

Self-monitoring of blood pressure in patients with hypertension related multi-morbidity: Systematic review and individual patient data meta-analysis

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Abstract

Background: Studies have shown that self-monitoring of blood pressure (BP) is effective when combined with co-interventions, but its efficacy varies in the presence of some co-morbidities. This study examined whether self-monitoring can reduce clinic BP in patients with hypertension-related co-morbidity.

Methods: A systematic review was conducted of articles published in Medline, Embase and the Cochrane Library up to January 2018. Randomised controlled trials of self-monitoring of BP were selected and individual patient data (IPD) were requested. Contributing studies were prospectively categorised by whether they examined a low/high intensity co-intervention. Change in BP and likelihood of uncontrolled BP at 12-months were examined according to number and type of hypertension-related co-morbidity in a one-stage IPD meta-analysis.

Results: A total of 22 trials were eligible, 16 of which were able to provide IPD for the primary outcome, including 6,522 (89%) participants with follow-up data. Self-monitoring was associated with reduced clinic systolic BP compared to usual care at 12-month follow-up, regardless of the number of hypertension-related co-morbidities (-3.12 mmHg, [95%CI -4.78, -1.46 mmHg]; *p* value for interaction with number of morbidities = 0.260). Intense interventions were more effective than low-intensity interventions in patients with obesity (*p*<0.001 for all outcomes), and possibly stroke (*p*<0.004 for BP control outcome only), but this effect was not observed in patients with coronary heart disease, diabetes or chronic kidney disease.

Conclusions: Self-monitoring lowers BP regardless of the number of hypertension-related co-morbidities, but may only be effective in conditions such obesity or stroke when combined with high intensity co-interventions.

Key words: Hypertension, randomised controlled trial, stroke, diabetes, coronary heart disease, obesity

Introduction

Hypertension is the most common individual condition in patients with multi-morbidity.¹ Multi-morbidity is defined as having two or more concomitant medical conditions and affects between 10%-50% of patients, depending on the population studied.¹⁻⁴ Increasing multi-morbidity is associated with reduced quality of life.^{5,6} Due to the complexities of studying individuals with multiple conditions, few studies have examined interventions specifically designed to improve outcomes in patients with multi-morbidity.⁷

Optimal management of blood pressure (BP) represents the most effective way to prevent stroke and cardiovascular disease.⁸ Self-monitoring and self-management of BP is effective in reducing BP in patients with hypertension.⁹ However, in patients with multi-morbidity, it is possible that such interventions may be less effective due to clinical inertia on the part of the treating physician^{10,11} or patient concerns about self-monitoring in the presence of certain co-morbidities.¹² Existing studies have failed to show that self-management can result in improvement in risk factor management in patients with multi-morbidity^{13,14} and individual trials usually contain too few individuals with multi-morbidity to examine outcomes with adequate power, particularly in sub-groups.

The BP-SMART collaboration previously carried out an individual patient data (IPD) meta-analysis of trials examining the efficacy of self-monitoring of BP, including data from 25 studies and 8,931 patients.^{15,16} This analysis showed reductions in BP with self-monitoring which increased with the intensity of co-intervention. However, pre-specified subgroup analyses suggested that in some individuals with hypertension related co-morbidity, such as stroke or myocardial infarction, this effect may be reduced.¹⁵ To better understand the effect of self-monitoring on clinic BP in a population with multi-morbidity, we systematically reviewed the literature for new trials and undertook IPD meta-analyses by number and type of hypertension related co-morbidities. In contrast to our previous work, the present study

aimed to account for the modifying effect of intensity of co-intervention in analysis of subgroups, which has been shown to be important in determining the efficacy of self-monitoring.¹⁵ Hypertension was considered as the illness, along with co-morbidities commonly associated with hypertension (coronary heart disease [CHD], stroke [including transient ischemic attack], diabetes, chronic kidney disease [CKD; defined as stage 3a or above] and obesity [BMI of $\geq 30\text{kg/m}^2$]).

Methods

Study design

This work extends a previous systematic review and individual patient data analysis of self-monitoring of BP in hypertensive patients.^{15,16} Searches of the literature were undertaken to identify new trials published since the previous review providing data on the efficacy of self-monitoring of BP which could be combined with data from the original BP-SMART collaboration.^{15,16} Where available, these data were combined and analysed in a one-stage IPD meta-analysis.

