Learning implementation of a guideline based decision support system to improve hypertension treatment in primary care in China: pragmatic cluster randomised controlled trial

Jiali Song,[1] Xiuling Wang,[1] Bin Wang,[1] Yilan Ge,[1] Lei Bi,[1] Fuyu Jing,[1] Huijun Jin,[1] Teng Li,[1] Bo Gu,[2] Lili Wang,[1] Jun Hao,[3] Yanyan Zhao,[3] Jiamin Liu,[1] Haibo Zhang,[1] Xi Li,[1,2] Jing Li,[1] Wenjun Ma,[4] Jiguang Wang,[5] Sharon-Lise T Normand,[6,7] Jeph Herrin,[8] Jane Armitage,[9,10] Harlan M Krumholz,[8,11,12] Xin Zheng[1,2,13,14]; on behalf of the LIGHT Collaborative Group

For numbered affiliations see end of the article

Correspondence to: X Zheng zhengxin@fuwai.com (ORCID 0000-0002-6403-4790)

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ABSTRACT

OBJECTIVE

To evaluate the effectiveness of a clinical decision support system (CDSS) in improving the use of guideline accordant antihypertensive treatment in primary care settings in China.

DESIGN

Pragmatic, open label, cluster randomised trial.

SETTING

94 primary care practices in four urban regions of China between August 2019 and July 2022: Luoyang (central China), Jining (east China), and Shenzhen (south China, including two regions).

PARTICIPANTS

94 practices were randomised (46 to CDSS, 48 to usual care). 12 137 participants with hypertension who used up to two classes of antihypertensives and had a systolic blood pressure <180 mm Hg and diastolic blood pressure <110 mm Hg were included.

INTERVENTIONS

Primary care practices were randomised to use an electronic health record based CDSS, which recommended a specific guideline accordant regimen for initiation, titration, or switching of antihypertensive (the intervention), or to use the same electronic health record without CDSS and provide treatment as usual (control).

MAIN OUTCOME MEASURES

The primary outcome was the proportion of hypertension related visits during which an appropriate (guideline accordant) treatment was provided. Secondary outcomes were the average reduction in systolic blood pressure and proportion of participants with controlled blood pressure (<140/90 mm Hg) at the last scheduled follow-up. Safety outcomes were patient reported antihypertensive treatment related events, including syncope, injurious fall, symptomatic hypotension or systolic blood pressure <90 mm Hg, and bradycardia.

RESULTS

5755 participants with 23 113 visits in the intervention group and 6382 participants with 27 868 visits in the control group were included. Mean age was 61 (standard deviation 13) years and 42.5% were women. During a median 11.6 months of follow-up, the proportion of visits at which appropriate treatment was given was higher in the intervention group than in the control group (77.8% (17 975/23 113) *v* 62.2% (17 328/27 868); absolute difference 15.2 percentage points (95% confidence interval (CI) 10.7 to 19.8); P<0.001; odds ratio 2.17 (95% CI 1.75 to 2.69); P<0.001). Compared with participants in the control group, those in the intervention group had a 1.6 mm Hg (95% CI −2.7 to −0.5) greater reduction in systolic blood pressure (−1.5 mm Hg *v* 0.3 mm Hg; P=0.006) and a 4.4 percentage point (95% CI −0.7 to 9.5) improvement in blood pressure control rate (69.0% (3415/4952) *v* 64.6% (3778/5845); P=0.07). Patient reported antihypertensive treatment related adverse effects were rare in both groups.

CONCLUSIONS

Use of a CDSS in primary care in China improved the provision of guideline accordant antihypertensive treatment and led to a modest reduction in blood pressure. The CDSS offers a promising approach to delivering better care for hypertension, both safely and efficiently.

TRIAL REGISTRATION

ClinicalTrials.gov NCT03636334.

WHAT IS ALREADY KNOWN ON THIS TOPIC

Hypertension care in China is suboptimal, with a large geographical variation

Improving the performance of primary care doctors by ensuring their prescribing behaviour follows current guidelines is a key step towards improving blood pressure control and patient outcomes

Although clinical decision support systems have the potential to improve hypertension care in a low cost and efficient way, evidence for their effectiveness in improving the use of guideline accordant antihypertensive treatment in primary care is limited

WHAT THIS STUDY ADDS

The use of a clinical decision support system in primary care in China statistically significantly improved guideline accordant antihypertensive treatment and led to a modest reduction in blood pressure

Introduction

Hypertension is the leading modifiable risk factor for cardiovascular disease and death, affecting an estimated 1.3 billion people worldwide in 2019.[1-3] Based on the data from a nationwide survey in 2012-15, around 245 million Chinese adults had hypertension, and the treatment and control rates were low at 41% and 15%, respectively.[4] The use of evidence based antihypertensive treatments, a key strategy for lowering blood pressure and reducing cardiovascular risk,[5-8] is suboptimal in China. Inappropriate prescribing

behaviour and clinical inertia are common.[9-11] Among patients treated for hypertension, 68% were taking only one drug,[4] and about 8% of drugs used were not recommended by guidelines.[11]

Improving the performance of primary care doctors—the mainstay of the hypertension care workforce in China—is a key first step towards improving blood pressure control and patient outcomes.[9] However, China is facing multiple challenges to achieve this goal, given the constrained and unevenly distributed resources.[9 10 12] In 2021, primary care doctors provided half of the outpatient care (4.3 billion visits) in China.[13] Despite such heavy workloads, they often have inadequate training. In 2021, 56% of doctors in community health centres had an education level below medical college.[14] Continuing education and financial incentives for these doctors are also insufficient.[10] An affordable and scalable strategy is needed to improve blood pressure management.

