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NHS Health Checks: a Quasi Randomised Controlled Trial

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ABSTRACT

Objectives: To evaluate uptake, risk factor detection and management from the National Health Service Health Check (NHS HC) programme.

Design: Quasi-randomised controlled trial wherein participants were allocated to five cohorts based on birth year, with four cohorts being invited for an NHS HC between April 2011 and March 2015.

Setting: 151 General Practices in Hampshire, England, United Kingdom.

Participants: 366,005 participants born 1/4/1940 – 31/3/1976 eligible for an NHS Health Check.

Intervention: Invitation for an NHS HC.

Main outcome measures: Absolute percentage changes and odds ratios (ORs) of (i) detection of CVD 10-year risk scores >10% and >20%, current smokers, TC >5.5 mmol/L and >7.5 mmol/L; (ii) new diagnoses of hypertension, T2DM, CKD and AF; and (iii) new interventions with statins, antihypertensives, antiglycaemics and nicotine replacement therapy (NRT).

Results: HC attendance rose from 12% to 30% between 2011/12 and 2014/15. HC invitation increased detection of CVD risk scores >10% (2.0%-3.6), TC >5.5 mmol/L (4.1%-7.0%) and >7.5 mmol/L (0.3%-0.4%), hypertension diagnoses (0.3%-0.6%), and interventions with statins (0.3%-1.0%) and antihypertensives (0.1%-0.6%). There were no consistent differences in detection of CVD risk >20% or current smokers, NRT, or diagnoses of diabetes, AF or CKD. Multivariate analyses showed associations between HC invitation and detection of CVD risk >10% (OR 8.01, 95% CI 7.34-8.73), >20% (5.86, 4.83-7.10), TC> 5.5 mmol/L (3.72, 3.57-3.89), >7.5 mmol/L (2.89, 2.46-3.38), and diagnoses of hypertension (1.33, 1.20-1.47) and diabetes (1.34, 1.12-1.61). The ORs of CVD risk >10% plus statin or >20% plus statin, respectively, were 2.90 (2.36-3.57) and 2.60 (1.92-3.52), and hypertension plus antihypertensive treatment was 1.33 (1.18-1.50). There were no associations with AF, CKD, antiglycaemics or NRT.

Conclusions: HC invitation increases detection of cardiovascular risk factors, but corresponding absolute increases in evidence-based interventions are small.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This is the first study to investigate outcomes associated with invitation for an NSH Health Check using a quasi-randomised method together with an intention-to-treat analysis.
- This study included a large population of 366,005 participants in a mixture of urban, semi-urban and rural settings.
- Invitation for a Health Check increases detection of cardiovascular risk factors, but this does not translate into corresponding absolute increases in evidence-based interventions.
- The follow-up of 6 months to 3.5 years limited assessment of patient relevant outcomes (e.g. incident cardiovascular disease).
- There was insufficient information to consider outcomes related to alcohol consumption and diet.

INTRODUCTION

Cardiovascular disease (CVD) is a significant cause of mortality and morbidity worldwide,[1] and results in substantial global healthcare expenditure.[2] In 2009, the National Health Service (NHS) in England began a Health Check (HC) programme with the intention of identifying and managing individuals at higher risk of CVD or related conditions, such as diabetes mellitus and kidney disease, and preventing such conditions. This is similar to national programmes in other countries including in Canada[3] and the United States.[4] Modelling by the UK Department of Health suggested that the NHS HC programme could prevent 1,600 strokes and heart attacks each year.[5] More recent estimation of the health benefits from microsimulation modelling using existing programme data suggest that the NHS HC programme results in approximately 300 fewer deaths and 1,000 people living free from disease (ischaemic heart disease, stroke, dementia and lung cancer) each year in England.[6]

Patients that are eligible to participant in the NHS HC programme are invited for HCs every five years. Patients are eligible if they are aged 40-74 and have no known CVD, diabetes, kidney disease or previous treatment with statins. The HC itself is performed in primary care, largely in general practice, and comprises an assessment of smoking status, diet, exercise, family history and more recently alcohol intake. Measurements are taken of body mass index (BMI), waist circumference, blood pressure (BP) and cholesterol, and a 10 and 20 year CVD risk score is calculated. Patients with systolic BP (SBP) or diastolic BP (DBP) ≥ 140 mmHg or 90 mmHg, respectively, have additional blood tests to measure kidney function. If impaired kidney function is detected, that is an estimated glomerular filtration rate (eGFR) < 60 ml / min / 1.73 m^2, the blood test is repeated within two weeks to confirm a diagnosis of CKD.[7] Any HC attendee with BMI ≥ 30 kg / m^2 (≥ 25 kg / m^2 in non-white ethnic groups) or SBP or DBP above ≥ 140 mmHg or 90 mmHg, respectively, are also screened for type 2 diabetes mellitus (T2DM) by measuring HbA1c or fasting glucose. If CVD risk factors are newly identified or conditions newly diagnosed during the HC, patients are offered appropriate management, including lifestyle advice, treatments and referrals to local services.

The HC programme has been contentious from its inception. There have been concerns of a lack of proven effectiveness to justify the yearly expenditure,[8] which is thought to be around £450 million.[9] A systematic review of randomised controlled trials found that general health checks provide no overall reduction in CVD or cancer mortality, only an increase in risk factor recording and diagnoses.[10] The

initial implementation of the NHS HC programme suffered early problems, such as low uptake,[11] variable implementation,[12] and poor understanding of the aims and purpose of the HC among some invitees.[13] In addition, there were concerns about inequitable distribution of the HC and a resultant widening of health inequalities.[9] Proponents of the NHS HC programme argue that existing randomised trials, the most recent of which started in 1999, are not representative of more effective modern HCs and intervention strategies.[14] In addition, since the early years, participation has increased, with a 2018 study reporting that 48.2% of those invited for a HC have now attended.[15] Strategies have also increased uptake among some deprived and ethnic minority populations to or above the average.[16]

A number of studies have evaluated the effectiveness of the NHS HC programme.[16,17] HC attendance has been associated with increased CVD risk factor recording, detection of hypercholesterolaemia and hypertension, and increased prescribing of statins comparing attenders and matched non-attenders (HR 1.58, 95% 1.53–1.63) and antihypertensives (HR 1.06, 95% 1.03–1.10).[17] HC attendees have also been shown to have reduced CVD risk scores, blood pressures and serum lipids a year afterwards.[18] However, a significant limitation of existing studies is that they have used observational data comparing HC attenders and non-attenders. Only a proportion of those invited for a HC actually attend, and those attending are not representative of the eligible population.[16,17] In this study, these limitations are addressed by comparing outcomes in eligible populations invited (i.e. not just those who attend) and not invited for an NHS HC.

METHODS

Study population and data source

This study took place in Hampshire, a region in the south of England comprising over 1.5 million residents in a mixture of urban, suburban and rural settings. In Hampshire, the HC is commissioned by three Local Authorities: Southampton City Council, Portsmouth City Council and Hampshire County Council. The two largest urban areas in Hampshire are the cities of Southampton and Portsmouth, each with a population of around 200,000-250,000. There were 151 General Practices that contributed data to this study. The organisation of the HC programme in Hampshire involved assigning eligible patients into five separate cohorts. Cohorts assignment was based on date of birth (DOB), although the cohorts had comparable means and distributions of ages. Specifically, patients with years of birth ending in “0”

or “5” were assigned to one cohort, “1” or “6” to another cohort, “2” or “7” to another and so forth, mirroring the quinquennial invitation system used for NHS breast cancer screening. The first cohort (cohort 1) was invited for a HC in the year 1st April 2011 to 31st March 2012, while the subsequent cohorts (cohorts 2-5) were invited in the years beginning 1st April 2012-15. The study period was from 1st April 2011 to 31st March 2015. During this time, cohorts 1-4 were invited for HCs. Cohort 5 was not invited and was our control group. We compared outcomes in each of the invited cohorts 1-4 separately against those in cohort 5. The exact follow-up periods depended on the cohorts being compared and are described below.

The population for this study were eligible for a HC on 1st April 2011. This required a DOB between 1st April 1940 - 31st March 1976 and (as of 1st April 2011) (i) no history of vascular disease (e.g. coronary artery disease, cerebrovascular disease, atherosclerosis, peripheral vascular disease (PVD) or circulatory system disease); (ii) no previous diagnosis of hypertension, diabetes, chronic kidney disease (CKD), atrial fibrillation (AF), heart failure (HF), stroke or TIA; and (iii) no pre-existing records of receiving statins prescription, palliative care, a health check, or CVD risk assessment. These medical eligibility criteria matched the criteria used locally by GPs to identify and invite participants to participate in the HC programme. Using the participants DOBs, we assigned them into cohorts 1-5 to identify the years they were invited for a HC between 1st April 2011 and 31st March 2015 (or not invited in the case of cohort 5). As is explained below, for some analyses, we reapplied the eligibility criteria to identify participants still eligible for a HC at the start of each invitation year.

As there was a temporary pause in sending out HC invitations during the first half of the year beginning 1st April 2012 in the Hampshire County Council Local Authority, we excluded patients belonging to cohort 2 living in that area. We excluded patients with incomplete medical records (i.e. no GP attendance record before 1st April 2011) as we assumed that those patients had moved into the area after the start of the follow-up. We excluded patients with medical records not formatted according to READ Codes Version 2 (around 15% of the population).

We acquired data for this study from the Hampshire Health Record Analytical database (HHRA). At the time of the study, the HHRA linked anonymised clinical records from 151 primary care practices, secondary care (e.g. inpatient, outpatient, and A&E) from 3 acute (hospital) NHS trusts, and laboratory and pathology tests. The HHRA also contains deprivation indices for the populations served by the included GP practices. The HHRA covers a registered population of around 1.5 million patients.

Unfortunately, the organisation or the HHRA is such that some patients who die are removed from the database. As such, we did not use mortality or CVD events, which frequently result in death, as outcomes.

Information extracted and outcome measures

For each participant, we extracted from HHRA data concerning HC attendance, age, gender and individual level deprivation (IMD) at baseline. Ethnicity was poorly recorded (50% missing) and, thus, not extracted. We extracted data for the following outcomes: (i) recording of blood pressure (BP), total serum cholesterol (TC), smoking status (i.e., "current smoker", "ex-smoker", and "never smoker"), BMI, and 10-year CVD risk score (e.g. Framingham and QRISK); (ii) detection of CVD risk score >10%, CVD risk score >20%, current smoker, TC >5.5 mmol/L, TC >7.5 mmol/L, and BMI >30 kg/m^2; (iii) new diagnoses of hypertension, AF, diabetes and CKD (stage 3 and below); and (iv) new interventions with statins, antihypertensives, antiglycaemic medication, nicotine replacement, anti-obesity medication, stop-smoking advice/referral and weight management advice/referral. We identified outcomes only where corresponding Read codes had been recorded (e.g. we did not assume that BMI had been measured just because a weight management referral had been made). Data were extracted from the HHRA in January 2017.