Data sources and searches

A previously published search conducted in Medline, Embase and the Cochrane Library¹⁵ was updated to identify trials examining the efficacy of self-monitoring of BP in hypertensive patients, published up to January 2018 (eFigure 1).

Study Selection

At least two reviewers (KT, RM and WD) independently assessed the articles for eligibility and inclusion, disagreements were resolved by discussion. All published and unpublished controlled trials included in the analysis were required to fulfil the following criteria:

- **Population:** patients with hypertension, not being managed as an inpatient.

- **Intervention:** self-measurement of BP without medical professional input plus or minus other co-interventions.
- **Comparator:** no organised self-measurement of BP, although there may be some ad hoc measurement which would be difficult to prevent or assess.
- **Outcome:** systolic and/or diastolic BP measured in clinic, or by daytime ambulatory measurement.
- **Study design:** randomised trial of at least 100 participants followed up for at least 24 weeks (to ensure a minimum level of study quality and robustness of effect estimates)
- **Publication Date:** since 2000 (because changes in the technology used for self-monitoring make comparisons prior to this date less relevant).

All articles were managed and screened using the Covidence application (Vertitas Health Innovation Ltd, Melbourne, Australia).

Data extraction and quality assessment

Corresponding authors whose trials met the inclusion criteria were approached for provision of individual patient data including demographic details, antihypertensive medications, lifestyle factors and BP end points (clinic and/or ambulatory). All patients had hypertension, and data regarding other morbidities were also sought. This analysis focussed on morbidities commonly associated with hypertension (CHD, stroke, diabetes, CKD, and obesity), since recording of such data varied widely across trials and only these conditions commonly were captured frequently enough to enable data to be pooled in this analysis. Where data on even these conditions were missing, the morbidity was assumed not to be present in the population from that particular study (morbidities recorded by each study are listed in eTable 1). Study level data were extracted from published articles and checked by the original authors. In particular, any co-interventions were carefully documented and prospectively (prior to conducting the analysis) allocated to one of four levels of interventional support

based on a previous classification (Table 1).¹⁵⁻¹⁷ Due to limited sample sizes for the subgroup analyses planned in the present study, these classifications were condensed into two levels (low vs. high intensity) (Table 1). Study quality was assessed in terms of potential bias from randomisation, blinding, outcome assessment and method of analysis using an adaptation of the Cochrane risk of bias tool.¹⁵ Original data were kept on a secure server and re-coded to a consistent format across trials, where appropriate.

Outcome measures

The primary outcome was change in clinic BP (systolic and diastolic) between baseline and 12-month follow-up, by number of morbidities. Secondary analyses examined the likelihood of uncontrolled BP (as defined by the original study; determined by the study population and setting [see eTable 1 for BP targets]) at 12 months by number of co-morbidities. All outcomes were also assessed at 6-month follow-up. Further analyses explored subgroups by type of co-morbidity (in addition to hypertension: coronary heart disease [CHD], stroke, diabetes, chronic kidney disease [CKD] and obesity) and intensity of intervention (high vs. low intensity).

Data synthesis and analysis

Descriptive statistics were used to summarise the baseline characteristics of included patients by type of hypertension related co-morbidity. The overall impact of self-monitoring on blood pressure was assessed in a 2-stage individual patient data meta-analysis. For outcomes by co-morbidity, a one-stage individual patient data meta-analysis was conducted with both random intercept and random coefficients to account for study level effects and heterogeneity in treatment effects across studies. Linear regression was used for continuous outcomes (change in systolic and diastolic BP) and logistic regression for binary outcomes (odds of uncontrolled BP at follow-up). All analyses were conducted by intention-to-treat and each model was adjusted for age, sex, baseline clinic BP and level of intervention.

Subgroup analyses were used to examine the effect of self-monitoring on change in BP and likelihood of uncontrolled BP in patients with CHD, stroke, diabetes, CKD and obesity. In each model, the interaction between self-monitoring and intensity of co-intervention was explored (high vs. low intensity; defined in table 1). Sensitivity analyses were conducted to examine the impact of missing studies by including published aggregate data from those trials which were not able to provide individual patient data for this review. Funnel plots and Egger's test¹⁸ were used to assess the potential for publication bias.