A clinical decision support system (CDSS), characterised by integrating patient data and guideline recommendations at the point of care, has the potential to improve the performance of primary care doctors.[9 15] Despite its promise of delivering scalable and sustainable care, the CDSS has been rarely adopted in China.[10] Previous studies in resource constrained countries such as India have provided evidence of the effectiveness of CDSS for the management of hypertension in primary care settings.[16 17] These studies tested CDSS's effect on blood pressure change and showed inconsistent results.[16 17] Few studies have been primarily designed to systematically and quantitatively assess the effect of CDSS on guideline accordant treatment prescribing.[18]

We developed a CDSS that could generate a tailored antihypertensive regimen and tested whether the use of a CDSS could improve the provision of guideline accordant antihypertensive treatment compared with usual care in Chinese primary care settings. We also assessed the impact of the CDSS on blood pressure change and blood pressure control.

Methods

Trial design

The Learning Implementation of Guideline-based decision support system for Hypertension Treatment (LIGHT) trial was a pragmatic, cluster randomised trial conducted in 94 primary care practices in four urban regions of China: Luoyang (central China), Jining (east China), and Shenzhen (south China, including two regions). To ensure the wide feasibility of using electronic health record data and the CDSS, the trial was designed to recruit primary care practices in urban regions. Details of the trial rationale, design, and methods have been described previously.[19] In each region, after screening during a three month baseline period, eligible primary care practices were randomised to receive either CDSS guided treatment or usual care. Eligible patients were enrolled during the first three months after site randomisation. They were asked to attend the clinic in the primary care practice at least every three months, as recommended by the National Basic Public Health Services Programme (see supplementary appendix section S2)[20] and Chinese Guidelines for Hypertension Prevention and Management in Primary Care.[21] At each visit, a 1-3 month supply of antihypertensive drugs could be dispensed.[22] The duration of follow-up was nine months. Owing to the covid-19 pandemic in 2020, we extended the scheduled follow-up period in each region for about one month to four months according to the policies of local Centers for Disease Control and Prevention.

Recruitment and participants

Primary care practices were eligible for the trial if they stored at least one agent from each of four classes of antihypertensive drugs for hypertension treatment (angiotensin converting enzyme inhibitors or angiotensin receptor blockers, beta blockers, calcium channel blockers, diuretics); had computers and internet access to use the bespoke electronic health record for this trial; and had at least 100 local patients registered for hypertension management in the National Basic Public Health Services Programme.[20]

Patients were eligible for the trial if they had an established diagnosis of hypertension and were registered for hypertension management in the National Basic Public Health Services Programme[20]; had a systolic blood pressure <180 mm Hg and diastolic blood pressure <110 mm Hg; and were taking 0-2 classes of antihypertensive drugs. The diagnosis of hypertension was based on a systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg, or both, from three measurements on different days, or the patients were taking antihypertensive drugs according to the Chinese Guidelines for Hypertension Prevention and Management in Primary Care.[21] Patients were excluded if they had a self-reported history of coronary artery disease, chronic kidney disease, or heart failure, or were intolerant to two or more classes of antihypertensive drugs (see supplementary appendix section S3).

Interventions

The CDSS was developed using the hypertension treatment guideline for primary care in China,[21] which is generally consistent with international guidelines.[23 24] Based on the measured blood pressure, current use of antihypertensive drugs, specific clinical indications, contraindications, and patient reported drug adverse effects or intolerance, the CDSS would generate recommendations to escalate treatment until patients achieved blood pressure control; recommend guideline accordant regimen, including the class and dose of antihypertensive drugs; and optimise treatment for patients with specific indications (eg, diabetes), intolerance, or contraindication. To ensure feasibility and patient safety, the CDSS would not recommend a regimen for patients with complications such as coronary artery disease, chronic kidney disease, or heart failure.

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Supplementary appendix section S4 depicts use of the CDSS. Before prescribing took place during each visit, the doctors had to click an icon to obtain CDSS recommendations before receiving a regimen. We encouraged doctors to discuss the CDSS recommended regimen with patients. The final prescription was up to the shared decision between doctors and patients. If doctors did not follow the recommendations, a pop-up alert reminded them to adjust the prescription. If doctors refused to follow the alert, the relevant reasons were collected. Additional alerts were triggered if prescriptions involved contraindicated drugs, under-dosage, or over-dosage. Doctors in the control group used the same electronic health record to collect data but did not receive recommendations or alerts. Prescribing decisions were based on their knowledge and experience.

Randomisation and blinding

Primary care practices were randomised to intervention group or control group (1:1 ratio) using a central computerised randomisation program. Randomisation was performed in four regions sequentially (see supplementary appendix section S5) and stratified by the proportion of hypertension related visits with guideline accordant treatment during the baseline period, and the characteristics of the primary care practice (including the hospital to which the practice was affiliated, the type of primary care practice, or district; see supplementary appendix section S6 for details of the stratifying factors for each region). Given the nature of the intervention, it was not possible to blind the practice allocation to the doctors. Participants were not informed of their allocation, as consent for the study was waived. To minimise the bias for outcome analyses, the independent statistician was fully blinded to practice allocation.

