of reminders, communications and consultations varied among the studies.

3.5. Effectiveness

3.5.1. Physical outcomes

3.5.1.1. Blood pressure. Blood pressure was measured at the baseline and less than 6 months after intervention in 12 studies which involved health care providers support (Kim et al., 2016; Lee et al., 2016; Moore et al., 2014; Bove et al., 2013; McKinstry et al., 2013; Rifkin et al., 2013; Magid et al., 2013; Margolis et al., 2013; Bennett et al., 2012; Yoo et al., 2009; Madsen et al., 2008; Xu et al., 2017). The pooled results indicate a significantly enhanced SBP reduction (SBP MD: −5.50 mmHg, 95% CI: −9.85 to −1.16, p < .05,

$I^2 = 96\%$, Fig. 3). Three studies measured the blood pressure at the baseline and 12 months after intervention (Green et al., 2008; Margolis et al., 2013; Bennett et al., 2012), and the pooled results indicate that eHealth enhanced the SBP and DBP reduction (SBP MD: −7.68 mmHg, 95% CI: −9.95 to −5.41, p < .001, $I^2 = 27\%$, Fig. 3; DBP MD: −3.36 mmHg, 95% CI: −4.80 to −1.92, p < .001, $I^2 = 30\%$, Fig. 4). Two studies measured the blood pressure at the baseline

and 18 months after intervention (Margolis et al., 2013; Bennett et al., 2012), and the pooled results reveal that eHealth interventions significantly enhanced SBP and DBP reduction (SBP MD: −6.26 mmHg, 95% CI: −9.29 to −3.23, p < .001, $I^2 = 0\%$, Fig. 3; DBP MD: −2.53 mmHg, 95% CI: −4.72 to −0.34, p < .05, $I^2 = 0\%$, Fig. 4). Studies using 'system generating feedback by using automated email reminders' mode reported that eHealth
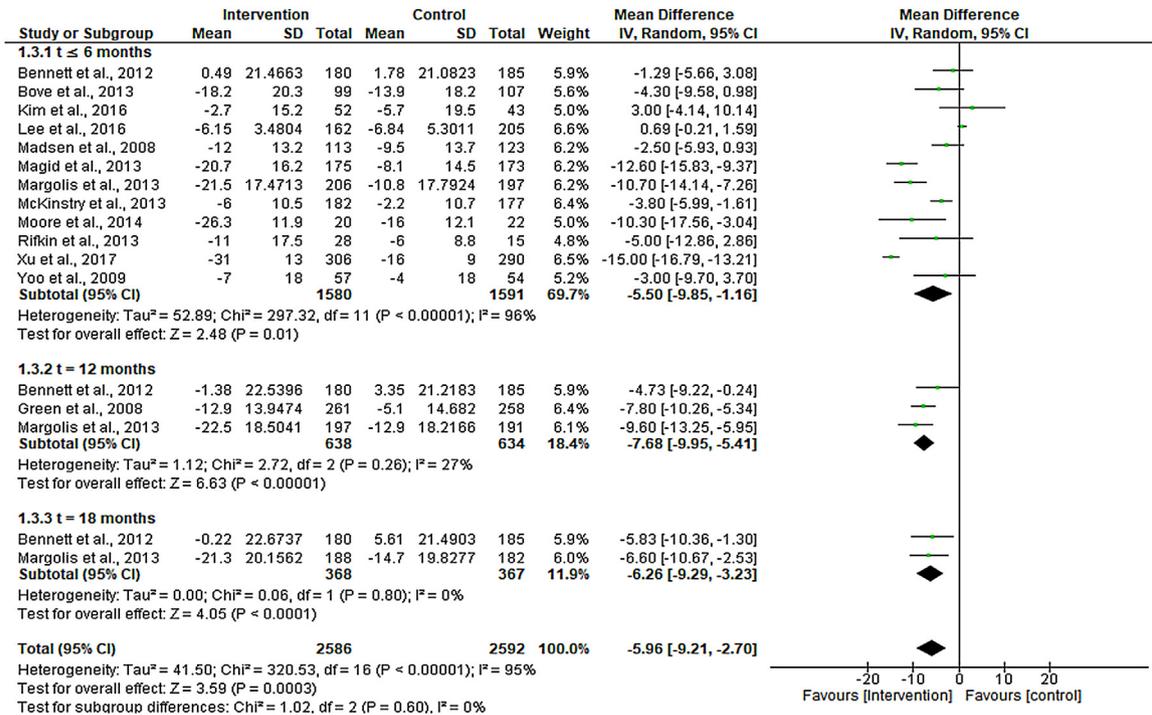

