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ORIGINAL RESEARCH ARTICLE

The Cost of Uncontrolled Blood Pressure in Australian General Practice: A Modelling Study Using Electronic Health Records (MedicineInsight)

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Abstract

Background Hypertension is the most common condition seen in Australian general practice. Despite hypertension being amenable to lifestyle modifications and pharmacological treatment, only around half of these patients have controlled blood pressure levels (< 140/90 mmHg), placing them at an increased risk of cardiovascular disease.

Objective We aimed to estimate the health and acute hospitalisation costs of uncontrolled hypertension among patients attending general practice.

Methods We used population data and electronic health records from 634,000 patients aged 45–74 years who regularly attended an Australian general practice between 2016 and 2018 (MedicineInsight database). An existing worksheet-based costing model was adapted to calculate the potential cost savings for acute hospitalisation of primary cardiovascular disease events by reducing the risk of a cardiovascular event over the next 5 years through improved systolic blood pressure control. The model estimated the number of expected cardiovascular disease events and associated acute hospital costs under current levels of systolic blood pressure and compared this estimate with the expected number of cardiovascular disease events and costs under different levels of systolic blood pressure control.

Results The model estimated that across all Australians aged 45–74 years who visit their general practitioner ($n = 8.67$ million), 261,858 cardiovascular disease events can be expected over the next 5 years at current systolic blood pressure levels (mean 137.8 mmHg, standard deviation = 12.3 mmHg), with a cost of AUD$1813 million (in 2019–20). By reducing the systolic blood pressure of all patients with a systolic blood pressure greater than 139 mmHg to 139 mmHg, 25,845 cardiovascular disease events could be avoided with an associated reduction in acute hospital costs of AUD$179 million. If systolic blood pressure is lowered further to 129 mmHg for all those with systolic blood pressure greater than 129 mmHg, 56,169 cardiovascular disease events could be avoided with potential cost savings of AUD$389 million. Sensitivity analyses indicate that potential cost savings range from AUD$46 million to AUD$1406 million and AUD$117 million to AUD$2009 million for the two scenarios, respectively. Cost savings by practice range from AUD$16,479 for small practices to AUD$82,493 for large practices.

Conclusions The aggregate cost effects of poor blood pressure control in primary care are high, but cost implications at the individual practice level are modest. The potential cost savings improve the potential to design cost-effective interventions, but such interventions may be best targeted at a population level rather than at individual practices.

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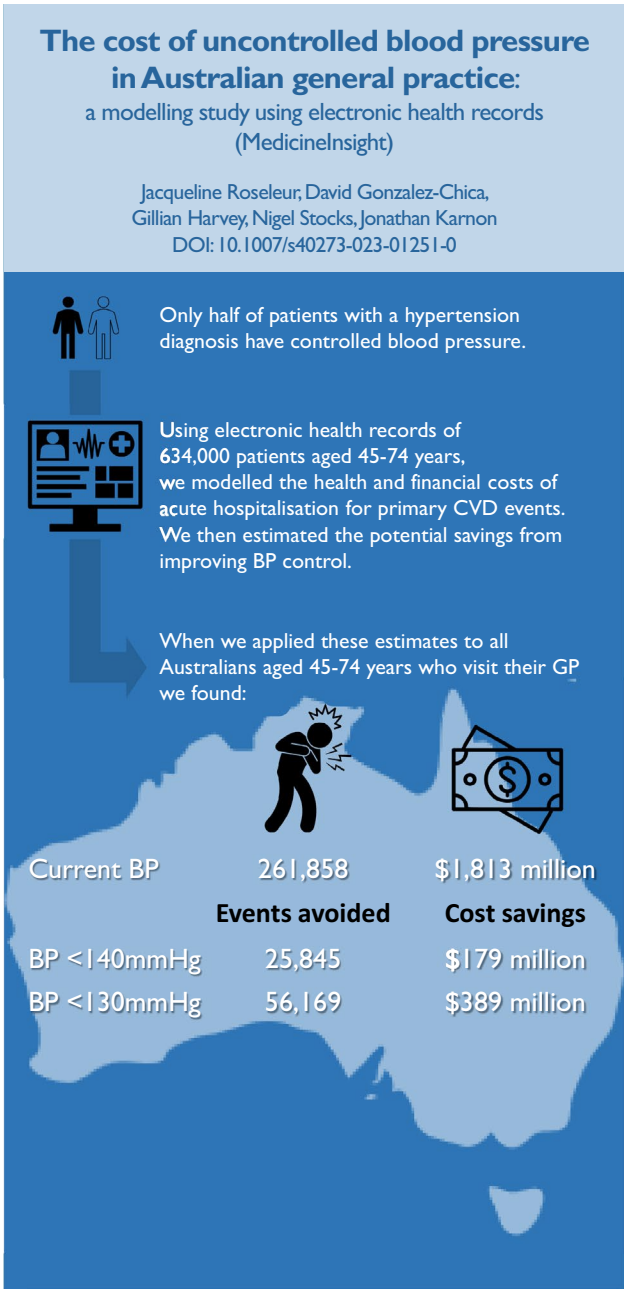
Graphical Abstract



Key Points for Decision Makers

Only half of patients with hypertension have their blood pressure controlled, increasing their risk of cardiovascular disease.

In this study, we estimated the health and financial costs of uncontrolled hypertension among Australians aged 45–74 years who visit their general practitioner.

By improving blood pressure control, 25,845 cardiovascular events, costing AUD$179 million in acute hospitalisation, can be avoided over the next 5 years.

1 Introduction

Globally, approximately one-third of adults aged 30–79 years have hypertension [1]. These adults are at an increased risk of cardiovascular disease (CVD), with hypertension responsible for over 10 million deaths in 2019 [2]. The global financial burden of suboptimal blood pressure (BP) control was estimated to be US$372 billion in 2010, representing about 10% of the world's overall healthcare expenditure [3].

In Australia, elevated BP accounted for 5.8% of the total burden of disease in 2015 [4], and CVD cost the health system AUD$11.8 billion in 2018–19 [5]. Furthermore, the loss in gross domestic product from hypertension over the working lifetime of the Australian population was estimated to be AUD$137.2 billion [6].