Effectiveness outcomes

The primary outcome was the proportion of hypertension related visits at which appropriate treatment was provided. Appropriate treatment was defined as a prescription in line with prespecified specifications (see supplementary appendix section S7). This specification was based on the current countrywide guideline[21] and adapted to the treatment scenarios for this trial. Briefly, these included initiating and titrating antihypertensive treatments for patients with inadequate blood pressure control, switching to guideline accordant antihypertensive drugs, and refraining from prescribing contraindicated drugs. The appropriateness of the prescription was automatically assessed using a computerised algorithm. Secondary outcomes included the proportion of hypertension related visits with acceptable treatment, defined as either appropriate or non-appropriate but with acceptable reasons for failing to titrate antihypertensive treatment (acceptable reasons were self-reported and self-measured home blood pressure within the acceptable range, or possible antihypertensive treatment related events (syncope, injurious fall, hypotension, or bradycardia)); outcome measures with average change in systolic blood pressure from baseline to the last scheduled follow-up; and the proportion of participants with controlled blood pressure (<140/90 mm Hg) at the last scheduled follow-up. An exploratory outcome was the proportion of participants with vascular events (a composite of cardiac death, non-fatal stroke, and non-fatal myocardial infarction).

Safety outcome

The safety outcome was patient reported antihypertensive treatment related events of syncope, injurious fall, symptomatic hypotension or systolic blood pressure <90 mm Hg, or bradycardia (see supplementary appendix section S8).

Data collection

We provided a bespoke electronic health record for each primary care practice. Baseline characteristics of practices and participants were collected through questionnaires in this electronic health record. For sites not equipped to use electronic health records, we installed the bespoke electronic health record in their computers. For sites equipped to use local electronic health records, we embedded our electronic health record into the existing one as a module to improve workflow. At each visit, blood pressure was measured twice with an automated sphygmomanometer (Omron HBP-1300) after five minutes of rest with an interval of 1-2 minutes, and the mean of two measurements was recorded. In the electronic health record, doctors recorded the measured blood pressure, medical history, antihypertensive drug use, self-measured home blood pressure (if provided), patient reported treatment related adverse events (see supplementary appendix section S8), drug intolerance, drug adherence (see supplementary appendix section S9), and vascular events.

Sample size

We conducted a pragmatic randomised trial to assess the effectiveness of a CDSS in different settings. Owing to the lack of similar previous studies for reference, we estimated statistical power based on the number of potentially eligible sites in the Luoyang region initially. We assumed that at least 10 sites would be needed in the intervention group and 10 in the control group and that the baseline appropriate rate of treatment would be 55%. With a moderate intra-site correlation of 0.05 and a within patient correlation of 0.1, under the maximum type I error of two sided α=0.05 and statistical power of 90%, we determined that three hypertension related visits per patient would be needed for 50 patients at each site to detect an 18% absolute difference in the proportion of appropriate treatments (ie, 55% appropriate treatments in the control group, 73% in the intervention group). Subsequent enrolment and randomisation were to be carried out in four regions involving 94 participating sites. Under the same assumptions as above and maximum 25% loss to follow-up of patient at each visit, we determined

that about 12 000 patients would provide at least 90% power to detect a difference of 4% in the appropriate treatment rate—an average effect of CDSS use reported in a previous study.[25]

Statistical analysis

All analyses were based on the intention-to-treat principle. After cluster randomisation of primary care practices, all the data of enrolled patients from each visit during the study period were included for analyses, regardless of whether the primary care practice or patient completed the study. We summarised the characteristics of the practices, doctors, and participants by study group. Standardised differences between the two groups were calculated by generalised mixed effects regression models, with sites as the random effect. A standardised difference >0.25 indicated imbalance.[26 27] The analysis unit for the appropriate or acceptable treatment rates was visit, and for the other outcomes was participant. We used generalised linear mixed effect regression models with a logit and identity link function for the binary and continuous response variables, respectively. In these models, we included both practice and participant as random intercepts for visit level analysis and included practice as random intercepts for participant level analysis. The estimates of the intervention effect were obtained by averaging over the random effects. The region, baseline rate of appropriate antihypertensive treatment (median or higher or less than median), and calendar time were included as fixed effects. No data were missing for covariates. The analysis of the primary outcome and secondary outcome of acceptable appropriate treatment rate was based on available data of visits. The analyses of average change in systolic blood pressure and the proportion of participants with controlled blood pressure were based on the last scheduled visit, and without imputation. As a sensitivity analysis, we conducted multiple imputation for the missing blood pressure data of the last scheduled follow-up. We also conducted an analysis of blood pressure control defined as a systolic blood pressure <130 mm Hg and a diastolic blood pressure <80 mm Hg. Subgroup analyses were performed by implementation region; baseline tertiles of site appropriate treatment rates; education level of doctors; and age, sex, education level, use of antihypertensive drugs, and baseline systolic blood pressure of participants. In addition, we conducted additional analyses for outcomes among the patients with baseline blood pressure ≥140/90 mm Hg.

We considered a P value <0.05 (two sided test) to be statistically significant for the primary outcome. We also used a significance level of 0.05 for other outcomes, but these findings should be interpreted with caution as the analyses were not statistically powered. Additional details on statistical analyses are provided in the statistical analysis plan and in supplementary appendix sections S10 and S11 and tables S2 and S3. SAS version 9.4 (SAS Institute) was used for all statistical analyses.

Patient and public involvement

No patients were involved in the design of the study or review of our manuscript. We were unable to involve patients and members of the public in this study owing to lack of funding and expertise in conducting patient and public involvement focus groups. Although no patients or members of the public were directly involved in this study, the clinical investigators' clinical practice with patients informed the design and rationale of this study.