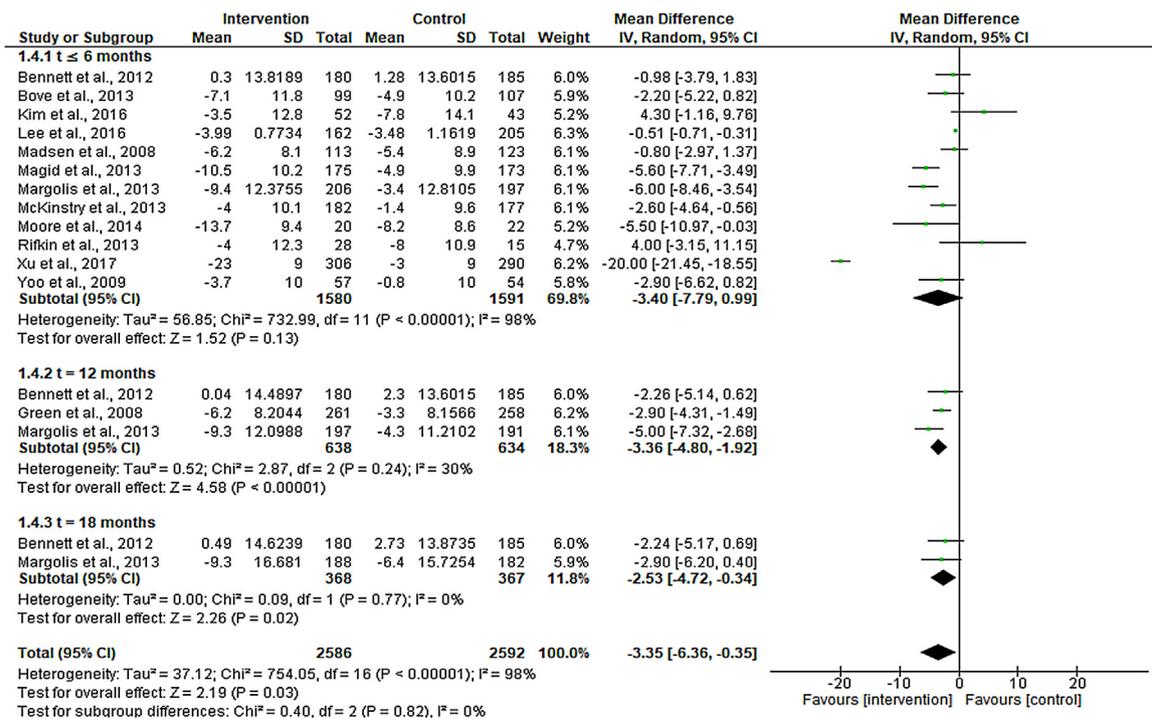**Fig. 3.** Forest plot of the effect of eHealth interventions on SBP reduction.

Fig. 4. Forest plot of the effect of eHealth interventions on DBP reduction.

interventions could enhance SBP reduction as well (Nolan et al., 2012; Green et al., 2008).

Subgroup analysis was performed to explore and compare the effect of two delivery modes on blood pressure reduction. The pooled results show that comparing with eHealth without health care providers support, eHealth with health care providers support had a larger effect on SBP reduction (MD: −5.70 mmHg, 95% CI: −9.68 to −1.73, p < .01, $I^2 = 96\%$, Fig. 5), which was favourable but not significant in decreasing DBP (Fig. 6).

3.5.1.2. Blood pressure control. Ten studies reported the blood pressure control results. Among them, five studies with comparable baseline data defined blood pressure low than 140/90 mmHg as adequate blood pressure control (Moore et al., 2014; Bove et al., 2013; Magid et al., 2013; Margolis et al., 2013; Green et al., 2008). The measurement points of blood pressure control were at 3-month (Moore et al., 2014), 6-month (Bove et al., 2013; Margolis et al., 2013; Magid et al., 2013), and 12-month (Green et al., 2008) after the intervention. The pooled results of these five studies show that eHealth interventions significantly decreased 31% of the patients with inadequate blood pressure control compared with the control group (RR: 0.69, 95% CI: 0.57–0.84, p < .001, $I^2 = 64\%$, Fig. 7).