Hypertension is largely managed in primary care and is the most common condition seen by a general practitioner (GP) in Australia [7]. Despite hypertension being amenable to lifestyle modifications and pharmacological treatment, only around half of the patients attending general practice have controlled hypertension (BP < 140/90 mmHg) [8]. Poor BP control puts patients at an increased risk of CVD and all-cause and CVD mortality. A US cohort study found that patients who received antihypertensive treatment but remained uncontrolled were twice as likely to die from CVD than those without hypertension. In contrast, treated and controlled patients had similar risks to patients without hypertension [9].

Primary care workers, particularly GPs, have a vital role in supporting patients to achieve recommended BP targets [10]. There has been a recognition that hypertension management according to CVD risk is more effective and cost effective than relying exclusively on BP levels [11, 12]. Therefore, Australian guidelines recommend that GPs conduct a CVD risk assessment for patients aged 45–74 years without a history of CVD. Subsequently, management decisions to treat hypertension should be guided by a patient's risk of a primary CVD event over the next 5 years [13, 14].

A range of possible interventions could improve BP management in primary care. However, with constraints on healthcare budgets, decision makers need information on the potential impact interventions may have on patients and the health system. These include the health costs experienced by patients owing to the morbidity and mortality from CVD events and the associated financial costs borne by the health system. Therefore, this study aimed to estimate the financial and health costs of uncontrolled hypertension for patients attending general practice.

2 Methods

This study used population data and data from MedicineInsight [15], a large and comprehensive Australian general practice electronic health record (EHR) database, to populate a model and calculate the potential cost savings for acute hospitalisation from improved BP control in patients diagnosed with hypertension.

2.1 Model Structure

We adapted an existing model [16] to calculate the potential cost savings for acute hospitalisation by reducing the risk of a cardiovascular event over the next 5 years through improved systolic BP (SBP) control. The model estimated the number of expected CVD events and associated costs under current levels of BP control. Next, the model estimated the number of expected CVD events and associated costs under different levels of BP control. Comparing these estimates, the model estimated the potential reduction in CVD events and associated costs from improving BP control. The structure of the model is shown in Fig. 1.

We modelled two scenarios in all patients diagnosed with hypertension attending general practice. We assumed all patients above a specified BP target achieved the target BP level as follows: (1) for patients with an SBP ≥ 140 mmHg, we recalculated their CVD risk assuming an SBP of 139 mmHg, and (2) for patients with an SBP ≥ 130 mmHg, we recalculated their CVD risk assuming an SBP of 129 mmHg:

1. Potential risk reduction (SBP = 139 mmHg) = $\text{CVDRisk}_{\text{Uncontrolled}} - \text{CVDRisk}_{\text{Controlled(139 mmHg)}}$
2. Potential risk reduction (SBP = 129 mmHg) = $\text{CVDRisk}_{\text{Uncontrolled}} - \text{CVDRisk}_{\text{Controlled(129 mmHg)}}$

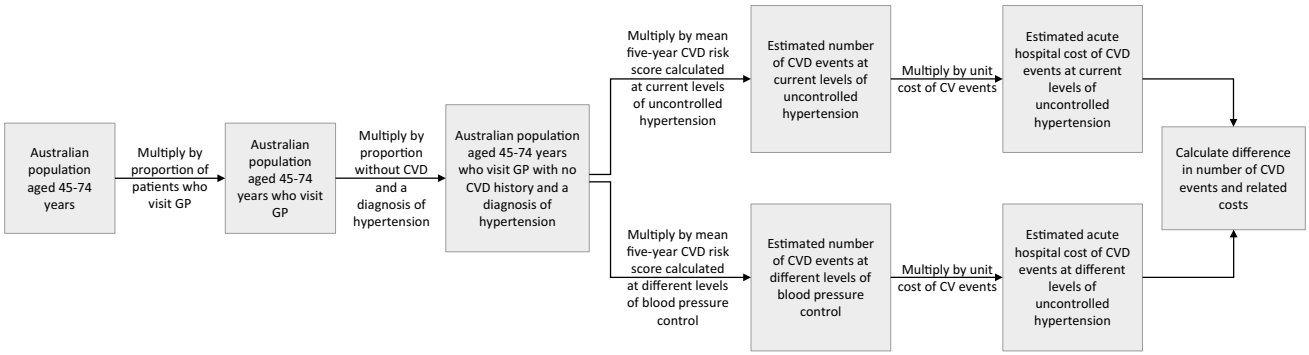


Fig. 1 Model structure. *CV* cardiovascular, *CVD* cardiovascular disease, *GP* general practitioner

In addition, we estimated the costs of uncontrolled BP at the practice level by practice size (i.e. the number of regular patients attending the practice). Practices were divided into quartiles based on practice size.

2.2 Model Population

As the Australian National Vascular Disease Prevention Alliance risk assessment algorithm assesses a patient's risk of developing CVD [14], this study focused on Australian individuals aged between 45 and 74 years without a history of CVD. In addition, we only included those patients who visit their GP in the model. This criterion was used to represent a population who already have contact with their primary care providers, thereby providing opportunities for GPs and primary care nurses to engage patients in lifestyle and pharmacological interventions to reduce BP and CVD risk.

2.3 Model Inputs

Population statistics and estimates using individual patient data from MedicineInsight were used to derive model inputs. Separate sex and age (in 5-year age groups) cohorts of the Australian population aged 45–74 years were constructed based on the 2021 Australian population data [17]. Data on the proportion of patients who visit their GP by age and sex were drawn from the Patient Experiences in Australia survey [18]. We used the results of the 2018–19 survey as data from 2019–20 and 2020–21 reflect changes in attendance because of the coronavirus disease 2019 pandemic.