Results

Characteristics of practices and participants

A total of 94 primary care practices were randomised (46 to CDSS and 48 to usual care), of which two in the CDSS group withdrew after enrolment. During the baseline period, median appropriate treatment rates of primary care practices in the CDSS group and usual care group were 63.0% and 60.0%, respectively. Between August 2019 and 2021, 12 137 participants were enrolled in the trial: 5755 in the CDSS group (median 123 participants per cluster) and 6382 participants in the usual care group (median 135 participants per cluster). The median duration of follow-up was 11.6 months, during which a total of 23 113 visits (median 4.0 visits per participant) in the CDSS group and 27 868 visits (median 4.0 visits per participant) in the usual care group were included. Overall, 86.0% (4952/5755) of participants in the CDSS group and 91.6% (5845/6382) in the usual care group completed follow-up (fig 1, also see supplementary appendix table S4).

Baseline characteristics of primary care practices, doctors, and participants were well balanced between the two groups (table 1). The mean age of the doctors was 46 (standard deviation (SD) 12) years, 59.1% were women, 91.0% had an educational attainment of medical college level or higher, and all were licensed. The mean age of the participants was 61 (SD 13) years and 42.5% were women. The mean systolic blood pressure of the participants was 134.1 (SD 14.8) mm Hg, and 92.3% were using at least one class of antihypertensive drug.

Primary outcome

The proportion of hypertension related visits with appropriate treatment was significantly higher in the CDSS group (77.8% *v* 62.2%; absolute difference 15.2 percentage points (95% confidence interval (CI) 10.7 to 19.8); P<0.001; odds ratio 2.17 (95% CI 1.75 to 2.69); P<0.001) compared with the usual care group (table 2, fig 2, also see supplementary appendix section S11). Subgroup analyses showed that the CDSS improved appropriate treatment across regions and subgroups (fig 3).

Secondary and exploratory outcomes

The proportion of hypertension related visits with acceptable treatment was higher in the CDSS group (84.7% *v* 70.4%, absolute difference 12.6 percentage points (95% CI 8.1 to 17.2); P<0.001) than in the usual

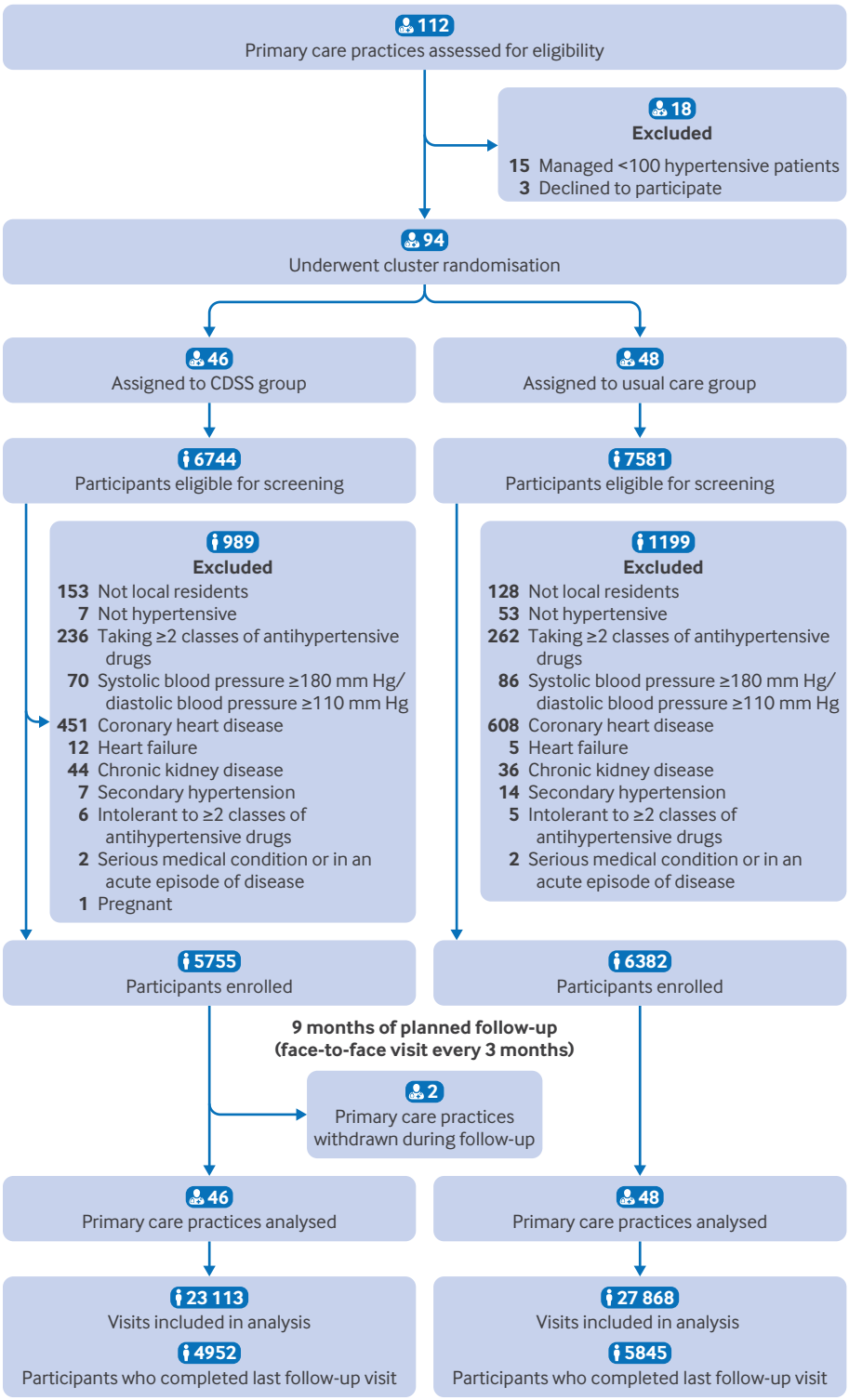

Fig 1 | Enrolment, randomisation, and follow-up. CDSS=clinical decision support system

care group. Participants in the CDSS group had a 1.6 mm Hg (95% CI −2.7 to −0.5) greater reduction in systolic blood pressure (−1.5 (SD 16.2) mm Hg *v* 0.3 (SD 16.1) mm Hg; P=0.006) and a non-significant improvement in blood pressure control of 4.4 percentage points (95% CI −0.7 to 9.5) (69.0% *v* 64.6%; P=0.07) compared with those in the usual care group. When analysis was limited to those with baseline blood pressure ≥140/90 mm Hg, participants in the CDSS group had a 1.9 mm Hg (95% CI −3.6 to −0.3; P=0.02) greater reduction in systolic blood pressure and an improvement in blood pressure control of 5.0 percentage points (95%