3.5.1.3. Body mass index. Six studies measured the body mass index at 3-month (Yoo et al., 2009), 6-month (Bove et al., 2013; McKinstry et al., 2013; Margolis et al., 2013; Bennett et al., 2012), 12-month (Green et al., 2008; Margolis et al., 2013; Bennett et al., 2012) and 18-
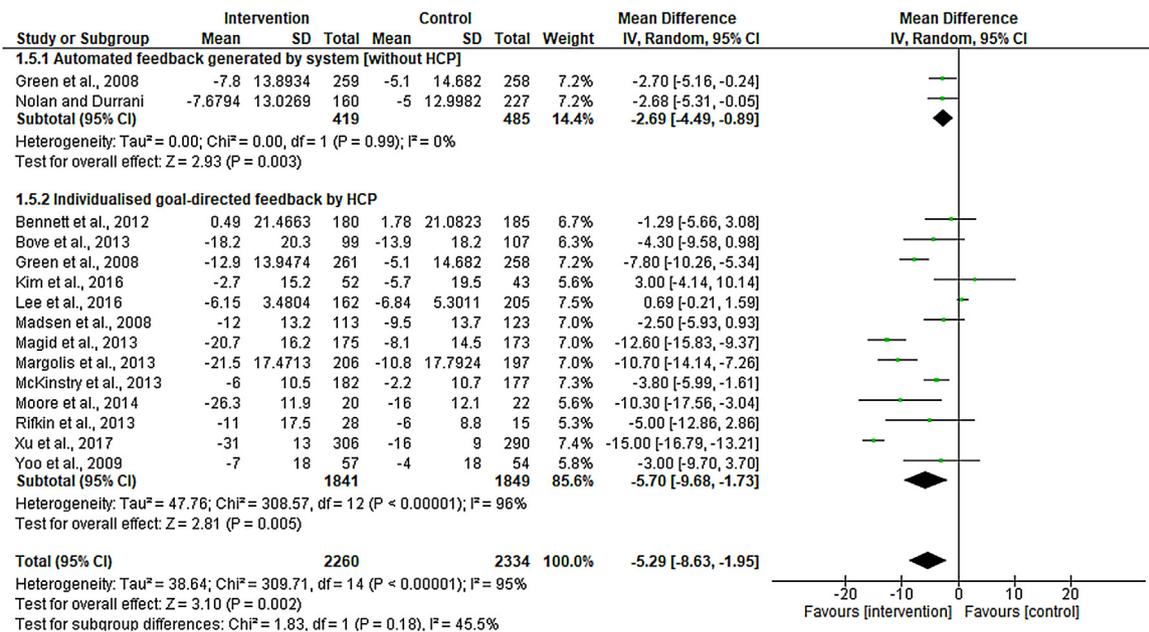
Fig. 5. Forest plot of the effect of eHealth interventions on SBP reduction (Subgroup analysis).
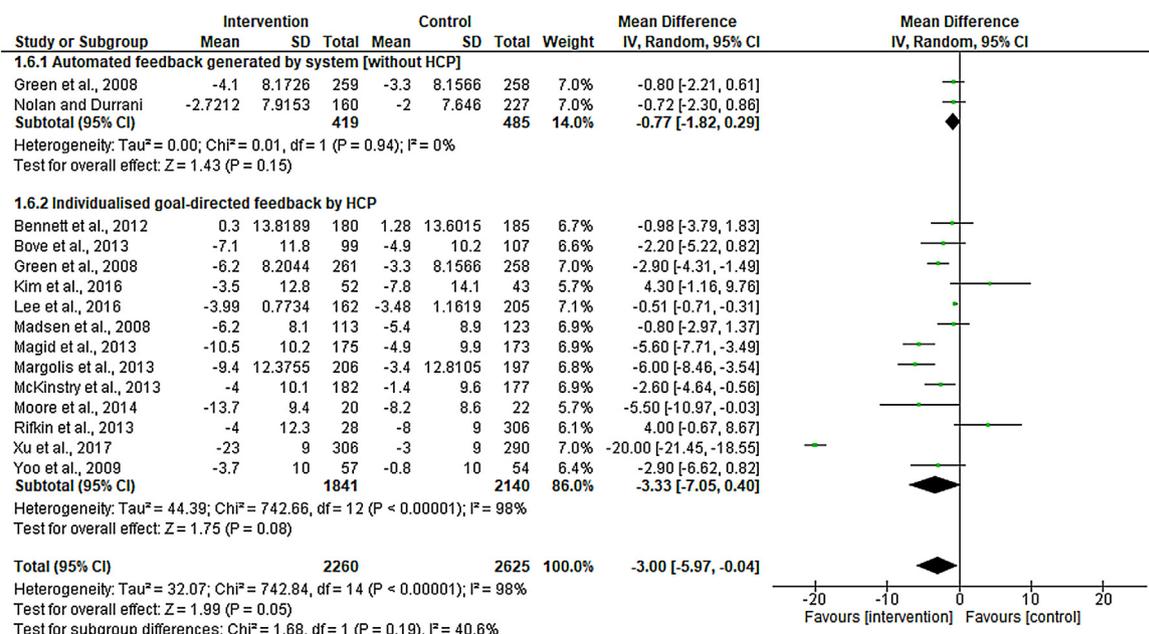
Fig. 6. Forest plot of the effect of eHealth interventions on DBP reduction (Subgroup analysis).
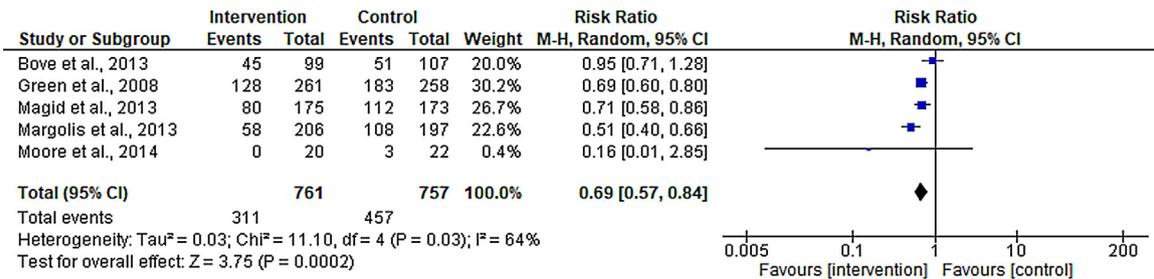
Fig. 7. Forest plot of the effect of eHealth interventions on blood pressure control.

month (Margolis et al., 2013; Bennett et al., 2012) after the intervention. The pooled result demonstrated that eHealth interventions had no significant effect on body mass index (Fig. 8).

3.5.1.4. Body weight. Three studies measured the effect of eHealth interventions on body weight at the baseline and at 3-month (Moore et al., 2014; Yoo et al., 2009) and 6-month after the intervention (Bennett et al., 2012). The pooled result reports eHealth interventions had significant reduction of body weight (MD: −1.08 kg, 95% CI: −2.04 to −0.13, p < .05, $I^2 = 0\%$, Fig. 9).