Follow-up periods and statistical analysis

For each cohort overall and for HC attendees / non-attendees within each cohort separately, we calculated baseline means and standard derivations of age, gender and deprivation index. We calculated proportions (%) with outcomes occurring between 1st April 2011 and 31st March 2015. We calculated absolute differences in these proportions for each of cohorts 1-4 vs. 5 (i.e. invited vs non-invited) as well as the range (i.e. of absolute differences for cohorts 1-4 vs. 5). We also compared proportions with outcomes among attendees and non-attendees. Given the large sample sizes, p-values for differences in proportions were generally highly significant and, thus, not reported.

In the second stage of our analysis, we calculated ORs for each outcome. We employed multivariable logistic regression models adjusted for age and gender. We calculated ORs for each invited cohort (i.e. cohorts 1-4) separately, with the reference being uninvited cohort 5. All analyses were by intention to treat. We did sensitivity analysis by excluding those who attended opportunistically. In these analyses, follow-up was from the start of the invitation year of the invited cohort until 31st March 2015. For cohorts

1-4 vs. 5, follow-up periods were from 1st April 2011, 1st April 2012, 1st April 2013, 1st April 2014, respectively, until 31st March 2015. We included only participants still eligible at the start of the invitation year. As invitations were sent out throughout each year rather than all at the start, participants were invited on average six months from the start of their invitation years. This corresponds to follow-up periods for comparisons of cohorts 1-4 vs. 5, respectively, of 3.5, 2.5, 1.5 and 0.5 years.

This study received ethical approval from the Research Ethics Committee at the University of Southampton ID: 24358) and approval from the Hampshire Health Record Information Governance Group. Data extraction was implemented using SQL server 2008 R2, and statistical analyses were conducted using R.[19]

Patient involvement

There were no patients directly involved in this study

RESULTS

Study sample and baseline characteristics

The derivation of the study population and five cohorts is shown in figure 1. 399,420 met our inclusion criteria and had medical records formatted as READ Codes Version 2. From those, we excluded 6,641 without a recorded DOB and a further 26,774 patients without entries in their health records from before 1st April 2011 who likely moved into Hampshire after the start of the follow-up period. The remaining 366,005 participants formed our study population. Table 1 summarises their baseline characteristics broken down into cohorts 1-5. The cohorts had similar proportions of male gender (within 1%) and mean deprivation scores (within one centile). The cohorts differed more markedly in mean age, although the maximum difference was just 3 years between cohorts 1 and 5. The age differences reflected the HC invitation system in Hampshire which, as is described above, is based on DOB. However, figure 2 comprises histograms showing broadly similar distributions of ages within each cohort.

Table 1. Demographic information of the five cohorts overall and broken down into HC attendees and non-attendees within each cohort.

	Cohort 1			Cohort 2			Cohort 3			Cohort 4			Cohort 5		
	All	Att	DNA	All	Att	DNA	All	Att	DNA	All	Att	DNA	All	Att	DNA
N	**76146**	9464	66682	**39232**	9868	29364	**80220**	19991	60229	**81676**	21188	60488	**88731**	4232	84499
% male	**47.5**	45.6	47.8	**46.5**	40.7	48.3	**47.0**	41.0	49.0	**47.4**	41.9	49.3	**47.2**	48.0	47.1
Age range	**(40, 70)**	(40, 70)	(40, 70)	**(39, 69)**	(39, 69)	(39, 69)	**(38, 68)**	(38, 68)	(38, 68)	**(37, 67)**	(37, 67)	(37, 67)	**(36, 71)**	(36, 71)	(36, 71)
Mean age (SD)	**51(9.0)**	54(9.9)	50(8.7)	**50(9.1)**	53(9.5)	49(8.7)	**49(9.0)**	52(9.6)	48(8.6)	**48(9.9)**	51(9.4)	47(8.8)	**48(9.5)**	59(10.4)	48(9.5)
Mean decile (SD)	**7.3(2.6)**	7.8(2.4)	7.3(2.6)	**7.3(2.6)**	7.9(2.3)	7.2(2.7)	**7.3(2.6)**	7.7(2.4)	7.2(2.7)	**7.3(2.6)**	7.7(2.4)	7.2(2.7)	**7.3(2.6)**	7.5(2.6)	7.3(2.6)

Attended (Att), number (N), did not attend (DNA), standard deviation (SD)

HC attendees in all cohorts were more likely to be female, older and less deprived compared to those who did not attend (Table 1). Proportions within each invited cohort (i.e. cohorts 1-4) attending HCs increased year on year during the follow-up, and for cohorts 1-4 were 12%, 27%, 28% and 30%, respectively. Despite not being formally invited, a number of patients in cohort 5 attended a HC during the follow-up period. These patients had likely responded to local or national advertising for the HC programme or had been offered HCs opportunistically by their GPs.

Proportions of risk factor recording, detection, diagnoses and interventions

Table 2 summarises the proportions of patients with recording and detection of risk factors, new diagnoses, and new interventions during the follow-up period, which varied by cohort. The results are shown for each cohort overall and separately for attendees and non-attendees within each cohort. Proportions generally increased year on year for cohorts 1-4, reflecting increasing attendance, and were lowest in the uninvited cohort 5. There were increases in absolute proportions in invited cohorts 1-4 with recorded BP (range for cohorts 1-4 vs. 5 = 5.0%-7.9%), BMI (5.0%-13.4%), TC (8.4%-17.5%), CVD risk (7.3%-19.6%) and smoking status (2.8%-7.0%). In addition, there was increased detection of CVD risk >10% (2.0%-3.6%), SBP >140 / DBP >90 (0.9%-2.1%), BMI >30 kg/m^2 (0.8%-2.5%), TC >5.5 mmol/L (4.1%-7.0%) and TC >7.5 mmol/L (0.3%-0.4%). There were modest or no consistent differences in proportions with detected CVD risk >20% (0.0%-0.6%) and current smoking (–0.2%-0.5%).

The proportions with detection of risk factors among those with recordings were lower in the invited cohorts (i.e. 1-4) compared to uninvited cohort 5, particularly for CVD risk >10% (–11.5% - –2.8%), >20% (–6.1% - –1.8%) and BMI >30 kg/m^2 (–2.8% - –1.1%). Even though smaller absolute numbers of high risk patients were identified by opportunistic testing, these data suggest a higher positive predictive value of opportunistic testing compared to the HC, which may reflect different risk profiles of patients.

HC resulted in minor or no increases in proportions with new diagnoses of hypertension (0.3%-0.6%), AF (0.0%-0.1%), CKD (0.1%) or diabetes (0.0%-0.1%). There were minor increases in proportions receiving statins (0.3%-1.0%), antihypertensives (0.1%-0.6%) and stop smoking advice (0.4%-0.9%), but no consistent difference in antiglycaemics (-0.1%-0.1%), NRT (0.0%) or anti-obesity medications (0.0%). There was an increase in weight advice / referrals (4.6%-10.5%).

Table 2. Proportions of participants with risk factor recording / detection, new diagnoses and new interventions in each of the five cohorts overall and for HC attendees and non-attendees within each cohort separately.

	C1			C2			C3			C4			C5		
	All	Att	DNA	**All**	Att	DNA	**All**	Att	DNA	**All**	Att	DNA	**All**	Att	DNA
RECORDING %															
BP	**72.3**	98.6	68.5	**75.2**	98.6	67.3	**74.3**	98.7	66.3	**73.3**	98.6	64.4	**67.3**	99.1	65.7
BMI	**48.4**	97.7	41.4	**56.5**	98.5	42.3	**56.5**	98.5	42.5	**56.8**	98.6	42.2	**43.4**	98.0	40.6
TC	**41.5**	97.6	33.6	**49.5**	97.1	33.6	**49.4**	97.0	33.6	**50.6**	97.2	34.2	**33.1**	96.1	30.0
CVD risk	**23.0**	89.0	13.7	**32.8**	89.4	13.8	**33.2**	89.1	14.7	**35.3**	92.3	15.3	**15.7**	90.2	11.9
Smoking status	**71.8**	98.5	68.1	**75.8**	98.9	68.0	**75.7**	98.7	68.1	**76.0**	98.4	68.2	**69.0**	98.7	67.6
DETECTION %															
CVD risk >10%	**7.7**	29.0	4.7	**9.3**	23.0	4.7	**9.0**	22.2	4.6	**8.8**	20.7	4.6	**5.7**	44.5	3.8
% of CVD risk recorded with >10%	**33.6**	32.6	34.5	**28.4**	25.7	34.3	**27.0**	24.9	31.1	**24.9**	22.5	30.1	**36.4**	49.3	31.5
CVD risk >20%	**2.2**	8.1	1.3	**2.4**	5.2	1.4	**2.1**	4.4	1.3	**1.8**	3.6	1.2	**1.8**	15.0	1.1
% of CVD risk recorded with >20%	**9.4**	9.1	9.6	**7.2**	5.8	10.1	**6.3**	5.0	9.1	**5.1**	3.9	7.8	**11.2**	16.6	9.1
SBP >140 or DBP > 90	**17.8**	24.6	16.8	**17.5**	20.1	16.6	**17.3**	20.6	16.3	**16.6**	19.7	15.6	**15.7**	29.9	14.9
% of BP recorded with >140 or >90	**24.6**	25.0	24.5	**23.3**	20.4	24.7	**23.3**	20.8	24.5	**22.7**	20.0	24.2	**23.3**	30.2	22.7
Current smoker	**20.7**	17.0	21.2	**20.8**	14.6	22.8	**20.9**	14.4	23.1	**21.4**	16.3	23.2	**20.9**	18.4	21.1
% of smoking status recorded who currently smoke	**28.8**	17.3	31.1	**27.4**	14.8	33.6	**27.6**	14.6	33.9	**28.2**	16.6	34.1	**30.3**	18.6	31.2
BMI >30	**12.6**	18.0	11.9	**13.9**	17.6	12.7	**13.8**	17.9	12.4	**14.3**	19.7	12.3	**11.8**	20.1	11.4
% BMI recoded with >30	**26.1**	18.5	28.7	**24.7**	17.9	30.0	**24.4**	18.2	29.1	**25.1**	20.0	29.2	**27.2**	20.5	28.0
TC > 5.5	**19.1**	44.1	15.5	**22.0**	43.1	14.9	**21.4**	41.4	14.8	**21.6**	39.8	15.2	**15.0**	48.8	13.3
% of TC recorded with >5.5	**46.0**	45.2	46.2	**44.3**	44.4	44.3	**43.3**	42.7	43.9	**42.7**	40.9	44.4	**45.3**	50.8	44.4
TC > 7.5	**1.4**	2.7	1.2	**1.5**	2.4	1.2	**1.5**	2.5	1.1	**1.5**	2.3	1.3	**1.1**	3.3	1.0
% of TC recorded with >7.5	**3.3**	2.8	3.6	**3.1**	2.5	3.6	**3.0**	2.6	3.3	**3.1**	2.4	3.8	**3.4**	3.4	3.4
DIAGNOSES %															
Hypertension	**4.2**	4.7	4.1	**4.1**	3.7	4.3	**3.9**	3.0	4.2	**4.0**	2.5	4.5	**3.6**	6.5	3.5
% of SBP >140 or DBP > 90 with hypertension diagnosis	**18.0**	15.1	18.7	**17.7**	13.6	19.3	**17.5**	11.5	20.1	**17.8**	9.3	21.6	**17.3**	16.4	17.4
AF	**0.5**	0.5	0.5	**0.4**	0.4	0.4	**0.4**	0.4	0.5	**0.4**	0.2	0.4	**0.4**	0.9	0.3
CKD	**0.3**	0.3	0.3	**0.3**	0.4	0.3	**0.3**	0.2	0.3	**0.3**	0.1	0.3	**0.2**	0.6	0.2
Diabetes	**1.3**	0.9	1.3	**1.2**	0.7	1.4	**1.3**	0.6	1.5	**1.3**	0.6	1.6	**1.2**	1.2	1.2
INTERVENTIONS %															
Statin	**4.9**	7.7	4.5	**5.0**	5.6	4.8	**4.4**	4.5	4.4	**4.3**	3.3	4.6	**4.0**	13.0	3.6
% of CVD>10% prescribed statins	**22.5**	16.5	27.8	**18.8**	12.7	28.8	**17.6**	11.4	27.5	**16.2**	9.3	27.0	**23.6**	19.0	26.2
% of CVD>20% prescribed statins	**40.7**	31.5	48.8	**37.9**	28.7	49.4	**38.2**	27.4	50.2	**36.5**	23.0	50.8	**41.9**	33.9	47.5
Antihypertensive	**7.6**	8.0	7.5	**7.7**	6.9	7.9	**7.3**	6.1	7.7	**7.2**	5.8	7.7	**7.1**	10.6	6.9
% of hypertensives prescribed antihypertensive	**78.5**	79.6	78.3	**78.5**	77.7	78.7	**78.4**	79.3	78.2	**77.7**	77.3	77.8	**78.3**	85.0	77.7
Antiglycaemics	**1.1**	0.7	1.2	**1.0**	0.6	1.2	**1.1**	0.5	1.3	**1.2**	0.5	1.4	**1.1**	1.1	1.1
% of diabetics prescribed antiglycaemics	**74.2**	66.7	74.9	**74.4**	66.7	75.7	**74.9**	60.5	76.9	**73.2**	59.2	75.1	**76.7**	73.1	76.9
Nicotine replacement	**1.1**	0.9	1.1	**1.1**	0.9	1.2	**1.1**	0.8	1.2	**1.1**	0.8	1.2	**1.1**	1.2	1.1
% of current smokers prescribed nicotine replace	**4.6**	4.7	4.5	**4.7**	5.2	4.6	**4.7**	5.1	4.7	**4.6**	4.4	4.6	**4.6**	6.2	4.6
Stop smoking advice	**7.4**	9.9	7.1	**7.9**	8.5	7.8	**7.6**	7.7	7.5	**7.7**	8.4	7.5	**7.0**	10.3	6.9