All analyses were conducted using STATA version 14.1 (Special Edition, StataCorp, College Station, Texas, USA). Data are presented as proportions of the total study population, means with standard deviation with 95% confidence intervals unless otherwise stated.

Role of the funding source

The funders played no role in the design or execution of the study and no role in the preparation of this manuscript. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health and Social Care.

Results

The previous literature review identified 36 studies for which data from 25 randomised controlled trials were obtained.¹⁵ The updated search conducted for this analysis returned 1,377 new studies (eFigure 2) and after title and abstract screening, 32 full text articles were assessed. In total, three new trials were identified as eligible for inclusion in the BP-SMART database. Of these, one provided IPD and the remaining two studies were unable to provide data or did not respond (eFigure 2).

The total dataset included 26 studies published between 2005 and 2016 including data from 10,713 participants (eTable 1). Data for the primary outcome (change in clinic BP at 12 months) were available in 16 studies and 7,360 participants, of which 6,522 (88.6%) had complete follow-up data and were included in the final analysis.^{9,19-42} On average, self-monitoring reduced clinic blood pressure by 3.11/1.49 mmHg (systolic/diastolic), although there was significant heterogeneity across studies ($I^2 = 59.6\%-75.4\%$, $p < 0.001$; eFigures 3 and 4). Inclusion of aggregate data from studies which were not able to provide IPD did not affect the overall results (eFigure 5). There was no evidence of publication bias among studies included in this review (Egger's test¹⁸ = 0.07, $p = 0.977$; eFigure 6).

Patients had between 1-6 morbidities (median 2, IQR 1,2) including hypertension, which was present in all participants (eTable 2). The characteristics of patients with different hypertension related co-morbidities were broadly similar, although patients with a history of CHD and stroke were older and those with diabetes were more commonly male, with a higher proportion of smokers and were prescribed more BP lowering medications at baseline (eTable 2).

Effect of self-monitoring by number of hypertension related co-morbidities

In patients with hypertension but no other hypertension related co-morbidities, self-monitoring was associated with a 3.80 mmHg reduction (95% CI 5.84, 1.76 mmHg) in clinic systolic BP and 1.86 mmHg reduction (95% CI 2.80, 0.92 mmHg) in clinic diastolic BP at 12-month follow-up (figure 1). There was no difference in the effectiveness of self-monitoring by increasing numbers of co-morbidities (SBP p for interaction = 0.260; DBP p for interaction = 0.079). Self-monitoring of BP was associated with reduced odds of having uncontrolled clinic BP at 12-month follow-up (OR 0.68, 95% CI 0.52, 0.87), and this was similar in patients with increasing numbers of co-morbidities (p for interaction = 0.607). Similar findings were observed at 6-month follow-up (eFigure 7).

Effect of self-monitoring by intervention intensity within specific morbidities

Self-monitoring was associated with lower clinic systolic BP in patients with diabetes (-3.71 mmHg, 95% CI -5.76, -1.66 mmHg) and obesity (-2.81 mmHg, 95% CI -4.94, -0.68 mmHg), but not patients with CHD, stroke or CKD (figure 2). There was a significant interaction between the effect of self-monitoring and intervention intensity in patients with obesity (p value for interaction = <0.001) (figure 2). Similar findings were observed for diastolic BP (eFigure 8) and at 6-month follow-up (eFigures 9 and 10).

For patients with diabetes and obesity, self-monitoring reduced the likelihood of uncontrolled clinic BP at 12-month follow-up (figure 3). A significant interaction between the effect of self-monitoring and intensity of intervention was observed in patients with stroke (OR 1.14, 95%CI 0.74-1.1.76 [low intensity] vs. OR 0.37, 95%CI 0.19-0.70 [high intensity]; interaction = 0.004) and obesity (OR 1.12, 95%CI 0.82-1.53 [low intensity] vs. OR 0.49, 95%CI 0.38-0.63 [high intensity]; interaction = <0.001). At 6-month follow-up, self-monitoring was associated with a reduced likelihood of uncontrolled clinic BP in patients with diabetes, CKD and obesity (eFigure 11). In patients stroke, diabetes, CKD and obesity, there was a significant interaction between the effect of self-monitoring and intensity of intervention, with those receiving high intensity interventions being less likely to have uncontrolled clinic BP at 6-month follow-up.