Table 1 | Baseline characteristics of primary care practices, doctors, and participants. Values are number (percentage) unless stated otherwise

Characteristics	CDSS group	Usual care group	Standardised difference*
Primary care practices			
No of practices	46	48	
Variables per practice site:			
Median (IQR) No of residents	18 476 (9645-29 653)	19 812 (6949-32 926)	0.07
Median (IQR) No of hypertensive patients managed	829 (622-1171)	925 (588-1461)	0.09
Median (IQR) No of in-service doctors	8 (3-11)	8 (5-10)	0.10
Median (IQR) appropriate treatment rate	0.63 (0.54-0.68)	0.60 (0.53-0.68)	0.07
Participating doctors			
No of doctors	196	183	
Median (IQR) No of participating doctors per site	6 (3-9)	5 (3-7)	0.05
Mean (SD) age (years)	45.6 (12.5)	45.9 (12.2)	0.02
Women	119 (60.7)	105 (57.4)	0.07
Education level†:			
Medical college or higher	180 (91.8)	165 (90.2)	0.06
Junior medical college	14 (7.1)	16 (8.7)	0.06
Technical school	2 (1.0)	2 (1.1)	0.007
Licensed	196 (100)	183 (100)	NA
Participants			
No of participants	5755	6382	
Median (IQR) No of participants per site	123 (91-150)	135 (101-152)	0.19
Mean (SD) age (years)	60.1 (13.0)	61.4 (13.1)	0.01
Women	2396 (41.6)	2760 (43.2)	0.05
Education level:			
Primary school or lower	1028 (17.9)	1122 (17.6)	0.03
Middle school	1978 (34.4)	2006 (31.4)	0.08
High school or higher	2749 (47.8)	3254 (51.0)	0.08
Current smoker	919 (16.0)	875 (13.7)	0.08
Disease history:			
Diabetes mellitus	982 (17.1)	1199 (18.8)	0.03
Hyperlipidaemia	870 (15.1)	1159 (18.2)	0.11
Stroke	243 (4.2)	256 (4.0)	0.01
Blood pressure:			
Mean (SD) systolic blood pressure (mm Hg):	134.1 (14.7)	134.0 (14.9)	0.002
<140	3901 (67.8)	4243 (66.5)	0.03
≥140 and <160	1531 (26.6)	1778 (27.9)	0.03
≥160	323 (5.6)	361 (5.7)	<0.001
Mean (SD) diastolic blood pressure (mm Hg):	79.2 (10.2)	79.1 (10.4)	0.007
<90	4889 (85.0)	5372 (84.2)	0.02
≥90 and <100	717 (12.5)	868 (13.6)	0.03
≥100	149 (2.6)	142 (2.2)	0.03
Controlled blood pressure (<140/90)	3615 (62.8)	3909 (61.3)	0.03
Controlled blood pressure (<130/80)	1590 (27.6)	1829 (28.7)	0.02
No of classes of antihypertensives used‡:			
0	456 (7.9)	478 (7.5)	0.007
1	3414 (59.3)	3935 (61.7)	0.04
2	1885 (32.8)	1969 (30.9)	0.05

CDSS=clinical decision support system; IQR=interquartile range; NA=not available; SD=standard deviation.
*Calculated using generalised mixed effects regression models with site as a random effect.
†Medical college: five years of education after 12 years of primary and secondary education; junior medical college: three years of education after 12 years of primary and secondary education; technical school: three years of medical education after nine years of primary and secondary education.
‡From four classes of antihypertensive drugs: angiotensin converting enzyme inhibitors or angiotensin receptor blockers, calcium channel blockers, diuretics, and other antihypertensive drugs (beta blockers were not included).

CI −1.0 to 11.1; P=0.08) compared with those in the usual care group (see supplementary appendix table S5). After multiple imputation for missing blood pressure data from the last scheduled follow-up, the use of CDSS significantly improved the rate of blood pressure control of 4.1 percentage points (95% CI 3.5 to 4.8; P<0.001) (see supplementary appendix table S6). In addition, when using a definition for blood pressure control as systolic blood pressure <130 mm Hg and diastolic blood pressure <80 mm Hg, the effectiveness of the CDSS on blood pressure control was consistent with the main analysis (see supplementary appendix table S7). The proportion of patients with good adherence to prescribed drugs in the CDSS group was lower than in the usual care group (3343/5706 (58.6%) *v* 4642/6291 (73.8%), standardised difference 0.33). CDSS use resulted in better blood pressure control among patients with good drug adherence, but not among those with poor drug adherence (see supplementary appendix table

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Table 2 | Primary, secondary, and exploratory outcomes. Values are number with outcome/total number in group (percentage) unless stated otherwise