% of current smokers given advice	**22.8**	26.8	22.4	**23.7**	24.5	23.5	**22.7**	23.5	22.6	**22.7**	23.8	22.5	**22.3**	25.3	22.1
Weight advice/referral	**12.9**	55.5	6.8	**18.3**	52.3	6.8	**18.4**	51.7	7.4	**18.8**	49.6	8.0	**8.3**	55.7	5.9
% of BMI>30 givenadvice/referal	**26.8**	63.2	19.0	**31.5**	60.1	18.2	**33.3**	60.0	20.6	**34.4**	57.7	21.3	**20.8**	60.8	17.2
Anti-obesity	**0.3**	0.2	0.3	**0.3**	0.2	0.4	**0.3**	0.3	0.3	**0.3**	0.3	0.3	**0.3**	0.2	0.3
% of BMI>30 prescribed anti-obesity	**1.8**	1.0	2.0	**2.0**	0.9	2.5	**1.8**	1.2	2.1	**1.8**	1.0	2.2	**2.1**	0.7	2.2

Attended (Att), Blood pressure (BP), body mass index (BMI), total cholesterol (TC), cardiovascular disease (CVD), systolic blood pressure (SBP), diastolic blood pressure (DBP), atrial fibrillation (AF), chronic kidney disease (CKD)

Proportions receiving statins were lower among HC invited cohorts compared to non-invited following detection of CVD risk >10% (–7.4% - –1.1%) and >20% (–5.4% - –1.2%). Similarly, antiglycaemic interventions among new cases of diabetes were lower (–3.5% - –1.8%), as were new anti-obesity prescriptions following detection of BMI >30 kg/m^2 (–0.3% - –0.1%). Differences in proportions receiving antihypertensives following new hypertension diagnoses were inconsistent (–0.6% - 0.2%), but there was an increase in proportions among HC invitees receiving weight advice / referral following detection of BMI >30 kg/m^2 (6.0%-13.6%).

Odds ratios of risk factor detection, diagnoses and interventions

Table 3 summarises the ORs and 95% confidence intervals from the regression analyses. Compared to uninvited cohort 5 (including and excluding those who attended opportunistically), the odds of detection of risk factors, new diagnoses and interventions were generally higher in invited cohorts 1-4, and they increased year on year throughout the study period. For cohort 4 vs. 5, there were large and significant increases in the odds of detecting CVD risk >10% (OR 8.01, 7.34-8.73), CVD risk >20% (OR 5.86, 4.83-7.10) TC> 5.5 mmol/L (OR 3.72, 3.57-3.89), TC >7.5 mmol/L (OR 2.89, 2.46-3.38) and BMI > 30 kg/m^2 (OR 2.05, 1.96-2.14). These may be conservative given that the average follow-up was just 6 months, and for some participants almost none, while many outcomes from the HC would likely take longer to occur. There were significant increases in detection of current smokers (OR 1.22, 1.18-1.26) and elevated BP (OR 1.64, 1.57-1.70). There were modest increases in new diagnoses of hypertension (OR 1.33, 1.20-1.47) and diabetes (OR 1.34, 1.12-1.61), but not AF (OR 1.00, 0.72-1.39) or CKD (OR 0.69, 0.36-1.32). In terms of new interventions, there were increases in weight advice / referrals (OR 8.36, 7.89-8.86), stop smoking advice (OR 1.65, 1.51-1.79), statins (OR 1.54, 1.39-1.71) and antihypertensives (OR 1.15, 1.06-1.24). The ORs of CVD risk >10% plus statin or >20% plus statin, respectively, were 2.90 (2.36-3.57) and 2.60 (1.92-3.52). The OR of hypertension diagnosis plus antihypertensive treatment was 1.33 (1.18-1.50). There were no significant differences in prescriptions of NRT (OR 0.92, 0.71-1.20), antiglycaemics (OR 1.18, 0.97-1.44) or anti-obesity medications (OR 1.00, 0.68-1.48).

Table 3. Age and gender adjusted odds ratios with 95% confidence intervals for associations between invitation for an NHS health check and the detection of CVD risk factors, new diagnoses and interventions. Results are shown for the comparisons of cohorts 1-4 against all of cohort 5 and against patients in cohort 5 who we confirmed did not attend (DNA) a HC incidentally.

	Cohort1 vs		Cohort2 vs		Cohort3 vs		Cohort4 vs	
	Cohort5 All	Cohort5 DNA	Cohort5 All	Cohort5 DNA	Cohort5 All	Cohort5 DNA	Cohort5 All	Cohort5 DNA
DETECTION %								
CVD risk >10%	1.20 (1.15-1.25)	1.71 (1.64-1.80)	1.93 (1.82-2.04)	2.66 (2.50-2.83)	3.28 (3.08-3.50)	3.98 (3.71-4.27)	8.01 (7.34-8.73)	11.17 (10.13-12.33)
CVD risk >20%	1.07 (0.99-1.15)	1.49 (1.37-1.63)	1.44 (1.29-1.61)	1.90 (1.69-2.15)	2.83 (2.48-3.23)	3.12 (2.72-3.58)	5.86 (4.83-7.10)	7.18 (5.82-8.85)
SBP >140 or DBP > 90	1.04 (1.01-1.07)	1.06 (1.03-1.09)	1.08 (1.05-1.12)	1.10 (1.06-1.14)	1.23 (1.19-1.27)	1.26 (1.21-1.30)	1.64 (1.57-1.70)	1.69 (1.62-1.76)
Current smoker	1.03 (1.01-1.06)	1.03 (1.01-1.06)	1.05 (1.02-1.09)	1.05 (1.02-1.09)	1.05 (1.02-1.08)	1.05 (1.03-1.08)	1.22 (1.18-1.26)	1.23 (1.19-1.27)
BMI >30	1.09 (1.06-1.12)	1.14 (1.11-1.18)	1.26 (1.21-1.31)	1.31 (1.26-1.36)	1.46 (1.41-1.51)	1.52 (1.47-1.58)	2.05 (1.96-2.14)	2.18 (2.09-2.28)
TC > 5.5	1.19 (1.16-1.23)	1.33 (1.29-1.37)	1.67 (1.61-1.72)	1.83 (1.77-1.90)	2.10 (2.03-2.17)	2.27 (2.19-2.34)	3.72 (3.57-3.89)	4.20 (4.02-4.39)
TC > 7.5	1.12 (1.02-1.22)	1.19 (1.08-1.30)	1.42 (1.26-1.59)	1.52 (1.35-1.71)	1.66 (1.47-1.87)	1.76 (1.56-1.99)	2.89 (2.46-3.38)	3.15 (2.67-3.72)
DIAGNOSES %								
Hypertension	1.04 (0.99-1.09)	1.03 (0.98-1.09)	1.06 (0.98-1.14)	1.04 (0.97-1.12)	1.10 (1.02-1.19)	1.10 (1.02-1.19)	1.33 (1.20-1.47)	1.34 (1.20-1.48)
AF	1.14 (0.98-1.32)	1.11 (0.95-1.30)	0.91 (0.72-1.14)	0.89 (0.71-1.13)	1.33 (1.06-1.67)	1.31 (1.05-1.65)	1.00 (0.72-1.39)	1.01 (0.72-1.40)
CKD	1.01 (0.84-1.22)	0.98 (0.81-1.19)	1.22 (0.93-1.61)	1.18 (0.90-1.57)	1.08 (0.77-1.51)	1.06 (0.76-1.49)	0.69 (0.36-1.32)	0.68 (0.36-1.30)
Diabetes	0.99 (0.91-1.08)	0.97 (0.88-1.06)	0.95 (0.84-1.09)	0.94 (0.82-1.07)	1.12 (0.99-1.28)	1.12 (0.98-1.27)	1.34 (1.12-1.61)	1.36 (1.13-1.64)
INTERVENTIONS %								
Statin	1.06 (1.01-1.11)	1.12 (1.06-1.18)	1.17 (1.09-1.25)	1.21 (1.13-1.30)	1.26 (1.16-1.35)	1.27 (1.18-1.37)	1.54 (1.39-1.71)	1.58 (1.42-1.76)
Antihypertensive	0.99 (0.95-1.03)	0.99 (0.95-1.03)	1.04 (0.99-1.10)	1.04 (0.98-1.09)	1.04 (0.98-1.10)	1.04 (0.98-1.10)	1.15 (1.06-1.24)	1.15 (1.07-1.24)
Antiglycaemics	0.93 (0.85-1.02)	0.92 (0.83-1.01)	0.90 (0.79-1.04)	0.90 (0.78-1.03)	1.04 (0.91-1.20)	1.03 (0.90-1.19)	1.18 (0.97-1.44)	1.19 (0.97-1.45)
Nicotine	1.00 (0.91-1.10)	1.01 (0.92-1.11)	1.05 (0.91-1.22)	1.07 (0.92-1.24)	1.04 (0.88-1.22)	1.08 (0.91-1.28)	0.92 (0.71-1.20)	0.96 (0.73-1.25)
Stop smoking advice	1.08 (1.04-1.12)	1.12 (1.08-1.16)	1.19 (1.13-1.26)	1.23 (1.17-1.30)	1.28 (1.20-1.35)	1.32 (1.25-1.40)	1.65 (1.51-1.79)	1.74 (1.60-1.90)
Weight advice/referral	1.50 (1.45-1.55)	2.14 (2.07-2.22)	2.84 (2.73-2.95)	3.98 (3.81-4.16)	4.21 (4.04-4.40)	5.69 (5.42-5.98)	8.36 (7.89-8.86)	14.33 (13.31-15.43)