Discussion

Summary of findings

This is the largest IPD meta-analysis to date of self-monitoring in hypertension including individual patient data from 6,522 patients and 16 trials of self-monitoring of BP in hypertension.^{9,19-42} Self-monitoring was found to be effective at lowering BP,^{15,17,43} and this effect was observed regardless of the number of hypertension related co-morbidities

present. This study confirms that self-monitoring is effective in patients with obesity.¹⁵ In contrast to previous studies, there was some limited evidence that patients with stroke may benefit from self-monitoring when it is combined with a high intensity co-intervention. Such co-interventions might include self-management, pharmacist support, tailored education and lifestyle counselling. Self-monitoring of BP can therefore be recommended as part of a multifaceted approach to managing hypertensive patients with hypertension related co-morbidity.

Strengths and weaknesses

This is the largest, and to our knowledge only, individual patient data meta-analysis of trials examining the efficacy of self-monitoring of BP in hypertensive patients with a hypertension related co-morbidity. Having access to individual patient data provided a unique opportunity to study the effect of self-monitoring within specific morbidities, something which is not possible in standard meta-analyses.¹⁷ As is common in this type of review, it was not possible to obtain data from all eligible studies, due to inability to make contact with authors, or data no longer being held in a format that could be transferred across institutions and analysed. Despite this, complete follow-up data were available from 6,522 participants in 16 studies that provided data on the primary outcome (at 12-month follow-up). Our sensitivity analyses suggest that missing studies would have had little impact on the overall association between self-monitoring and blood pressure. Because our analyses examined the number and type of hypertension related co-morbidity, it was not possible to combine individual patient data with aggregate data from unavailable trials (where patients have varying morbidities) to examine the impact of these missing data on our hypertension related co-morbidity subgroups.

The focus of this analysis was on the extent to which hypertension related co-morbidity modifies the effect of self-monitoring on BP. Co-morbidities were characterised in terms of 6

conditions related to hypertension (hypertension, diabetes, CKD, CHD, stroke and obesity) for which sufficient data were available. However, some included studies did not collect information about these conditions (see eTable 1 for details), which may have led to an under representation of the prevalence of each condition in the study cohort. In addition, there are many other co-morbidities that can be used to define multi-morbidity¹ and may have been present in some patients but were not captured as part of the original studies contributing data to these analyses.

For the present study, we developed a one-stage analytical model with study-level random effects for each intervention and control group. In contrast, our previous analysis included a single study-level covariate which gave less weight to the individual study effects and potentially underestimated the between study variance. This change in analytical approach had little effect in most of our analyses, except that which examined patients with CKD. In that analysis one study (contributing 15 patients)⁴² suggested that self-monitoring increases systolic BP by 41.2 mmHg, compared to the remaining 7 studies (contributing 292 patients) which showed a 5.1 mmHg reduction at 12-month follow-up. Since the present analysis gives more weight to individual studies, our combined findings were drawn towards the null whereas in our previous paper they were not.¹⁵ Such subgroup analyses, with very small sample sizes and imprecise point estimates should be interpreted with caution. Indeed, differences between results at 6-month and 12-month follow-up could be explained by the larger number of studies and participants available for assessment of outcomes at 6-month follow-up.

The nature of interventions categorised as high and low intensity were quite heterogeneous and significantly more patients and trials would be required to identify exactly which type of co-interventions is most effective in which condition. Included studies had rates of follow-up which varied between 58% and 99% with most studies following-up around 90% of

participants. Our previous analysis using this dataset suggested the impact of differential follow-up in individual studies was negligible.¹⁵

Studies included in this review used various different measurement protocols for both clinic and home BP readings (e.g. number of readings, days, period of rest prior to measurement, etc.). Where individual BP readings were available from each included study, the definition of clinic and home BP was standardised (clinic BP = mean of the second and third readings; home BP = mean of six days of readings, after discarding the first day's readings). However, for the majority of studies this standardisation was not possible. Whilst this may have affected the absolute values for blood pressure reported in each trial, we do not think this would have affected the overall findings, since each randomised group were subjected to the same measurement procedures within each study. Our analyses also took into account random treatment effects across studies, which could include those brought about by varying measurement protocols between studies.