3.5.1.5. Cholesterol. Three studies measured the effectiveness of eHealth interventions on total cholesterol at 3-month (Yoo et al., 2009) and 6-month (Bove et al., 2013; McKinstry et al., 2013) after the intervention, and indicated no significant results (MD: −0.20 mmol/l, 95% CI: −0.49 to −0.08, p = 0.16, $I^2 = 71\%$, Fig. 10).

Two studies (Bove et al., 2013; Yoo et al., 2009) measured high-density (MD: −0.01 mmol/l, 95% CI: −0.11 to 0.10, p = .92, $I^2 = 0\%$) and low-density lipoprotein cholesterol (MD: −0.14 mmol/l, 95% CI: −0.39 to 0.11, p = 0.27, $I^2 = 71\%$) and yielded no significant results (Fig. 10).

3.5.2. Self-care behavioural outcomes

3.5.2.1. Medication adjustment. Five studies reported antihypertensive medication adjustment at 3-month (Moore et al., 2014) and 6-month (Lee et al., 2016; Magid et al., 2013; Margolis et al., 2013; Rifkin et al., 2013) after the intervention. Four studies recruited patients with inadequate blood pressure control (Magid et al., 2013; Margolis et al., 2013; Moore et al., 2014; Rifkin et al., 2013), three of which demonstrate that the intervention involved medication adjustment (Magid et al., 2013; Margolis et al.,
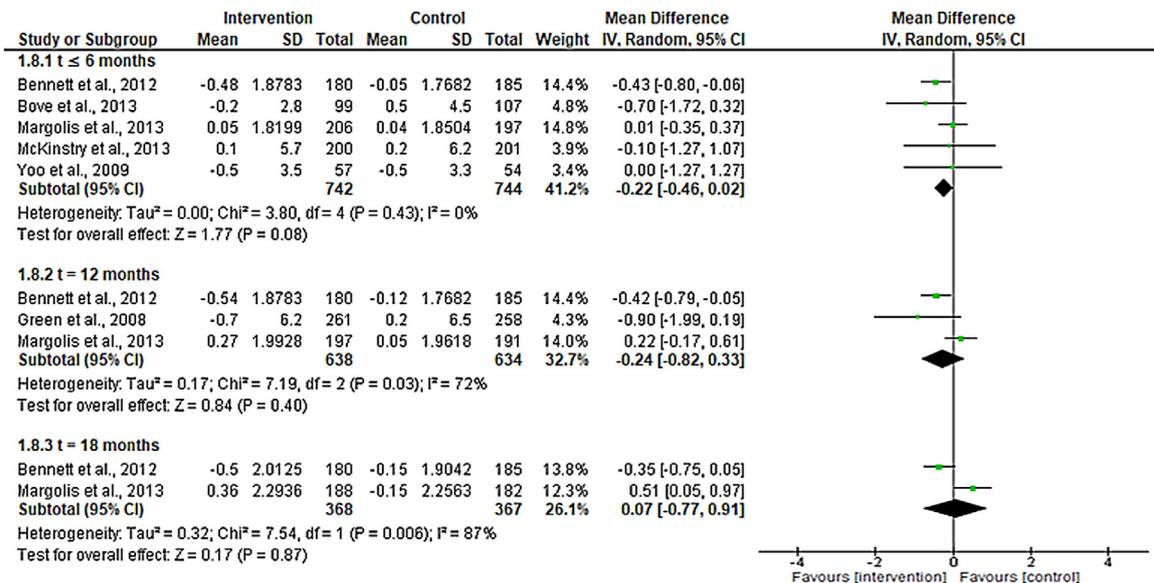

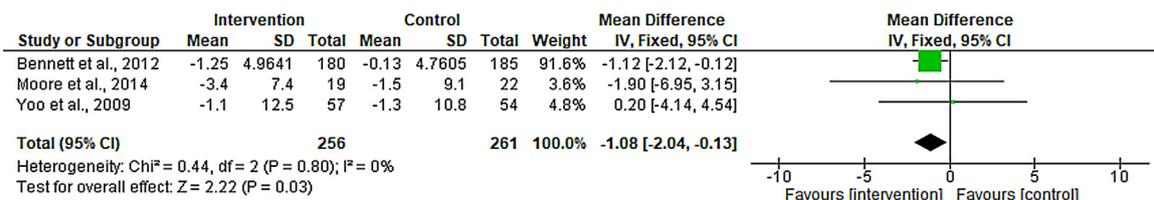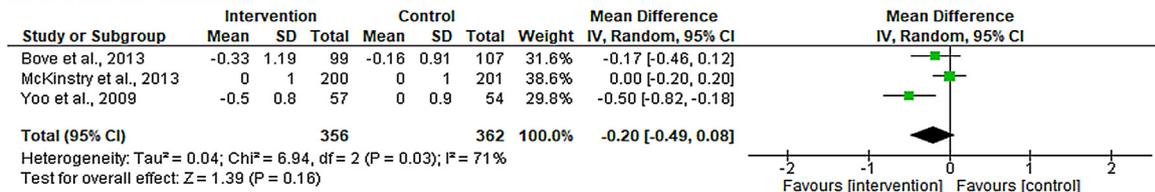Fig. 8. Forest plot of the effect of eHealth interventions on body mass index.

Fig. 9. Forest plot of the effect of eHealth interventions on body weight.