Anti-obesity	1.06	(0.88-1.26)	1.06	(0.88-1.27)	1.11	(0.85-1.44)	1.11	(0.85-1.44)	1.09	(0.83-1.44)	1.08	(0.82-1.42)	1.00	(0.68-1.48)	1.00 (0.68-1.49)			
CVD>10% & statin	1.12	(1.03-1.21)	1.35	(1.24-1.48)	1.27	(1.12-1.43)	1.49	(1.31-1.70)	1.78	(1.54-2.07)	1.90	(1.63-2.21)	2.90	(2.36-3.57)	3.27 (2.63-4.06)			
CVD>20% & statin	1.03	(0.92-1.15)	1.25	(1.11-1.42)	1.07	(0.90-1.28)	1.28	(1.06-1.54)	1.58	(1.29-1.94)	1.67	(1.36-2.06)	2.60	(1.92-3.52)	2.95 (2.15-4.04)			
HTN & antihypertensive	1.04	(0.98-1.10)	1.04	(0.98-1.10)	1.06	(0.97-1.15)	1.05	(0.96-1.14)	1.11	(1.02-1.21)	1.11	(1.02-1.21)	1.33	(1.18-1.50)	1.33 (1.18-1.50)			

Body mass index (BMI), total cholesterol (TC), cardiovascular disease (CVD), systolic blood pressure (SBP), diastolic blood pressure (DBP), atrial fibrillation (AF), chronic kidney disease (CKD)

DISCUSSION

This study evaluated the NHS HC programme in Hampshire from its implementation in April 2011 until March 2015. HC attendance following invitation increased year on year and as of 2015 was 30%. Attendees were older, from less deprived backgrounds and less likely to be male than those who were invited but chose not to attend. A significant finding was the large increase of up to 17.5% in the proportion of patients with measurements of TC among HC invited cohorts compared to non-invited. As might be expected, this led to large increases in detection of elevated TC >5.5 mmol/L and CVD risk >10%, as well as TC >7.5 mmol/L and CVD risk >20%. Notwithstanding, there were only small increases in detection plus treatment with statins. Explanations for this might include guidance during the study period recommending statins for CVD risk >20%, whereas the largest increased was in detection of CVD risk > 10%. Nonetheless, even among those with CVD risk >20% only 36.5%-40.7% (range for the invited cohorts) of participants were prescribed statins. This is substantially lower than the expected 75% prescription rate quoted in Public Health England and NHS literature.[20] In the uninvited group, rates of statin prescriptions following identification of CVD risk >20% were slightly higher (41.9%), but still lower than expected. Accordingly, there may be a more general issue relating to the step up from risk factor identification to diagnosis, and from diagnosis to treatment across general practice that would represent a missed opportunity at a population level for primary prevention of CVD. More specifically to the HC, there is a lack of a defined follow-up pathway following identification of increased 10-year CVD risk. Public Health England commissions and pays for the HC itself but follow-up is then a cost to General Practices which maybe a barrier.

Statin prescription rates may have increased since the study period, as updated NICE guidance now recommends statins for CVD risk >10% and a recent large and well-publicised review reported a more favourable risk / benefit profile of statins than thought previously.[21] Statin prescription rates resulting from a HC may also be higher outside of Hampshire, as they are known to vary regionally.[22]

Other notable findings of this study included increased detection of elevated BP among HC invited cohorts, as well as modest increases in new diagnoses of hypertension and treatment. Those attending HCs were more likely to be diagnosed with diabetes, but the corresponding increase in prescriptions of antiglycaemics did not reach significance. According to HC guidance, diabetes screening is performed only in those deemed “at risk” with BMI ≥ 30 kg / m^2 (≥ 25 kg / m^2 in non-white ethnic groups) or SBP or DBP above ≥ 140 mmHg or 90 mmHg. Data regarding the sensitivity of these criteria are limited, but one US study reported that a BMI cut off of ≥ 25 kg / m^2 “would miss 36% of Asian Americans with newly diagnosed type 2 diabetes”,[23] so the HC may also have missed cases.

There was no significant increase in new diagnoses of CKD. This was likely because kidney function tests were performed only in HC patients with SBP or DBP ≥ 140 mmHg or 90 mmHg. A formal diagnoses of CKD would have

required a repeat blood test, something which would need to have been organised by the GP and agreed to by the patient.

The HC did not result in any significant increase in new diagnoses of AF. NICE Hypertension clinical guideline 127 states that practitioners should manually palpate the pulse before measuring blood pressure.[16] However, this may not have been performed consistently or reliably during the HC. Manual palpation is not necessary with electronic sphygmomanometers, and any patient with an irregular pulse would have further required an ECG to diagnose AF.

There were increases in detection of smokers and BMI >30 kg/m^2, as well as corresponding increases in lifestyle advice / referrals, particularly for high BMI. However, there was no significant difference in NRT or anti-obesity medications.

The HC had lower positive predictive values (or yield) for detection of risk factors than checks performed opportunistically. Most notably, lower proportions of CVD risk scores measured during the HC were >10% (–11.5% - –2.8%) and >20% (–6.1% - –1.8%). This may have been because GPs targeted opportunistic checks at those who were already symptomatic or because HC attendees were healthier with a lower prevalence of risk factors. A recent cohort study of 18 general practices in South London also found that participants taking up an opportunistic HC were at higher CVD risk (17% of invited HC and 22% of opportunistic HC with CVD risk score ≥10%), and that in younger adults in more deprived areas the opportunistic HC constituted a higher proportion of all HC performed. It was concluded that GPs were successfully targeting groups at higher risk who may otherwise face barriers to attendance at a pre-arranged HC.[24]

Our findings build on existing studies that showed increasing rates of participation in the HC programme[17] and the fact that attendees tend to be older, female and non-smokers.[25] We also found that HC attendees were from higher socioeconomic groups compared to non-attendees. This reflects previous studies in Stoke on Trent[26] and across England.[27] However, a study in Bristol and[28] a national study[22] found similar rates across socioeconomic groups, but underrepresentation of ethnic minorities. A study in London reported that attendance of ethnic minorities can be increased by targeted campaigns and IT support for GPs.[17] There is likely substantial regional variability in the provision of such campaigns and support, which may in turn give rise to variability in the equity of HC attendance. Another London study found higher uptake in deprived groups (29). Although rates of attendance may differ in different demographic groups, HC attendance is associated with reduced gender and deprivation inequality in the recording and detection of CVD risk factors.[29]

Earlier studies report associations between HC attendance and increased recording and detection of CVD risk factors and use of interventions. HC attendance has been associated with subsequent CVD risk reduction through increased use of statins.[18] It has also been shown that a year after completing a HC, attendees have modest but significant reductions in CVD risk scores, diastolic blood pressure, TC levels and lipid ratios.[27] Chang et al. [30] found that a third of HC attendees with CVD risk scores > 20% go on to be prescribed statins. Similar to our study, Smith et al. reported

a limited effect of HC attendance on detection rates and treatment of diabetes which, as is explained above, is likely because measuring blood glucose or HBA1c is not a standard part of the HC.[16,27]

The increases in proportions of new prescriptions we observed were much smaller than those found in the two large previous matched studies.[31] This is to be expected given that those studies compared attendees vs. non-attendees. In addition, it may reflect the fact that attendees had higher baseline risk than the matched non-attendees. This study has a significant advantage as we did not need to match and instead used a real uninvited population.

Strengths of this study included the biggest sample size to date for a HC study comprising 277,274 patients invited for a HC and 88,731 patients who were not. It is the first HC study to employ a quasi-randomised method and an intention to treat analysis. Specifically, patients were allocated to either HC invited or non-invited groups according to their dates of birth. We were able to evaluate the HC programme at the level of invitation, which is advantageous compared to previous studies which compared attendance vs. non-attendance. There were also weaknesses in our methods. First, our follow-up periods were short, varying from an average of six months to 3.5 years. Process outcomes may have occurred after the end of follow-up, particularly in the case of new treatments that may have required further appointments and monitoring (e.g. for new prescriptions of antihypertensive). In addition, we were unable to observe clinically important outcomes, such as incident cardiovascular disease. For every 100 people invited for a HC in 2012/13, an extra one person was prescribed a statin. Based on a literature reported NNT for primary prevention of cardiovascular events,[32] one event may be prevented for every 560 people invited for a HC, but this estimation does not account for duration of treatment or adherence. Improving NNTs would require greater uptake of the HC and / or greater prescribing among those with identified CVD risk. A second limitation of our study was that we were missing all data including at baseline for an unknown number of patients who died during the follow-up, which was a consequence of how our data source, the HHRA, was organised. These deaths will selectively have reduced numbers of those at highest risk from our population. They will tend to have been in poorer and higher risk groups and, therefore, less likely to attend a HC. The numbers would have been balanced between the cohorts, so should not have affected our between-cohort comparisons. However, they might have reduced the overall risk profile, and differentially within cohorts favour attendance. A third limitation was contamination bias, as some patients in the uninvited group attended a HC. Contamination was largely inevitable given advertising and public awareness of the HC and given that all included GP practices were involved in delivering the programme. Contamination likely led to an underestimation of the effectiveness of the HC programme in our study. Fourth, we had limited details on some factors, including diet and alcohol intake, and non-medical interventions, such as lifestyle advice. Lifestyle advice may have ranged from brief general advice to individually tailored advice with subsequent follow-up. However, such variation likely had a small effect on our results given an earlier study that reported a lack of an association between the intensity of lifestyle advice as part of a HC and related CVD risk reduction.[5] Fifth, there were potential coding errors or omissions by GPs in recording attendance, measurements, diagnoses and interventions. Coding errors would have affected the intervention and non-intervention

groups equally. Sixth, we missed data on HC undertaken in community pharmacies and other non GP settings though this was a small minority. Our population was not necessarily representative of the UK, and we had no data on ethnicity. Hampshire does comprise significant urban, suburban and rural populations, but the proportion of ethnic minorities is lower than the national average and this may limit the generalisability of our results. Finally, our study period ended in 2015, and clinical guidance as well as engagement by GPs and patients with the HC programme may have changed since then.