Outcomes*	CDSS group	Usual care group	Intervention effect (95% CI)	P value
Primary outcome				
Visits with appropriate treatment	17 975/23 113 (77.8)	17 328/27 868 (62.2)	15.2 (10.7 to 19.8)†	<0.001
Secondary outcomes				
Visits with acceptable appropriate treatment	19 581/23 113 (84.7)	19 622/27 868 (70.4)	12.6 (8.1 to 17.2)†	<0.001
Mean (SD) change in systolic blood pressure (mm Hg)	−1.5 (16.2)	0.3 (16.1)	−1.6 (−2.7 to −0.5)‡	0.006
Blood pressure controlled at 9 months (<140/90 mm Hg)	3415/4952 (69.0)	3778/5845 (64.6)	4.4 (−0.7 to 9.5)†	0.07
Exploratory outcome				
Vascular events	59/5755 (1.0)	44/6382 (0.7)	0.1 (−0.3 to 0.5)†	0.43

CDSS=clinical decision support system; CI=confidence interval; SD=standard deviation.
*For visit level analysis (appropriate or acceptable treatment), both practice and participant were included as random intercepts. For other participant level analysis, practice was included as random intercepts. The region, baseline appropriate antihypertensive treatment rate (≥median or <median), and calendar time were included as fixed effects in all models.
†Absolute difference (percentage points).
‡Mean change in blood pressure.

S8). The proportion of participants reporting vascular events between the two groups was similar (1.0% *v* 0.7%; absolute difference 0.1 percentage points (95% CI −0.3 to 0.5; P=0.43) (table 2).

Safety outcomes

The rates of patient reported antihypertensive treatment related adverse effects were low and similar between the two groups (see supplementary appendix table S9).

Discussion

In this large, cluster randomised trial conducted in 94 primary care practices in China, the use of a CDSS led to a 15 percentage point absolute increase in the proportion of hypertension related visits with guideline accordant prescribed treatment, and a modest reduction in systolic blood pressure of 1.6 mm Hg. Patient reported treatment related adverse events were rare. The CDSS appeared effective across regions and sites with varying baseline guideline accordant treatment rates, and in settings with different educational attainment of the primary care doctors.

Comparison with other studies

In this trial we quantified the effectiveness of CDSS for enhancing primary hypertension care using comprehensive guideline based metrics. The observed effect of the CDSS corresponded to an estimated 26% relative increase[28] in guideline accordant treatment. Previous studies have assessed the effectiveness of CDSSs on a range of process outcomes for hypertension care, including drug prescribing, clinical tests completed, and number of clinic visits, and reported absolute 2 to 20 percentage point improvements in the corresponding process outcome,[29-32] but few provided evidence on the extent of guideline based prescribing. A trial conducted in 14 US hospitals, assessed a CDSS designed to improve appropriate drug prescribing.[18] The CDSS could recommend a pharmacologically appropriate drug class based on several patient characteristics, including age, race, and disease (ie, diabetes, coronary artery disease, and heart failure) but did not provide dosage to intensity treatment. The CDSS in the current study was not designed to guide treatment for coronary artery disease or heart failure for two reasons—firstly, because patients with these conditions are more likely to follow regimens provided by doctors from hospitals rather than primary care practices, and, secondly, because of concern about the complexity of an individualised and specific algorithm and patient safety.

This trial provided insights into the effectiveness of CDSS as a single factor intervention for improving the control of hypertension in primary care. Several previous CDSS studies focused on change in blood pressure, and the results were mixed,[16 17 32] partly because blood pressure could be affected by multiple factors. In the current study, the marginal effect of using a CDSS on blood pressure control should be interpreted in light of several points. Unlike other studies that enrolled patients with uncontrolled blood pressure,[16 17] this trial included two thirds of patients with blood pressure under control at baseline. Therefore, the overall effect of a CDSS on blood pressure could have been diluted. This point can be supported by the finding of the subgroup analysis, which showed a larger CDSS related reduction in systolic blood pressure among patients with uncontrolled blood pressure than those with controlled blood pressure at baseline. Moreover, the potential benefit of the CDSS on blood pressure control in this study may be offset by poor adherence of patients to prescribed

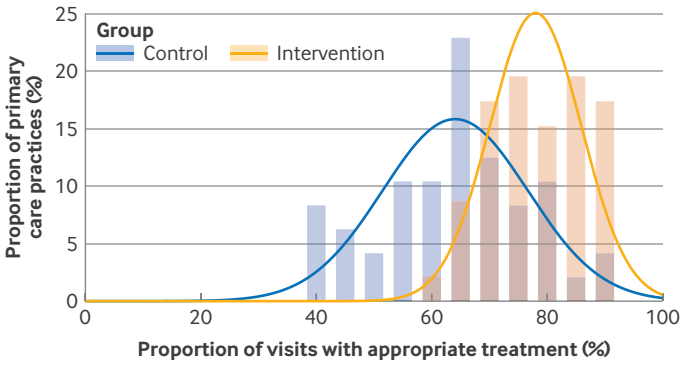

Fig 2 | Distribution of proportion of hypertension related visits with appropriate (guideline based) treatment