1. Total cholesterol

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Bove et al., 2013	-0.33	1.19	99	-0.16	0.91	107	31.6%	-0.17 [-0.46, 0.12]
McKinstry et al., 2013	0	1	200	0	1	201	38.6%	0.00 [-0.20, 0.20]
Yoo et al., 2009	-0.5	0.8	57	0	0.9	54	29.8%	-0.50 [-0.82, -0.18]
Total (95% CI)			**356**			**362**	**100.0%**	**-0.20 [-0.49, 0.08]**

Heterogeneity: Tau² = 0.04; Chi² = 6.94, df = 2 (P = 0.03); I² = 71%
Test for overall effect: Z = 1.39 (P = 0.16)

2. HDL cholesterol

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Bove et al., 2013	-0.37	0.99	99	-0.34	0.75	107	17.6%	-0.03 [-0.27, 0.21]
Yoo et al., 2009	0.1	0.3	57	0.1	0.3	54	82.4%	0.00 [-0.11, 0.11]
Total (95% CI)			**156**			**161**	**100.0%**	**-0.01 [-0.11, 0.10]**

Heterogeneity: Chi² = 0.05, df = 1 (P = 0.82); I² = 0%
Test for overall effect: Z = 0.10 (P = 0.92)

3. LDL cholesterol

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Bove et al., 2013	-0.02	0.32	99	0.02	0.3	107	61.7%	-0.04 [-0.12, 0.04]
Yoo et al., 2009	-0.4	0.7	57	-0.1	0.7	54	38.3%	-0.30 [-0.56, -0.04]
Total (95% CI)			**156**			**161**	**100.0%**	**-0.14 [-0.39, 0.11]**

Heterogeneity: Tau² = 0.02; Chi² = 3.46, df = 1 (P = 0.06); I² = 71%
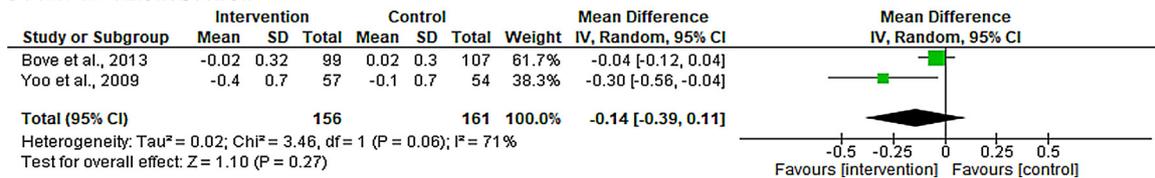Test for overall effect: Z = 1.10 (P = 0.27)

Fig. 10. Forest plot of the effect of eHealth interventions on cholesterol.

2013; Moore et al., 2014). The pooled results demonstrate that eHealth intervention significantly changed the antihypertensive medication adjustment (SMD: 0.49, 95% CI: 0.03–0.94, p < .05, $I^2 = 92\%$, Fig. 11).

3.5.2.2. Medication adherence. Eight studies assessed the medication adherence of patients by using the Morisky Medication Adherence Scale (Kim et al., 2016; Margolis et al., 2013; McKinstry et al., 2013; Rifkin et al., 2013; Xu et al., 2017), Hill-Bone Compliance to Hypertension Therapy Scale (Bennett et al., 2012), Medication Adherence Self-efficacy Scale (Bove et al., 2013) and the calculated medication possession ratio (Magid et al., 2013). Four studies that measured medication adherence at 6-month post intervention were included in the meta-analysis (Bennett et al., 2012; Kim et al., 2016; Margolis et al., 2013; Rifikin et al., 2013), and the pooled results indicate no significant differences on the medication adherence between the two groups (SMD: −0.12, 95% CI−0.35 to 0.10, p = 0.28, $I^2 = 55\%$, Fig. 12).

3.5.2.3. Lifestyle modification. Two studies conducted in western countries measured the sodium intake by Hill-Bone Compliance to Hypertension Therapy Scale (Margolis et al., 2013) and self-designed questionnaire (Bennett et al., 2012) at 6, 12 and 18 months after the intervention. The pooled result shows that eHealth interventions had a significant effect on sodium intake at 6, 12, and 18 months (Fig. 13). Three studies measured the effect of eHealth interventions on alcohol intake, smoking and physical activity at the baseline at 6 months after the intervention (Kim et al., 2016; Margolis et al., 2013; McKinstry et al., 2013). The pooled analysis shows that eHealth interventions had no significant effect on alcohol intake (SMD: 0.01, 95% CI: −0.12 to 0.14, p = .91, $I^2 = 0\%$), smoking (SMD: −0.01, 95% CI: −0.14 to 0.12, p = .88, $I^2 = 37\%$) and physical activity (SMD: −0.02, 95% CI: −0.15 to 0.11, p = 0.76, $I^2 = 0\%$) (Fig. 13). The study conducted in China measured sodium and alcohol intake, smoking and physical activity at the baseline and at 6 months after the intervention, and the pooled results shows that eHealth intervention
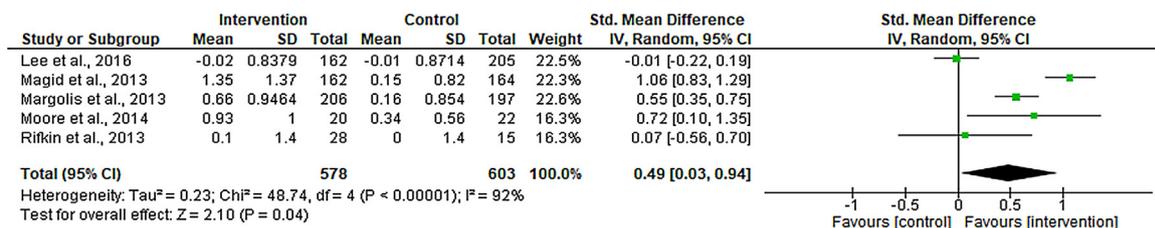
Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Lee et al., 2016	-0.02	0.8379	162	-0.01	0.8714	205	22.5%	-0.01 [-0.22, 0.19]
Magid et al., 2013	1.35	1.37	162	0.15	0.82	164	22.3%	1.06 [0.83, 1.29]
Margolis et al., 2013	0.66	0.9464	206	0.16	0.854	197	22.6%	0.55 [0.35, 0.75]
Moore et al., 2014	0.93	1	20	0.34	0.56	22	16.3%	0.72 [0.10, 1.35]
Rifkin et al., 2013	0.1	1.4	28	0	1.4	15	16.3%	0.07 [-0.56, 0.70]
Total (95% CI)			**578**			**603**	**100.0%**	**0.49 [0.03, 0.94]**