In conclusion, this study evaluated the NHS HC programme and showed that participation increased year on year between 2011 and 2015. The HC programme resulted in large increases in the detection of patients with CVD risk factors, particularly raised cholesterol and 10-year CVD risk scores >10%. However, there was little evidence of an associated increase in evidence based medical therapies, despite such therapies now being recommended in national clinical guidance. Indeed, rates of uptake, diagnosis and treatment were well below those expected by Department of Health.[33] Future work should focus on improving uptake, including through use of non-GP settings (e.g. pharmacy etc.)[34] and by better communication of the programme[35,36] and invitation methods driven by behavioural insights.[37] Further support is also required in decision making for patients and GPs following identification of new risk factors as part of the NHS HC, potentially including incentivisation (e.g. payment by results). Finally, further studies are needed to assess the longer-term effects of the HC on clinical outcomes.

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Figures

Figure 1. Derivation of the study population and five cohorts included in this study. Cohorts 1-4 were invited for HCs in the years beginning 1st April 2011, 12, 13 and 14 respectively, while cohort 5, which was the control group, was not invited.

Figure 2. Histograms showing the distribution of ages within the five cohorts.

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Declaration of competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Ethics approval

This study received ethnical approval from the Research Ethics Committee at the University of Southampton ID: 24358) and approval from the Hampshire Health Record Information Governance Group.

Contributorship

The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. All authors conceived and designed the study; FS performed the data acquisition from the Hampshire Health Record Database and OJK performed the data analysis; OJK and FS drafted the manuscript which was reviewed and amended by all authors. All authors, external and internal, had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. PR is guarantor.

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Transparency declaration

PR 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.

Data sharing

No additional data are available.

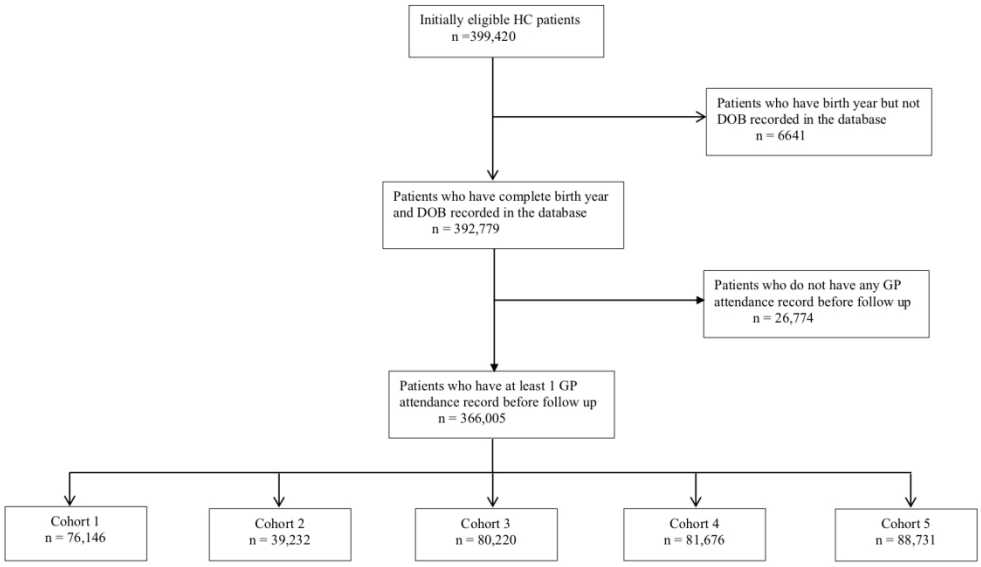

Figure 1. Derivation of the study population and five cohorts included in this study. Cohorts 1-4 were invited for HCs in the years beginning 1st April 2011, 12, 13 and 14 respectively, while cohort 5, which was the control group, was not invited.

146x83mm (300 x 300 DPI)

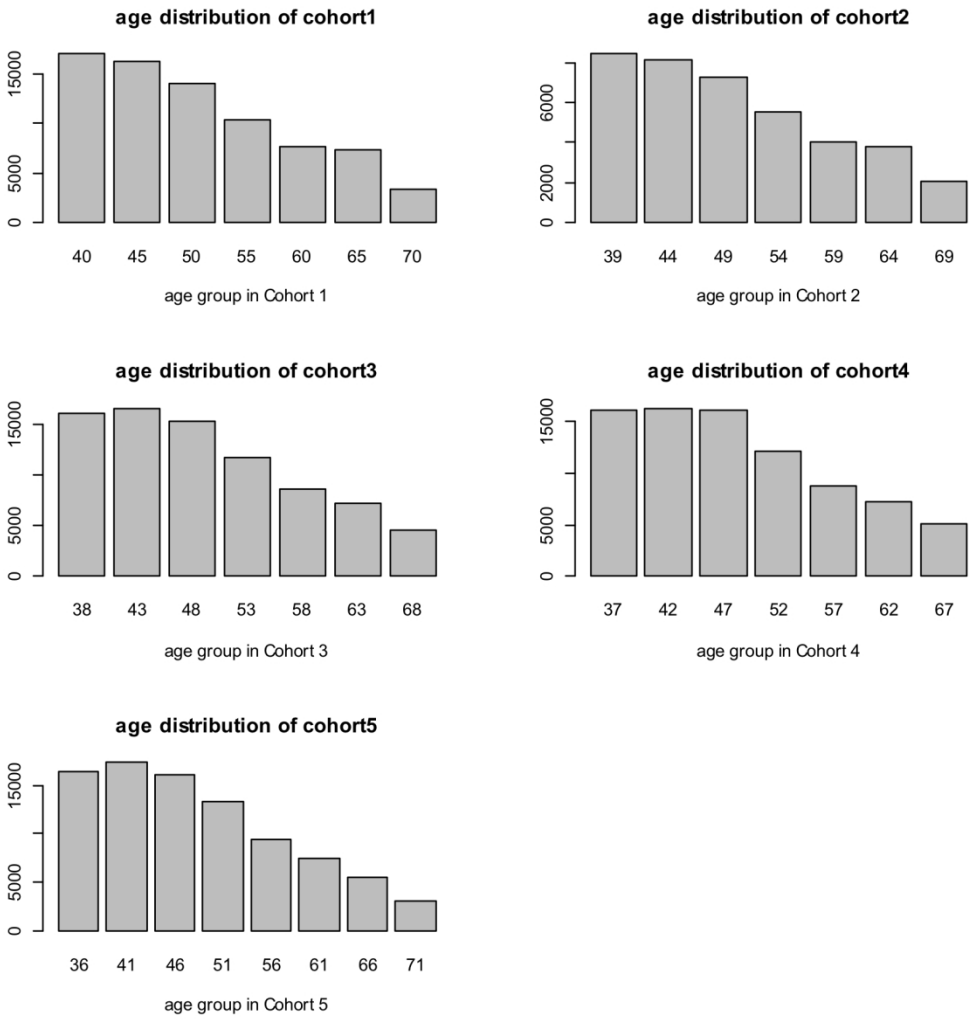

Figure 2. Histograms showing the distribution of ages within the five cohorts.

150x158mm (300 x 300 DPI)

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Evaluating the Effectiveness of the NHS Health Check Programme in South England: a Quasi-Randomised Controlled Trial

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Evaluating the Effectiveness of the NHS Health Check Programme in South England: a Quasi-Randomised Controlled Trial

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ABSTRACT

Objectives: Evaluate uptake, risk factor detection and management from the National Health Service (NHS) Health Check (HC).

Design: Quasi-randomised controlled trial wherein participants were allocated to five cohorts based on birth year. Four cohorts were invited for an NHS HC between April 2011 and March 2015.

Setting: 151 General Practices in Hampshire, England, United Kingdom.

Participants: 366,005 participants born 1/4/1940 – 31/3/1976 eligible for an NHS HC.

Intervention: Invitation for an NHS HC.

Main outcome measures: Absolute percentage changes and odds ratios (ORs) of (i) detection of cardiovascular (CVD) 10-year risk scores >10% and >20%, current smokers, total cholesterol (TC) >5.5 mmol/L and >7.5 mmol/L; (ii) new diagnoses of hypertension, type 2 diabetes mellitus (T2DM), chronic kidney disease (CKD) and atrial fibrillation (AF); and (iii) new interventions with statins, antihypertensives, antiglycaemics and nicotine replacement therapy (NRT).

Results: HC attendance rose from 12% to 30% between 2011/12 and 2014/15. HC invitation increased detection of CVD risk scores >10% (2.0%-3.6), TC >5.5 mmol/L (4.1%-7.0%) and >7.5 mmol/L (0.3%-0.4%), hypertension diagnoses (0.3%-0.6%), and interventions with statins (0.3%-1.0%) and antihypertensives (0.1%-0.6%). There were no consistent differences in detection of CVD risk >20% or current smokers, NRT, or diagnoses of diabetes, AF or CKD. Multivariate analyses showed associations between HC invitation and detection of CVD risk >10% (OR 8.01, 95% CI 7.34-8.73), >20% (5.86, 4.83-7.10), TC >5.5 mmol/L (3.72, 3.57-3.89), >7.5 mmol/L (2.89, 2.46-3.38), and diagnoses of hypertension (1.33, 1.20-1.47) and diabetes (1.34, 1.12-1.61). ORs of CVD risk >10% plus statin and >20% plus statin, respectively, were 2.90 (2.36-3.57) and 2.60 (1.92-3.52), and hypertension plus antihypertensive was 1.33 (1.18-1.50). There were no associations with AF, CKD, antiglycaemics or NRT. Detection of several risk factors varied inversely by deprivation.

Conclusions: HC invitation increased detection of cardiovascular risk factors, but corresponding increases in evidence-based interventions were modest.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This is the first study to investigate outcomes associated with invitation for a National Health Service Health Check using a quasi-randomised method together with an intention-to-treat analysis.
- This study included a large population of 366,005 participants in a mixture of urban, semi-urban and rural settings.
- Invitation for a Health Check increased detection of cardiovascular risk factors, but this translated into only modest increases in evidence-based interventions.
- The follow-up of 6 months to 3.5 years limited assessment of patient relevant outcomes (e.g. incident cardiovascular disease).
- There was insufficient information to consider outcomes related to alcohol consumption and diet.