As of October 2018, MedicineInsight included de-identified data from patients attending over 2700 GPs and 660 general practices across all states and territories (8.2% of all Australian practices) [15]. Patients in the database are comparable to but not representative of the general population as measured by sociodemographic variables and clinical conditions [15]. Details of the data collection process are published elsewhere [15]. In summary, data from patients' EHRs are collected monthly and include diagnoses, reasons for encounters, prescriptions, immunisations, clinical measurements (e.g. BP, pulse, weight), laboratory test orders and results, and patient sociodemographic information. Patients within each practice receive a unique identification number that allows the patient to be followed over time. We identified 634,000 patients aged 45–74 years who attended an Australian general practice at least three times in any 2 consecutive years between 2016 and 2018 [19] and almost 70% of patients had data available since 2011. Extraction algorithms for identifying chronic condition diagnoses have been validated [20].

2.3.1 Prevalence of Existing CVD and Hypertension

Using MedicineInsight, we estimated the proportion of patients without a history of CVD by identifying patients without CVD recorded in their EHR (i.e. ischaemic heart disease, heart failure, stroke, peripheral artery disease or aortic disease). All available data in the patient's EHR were reviewed to identify those without a history of CVD.

We then identified patients with a diagnosis of hypertension. The methods used to identify patients diagnosed with hypertension are described in detail elsewhere [8, 21]. Briefly, patients were considered to have hypertension if (1) the condition was recorded as a diagnosis, reason for encounter or reason for prescription or (2) if the patient received a prescription for antihypertensive therapy preceded by an elevated BP (i.e. BP higher than 140/90 mmHg). By including an elevated BP, we aimed to reduce the misclassification of patients taking antihypertensive therapy for conditions other than hypertension (e.g. heart failure, myocardial infarction) [22]. Antihypertensive medications included angiotensin-converting enzyme inhibitors and angiotensin II receptor blockers (Anatomical Therapeutic Chemical [ATC] C09), beta-blockers (ATC C07), calcium channel blockers (ATC C08), diuretics (ATC C03) and alpha-blockers (ATC C02).

2.3.2 CVD Risk

First, we determined whether patients had recorded information available on the different risk factors required to calculate their CVD risk. For SBP, we only considered values recorded between 2017 and 2018 and calculated the mean of the measures in this period. For patients with only one SBP recorded, this value was used (7.0% of sample). The mean number of SBP values recorded was 6.1 (standard deviation [SD] 5.0) and the median was 5 with an interquartile range of 3–8. As cholesterol tests are performed less frequently than BP readings, we included the most recent reported result for total and high-density lipoprotein cholesterol between 2015 and 2018. Where smoking status was not recorded, patients were assumed to be non-smokers (3.7% of the sample) [21]. As left ventricular hypertrophy is challenging to identify in the EHR, we assumed left ventricular hypertrophy was absent for all patients. Patients were considered to have diabetes melltius when the patient record had "diabetes" as a diagnosis, encounter reason or prescription reason, or were prescribed antidiabetic medications (ATC A10; except for those with a diagnosis of polycystic ovarian syndrome).

Thereafter, for those patients with diagnosed hypertension and with enough information available in their EHR to calculate CVD risk, we calculated the risk of a primary CVD event over the next 5 years by applying the Australian National Vascular Disease Prevention Alliance risk assessment and risk management algorithm (Table 1) [13, 14]. Next, we recalculated the risk of a primary CVD event over the next 5 years under the two scenarios described above: (1) for patients with an SBP $\geq$ 140 mmHg, we recalculated their CVD risk assuming an SBP of 139 mmHg and (2) for patients with an SBP $\geq$ 130 mmHg, we recalculated their CVD risk assuming an SBP of 129 mmHg. We assumed a relative risk reduction of 0.80 (95% confidence interval [CI] 0.77–0.83) in CVD events for every 10 mmHg reduction in SBP based on a meta-analysis of 613,815 patients enrolled in randomised controlled trials [23].The calculated CVD risk was then allocated to the following conditions to reflect the conditions included in the Framingham risk score: unstable angina (UA), myocardial infarction (MI), stroke, transient ischaemic attack (TIA), heart failure (HF), peripheral artery disease (PAD) and coronary heart disease (CHD) death [24]. After that, using data from the National Hospital Morbidity Database [25] and CHD deaths reported by the Australian Institute of Health and Welfare [26], we calculated the proportions of UA, MI, stroke, TIA, HF, PAD and CHD deaths out of all CVD hospitalisation episodes and CHD deaths in a year using the following formula, as illustrated for UA as a proportion of all events – P(UA) [27]:

$$P(\text{UA}) = \frac{\text{No. UA}}{\text{No.(UA + MI + stroke + TIA + HF + PAD + CHD death)}}.$$

The International Statistical Classification of Diseases and Related Health Problems, Tenth Revision codes used for each condition are presented in Table 2.

2.3.3 Costs

The costs associated with a CVD event include hospital costs for each condition specified above. These were estimated using the Australian Refined Diagnostic Related Group and 2018–19 Independent Hospital Pricing Authority data (Table 2) [28]. We calculated a weighted average cost for each condition using the number of separations for each complexity level to account for different complexity levels. In the base case, we assumed CHD death did not incur costs. Costs were adjusted to reflect 2019–20 costs using the consumer price index for health (Table 1) [29].

2.4 Statistical Methods

Analyses of MedicineInsight data to describe the patient population (prevalence of CVD, prevalence of hypertension and proportion with enough information for a CVD risk calculation) were performed in STATA 16.1 (StataCorp, College Station, TX, USA) using practices as clusters and conditioned on the number of consultations to minimise selection bias (i.e. the likelihood of receiving medical treatments or a diagnosis increases with the number of visits to the practice) [33]. Excel was used for the costing model.

The Human Research Ethics Committee of the University of Adelaide exempted this study from ethical review as it used existing and non-identifiable data. Access to the data for this study was approved by the MedicineInsight Data Governance Committee (project 2016-007).