Heterogeneity: Tau² = 0.23; Chi² = 48.74, df = 4 (P < 0.00001); I² = 92%
Test for overall effect: Z = 2.10 (P = 0.04)

Fig. 11. Forest plot of the effect of eHealth interventions on antihypertensive medication adjustment.

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bennett et al., 2012	-1.06	2.6833	180	-0.37	2.5843	185	35.0%	-0.26 [-0.47, -0.06]
Kim et al., 2016	-0.1	1.4	52	-0.2	1.4	43	19.0%	0.07 [-0.33, 0.47]
Margolis et al., 2013	-10.7	52.4139	206	5.9	76.1516	197	36.0%	-0.25 [-0.45, -0.06]
Rifkin et al., 2013	-0.1	1.3	28	-0.8	1.7	15	10.0%	0.47 [-0.16, 1.11]
Total (95% CI)			**466**			**440**	**100.0%**	**-0.12 [-0.35, 0.10]**

Heterogeneity: Tau² = 0.03; Chi² = 6.67, df = 3 (P = 0.08); I² = 55%
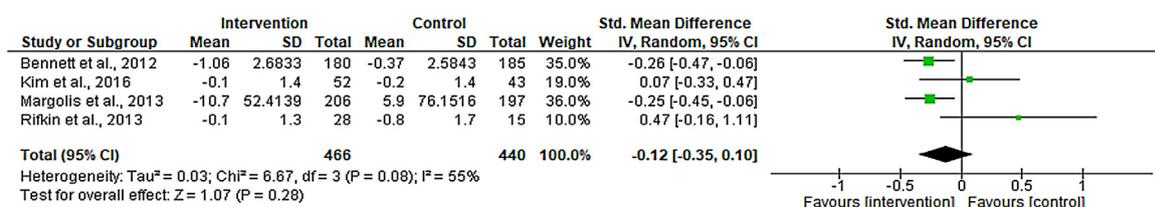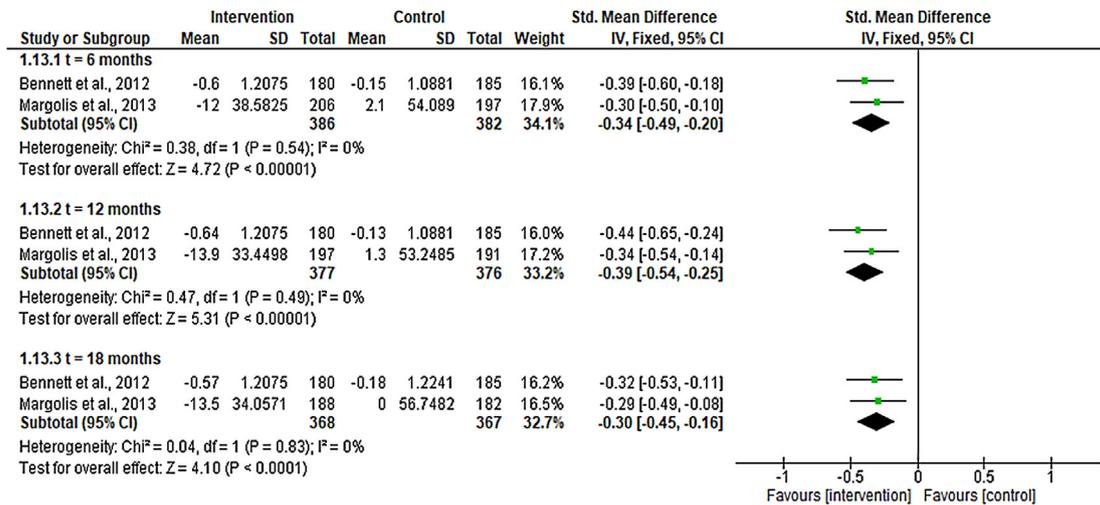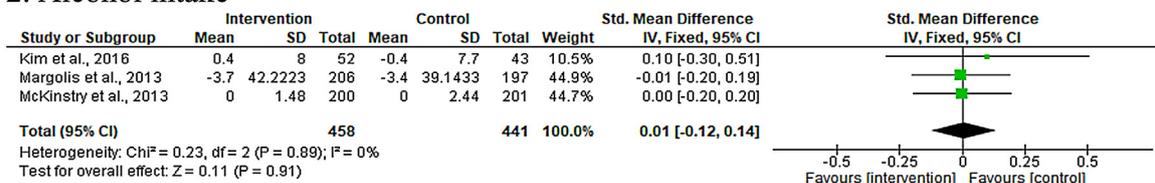Test for overall effect: Z = 1.07 (P = 0.28)