INTRODUCTION

Cardiovascular disease (CVD) is a significant cause of mortality and morbidity worldwide,[1] and results in substantial global healthcare expenditure.[2] In 2009, the National Health Service (NHS) in England began a Health Check (HC) programme with the intention of identifying and managing individuals at higher risk of CVD or related conditions, such as diabetes mellitus and kidney disease, and preventing such conditions. This is similar to national programmes in other countries including in Canada[3] and the United States.[4] Modelling by the UK Department of Health suggested that the NHS HC programme could prevent 1,600 strokes and heart attacks each year, although the modelling assumptions, particularly with regard to uptake, may have overestimated effectiveness.[5] More recent estimation of the health benefits from microsimulation modelling using existing programme data suggest that the NHS HC programme results in approximately 300 fewer deaths and 1,000 people living free from disease (ischaemic heart disease, stroke, dementia and lung cancer) each year in England.[6]

Patients that are eligible to participate in the NHS HC programme are invited for HCs every five years. Patients are eligible if they are aged 40-74 and have no known CVD, diabetes, kidney disease or previous treatment with statins. The HC itself is performed in primary care, largely in general practice, and comprises an assessment of smoking status, diet, exercise, family history and more recently alcohol intake. Measurements are taken of body mass index (BMI), waist circumference, blood pressure (BP) and cholesterol, and a 10 year CVD risk score is calculated. Patients with systolic BP (SBP) or diastolic BP (DBP) ≥ 140 mmHg or 90 mmHg, respectively, have additional blood tests to measure kidney function. If impaired kidney function is detected, that is an estimated glomerular filtration rate (eGFR) < 60 ml/min/1.73 m^2, the blood test is repeated within two weeks to confirm a diagnosis of chronic kidney disease (CKD).[7] Any HC attendee with BMI ≥ 30 kg/m^2 (≥ 25 kg/m^2 in non-white ethnic groups) or SBP or DBP above ≥ 140 mmHg or 90 mmHg, respectively, are also screened for type 2 diabetes mellitus (T2DM) by measuring glycated hemoglobin (HbA1c) or fasting glucose. If CVD risk factors are newly identified or conditions newly diagnosed during the HC, patients are offered appropriate management, including lifestyle advice, treatments and referrals to local services.

The HC programme has been contentious from its inception. There have been concerns of a lack of proven effectiveness to justify the yearly expenditure,[8] which is thought to be around £450 million.[9] A systematic review of randomised controlled trials found that general health checks provide no overall

reduction in CVD or cancer mortality, only an increase in risk factor recording and diagnoses.[10] The initial implementation of the NHS HC programme suffered early problems, such as low uptake,[11] variable implementation,[12] and poor understanding of the aims and purpose of the HC among some invitees.[13] In addition, there were concerns about inequitable distribution of the HC and a resultant widening of health inequalities.[9] Proponents of the NHS HC programme argue that existing randomised trials, the most recent of which started in 1999, are not representative of more effective modern HCs and intervention strategies.[14] In addition, since the early years, participation has increased, with a 2018 study reporting that 48.2% of those invited for a HC have now attended.[15] Strategies have also increased uptake among some deprived and ethnic minority populations to or above the average.[16]

A number of studies have evaluated the effectiveness of the NHS HC programme.[16,17] HC attendance has been associated with increased CVD risk factor recording, detection of hypercholesterolaemia and hypertension, and increased prescribing of statins comparing attendees and matched non-attendees (hazard ratio [HR] 1.58, 95% 1.53–1.63) and antihypertensives (HR 1.06, 95% 1.03–1.10).[17] HC attendees have also been shown to have reduced CVD risk scores, blood pressures and serum lipids a year afterwards.[18] However, a significant limitation of existing studies is that they have used observational data comparing HC attendees and non-attendees. Only a proportion of those invited for a HC actually attend, and those attending are not representative of the eligible population.[16,17] This study aims to evaluate the effect of invitation for a HC (i.e. not just attendance) in terms of uptake and risk factor detection and management in eligible participants.

METHODS

Study population and data source

This study took place in Hampshire, a region in the south of England comprising over 1.5 million residents in a mixture of urban, suburban and rural settings. In Hampshire, the HC is commissioned by three Local Authorities: Southampton City Council, Portsmouth City Council and Hampshire County Council. The two largest urban areas in Hampshire are the cities of Southampton and Portsmouth, each with a population of around 200,000-250,000. There were 151 General Practices that contributed data to this study, around 80% of the total in the region. The organisation of the HC programme in Hampshire involved assigning eligible patients into five separate cohorts. Cohort assignment was based on date

of birth (DOB), although the cohorts had comparable means and distributions of ages. This method of assignment (i.e. based on birth year) constituted a form of "quasi-randomisation".[19] Specifically, patients with years of birth ending in "0" or "5" were assigned to one cohort, "1" or "6" to another cohort, "2" or "7" to another and so forth, mirroring the quinquennial invitation system used for NHS breast cancer screening. The first cohort (cohort 1) was invited for a HC in the year 1st April 2011 to 31st March 2012, while the subsequent cohorts (cohorts 2-5) were invited in the years beginning 1st April 2012-15. The study period was from 1st April 2011 to 31st March 2015. During this time, cohorts 1-4 were invited for HCs. Cohort 5 was eligible for a HC but not invited (i.e. until after the follow-up period ended) and was our control group. We compared outcomes in each of the invited cohorts 1-4 separately against those in cohort 5. The exact follow-up periods depended on the cohorts being compared and are described below.

The population for this study were eligible for a HC on 1st April 2011. This required a DOB between 1st April 1940 - 31st March 1976 and (as of 1st April 2011) (i) no history of vascular disease (e.g. coronary artery disease, cerebrovascular disease, atherosclerosis, peripheral vascular disease (PVD) or circulatory system disease); (ii) no previous diagnosis of hypertension, diabetes, CKD, atrial fibrillation (AF), heart failure (HF), stroke or transient ischaemic attack (TIA); and (iii) no pre-existing records of receiving statins prescription, palliative care, a health check, or CVD risk assessment. These medical eligibility criteria matched the criteria used locally by general practices (GPs) to identify and invite participants to participate in the HC programme. The Read Codes for eligibility and outcomes are included as supplementary information. Using the participants DOBs, we assigned them into cohorts 1-5 to identify the years they were invited for a HC between 1st April 2011 and 31st March 2015 (or not invited in the case of cohort 5). As is explained below, for some analyses, we reapplied the eligibility criteria to identify participants still eligible for a HC at the start of each invitation year.

As there was a temporary pause in sending out HC invitations during the first half of the year beginning 1st April 2012 in the Hampshire County Council Local Authority, we excluded patients belonging to cohort 2 living in that area (~40,000 participants). We excluded patients with no recorded DOB (6,641) or no GP attendance record before 1st April 2011 (26,774), as we assumed that those patients had moved into the area after the start of the follow-up. We excluded patients with medical records not formatted according to Read Codes Version 2 (~70,000). In total, we excluded around 35% of the population.

We acquired data for this study from the Hampshire Health Record Analytical database (HHRA). At the time of the study, the HHRA linked anonymised clinical records from 151 primary care practices, secondary care (e.g. inpatient, outpatient, and accident and emergency) from 3 acute (hospital) NHS trusts, and laboratory and pathology tests. The HHRA also contained deprivation indices for the populations served by the included GP practices. The HHRA covers a registered population of around 1.5 million patients. Unfortunately, the organisation or the HHRA is such that some patients who die are removed from the database. As such, we did not use mortality or CVD events, which frequently result in death, as outcomes.

Information extracted and outcome measures

For each participant, we extracted from HHRA data concerning HC attendance, age, gender and individual level deprivation (IMD) at baseline. Ethnicity was poorly recorded (50% missing) and, in any case, this information was not released for analysis due to concerns about identifiability. We extracted data for the following outcomes: (i) recording of BP, total serum cholesterol (TC), smoking status (i.e., "current smoker", "ex-smoker", and "never smoker"), BMI, and 10-year CVD risk score (e.g. Framingham and QRISK); (ii) detection of CVD risk score >10%, CVD risk score >20%, current smoker, TC >5.5 mmol/L, TC >7.5 mmol/L, and BMI >30 kg/m^2; (iii) new diagnoses of hypertension, AF, diabetes and CKD (≥ stage 3); and (iv) new interventions with statins, antihypertensives, antiglycaemic medication, nicotine replacement therapy (NRT), anti-obesity medication, stop-smoking advice/referral and weight management advice/referral. We identified outcomes only where corresponding Read Codes had been recorded (e.g. we did not assume that BMI had been measured just because a weight management referral had been made). Data were extracted from the HHRA in January 2017.

Follow-up periods and statistical analysis

For each cohort overall and for HC attendees / non-attendees within each cohort separately, we calculated baseline means and standard deviations of age, gender and IMD. We calculated proportions (%) with outcomes occurring between 1st April 2011 and 31st March 2015. We calculated absolute differences in these proportions for each of cohorts 1-4 vs. 5 (i.e. invited vs non-invited) as well as the range (i.e. of absolute differences for cohorts 1-4 vs. 5). We also compared proportions with outcomes among attendees and non-attendees. Given the large sample sizes, p-values for differences in proportions were generally highly significant and, thus, not reported.

In the second stage of our analysis, we calculated odds ratios (ORs) for each outcome. We employed multivariable logistic regression models adjusted for age and gender. We calculated ORs for each invited cohort (i.e. cohorts 1-4) separately, with the reference being uninvited cohort 5. The rationale for this approach was to capture changes in performance over a time period when awareness and experience among patients and providers was increasing. Evaluation of earlier years (e.g. cohort 1) is still of interest because of longer follow-up, but the most recently invited cohort (i.e. cohort 4) may be most reflective of current practice. Finally, to examine whether the impact of the programme differed by deprivation, we re-ran the regression analysis for the most recently invited cohort (i.e. cohort 4) vs. uninvited cohort 5 while including an interaction term for IMD.

All analyses were by intention-to-treat. We did sensitivity analysis by excluding those who attended opportunistically. In these analyses, follow-up was from the start of the invitation year of the invited cohort until 31st March 2015. Specifically, for cohorts 1-4 vs. 5, follow-up periods were from 1st April 2011, 1st April 2012, 1st April 2013, 1st April 2014, respectively, until 31st March 2015. We included only participants still eligible at the start of the invitation year. As invitations were sent out throughout each year rather than all at the start, participants were invited on average six months from the start of their invitation years. This corresponds to follow-up periods for comparisons of cohorts 1-4 vs. 5, respectively, of 3.5, 2.5, 1.5 and 0.5 years. This study received ethical approval from the Research Ethics Committee at the University of Southampton ID: 24358) and approval from the Hampshire Health Record Information Governance Group. Data extraction was implemented using SQL server 2008 R2, and statistical analyses were conducted using R (Version 3.5.1, R Foundation for Statistical Computing, Vienna, Austria).[20]

Patient and public involvement

There were no patients directly involved in the planning or design of this study.

RESULTS

Study sample and baseline characteristics

The derivation of the study population and five cohorts is shown in figure 1. 399,420 met our inclusion criteria and had medical records formatted as Read Codes Version 2. From those, we excluded 6,641 without a recorded DOB and a further 26,774 patients without entries in their health records from before 1st April 2011 who likely moved into Hampshire after the start of the follow-up period. The remaining

366,005 participants formed our study population. Table 1 summarises their baseline characteristics broken down into cohorts 1-5. The cohorts had similar proportions of male gender (within 1%) and mean deprivation scores (within one centile). The cohorts differed more markedly in mean age, although the maximum difference was just 3 years between cohorts 1 and 5. The age differences reflected the HC invitation system in Hampshire which, as is described above, is based on DOB. However, figure 2 comprises histograms showing broadly similar distributions of ages within each cohort.