2.5 Sensitivity Analysis

We undertook univariate and multivariate sensitivity analyses. In the univariate sensitivity analyses, rather than using the mean of all BPs recorded between 2017 and 2018, we used the lowest BP and the highest BP recorded between 2017 and 2018. We also applied the upper and lower CIs for the relative risk reduction. The proportion of patients without a history of CVD may have been overestimated and the proportion of patients with a diagnosis of hypertension may have been underestimated if these conditions were not recorded in the EHR. We therefore also undertook a sensitivity analysis where we decreased the proportion of patients without a history of CVD based on data published by the Australian Institute of Health and Welfare [26] (i.e. a decrease of 4%, 5% and 6% in age groups 45–54 years, 55–64 years and 65–74 years, respectively). In the base case, we assumed that patients with an uncertain hypertension status did not have a diagnosis of hypertension, whereas in

Table 1 Model inputs

Variable	Description, age (years)		Values	Source
Population	45–49		Male: 813,286; female: 831,373	ABS [17]
	50–54		Male: 782,401; female: 822,505	
	55–59		Male: 752,387; female: 786,368	
	60–64		Male: 708,837; female: 750,995	
	65–69		Male: 617,423; female: 660,622	
	70–74		Male: 554,506; female: 583,878	
Proportion of patients who visited their GP at least once in a year	45–49		Male: 77.6%; female: 87.1%	ABS [18]
	50–54		Male: 77.6%; female: 87.1%	
	55–59		Male: 86.7%; female: 90.1%	
	60–64		Male: 86.7%; female: 90.1%	
	65–69		Male: 92.7%; female: 94.2%	
	70–74		Male: 92.7%; female: 94.2%	
Proportion of patients without a history of CVD	45–49		Male: 96.1%; female: 98.3% Sensitivity analysis: male: 92.2%; female: 94.3%	MedicineInsight [26]
	50–54		Male: 93.3%; female: 97.5% Sensitivity analysis: male: 89.5%; female: 93.6%	
	55–59		Male: 89.9%; female: 95.7% Sensitivity analysis: male: 85.4%; female: 90.9%	
	60–64		Male: 85.1%; female: 93.7% Sensitivity analysis: male: 80.8%; female: 89.1%	
	65–69		Male: 79.7%; female: 90.8% Sensitivity analysis: male: 74.9%; female: 85.3%	
	70–74		Male: 74.0%; female: 86.1% Sensitivity analysis: male: 69.6%; female: 80.9%	
Proportion of patients with a diagnosis of hypertension in those without a history of CVD	45–49		Male: 29.4%; female: 17.7% Sensitivity analysis: male: 31.8%; female: 19.9%	MedicineInsight
	50–54		Male: 38.5%; female: 25.5% Sensitivity analysis: male: 41.0%; female: 28.1%	
	55–59		Male: 48.0%; female: 34.1% Sensitivity analysis: male: 50.6%; female: 36.9%	
	60–64		Male: 57.4%; female: 43.7% Sensitivity analysis: male: 60.0%; female: 47.0%	
	65–69		Male: 64.0%; female: 52.6% Sensitivity analysis: male: 66.6%; female: 56.5%	
	70–74		Male: 69.1%; female: 62.4% Sensitivity analysis: male: 71.7%; female: 66.4%	
Relative risk per 10-mmHg SBP reduction			0.80 (0.77–0.83)	[30]
Mean 5-year CVD risk	45–49	Male	Current SBP: 5.6%; SBP = 139 mmHg: 5.0%; SBP = 129 mmHg: 4.4%	MedicineInsight
		Female	Current SBP: 3.4%; SBP = 139 mmHg: 3.1%; SBP = 129mmHg: 2.7%	
	50–54	Male	Current SBP: 7.4%; SBP = 139 mmHg: 6.6%; SBP = 129 mmHg: 5.7%	
		Female	Current SBP: 4.3%; SBP = 139 mmHg: 3.9%; SBP = 129 mmHg: 3.5%	
	55–59	Male	Current SBP: 9.4%; SBP = 139 mmHg: 8.4%; SBP = 129 mmHg: 7.3%	
		Female	Current SBP: 5.4%; SBP = 139 mmHg: 5.0%; SBP = 129 mmHg: 4.4%	
	60–64	Male	Current SBP: 11.6%; SBP = 139 mmHg: 10.4%; SBP = 129 mmHg: 9.0%	
		Female	Current SBP: 6.7%; SBP = 139 mmHg: 6.0%; SBP = 129 mmHg: 5.3%	
	65–69	Male	Current SBP: 13.7%; SBP = 139 mmHg: 12.4%; SBP = 129 mmHg: 10.7%	
		Female	Current SBP: 7.9%; SBP = 139 mmHg: 7.1%; SBP = 129 mmHg: 6.2%	

Table 1 (continued)

Variable	Description, age (years)		Values	Source
	70–74	Male	Current SBP: 15.7%; SBP = 139 mmHg: 14.2%; SBP = 129 mmHg: 12.4%	
		Female	Current SBP: 9.1%; SBP = 139 mmHg: 8.1%; SBP = 129 mmHg: 7.0%	
CVD events allocation	45–49	Male	UA: 8.3%; MI: 40.4%; stroke: 22.7%; TIA: 5.0%; HF: 11.2%; PAD: 8.3%; CHD death: 4.1%	AIHW [25, 26]
		Female	UA: 7.6%; MI: 23.6%; stroke: 37.2%; TIA: 7.5%; HF: 11.8%; PAD: 10.7%; CHD death: 1.6%	
	50–54	Male	UA: 9.8%; MI: 38.2%; stroke: 22.9%; TIA: 4.5%; HF: 10.2%; PAD: 10.4%; CHD death: 4.1%	
		Female	UA: 9.4%; MI: 25.6%; stroke: 32.8%; TIA: 9.1%; HF: 11.2%; PAD: 10.0%; CHD death: 1.8%	
	55–59	Male	UA: 9.5%; MI: 35.6%; stroke: 22.3%; TIA: 5.3%; HF: 10.2%; PAD: 12.3%; CHD death: 4.9%	
		Female	UA: 9.4%; MI: 27.3%; stroke: 29.2%; TIA: 9.3%; HF: 11.7%; PAD: 10.3%; CHD death: 2.7%	
	60–64	Male	UA: 8.8%; MI: 31.7%; stroke: 23.6%; TIA: 5.4%; HF: 11.8%; PAD: 14.3%; CHD death: 4.4%	
		Female	UA: 9.0%; MI: 25.7%; stroke: 25.5%; TIA: 9.6%; HF: 15.6%; PAD: 12.1%; CHD death: 2.5%	
	65–69	Male	UA: 8.6%; MI: 26.9%; stroke: 24.1%; TIA: 5.3%; HF: 14.2%; PAD: 15.6%; CHD death: 5.3%	
		Female	UA: 8.4%; MI: 22.0%; stroke: 27.8%; TIA: 9.2%; HF: 17.5%; PAD: 12.0%; CHD death: 3.1%	
	70–74	Male	UA: 7.3%; MI: 22.3%; stroke: 25.1%; TIA: 5.7%; HF: 18.5%; PAD: 16.7%; CHD death: 4.4%	
		Female	UA: 6.9%; MI: 19.5%; stroke: 28.3%; TIA: 8.0%; HF: 22.5%; PAD: 12.2%; CHD death: 2.7%	
Hospitalisation cost per event	Base case		UA: AUD$2964; MI: AUD$9762; stroke: AUD$10,118; TIA: AUD$3408; HF: AUD$3244; PAD: AUD$5317; CHD death: AUD$0	IHPA [28]
	Sensitivity analysis		UA: AUD$9155; MI: AUD$16,410; stroke: AUD$12,754; TIA: AUD$4992; HF: AUD$15,520; PAD: AUD$13,827; CHD death: AUD$16,410	[31–33]