Comparison with previous literature

The efficacy of self-monitoring in patients with multi-morbidity has been debated, with some studies suggesting it may be beneficial,^{13,14} and others questioning its effectiveness in specific morbidities.²⁹ This study confirms the beneficial effects of self-monitoring of BP in hypertension related co-morbidity and patients with specific conditions such as obesity and demonstrates possible effects in stroke, highlighting the importance of intensity of co-intervention for certain conditions. This study is novel in comparison with our previous review¹⁵ due to the inclusion of additional data, better characterisation of multi-morbidity within studies and updated analysis taking into account the intensity of co-intervention within subgroups.

Previous reviews have attempted to define the effects of self-monitoring as part of a wider self-management intervention, in patients with diabetes and CKD,⁴⁴ and those with previous stroke.⁴⁵ The present analysis included nearly four times as many patients with diabetes and/or CKD but was still underpowered to show whether self-monitoring is effective at reducing blood pressure when combined with co-interventions such as self-management or 1:1 counselling in patients with specific morbidities. Where more data were available at 6-month follow-up, and examining the likelihood of uncontrolled BP rather than change in BP, there was some evidence to suggest that self-monitoring is effective in patients with stroke, diabetes, CKD and obesity, in combination with high intensity co-interventions. This latter finding was also seen in patients with stroke and obesity at 12-month follow-up.

Implications for practice

Many previous studies have considered the impact of self-monitoring in hypertension,¹⁵ or patients with specific morbidities.^{23,29,40} However in practice, patients present with multiple morbidities and so it is important to consider the efficacy of self-monitoring in the context of multi-morbidity. The findings of this review suggest that self-monitoring can be recommended as part of a multifaceted approach to managing hypertensive patients with hypertension related co-morbidity. There was some variation in the effectiveness of self-monitoring within specific morbidities, and this can only be partly explained by the use of high vs. low intensity interventions. However, the present findings suggest that where individuals have a history of obesity and possibly stroke, self-monitoring is likely to be effective when combined with intensive co-interventions such as self-management, pharmacist support, tailored education or lifestyle advice. Understanding the relative cost effectiveness of the different co-interventions is likely to be important when deciding which should be encouraged in routine practice. The present analysis suggests that targeting individuals with hypertension related co-morbidity is appropriate and this may make the financial case for costlier interventions stronger, since patients with such co-morbidities are

at greater risk of cardiovascular disease.¹ Further work should use these individual patient data to quantify the impact of self-monitoring on outcomes other than BP, as others have attempted using aggregated data in previous reviews.⁴⁵

Conclusions

Self-monitoring of BP leads to clinically significant BP reductions in patients with hypertension related co-morbidity and can be recommended as part of a wider management plan in routine clinical practice. Some limited evidence suggests that patients with stroke and/or obesity should be targeted for self-monitoring interventions that are combined with systematic medication titration, pharmacist support, education or lifestyle to maximise the likelihood of blood pressure control at follow-up.

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Figure legends

Figure 1. Effect of self-monitoring on clinic blood pressure at 12-month follow-up by number of hypertension related co-morbidities (16 studies)

Blood pressure difference given in mm Hg. Analyses adjusted for age, sex, baseline blood pressure and level of intervention, with study level random effects for intervention and usual care. sBP=systolic blood pressure; dBP=diastolic blood pressure; CI=confidence intervals; OR=odds ratio. Uncontrolled blood pressure defined by thresholds specified in each contributing study (see eTable 2 for details).

Figure 2. Effect of self-monitoring on clinic systolic blood pressure at 12-month follow-up by intervention intensity within specific morbidities

*Two studies only provided one patient each to the model. Blood pressure difference given in mm Hg. Analyses adjusted for age, sex and baseline blood pressure with study level random effects for intervention and usual care. sBP=systolic blood pressure; CI=confidence intervals; CHD=coronary heart disease; CKD=chronic kidney disease

Figure 3. Effect of self-monitoring on likelihood of uncontrolled clinic blood pressure at 12-month follow-up by intervention intensity within specific morbidities

*Two studies only provided one patient each to the model. Analyses adjusted for age, sex and baseline blood pressure with study level random effects for intervention and usual care. OR=odds ratio; CI=confidence intervals; CHD=coronary heart disease; CKD=chronic kidney disease. Uncontrolled blood pressure defined by thresholds specified in each contributing study (see eTable 2 for details).