Table 1. Demographic information of the five cohorts overall and broken down into HC attendees and non-attendees within each cohort.

	Cohort 1			Cohort 2			Cohort 3			Cohort 4			Cohort 5		
	All	Att	DNA	All	Att	DNA	All	Att	DNA	All	Att	DNA	All	Att*	DNA
n	**76146**	9464	66682	**39232**	9868	29364	**80220**	19991	60229	**81676**	21188	60488	**88731**	4232	84499
% male	**47.5**	45.6	47.8	**46.5**	40.7	48.3	**47.0**	41.0	49.0	**47.4**	41.9	49.3	**47.2**	48.0	47.1
Age range	**(40, 70)**	(40, 70)	(40, 70)	**(39, 69)**	(39, 69)	(39, 69)	**(38, 68)**	(38, 68)	(38, 68)	**(37, 67)**	(37, 67)	(37, 67)	**(36, 71)**	(36, 71)	(36, 71)
Mean age (SD)	**51(9.0)**	54(9.9)	50(8.7)	**50(9.1)**	53(9.5)	49(8.7)	**49(9.0)**	52(9.6)	48(8.6)	**48(9.9)**	51(9.4)	47(8.8)	**48(9.5)**	59(10.4)	48(9.5)
Mean IMD decile (SD)	**7.3(2.6)**	7.8(2.4)	7.3(2.6)	**7.3(2.6)**	7.9(2.3)	7.2(2.7)	**7.3(2.6)**	7.7(2.4)	7.2(2.7)	**7.3(2.6)**	7.7(2.4)	7.2(2.7)	**7.3(2.6)**	7.5(2.6)	7.3(2.6)

Attended (Att), number (n), did not attend (DNA), standard deviation (SD), Index of Multiple Deprivation (IMD - 1 = most deprived decile, 10 = least deprived), *some participants in cohort 5 attended a HC opportunistically (i.e. without receiving a formal invitation)

HC attendees in all cohorts were more likely to be female, older and less deprived compared to those who did not attend (Table 1). Proportions within each invited cohort (i.e. cohorts 1-4) attending HCs increased year on year during the follow-up, and for cohorts 1-4 were 12%, 27%, 28% and 30%, respectively. Despite not being formally invited, a number of patients in cohort 5 attended a HC during the follow-up period. These patients had likely responded to local or national advertising for the HC programme or had been offered HCs opportunistically by their GPs.

Proportions of risk factor recording, detection, diagnoses and interventions

Table 2 summarises the proportions of patients with recording and detection of risk factors, new diagnoses, and new interventions during the follow-up period, which varied by cohort. The results are shown for each cohort overall and separately for attendees and non-attendees within each cohort. Proportions generally increased year on year for cohorts 1-4, reflecting increasing attendance, and were lowest in the uninvited cohort 5. There were increases in absolute proportions in invited cohorts 1-4 with recorded BP (range for cohorts 1-4 vs. 5 = 5.0%-7.9%), BMI (5.0%-13.4%), TC (8.4%-17.5%), CVD risk (7.3%-19.6%) and smoking status (2.8%-7.0%). In addition, there was increased detection of CVD risk >10% (2.0%-3.6%), SBP >140 / DBP >90 (0.9%-2.1%), BMI >30 kg/m^2 (0.8%-2.5%), TC >5.5 mmol/L (4.1%-7.0%) and TC >7.5 mmol/L (0.3%-0.4%). There were modest or no consistent differences in proportions with detected CVD risk >20% (0.0%-0.6%) and current smoking (–0.2%-0.5%).

The proportions with detection of risk factors among those with recordings were lower in the invited cohorts (i.e. 1-4) compared to uninvited cohort 5, particularly for CVD risk >10% (–11.5% - –2.8%), >20% (–6.1% - –1.8%) and BMI >30 kg/m^2 (–2.8% - –1.1%). Even though smaller absolute numbers of high-risk patients were identified by opportunistic testing, these data suggest a higher positive predictive value of opportunistic testing compared to the HC, which may reflect different risk profiles of patients.

HC resulted in minor or no increases in proportions with new diagnoses of hypertension (0.3%-0.6%), AF (0.0%-0.1%), CKD (0.1%) or diabetes (0.0%-0.1%). There were minor increases in proportions receiving statins (0.3%-1.0%), antihypertensives (0.1%-0.6%) and stop smoking advice (0.4%-0.9%), but no consistent difference in antiglycaemics (-0.1%-0.1%), NRT (0.0%) or anti-obesity medications (0.0%). There was an increase in weight advice / referrals (4.6%-10.5%).

Table 2. Proportions of participants with risk factor recording / detection, new diagnoses and new interventions in each of the five cohorts overall and for HC attendees and non-attendees within each cohort separately.

	C1			C2			C3			C4			C5		
	All	Att	DNA	**All**	Att	DNA	**All**	Att	DNA	**All**	Att	DNA	**All**	Att	DNA
RECORDING %															
BP	**72.3**	98.6	68.5	**75.2**	98.6	67.3	**74.3**	98.7	66.3	**73.3**	98.6	64.4	**67.3**	99.1	65.7
BMI	**48.4**	97.7	41.4	**56.5**	98.5	42.3	**56.5**	98.5	42.5	**56.8**	98.6	42.2	**43.4**	98.0	40.6
TC	**41.5**	97.6	33.6	**49.5**	97.1	33.6	**49.4**	97.0	33.6	**50.6**	97.2	34.2	**33.1**	96.1	30.0
CVD risk	**23.0**	89.0	13.7	**32.8**	89.4	13.8	**33.2**	89.1	14.7	**35.3**	92.3	15.3	**15.7**	90.2	11.9
Smoking status	**71.8**	98.5	68.1	**75.8**	98.9	68.0	**75.7**	98.7	68.1	**76.0**	98.4	68.2	**69.0**	98.7	67.6
DETECTION %															
CVD risk >10%	**7.7**	29.0	4.7	**9.3**	23.0	4.7	**9.0**	22.2	4.6	**8.8**	20.7	4.6	**5.7**	44.5	3.8
% of CVD risk recorded with >10%	**33.6**	32.6	34.5	**28.4**	25.7	34.3	**27.0**	24.9	31.1	**24.9**	22.5	30.1	**36.4**	49.3	31.5
CVD risk >20%	**2.2**	8.1	1.3	**2.4**	5.2	1.4	**2.1**	4.4	1.3	**1.8**	3.6	1.2	**1.8**	15.0	1.1
% of CVD risk recorded with >20%	**9.4**	9.1	9.6	**7.2**	5.8	10.1	**6.3**	5.0	9.1	**5.1**	3.9	7.8	**11.2**	16.6	9.1
SBP >140 or DBP > 90 mmHg	**17.8**	24.6	16.8	**17.5**	20.1	16.6	**17.3**	20.6	16.3	**16.6**	19.7	15.6	**15.7**	29.9	14.9
% of BP recorded with >140 or >90	**24.6**	25.0	24.5	**23.3**	20.4	24.7	**23.3**	20.8	24.5	**22.7**	20.0	24.2	**23.3**	30.2	22.7
Current smoker	**20.7**	17.0	21.2	**20.8**	14.6	22.8	**20.9**	14.4	23.1	**21.4**	16.3	23.2	**20.9**	18.4	21.1
% of smoking status recorded who currently smoke	**28.8**	17.3	31.1	**27.4**	14.8	33.6	**27.6**	14.6	33.9	**28.2**	16.6	34.1	**30.3**	18.6	31.2
BMI >30 kg/m^2	**12.6**	18.0	11.9	**13.9**	17.6	12.7	**13.8**	17.9	12.4	**14.3**	19.7	12.3	**11.8**	20.1	11.4
% BMI recoded with >30	**26.1**	18.5	28.7	**24.7**	17.9	30.0	**24.4**	18.2	29.1	**25.1**	20.0	29.2	**27.2**	20.5	28.0
TC >5.5 mmol/L	**19.1**	44.1	15.5	**22.0**	43.1	14.9	**21.4**	41.4	14.8	**21.6**	39.8	15.2	**15.0**	48.8	13.3
% of TC recorded with >5.5 mmol/L	**46.0**	45.2	46.2	**44.3**	44.4	44.3	**43.3**	42.7	43.9	**42.7**	40.9	44.4	**45.3**	50.8	44.4
TC >7.5 mmol/L	**1.4**	2.7	1.2	**1.5**	2.4	1.2	**1.5**	2.5	1.1	**1.5**	2.3	1.3	**1.1**	3.3	1.0
% of TC recorded with >7.5 mmol/L	**3.3**	2.8	3.6	**3.1**	2.5	3.6	**3.0**	2.6	3.3	**3.1**	2.4	3.8	**3.4**	3.4	3.4
DIAGNOSES %															
Hypertension	**4.2**	4.7	4.1	**4.1**	3.7	4.3	**3.9**	3.0	4.2	**4.0**	2.5	4.5	**3.6**	6.5	3.5
% of SBP >140 or DBP > 90 with hypertension diagnosis	**18.0**	15.1	18.7	**17.7**	13.6	19.3	**17.5**	11.5	20.1	**17.8**	9.3	21.6	**17.3**	16.4	17.4
AF	**0.5**	0.5	0.5	**0.4**	0.4	0.4	**0.4**	0.4	0.5	**0.4**	0.2	0.4	**0.4**	0.9	0.3
CKD	**0.3**	0.3	0.3	**0.3**	0.4	0.3	**0.3**	0.2	0.3	**0.3**	0.1	0.3	**0.2**	0.6	0.2
Diabetes	**1.3**	0.9	1.3	**1.2**	0.7	1.4	**1.3**	0.6	1.5	**1.3**	0.6	1.6	**1.2**	1.2	1.2
INTERVENTIONS %															
Statin	**4.9**	7.7	4.5	**5.0**	5.6	4.8	**4.4**	4.5	4.4	**4.3**	3.3	4.6	**4.0**	13.0	3.6
% of CVD>10% prescribed statins	**22.5**	16.5	27.8	**18.8**	12.7	28.8	**17.6**	11.4	27.5	**16.2**	9.3	27.0	**23.6**	19.0	26.2
% of CVD>20% prescribed statins	**40.7**	31.5	48.8	**37.9**	28.7	49.4	**38.2**	27.4	50.2	**36.5**	23.0	50.8	**41.9**	33.9	47.5
Antihypertensive	**7.6**	8.0	7.5	**7.7**	6.9	7.9	**7.3**	6.1	7.7	**7.2**	5.8	7.7	**7.1**	10.6	6.9
% of hypertensives prescribed antihypertensive	**78.5**	79.6	78.3	**78.5**	77.7	78.7	**78.4**	79.3	78.2	**77.7**	77.3	77.8	**78.3**	85.0	77.7
Antiglycaemics	**1.1**	0.7	1.2	**1.0**	0.6	1.2	**1.1**	0.5	1.3	**1.2**	0.5	1.4	**1.1**	1.1	1.1
% of diabetics prescribed antiglycaemics	**74.2**	66.7	74.9	**74.4**	66.7	75.7	**74.9**	60.5	76.9	**73.2**	59.2	75.1	**76.7**	73.1	76.9
NRT	**1.1**	0.9	1.1	**1.1**	0.9	1.2	**1.1**	0.8	1.2	**1.1**	0.8	1.2	**1.1**	1.2	1.1
% of current smokers prescribed NRT	**4.6**	4.7	4.5	**4.7**	5.2	4.6	**4.7**	5.1	4.7	**4.6**	4.4	4.6	**4.6**	6.2	4.6
Stop smoking advice	**7.4**	9.9	7.1	**7.9**	8.5	7.8	**7.6**	7.7	7.5	**7.7**	8.4	7.5	**7.0**	10.3	6.9