ABS Australian Bureau of Statistics, *AIHW* Australian Institute of Health and Welfare, *CHD* coronary heart disease, *CVD* cardiovascular disease, *HF* heart failure, *IHPA* Independent Hospital Pricing Authority, *MI* myocardial infarction, *PAD* peripheral artery disease, *SBP* systolic blood pressure, *TIA* transient ischaemic attack, *UA* unstable angina

the sensitivity analysis, these patients were assumed to have a diagnosis of hypertension (see Table 1). In the multivariate sensitivity analyses, we combined the two univariate sensitivity analyses for the BP and a relative risk reduction to generate best-case and worst-case scenarios.

Furthermore, we searched the literature for Australian cost estimates for each condition to determine the possible range of potential cost savings. Then, we reran the model using these cost estimates. To account for the underestimated costs related to CHD death in the base case, we also assumed that CHD deaths attracted the same cost as a myocardial infarction (Table 1).

3 Results

3.1 MedicineInsight Sample

The original sample included 634,000 patients aged 45–74 years [mean age 59.3 years (SD 8.6), 55.7% female]. Of these, 94.4% (95% CI 94.2–94.6) of women and 87.1% (95% CI 86.7–87.4) of men did not have a history of CVD recorded. Confidence intervals are narrow because of the large sample size. The proportion of patients considered to have a diagnosis of hypertension amongst those without a history of CVD was 35.6% (95% CI 34.8–36.3) for women and 47.4% (95% CI 46.6–48.2) for men. The sample of patients with hypertension without a history of CVD consisted of 251,733 individuals (mean SBP 138.0 mmHg,

SD = 12.5 mmHg; 44.3% with an SBP above 139 mmHg in male patients, 40.0% in female patients; 76.2% with an SBP above 129 mmHg in male patients, 71.1% in female patients). Of these, 48.3% (95% CI 45.5–51.2) of women and 49.5% (95% CI 46.6–52.3) of men had enough data to calculate their CVD risk (mean SBP 137.8 mmHg, SD = 12.3 mmHg; 45.7% with an SBP above 139 mmHg in male patients, 41.0% in female patients; 79.6% with an SBP above 129 mmHg in male patients, 73.8% in female patients). Figure 2 shows the number of patients used to estimate each variable.

3.2 CVD Events and Costs

The results for the expected number of CVD events and related costs over a 5-year period across Australians aged 45–74 years who visit their GP (N = 8.7 million people) using the baseline (current) SBP levels and the two SBP control scenarios are presented in Table 3. At current SBP levels, 261,858 CVD events are expected to occur over a 5-year period (i.e. incidence of CVD among Australians aged 45–74 years visiting a GP of 3.0%), with a cost of AUD$1813 million for acute hospitalisation. Under a scenario where SBP is lowered to 139 mmHg for all patients with an SBP above 139 mmHg, 25,845 CVD events could be avoided (i.e. incidence of CVD of 2.7%), with an associated reduction in costs of AUD$179 million. If SBP is lowered further to 129 mmHg for all patients with an SBP above 129 mmHg, 56,169 CVD events could be avoided (i.e. incidence of CVD of 2.4%), with potential cost savings of AUD$389 million.

In the sensitivity analyses, applying the lowest and highest recorded baseline BP levels decreased and increased the expected costs by 20.4% (to AUD$1.443 million) and 23.4% (to AUD$2.238 million), respectively. Applying the upper and lower 95% CIs around the mean relative risk decreased and increased the expected costs savings in the scenario where SBP is lowered to 139 mmHg for patients with an SBP above 139 mmHg by 13.8% (to AUD$154 million) and 13.4% (to AUD$203 million), respectively. Combining the two univariate sensitivity analyses to generate best-case and worst-case scenarios resulted in cost savings of $46 million and $713 million, respectively.

In the scenario where SBP is lowered to 129 mmHg for patients with an SBP above 129 mmHg, applying the upper and lower 95% CIs around the mean relative risk decreased and increased the expected cost savings by 13.4% (to AUD$337 million) and 12.8% (to AUD$439 million), respectively. Combining the two univariate sensitivity analyses to generate best-case and worst-case scenarios resulted in cost savings of AUD$117 million and AUD$1.020 million, respectively.

In the sensitivity analysis of the alternative costs estimates, the potential cost savings could increase to AUD$353 million and AUD$767 million for the two base-case scenarios, respectively. Combining the alternative costs and the best-case scenario resulted in cost savings of AUD$1.406 million and AUD$2.009 million for the 139-mmHg and 129-mmHg SBP control scenarios, respectively. The results from additional sensitivity analyses are presented in Table 4.

Results by age and sex for the principal analyses are presented in Table 5. The potential reduction in CVD events increases with age as the proportion of patients with SBP above target levels also increases. As the proportion of men aged 70–74 years with SBP above the target is slightly lower than those aged 65–69 years (45.6% vs 46.2%), the expected reduction in CVD events and costs is also lower.