Fig. 12. Forest plot of the effect of eHealth interventions on medication adherence.
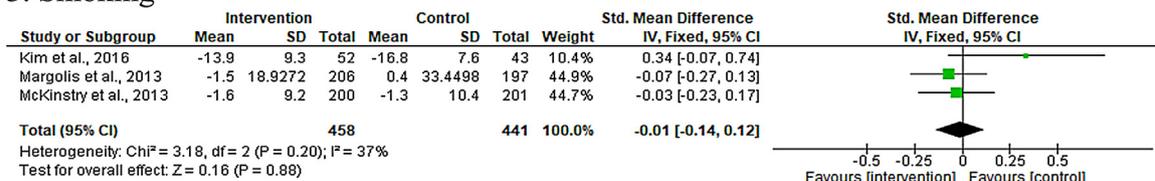
1. Sodium intake

2. Alcohol intake

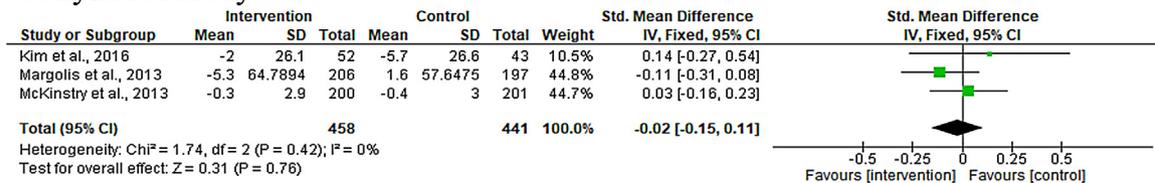## 3. Smoking

4. Physical activity

Fig. 13. Forest plot of the effect of eHealth interventions on lifestyle modification.

significantly enhanced these four outcomes compared with the control group (Xu et al., 2017).

3.5.3. Psychosocial well-being outcomes

3.5.3.1. Depression and stress. A study used full-automated patient–device interaction and reported no significant results for depression and stress as measured by Beck Depression Inventory-II and Perceived Stress Scale, respectively (Durrani et al., 2012).

3.5.3.2. Quality of life. Three studies measured the quality of life by using SF-12 (Green et al., 2008; Margolis et al., 2013) and EQ-5D (McKinstry et al., 2013) and reported no significant improvement in terms of quality of life.

3.5.3.3. Patient satisfaction. Two studies assessed patient satisfaction by using the Consumer Assessment of Healthcare Providers and Systems instrument (Margolis et al., 2013; Green et al., 2008) and reported no significant results. A study involved

asking the patients to rate their satisfaction about the hypertensive care that they received, which is higher for patients receiving eHealth interventions that in the control group (Magid et al., 2013).

4. Discussion

In this review, evidence revealed that eHealth interventions are conducive to hypertension control and could be a potential mean to promote hypertension self-care.

4.1. Summary of eHealth interventions

'System generating feedback by using automated email reminders' and 'health care providers supporting individualised goal-directed feedback through multiple media' modes were adopted to develop the eHealth interventions. High drop-out rate (> 20%) was found in the 'system generating feedback by using automated email reminders' mode probably because of insufficient tracking, motivation and communication without the

support of health care providers and the lack of blood pressure self-monitoring requirement during implementation (Nolan et al., 2012). The majority of the included studies (Kim et al., 2016; Lee et al., 2016; Moore et al., 2014; Bove et al., 2013; Margolis et al., 2013; Mckinstry et al., 2013; Rifkin et al., 2013; Bennett et al., 2012; Magid et al., 2013; Yoo et al., 2009; Madsen et al., 2008; Xu et al., 2017) used the 'health care providers supporting individualised goal-directed feedback through multiple media' mode to develop an eHealth intervention. Furthermore, a study conducted a three-arm randomised control trial, comparing these two modes with the usual care, which reported greater effect of health care providers supported arm and emphasised the importance of health care providers' role (Green et al., 2008).

Some strategies were adopted in eHealth interventions to help patients manage their blood pressure, modify their lifestyle and maintain their motivation. Blood pressure self-monitoring is widely used in eHealth interventions to facilitate track of blood pressure level for patients and to provide information to health care providers for follow-up. Goal-setting and decision-making were selected to promote lifestyle modification. Many unique technology techniques, such as personal account and individualised reminders, were adopted to facilitate motivation and maintenance of patients whether health care providers are involved or not. A combination of these components is effective and recommended to promote adherence to set of self-care behaviour (Whelton et al., 2017).