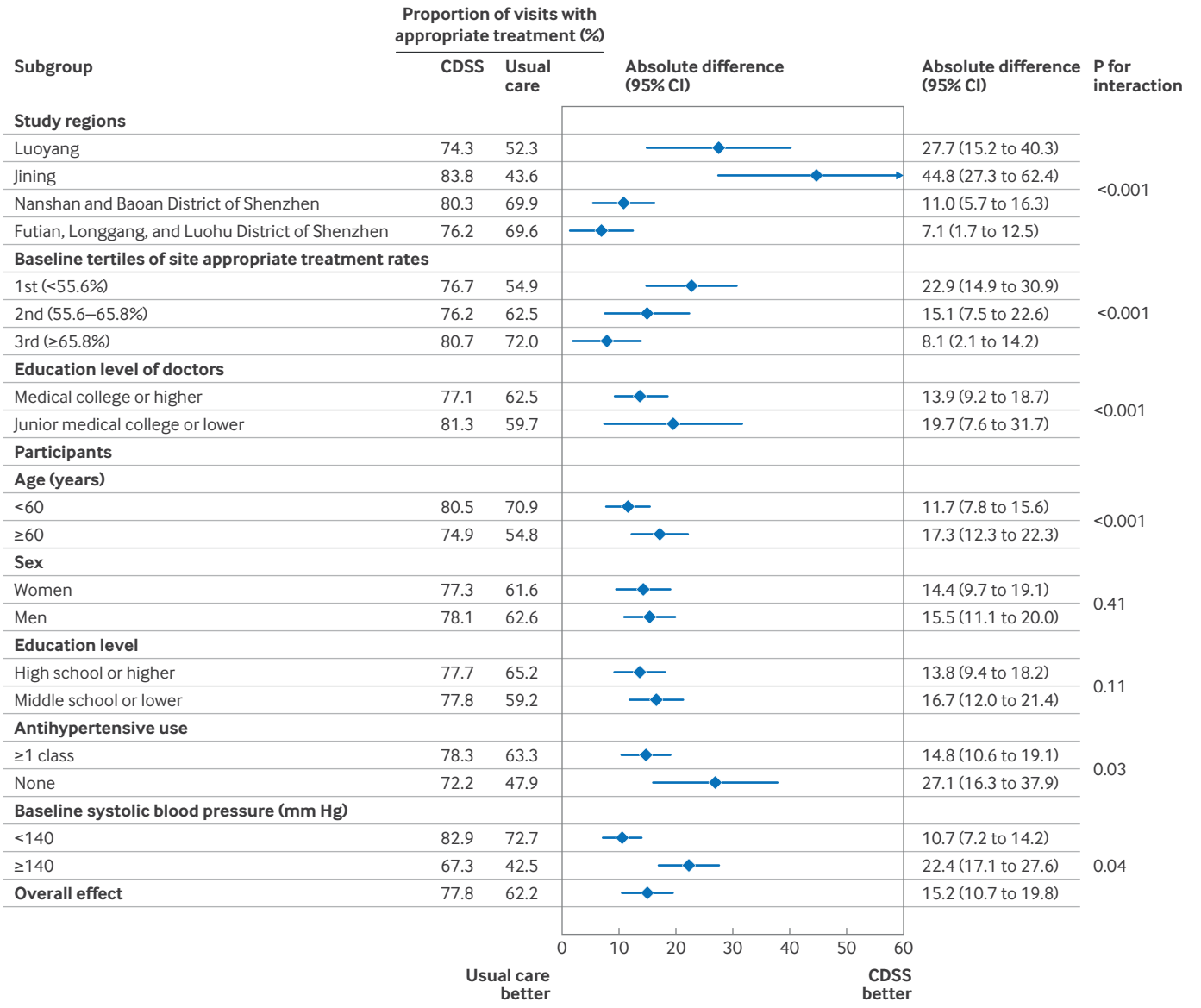

Fig 3 | Subgroup analysis of proportion of hypertension related visits with appropriate (guideline based) treatment. CDSS=clinical decision support system; CI=confidence interval

drugs, as we found that CDSS use led to significant blood pressure control among patients with good adherence, but not in the overall population. As this trial was primarily aimed at enhancing doctors' prescribing behaviour through CDSS use, it did not involve multicomponent interventions. In future research, integrating a patient engagement approach with CDSS use for enhancing shared decision making might improve patients' adherence to treatment and their long term outcomes.[33 34] Furthermore, the benefit of some appropriate treatments, such as switching to angiotensin converting enzyme inhibitors or angiotensin receptor blockers for patients with diabetes and blood pressure under control, was more reflected by the improvement of long term outcomes rather than reduction in blood pressure. Notably, a 4.4 percentage point improvement in blood pressure control rate, as observed in this study, could translate into a considerable reduction of cardiovascular mortality and morbidity in larger populations.[35]

Strengths of this study

The overall design of this study was distinguished by several unique features, which were considered to improve implementation, acceptance, and generalisability of CDSS use in primary care settings. Firstly, the CDSS was integrated into the clinical workflow by being embedded into the electronic health record that collected the relevant information for usual hypertension care. Without interruption to routine clinical care, simple data collection minimised the burden of CDSS use. As primary care doctors need

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to click an icon only once, the CDSS could provide immediate, specific, and tailored recommendations at the point of care without unnecessary alerts. These features rendered the CDSS more acceptable to primary care doctors,[15] even if they had little experience of using a CDSS.

Secondly, we included primary care practices, involving a large sample of hypertensive patients, across three urban cities with a broad range of baseline appropriate treatment rates and doctors with different levels of education. The large sample size enabled us to assess the effectiveness of CDSS across regions and various subgroups. We observed the effects of CDSS were different across regions, partly owing to the regional variations in appropriate treatment and blood pressure control rates at baseline. Nevertheless, substantial improvement in appropriate treatment was found in the overall population after accounting for heterogeneity in different sites from four regions, suggesting that CDSS had been well implemented and accepted in diverse clinical settings. Subgroup analyses indicated that CDSS could be generalised to other similar primary care settings in the future, particularly for underserved regions with poorer blood pressure control.

Thirdly, the CDSS was designed to serve as a tool to provide a decision aid for improving the process of shared decision making for hypertension care. The doctors were not mandated to follow recommendations generated from CDSS—the final prescription was based on a shared decision between doctors and patients. The reasons for CDSS recommendations not being followed were collected. The findings may provide valuable information for improving adherence to CDSS recommendations in the future.