Table 6 presents the potential reduction in CVD events and costs by practice size. Under a scenario where SBP is lowered to 139 mmHg for all patients with an SBP above 139 mmHg, small practices with an average of 705 (interquartile range: 539–881) patients could avoid two CVD events over a 5-year period with a cost reduction of AUD$16,479 whereas a large practice with an average of 2921 (interquartile range: 2589–3735) patients could avoid 12 CVD events with a cost saving of AUD$82,493. These cost savings increase to AUD$32,492 and AUD$162,657, respectively, in the sensitivity analysis using the alternative costs.

4 Discussion

This study estimated that failure to achieve BP targets of 139 mmHg results in 25,845 unnecessary CVD events over a 5-year period and excess costs of AUD$179 million across those patients aged 45–74 years attending general practice. Almost two-thirds of the excess costs occurred in male patients. Compared with female patients, the prevalence of hypertension was higher in male patients, and male patients had a higher mean 5-year CVD risk. Furthermore, approximately 50% of the excess costs occurred in those aged between 65 and 74 years, as a greater proportion of older patients have a hypertension diagnosis than younger patients. These findings suggest that these patient groups may be appropriate targets for interventions to improve BP control.

The estimated cost savings almost doubled to AUD$353 million over 5 years when using the alternative cost data in the sensitivity analysis. Even under the alternative scenario, these estimates underestimate the financial burden of CVD as they only include the costs incurred during the hospitalisation of the primary event. Approximately 15%

Table 2 ICD-10 codes and AR-DRG codes used to calculate the event allocation and costs for each condition

Condition	ICD-10 codes	AR-DRG codes
Unstable angina	I20.0—unstable angina	F72A—unstable angina, major complexity
		F72B—unstable angina, minor complexity
Myocardial infarction	I21—acute myocardial infarction	F10A—interventional coronary procedures, admitted for AMI, major complexity
		F10B—interventional coronary procedures, admitted for AMI, minor complexity
		F41A—circulatory disorders, adm for AMI W invasive cardiac inves int, major comp
		F41B—circulatory disorders, adm for AMI W invasive cardiac inves int, minor comp
		F60A—circulatory dsrd, adm for AMI W/O invas card inves intervention
		F60B—circulatory dsrd, adm for AMI W/O invas card inves intervention, transferred < 5 days
Stroke	I60—subarachnoid haemorrhage	B70A—stroke and other cerebrovascular disorders, major complexity
	I61—intracerebral haemorrhage	
	I62—other nontraumatic intracranial haemorrhage	B70B—stroke and other cerebrovascular disorders, intermediate complexity
	I63—cerebral infarction	B70C—stroke and other cerebrovascular disorders, minor complexity
	I64—stroke, not specified as haemorrhage or infarction	B70D—stroke and other cerebrovascular disorders, transferred < 5 days
Transient ischaemic attack	G45—transient cerebral ischaemic attacks and related syndromes	B69A—TIA and precerebral occlusion, major complexity
		B69B—TIA and precerebral occlusion, minor complexity
Heart failure	I50—heart failure	F62A—heart failure and shock, major complexity
		F62B—Heart Failure and Shock, Minor Complexity
		F62C—heart failure and shock, transferred <5 days
Peripheral artery disease	I70—atherosclerosis	F65A—peripheral vascular disorders, major complexity
	I71—aortic aneurysm and dissection	F65B—peripheral vascular disorders, minor complexity
	I72—other aneurysm and dissection	
	I74—arterial embolism and thrombosis	

Adm admitted, *AMI* acute myocardial infarction, *Card* cardiac, *Dsrd* disorder, *ICD-10* International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, *Int* intervention, *Invas* invasive, *Inves* investigative, *W* with, *W/O* without

of acute myocardial infarction survivors will experience a second myocardial infarction within 7 years [34], and 12% of patients will develop heart failure within 1 year [35]. Post-care and rehabilitation costs also contribute substantially to the financial burden of CVD. In addition to these health system costs, patients, their families, and carers incur substantial costs related to productivity losses, out-of-pocket expenses and informal care costs [6, 36]. However, those patients who avoid a CVD death will incur additional health costs. Using the annual average per person cost of AUD$109 reported by the Australian Institute for Health and Welfare [37], the patients who avoid a CVD death will incur hospital costs of AUD$557,006 over 5 years; equal to 0.3% of the potential costs savings from controlling SBP to 139 mmHg.

Comparisons with other data sources such as national data reported by the Australian Institute for Health and Welfare and Global Burden of Disease studies are difficult as these sources include costs related to all CVD events, including secondary CVD. Furthermore, not all patients with CVD have a hypertension diagnosis. Our study was specifically aimed at estimating the costs incurred by patients with a diagnosis of hypertension, attending general practice and with no history of CVD. However, we have attempted to compare our findings and present these comparisons in the Electronic Supplementary Material. Our findings are more consistent with Australian Institute for Health and Welfare estimates than with Global Burden of Disease estimates as our methods aligned more closely with those used by the Australian Institute for Health and Welfare.

Given the potential to improve care and reduce the health system costs associated with uncontrolled BP, a range of actions, such as pay-for-performance (P4P), practice facilitation and multi-faceted interventions, may be feasible and effective at a practice level. Pay-for-performance schemes are widespread in healthcare. However, the evidence on the effectiveness of these schemes remains inconclusive

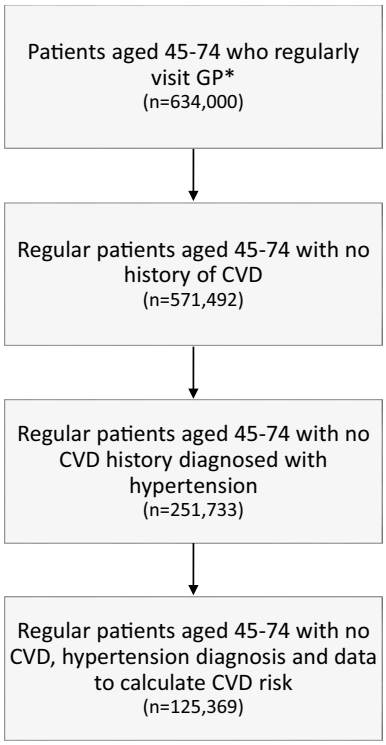


Fig. 2 Flow diagram of patients used to estimate model parameters. *Regular attendance defined as at least three visits in any 2 consecutive years between 2016 and 2018. *CVD* cardiovascular disease, *GP* general practitioner