Tables

Table 1. Definitions of high and low level intensity co-interventions

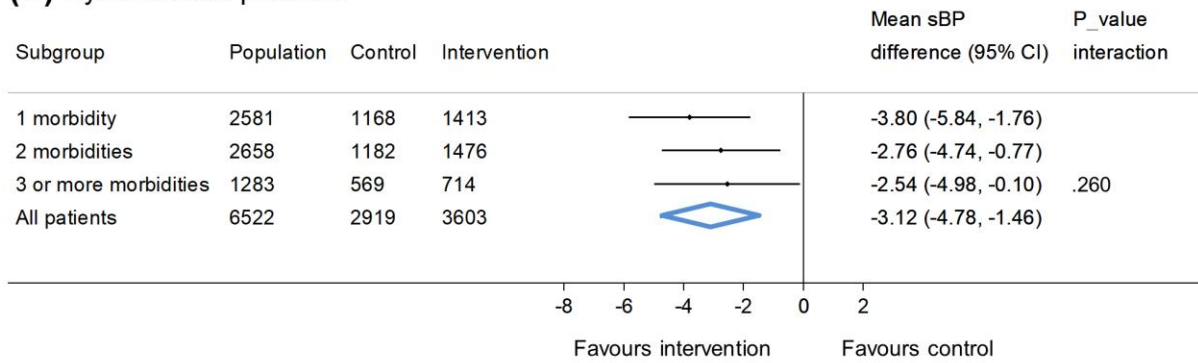
	Level	Name	Description
Low intensity intervention	Level 1	Self-monitoring with minimal additional contact	Self-monitoring with one off educational materials and initial instructions from a nurse.
	Level 2	Self-monitoring with automated feedback or support	Web based or telephonic tools provide feedback or support. But no regular 1:1 contact.
High intensity intervention	Level 3	Self-monitoring with an active intervention	Web based or telephonic tools provide feedback or support and education offered in regular classes. No regular 1:1 contact.
	Level 4	Self-monitoring with significant tailored support	Individually tailored support from study personnel, pharmacist or a clinician. Could include checking BP / medication or education/ lifestyle counselling.

This was based on previous work by Uhlig *et al.*,¹⁷ and Tucker *et al.*¹⁵

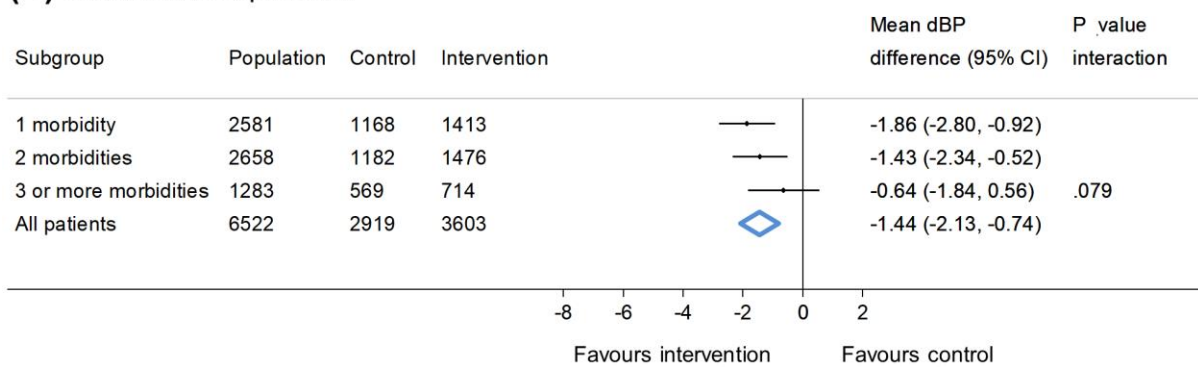
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Figure 1