Limitations of this study

Some limitations need to be considered. Firstly, we used a cluster randomised design to avoid contamination across groups. Doctors in the control group were, however, aware of the purpose of the trial and thus this might have had a positive impact on provision of usual care. If that was the case, the effect of CDSS might be underestimated. Secondly, this trial was conducted in primary care practices in urban China where most doctors have attained an education level of medical college or higher; the effectiveness of the CDSS in rural areas remains to be confirmed. It may be speculated that the CDSS would be equally or more effective in rural areas, since we observed similar improvements in practices with lower appropriate treatment rates at baseline or among doctors with lower education levels. Thirdly, the use of the CDSS was restricted to participants without coronary artery disease, chronic kidney disease, or heart failure, which limited the generalisability of the results. Fourthly, the trial was unable to evaluate the sustainability of the CDSS intervention and was underpowered to assess its effectiveness on cardiovascular events. Fifthly, we did not assess safety outcomes such as electrolyte disorders or renal dysfunction. Finally, we did not collect doctors' satisfaction with the intervention, which could help its implementation outside of the trial. This will be investigated in future studies.

Policy implications

Our study has implications for strengthening the primary care systems in China and other resource restricted regions or countries with heavy burdens of cardiovascular disease.[36-38] Unlike other multicomponent intervention strategies[39-41] that inherently require more resources to implement and are more complex to scale-up, CDSS could potentially serve as a low cost, efficient, scalable, and sustainable means to improve access and equity to high quality care of hypertension. Primary care practices included in this study might differ in some ways from those in other regions of China and other resource restricted regions or countries, such as the availability of health information systems, antihypertensive drugs, and qualification of primary care providers. Despite these limitations, in rural areas where computers are not equipped to use a CDSS, the CDSS could support decision making through mobile phones or tablets, where highly compatible electronic health records for hypertension management can be installed. Another difference is that in this study the antihypertensive drugs were dispensed every 1-3 months, but in many primary care settings from other resource restricted regions or countries, a shorter prescription period may be common since a reliable supply chain of antihypertensive drugs may be difficult owing to problems with storage capacity.[42] CDSS could be more useful when more frequent visits and prescriptions are needed. Of note, CDSS in this study was used by primary care doctors with higher education levels. As non-doctor health workers play an important role in task sharing or shifting strategies to mitigate the under-qualification and deficiency problems of primary care doctors,[41 43] future investigations could assess the effectiveness of CDSS among these staff with appropriate training and supervision.

Conclusions

The use of CDSS for hypertension management statistically significantly improved guideline accordant primary care for antihypertensive treatment and led to a modest reduction in blood pressure. This strategy offers a promising approach to delivering high quality care for hypertension efficiently and safely, particularly for resource constrained regions with a heavy burden of cardiovascular diseases like China.

AUTHOR AFFILIATIONS

[1]National Clinical Research Centre for Cardiovascular Diseases, State Key Laboratory of Cardiovascular Disease, Chinese Academy of Medical Sciences and Peking Union Medical College, Fuwai Hospital, National Centre for Cardiovascular Diseases, Beijing, China

[2]National Clinical Research Centre for Cardiovascular Diseases, Shenzhen, Fuwai Shenzhen Hospital, Chinese Academy of Medical Sciences, Shenzhen, China

[3]Medical Research and Biometrics Centre, State Key Laboratory of Cardiovascular Disease, Fuwai Hospital, National Centre for Cardiovascular Diseases, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, China

[4]Hypertension Centre, State Key Laboratory of Cardiovascular Disease, Chinese Academy of Medical Sciences and Peking Union Medical College, Fuwai Hospital, Beijing, China

[5]The Shanghai Institute of Hypertension, Ruijin Hospital, Shanghai Jiaotong University School of Medicine, Shanghai, China

[6]Department of Health Care Policy, Harvard Medical School, Boston, MA, USA

[7]Department of Biostatistics, Harvard T.H. Chan School of Public Health, Boston, MA, USA

[8]Section of Cardiovascular Medicine, Department of Internal Medicine, Yale University School of Medicine, New Haven, CT, USA

[9]Clinical Trial Service Unit and Epidemiological Studies Unit, Nuffield Department of Population Health, University of Oxford, Oxford, UK

[10]MRC Population Health Research Unit, Nuffield Department of Population Health, University of Oxford, Oxford, UK

[11]Centre for Outcomes Research and Evaluation, Yale-New Haven Hospital, New Haven, CT, USA

[12]Department of Health Policy and Management, Yale School of Public Health, New Haven, CT, USA

[13]Coronary Artery Disease Ward 2, Fuwai Shenzhen Hospital, Chinese Academy of Medical Sciences, Shenzhen, China

[14]Clinical Trial Centre, Fuwai Shenzhen Hospital, Chinese Academy of Medical Sciences, Shenzhen, China

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Ethical approval: This trial was approved by the central ethics committee at Fuwai Hospital (ID No 2017-939) and the collaborating centres. Individual level informed consent for use of the clinical decision support system was waived because of the minimal risk to the participants.

Data sharing: Data described in the manuscript will not be made publicly available. Data collected for the study will be made available publicly upon reasonable request. For further detailed data access policy and procedure, contact zhengxin@fuwai.com.

Transparency: The corresponding author (XZ) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Dissemination to participants and related patient and public communities: The findings of this study will be presented to researchers, doctors, and students through a conference. We will also increase the impact of the study by sharing the findings with policy makers, research communities, and the general public through social media. We will also present the findings in a blog to explain the results.

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Supplementary appendix: Sections S1-11, tables S1-10, and references