[38–40]. The evidence suggests that pay-for-performance schemes with the following design features are more effective: (1) measuring process indicators that are easy to track; (2) targeting incentives at individual clinicians or small groups; (3) payments conditional on providers' absolute performance rather than relative to other providers' performance; (4) designing the programme collaboratively with providers; and (5) incentives that are sufficiently large [38, 39]. In addition, when implementing pay-for-performance schemes, it is essential to consider whether pay-for-performance will reduce or exacerbate inequalities and have unintended consequences such as risk selection, spill-over effects, negative impacts on intrinsic motivation and gaming [38, 41, 42]. Australia implemented an opt-in programme (Practice Incentives Program) to encourage quality improvement in general practice through the Quality Improvement Incentive in August 2019 [43]. The program consists of ten measures, one of which reports on the proportion of patients aged 45–74 years without a CVD diagnosis with risk factors recorded to enable a CVD risk assessment. The first annual report monitoring the programme found that between October 2020 and July 2021, the proportion of patients with necessary risk factors recorded increased from 44.9 to 48.5% [44]. Identifying patients at an increased CVD risk allows for risk stratification, leading to greater efficiency by targeting those individuals at the highest risk [45]. A systematic review of evaluations of the Quality and Outcomes Framework implemented in the UK found that performance increased in the first year following the implementation of the Quality and Outcomes Framework but returned to pre-intervention rates in subsequent years [46]. Future monitoring is required to determine whether increases found in the first year will be sustained in Australia.

A systematic review of facilitation interventions found that primary care practices are almost three times more likely to adopt evidence-based guidelines through practice facilitation [47]. Facilitation entails visits by someone external to the practice to help implement changes, for example, using techniques such as audit and feedback, goal setting and consensus building [47]. Interventions with greater effects had fewer practices per facilitator, higher intensity interventions and interventions tailored to the practice context [47]. A more recent review found that implementing practice facilitation increased BP control by an average of 9.0% [48].

Facilitation is often a critical component of multi-faceted interventions [49]. This is because the successful translation of research evidence into health systems depends on the evidence's veracity, the context or environment in which the research is to be implemented, and how the research is implemented [50]. Therefore, the implementation of interventions must address multiple factors simultaneously to be successful [51]. For example, in the case of improving BP control, change needs to occur at both the clinician level (e.g. initiating or intensifying antihypertensive therapy,

Table 3 Potential reduction in the number of CVD events and costs under two blood pressure control scenarios over a 5-year period in patients with a diagnosis of hypertension

Scenario	Expected CVD events	Expected reduction in CVD events	Expected CVD costs Base case AUD million	Expected reduction in CVD costs Base case AUD million
Current SBP	261,858	–	AUD$1813	–
SBP control to 139 mmHg	236,013	25,845	AUD$1634	AUD$179
SBP control to 129 mmHg	205,689	56,169	AUD$1424	AUD$389

CVD cardiovascular disease, *SBP* blood pressure

Table 4 Sensitivity analyses of results under two blood pressure control scenarios over a 5-year period in patients with a diagnosis of hypertension

	Expected reduction in CVD costs AUD$ million	
	SBP control to 139 mmHg	SBP control to 129 mmHg
Base case using mean SBP	$179	$389
Univariate sensitivity analyses		
Lower proportion of patients without CVD	$169	$368
Higher proportion of patients with hypertension diagnosis	$189	$411
Applying the lower 95% CI relative risk	$203	$439
Applying the upper 95% CI relative risk	$154	$337
Using the lowest recorded SBP	$53	$135
Using the highest recorded SBP	$639	$920
Alternative costs	$353	$767
Multivariate sensitivity analysis		
Lowest SBP + applying the upper 95% CI relative risk	$46	$117
Highest SBP + applying the lower 95% CI relative risk	$713	$1020
Highest SBP + applying the lower 95% CI relative risk + alternative costs	$1406	$2009

CI confidence interval, *CVD* cardiovascular disease, *SBP* systolic blood pressure

Table 5 Potential reduction in the number of CVD events and costs under two blood pressure control scenarios over a 5-year period by age and sex in patients with a diagnosis of hypertension

Age (years)	Expected CVD events at baseline	Expected reduction in CVD events		Expected CVD costs at baseline AUD$ million	Expected reduction in CVD costs AUD$ million	
		SBP control to 139 mmHg	SBP control to 129 mmHg		SBP control to 139 mmHg	SBP control to 129 mmHg
Male patients						
45–49	9918	952	2126	$74	$7	$16
50–54	16,021	1626	3527	$118	$12	$26
55–59	26,388	2721	5864	$189	$19	$42
60–64	34,843	3558	7730	$246	$25	$54
65–69	40,121	4038	8749	$272	$27	$59
70–74	41,380	3961	8813	$274	$26	$58
Female patients						
45–49	4233	353	777	$32	$3	$6
50–54	7680	660	1466	$56	$5	$11
55–59	12,578	1094	2419	$90	$8	$17
60–64	18,466	1754	3777	$126	$12	$26
65–69	23,467	2327	4989	$158	$16	$34
70–74	26,762	2799	5930	$177	$18	$39

CVD cardiovascular disease, *SBP* systolic blood pressure

providing patient support) and at the patient level (e.g. medication adherence and self-management strategies). A systematic review of 100 articles reporting 121 comparisons concluded that "multilevel, multicomponent implementation strategies with and without team-based care are most effective for BP control among patients with hypertension" [52]. For example, through developing and implementing a system-level, multi-faceted quality improvement program for hypertension, the Kaiser Permanente Northern California, an integrated managed care consortium, improved BP control rates from 44 to 80% over 8 years [53].