4.2. Summary of eHealth effectiveness

eHealth interventions could influence medication adjustment and improve the number of medications of patients with hypertension (Lee et al., 2016; Magid et al., 2013; Margolis et al., 2013; Moore et al., 2014; Rifkin et al., 2013). This effect might be due to the eHealth interventions that improved the interaction and communication between patients and health care providers and the access of health care providers to patients' condition through devices, which are more convenient than traditional tools. Therefore, health care providers could assess the patient condition timely through the clinic and home blood pressure readings and adjust their antihypertensive medications. This phenomenon followed the content of the latest hypertension guideline (Whelton et al., 2017), which underlined the importance of home blood pressure measurements to support hypertension management. Additionally, four of these five studies included patients with inadequate blood pressure control (Magid et al., 2013; Margolis et al., 2013; Moore et al., 2014; Rifkin et al., 2013), and three studies mentioned that adjusting the medication was a part of intervention (Magid et al., 2013; Margolis et al., 2013; Moore et al., 2014). Therefore, eHealth interventions affect medication adjustment by increasing the patients' attention on disease condition (Moore et al., 2014) and the communication between health care providers and patients (Magid et al., 2013; Margolis et al., 2013). Considering that antihypertensive medication is a confounder variable that could influence the blood pressure, the assessment of the effect of eHealth intervention on blood pressure should be critical and cautious and should be judged based on the content and characteristics of intervention.

Considering that a 5 mmHg reduction of SBP and 2 mmHg reduction of DBP would decrease the risk of stroke by 13% and 11.5%, respectively (Reboldi et al., 2011), eHealth interventions with health care providers involving blood pressure reduction would have a significant clinical meaning based on the observed magnitude of blood pressure reduction (SBP MD: −5.96 mmHg, 95% CI: −9.21 to −2.70, p < .001, I^2 = 95%; DBP MD: −3.35 mmHg, 95% CI: −6.36 to −0.35, p < .05, I^2 = 98%). In comparing the two

delivery modes, the results of sub-group analysis indicate that eHealth interventions could greatly affect blood pressure reduction with the support of health care providers. However, the high heterogeneity of meta-analysis results needs to be taken critically. Integrating the findings of blood pressure control, a significant decrease of 31% patients with inadequate blood pressure control was observed (Moore et al., 2014; Bove et al., 2013; Magid et al., 2013; Margolis et al., 2013; Green et al., 2008). For the unsatisfied blood pressure control rate of patients worldwide (Merai et al., 2016; Li et al., 2015), eHealth interventions may be a promising alternative for blood pressure control, which still need further development and implementation. The content of eHealth interventions may also consider different cultures and habits. Additionally, eHealth interventions could statistically decrease 1.08 kg of body weight, resulting in about 1 mmHg for every 1 kg reduction in body weight (Whelton et al., 2017).

For self-care behavioural outcomes, eHealth interventions reported significant results for sodium intake from three studies (Bennett et al., 2012; Margolis et al., 2013; Xu et al., 2017,2017). In comparison with blood pressure control results, self-care behavioural outcomes were inconclusive. A few studies measured behavioural outcomes probably because of limited interventions and functions employed for lifestyle modification. However, hypertension-related set of self-care behaviour play an important role in hypertension treatment and management, particularly considering the definition of hypertension has been changed to over 130/80 mmHg in the latest hypertension guideline (Whelton et al., 2017).

4.3. Limitations

Some limitations in this review should be addressed. Only Chinese and English randomised control trial studies conducted from 2000 to 2017 were searched and included. The included randomized control trial studies had suboptimal quality and some methodological weakness, such as lack of clear information on randomised and allocation concealment and absence of blinding the outcome assessors. Additionally, the lack of unified definition for the threshold of blood pressure to define the target population and blood pressure control target and the varied dosage and strategies of the interventions may cause the heterogeneity of the meta-analysis. These limitations should be considered when interpreting and analysing findings. Furthermore, this review did not search for grey literature, or analysis healthcare resources utilisation and cost-effectiveness.

4.4. Implication for practice and research

eHealth is an arresting terminology that emerges with the rapid technological development and presents its potential to support health improvement and disease control. This review has targeted the interventions which combined novel technology and hypertension self-care and therefore indicated that eHealth interventions enhance the blood pressure control of patients. Although the findings were suboptimal with high heterogeneity or small effect size, eHealth studies should be further developed and implemented, because the importance of technology is increasing worldwide. eHealth with the support of health care providers is recommended to facilitate self-care in practice. The combination of different strategies, such as regular blood pressure self-monitoring, goal-setting and decision-making on lifestyle modification, tracking of performance by patients and health care providers, individualised recommendation and report, communication and consultation between patients and health care providers and education dissemination, could be highly effective when following the recommendation of the hypertension guideline (Whelton et al., 2017).

The limitation of current studies suggests the need for additional randomised controlled trials with rigorous study designs. Future studies should conduct rigorous randomisation and allocation concealment that are specified in the articles. The blinding of outcome assessors should be adopted to decrease detection bias. Adjusting antihypertensive medication needs researchers' attention and should be recorded and reported. Long-term follow-ups, process evaluation and cost-effectiveness could also be explored to further support eHealth interventions.

5. Conclusions

eHealth interventions enhance blood pressure control. However, their effectiveness on self-care behavioural change and psychosocial well-being is insufficient. Therefore, additional eHealth interventions with rigorous study design on hypertension self-care are needed to support a wide population and to address the increasing health care needs of patients with hypertension.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ijnurstu.2018.11.007.

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