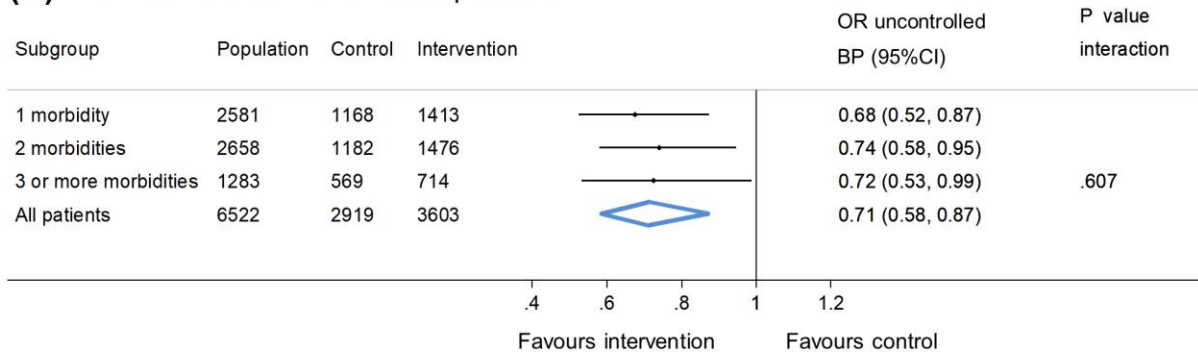
(A) Systolic blood pressure



(B) Diastolic blood pressure

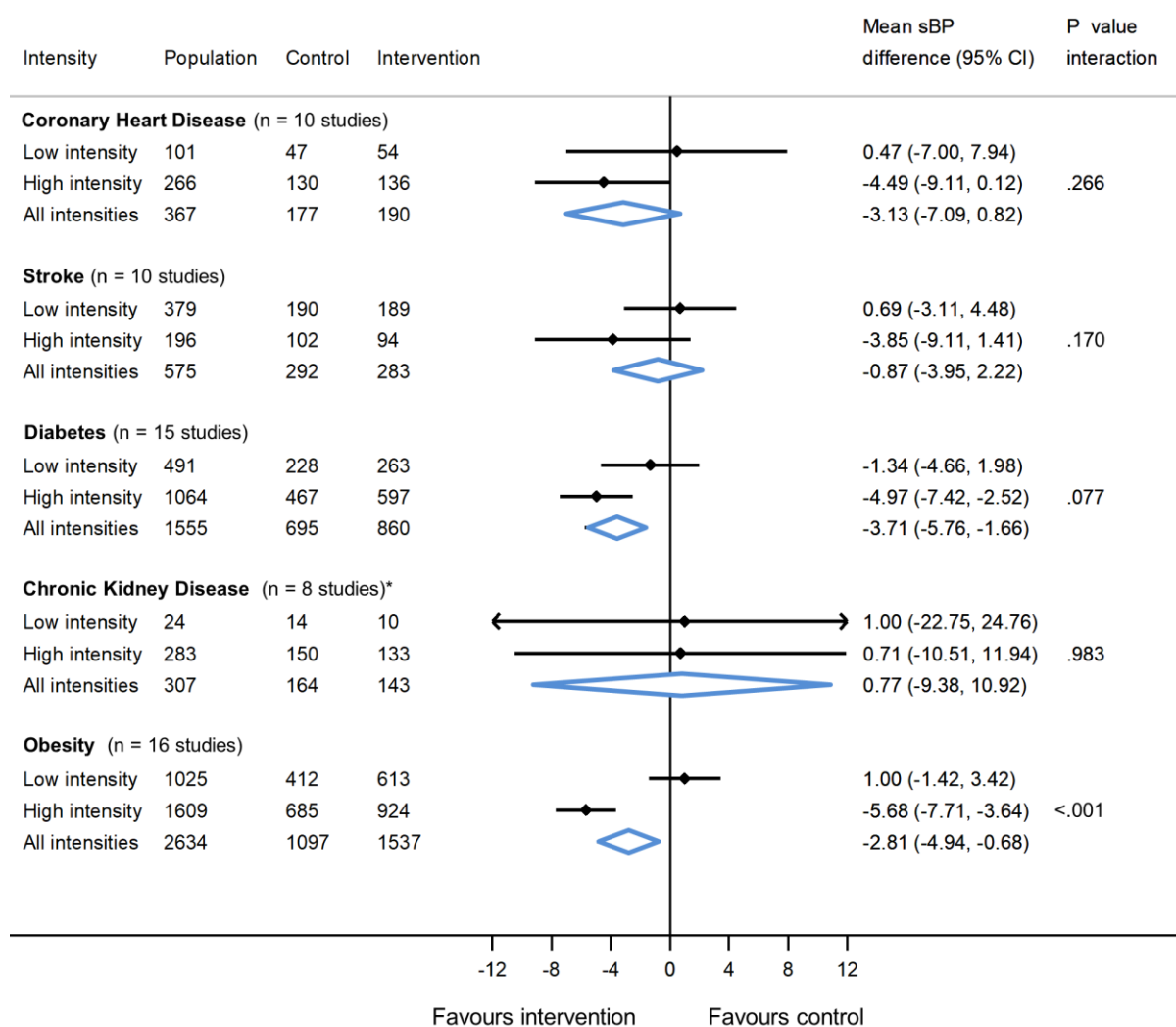


(C) Likelihood of uncontrolled blood pressure