Table 6 Potential reduction in the number of CVD events and costs under two blood pressure control scenarios over a 5-year period by practice size in patients with a diagnosis of hypertension

Practice size	Average number of patients seen by practice median (IQR)	Expected CVD events at baseline	Expected reduction in CVD events		Expected CVD costs at baseline AUD$	Expected reduction in CVD costs AUD$ base case		Expected reduction in CVD costs AUD$ sensitivity analysis[a]	
			SBP control to 139 mmHg	SBP control to 129 mmHg		SBP control to 139 mmHg	SBP control to 129 mmHg	SBP control to 139 mmHg	SBP control to 129 mmHg
Quartile 1	705 (539–881)	26	2	5	$179,473	$16,479	$36,751	$32,492	$72,465
Quartile 2	1248 (1121–1416)	45	5	10	$314,423	$31,455	$67,628	$62,022	$133,345
Quartile 3	1979 (1700–2105)	70	7	15	$482,647	$49,737	$106,281	$98,069	$209,561
Quartile 4	2921 (2589–3735)	117	12	26	$811,717	$82,493	$178,850	$162,657	$352,650

CVD cardiovascular disease, *IQR* interquartile range, *SBP* systolic blood pressure

[a]In the sensitivity analysis, alternative cost estimates from the literature were used to estimate the potential reduction in costs

Even when interventions are effective, investment to implement interventions depends on economic considerations. The evidence on the cost effectiveness of primary care interventions to improve hypertension in Australia is limited [54, 55]. The potential cost savings identified in our study from improving BP control makes it worthwhile investigating the effectiveness and cost effectiveness of primary care interventions to improve BP control and the feasibility and sustainability of these interventions. Exploring these interventions in the Australian system is crucial, which differs from other contexts. For example, in contrast to the UK health system where patients register with a practice, in Australia, patients can move between practices at any time.

Despite the significant health and financial burden of uncontrolled BP across all patients aged 45–74 attending general practice, the cost savings for the health system by practice are modest. Potential cost savings range from an average of AUD$16,479 for a small practice to AUD$82,493 for a large practice over 5 years. Furthermore, these saving are based on all patients achieving BP control, which is an unlikely achievement. Consequently, the cost effectiveness of interventions will likely differ by practice size. For example, low-resource interventions such as treatment intensification [56] may be feasible for smaller practices. In contrast, resource-intensive interventions, for example, those delivered by nurses [57], may not be feasible for small practices. Primary Health Networks, independent organisations that coordinate primary healthcare in a region, could support the implementation of more resource-intensive facilitation-based interventions across multiple practices, improving the cost effectiveness through economies of scale [58]. Furthermore, these health system cost savings will need to be invested into general practice to compensate GPs for the additional time and resources required to improve BP control levels in an environment of competing demands.

4.1 Strengths and Limitations

Our study is one of the first to estimate the acute hospital costs of uncontrolled BP using an extensive and comprehensive EHR database. In contrast to other studies where values for risk prediction were assumed, the large number of patients with available data in this study enabled a more accurate estimation of the risk of experiencing a cardiovascular event. However, this study has several limitations. First, only half of the patients with a hypertension diagnosis had enough data to calculate their CVD risk. However, the mean SBP and proportion of patients with uncontrolled SBP were similar when comparing patients with and without enough information recorded for a CVD risk calculation. Second, CVD risk should be assessed prior to the initiation of treatment. As we used the most recent measures for patients, we likely underestimated the CVD risk of patients who had initiated treatment and, therefore, the associated costs. We did account for this in terms of BP measures by using the maximum BP recorded between 2017 and 2018 in the sensitivity analysis, although were unable to do so for cholesterol measures. Moreover, for patients considered to be at high risk clinically (e.g. those aged over 60 years with diabetes), we used the calculated CVD risk with no adjustment for additional risk, thereby underestimating their CVD risk. However, as we were interested in the reduction in risk from improved BP control, this should not have a material impact on our findings. Third, our model did not account for competing risks where some of the baseline population will die of other causes in the 5 years, thereby reducing CVD

expenditure. This is likely to only have a minor effect on the results. Fourth, this study only considered the costs of acute hospitalisation for primary cardiovascular events. Despite hospital costs accounting for the majority of health spending [37], it does not represent the total cost of uncontrolled BP. However, taken together with existing evidence on the productivity losses experienced by patients [6], our study provides an estimate of the magnitude of the costs associated with uncontrolled BP.

5 Conclusions

There has been a call to action by the High Blood Pressure Research Council of Australia for a national commitment to improve BP control, with a focus on "the implementation and scaling up of proven strategies to improve BP management and control across the life course" [10]. The Australian Department of Health is investing AUD$229 million over 10 years to improve heart health and reduce stroke in Australia through the MRFF Cardiovascular Health Mission Roadmap [59]. This analysis should help decision makers better understand the clinical and economic importance of improving BP control in primary care and provides a starting point to investigate further the potential impacts of interventions targeted at improving BP control and reducing CVD risk. However, because of the modest implications at the individual practice level, such interventions may be best targeted at a population level rather than at individual practices.

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Declarations

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Conflict of interest Jacqueline Roseleur, David A. Gonzalez-Chica, Gillian Harvey, Nigel P. Stocks and Jonathan Karnon have no conflicts of interest that are directly relevant to the content of this article.

Ethics approval The Human Research Ethics Committee of the University of Adelaide exempted this study from ethical review as it used existing and non-identifiable data. Access to the data for this study was approved by the MedicineInsight Data Governance Committee (project 2016-007).

Consent to participate The data custodian, MedicineInsight, has provided consent for publication.

Consent for publication This study uses existing and non-identifiable data collected by MedicineInsight.

Availability of data and material Data may be obtained from MedicineInsight and are not publicly available. Third parties may express an interest in the information collected through MedicineInsight. The provision of information in these instances undergoes a formal approval process and is guided by the MedicineInsight independent external Data Governance Committee. This Committee includes general practitioners, consumer advocates, privacy experts and researchers.

Code availability Not applicable.

Authors' contributions JR and JK conceived the study. JR performed the analysis with support from JK. The first draft of the manuscript was written by JR and all authors provided critical feedback and commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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