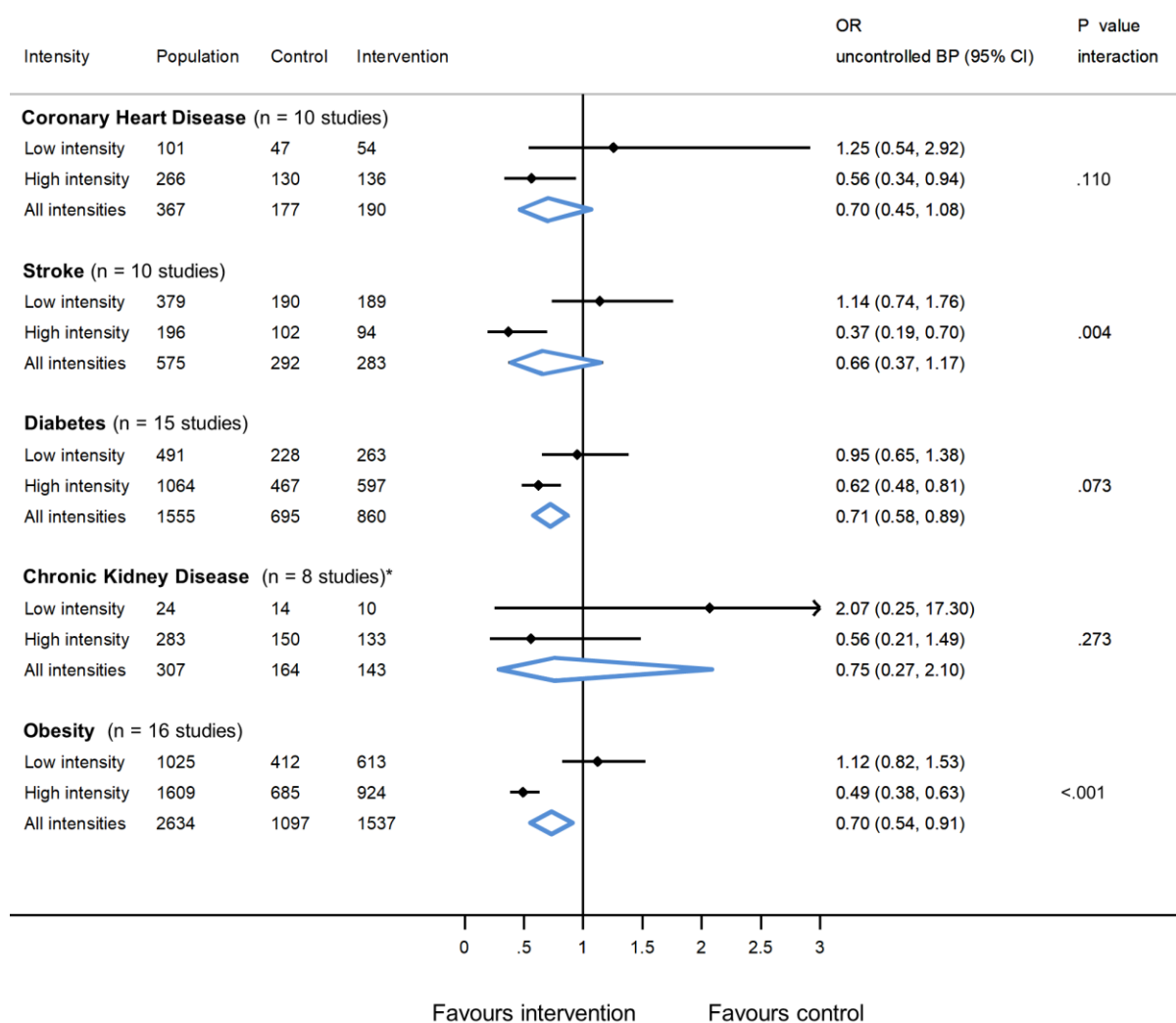
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Figure 2



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Figure 3



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