% of current smokers given advice	**22.8**	26.8	22.4	**23.7**	24.5	23.5	**22.7**	23.5	22.6	**22.7**	23.8	22.5	**22.3**	25.3	22.1
Weight advice/referral	**12.9**	55.5	6.8	**18.3**	52.3	6.8	**18.4**	51.7	7.4	**18.8**	49.6	8.0	**8.3**	55.7	5.9
% of BMI>30 kg/m^2 given advice/referal	**26.8**	63.2	19.0	**31.5**	60.1	18.2	**33.3**	60.0	20.6	**34.4**	57.7	21.3	**20.8**	60.8	17.2
Anti-obesity	**0.3**	0.2	0.3	**0.3**	0.2	0.4	**0.3**	0.3	0.3	**0.3**	0.3	0.3	**0.3**	0.2	0.3
% of BMI>30 kg/m^2 prescribed anti-obesity	**1.8**	1.0	2.0	**2.0**	0.9	2.5	**1.8**	1.2	2.1	**1.8**	1.0	2.2	**2.1**	0.7	2.2

Attended (Att), Blood pressure (BP), body mass index (BMI), total cholesterol (TC), cardiovascular disease (CVD), systolic blood pressure (SBP), diastolic blood pressure (DBP), atrial fibrillation (AF), chronic kidney disease (CKD), Nicotine replacement therapy (NRT)

Proportions receiving statins were lower among HC invited cohorts compared to non-invited following detection of CVD risk >10% (–7.4% - –1.1%) and >20% (–5.4% - –1.2%). Similarly, antiglycaemic interventions among new cases of diabetes were lower (–3.5% - –1.8%), as were new anti-obesity prescriptions following detection of BMI >30 kg/m^2 (–0.3% - –0.1%). Differences in proportions receiving antihypertensives following new hypertension diagnoses were inconsistent (–0.6% - 0.2%), but there was an increase in proportions among HC invitees receiving weight advice / referral following detection of BMI >30 kg/m^2 (6.0%-13.6%).

Odds ratios of risk factor detection, diagnoses and interventions

Table 3 summarises the ORs and 95% confidence intervals from the regression analyses. Compared to uninvited cohort 5 (including and excluding those who attended opportunistically), the odds of detection of risk factors, new diagnoses and interventions were generally higher in invited cohorts 1-4, and they increased year on year throughout the study period. For cohort 4 vs. 5, there were large and significant increases in the odds of detecting CVD risk >10% (OR 8.01, 7.34-8.73), CVD risk >20% (OR 5.86, 4.83-7.10) TC >5.5 mmol/L (OR 3.72, 3.57-3.89), TC >7.5 mmol/L (OR 2.89, 2.46-3.38) and BMI > 30 kg/m^2 (OR 2.05, 1.96-2.14). These may be conservative given that the average follow-up was just 6 months, and for some participants almost none, while many outcomes from the HC would likely take longer to occur. There were significant increases in detection of current smokers (OR 1.22, 1.18-1.26) and elevated BP (OR 1.64, 1.57-1.70). There were modest increases in new diagnoses of hypertension (OR 1.33, 1.20-1.47) and diabetes (OR 1.34, 1.12-1.61), but not AF (OR 1.00, 0.72-1.39) or CKD (OR 0.69, 0.36-1.32). In terms of new interventions, there were increases in weight advice / referrals (OR 8.36, 7.89-8.86), stop smoking advice (OR 1.65, 1.51-1.79), statins (OR 1.54, 1.39-1.71) and antihypertensives (OR 1.15, 1.06-1.24). The ORs of CVD risk >10% plus statin or >20% plus statin, respectively, were 2.90 (2.36-3.57) and 2.60 (1.92-3.52). The OR of hypertension diagnosis plus antihypertensive treatment was 1.33 (1.18-1.50). There were no significant differences in prescriptions of NRT (OR 0.92, 0.71-1.20), antiglycaemics (OR 1.18, 0.97-1.44) or anti-obesity medications (OR 1.00, 0.68-1.48).

Table 3. Age and gender adjusted odds ratios with 95% confidence intervals for associations between invitation for an NHS health check and the detection of CVD risk factors, new diagnoses and interventions. Results are shown for the comparisons of cohorts 1-4 against all of cohort 5 and against patients in cohort 5 who we confirmed did not attend (DNA) a HC incidentally.

	Cohort1 vs		Cohort2 vs		Cohort3 vs		Cohort4 vs	
	Cohort5 All	Cohort5 DNA	Cohort5 All	Cohort5 DNA	Cohort5 All	Cohort5 DNA	Cohort5 All	Cohort5 DNA
DETECTION %								
CVD risk >10%	1.20 (1.15-1.25)	1.71 (1.64-1.80)	1.93 (1.82-2.04)	2.66 (2.50-2.83)	3.28 (3.08-3.50)	3.98 (3.71-4.27)	8.01 (7.34-8.73)	11.17 (10.13-12.33)
CVD risk >20%	1.07 (0.99-1.15)	1.49 (1.37-1.63)	1.44 (1.29-1.61)	1.90 (1.69-2.15)	2.83 (2.48-3.23)	3.12 (2.72-3.58)	5.86 (4.83-7.10)	7.18 (5.82-8.85)
SBP >140 or DBP > 90 mmHg	1.04 (1.01-1.07)	1.06 (1.03-1.09)	1.08 (1.05-1.12)	1.10 (1.06-1.14)	1.23 (1.19-1.27)	1.26 (1.21-1.30)	1.64 (1.57-1.70)	1.69 (1.62-1.76)
Current smoker	1.03 (1.01-1.06)	1.03 (1.01-1.06)	1.05 (1.02-1.09)	1.05 (1.02-1.09)	1.05 (1.02-1.08)	1.05 (1.03-1.08)	1.22 (1.18-1.26)	1.23 (1.19-1.27)
BMI >30 kg/m^2	1.09 (1.06-1.12)	1.14 (1.11-1.18)	1.26 (1.21-1.31)	1.31 (1.26-1.36)	1.46 (1.41-1.51)	1.52 (1.47-1.58)	2.05 (1.96-2.14)	2.18 (2.09-2.28)
TC >5.5 mmol/L	1.19 (1.16-1.23)	1.33 (1.29-1.37)	1.67 (1.61-1.72)	1.83 (1.77-1.90)	2.10 (2.03-2.17)	2.27 (2.19-2.34)	3.72 (3.57-3.89)	4.20 (4.02-4.39)
TC >7.5 mmol/L	1.12 (1.02-1.22)	1.19 (1.08-1.30)	1.42 (1.26-1.59)	1.52 (1.35-1.71)	1.66 (1.47-1.87)	1.76 (1.56-1.99)	2.89 (2.46-3.38)	3.15 (2.67-3.72)
DIAGNOSES %								
HTN	1.04 (0.99-1.09)	1.03 (0.98-1.09)	1.06 (0.98-1.14)	1.04 (0.97-1.12)	1.10 (1.02-1.19)	1.10 (1.02-1.19)	1.33 (1.20-1.47)	1.34 (1.20-1.48)
AF	1.14 (0.98-1.32)	1.11 (0.95-1.30)	0.91 (0.72-1.14)	0.89 (0.71-1.13)	1.33 (1.06-1.67)	1.31 (1.05-1.65)	1.00 (0.72-1.39)	1.01 (0.72-1.40)
CKD	1.01 (0.84-1.22)	0.98 (0.81-1.19)	1.22 (0.93-1.61)	1.18 (0.90-1.57)	1.08 (0.77-1.51)	1.06 (0.76-1.49)	0.69 (0.36-1.32)	0.68 (0.36-1.30)
Diabetes	0.99 (0.91-1.08)	0.97 (0.88-1.06)	0.95 (0.84-1.09)	0.94 (0.82-1.07)	1.12 (0.99-1.28)	1.12 (0.98-1.27)	1.34 (1.12-1.61)	1.36 (1.13-1.64)
INTERVENTIONS %								
Statin	1.06 (1.01-1.11)	1.12 (1.06-1.18)	1.17 (1.09-1.25)	1.21 (1.13-1.30)	1.26 (1.16-1.35)	1.27 (1.18-1.37)	1.54 (1.39-1.71)	1.58 (1.42-1.76)
Antihypertensive	0.99 (0.95-1.03)	0.99 (0.95-1.03)	1.04 (0.99-1.10)	1.04 (0.98-1.09)	1.04 (0.98-1.10)	1.04 (0.98-1.10)	1.15 (1.06-1.24)	1.15 (1.07-1.24)
Antiglycaemics	0.93 (0.85-1.02)	0.92 (0.83-1.01)	0.90 (0.79-1.04)	0.90 (0.78-1.03)	1.04 (0.91-1.20)	1.03 (0.90-1.19)	1.18 (0.97-1.44)	1.19 (0.97-1.45)
Nicotine	1.00 (0.91-1.10)	1.01 (0.92-1.11)	1.05 (0.91-1.22)	1.07 (0.92-1.24)	1.04 (0.88-1.22)	1.08 (0.91-1.28)	0.92 (0.71-1.20)	0.96 (0.73-1.25)
Stop smoking advice	1.08 (1.04-1.12)	1.12 (1.08-1.16)	1.19 (1.13-1.26)	1.23 (1.17-1.30)	1.28 (1.20-1.35)	1.32 (1.25-1.40)	1.65 (1.51-1.79)	1.74 (1.60-1.90)
Weight advice/referral	1.50 (1.45-1.55)	2.14 (2.07-2.22)	2.84 (2.73-2.95)	3.98 (3.81-4.16)	4.21 (4.04-4.40)	5.69 (5.42-5.98)	8.36 (7.89-8.86)	14.33 (13.31-15.43)

Anti-obesity	1.06	(0.88-1.26)	1.06	(0.88-1.27)	1.11	(0.85-1.44)	1.11	(0.85-1.44)	1.09	(0.83-1.44)	1.08	(0.82-1.42)	1.00	(0.68-1.48)	1.00 (0.68-1.49)
CVD>10% and statin	1.12	(1.03-1.21)	1.35	(1.24-1.48)	1.27	(1.12-1.43)	1.49	(1.31-1.70)	1.78	(1.54-2.07)	1.90	(1.63-2.21)	2.90	(2.36-3.57)	3.27 (2.63-4.06)
CVD>20% and statin	1.03	(0.92-1.15)	1.25	(1.11-1.42)	1.07	(0.90-1.28)	1.28	(1.06-1.54)	1.58	(1.29-1.94)	1.67	(1.36-2.06)	2.60	(1.92-3.52)	2.95 (2.15-4.04)
HTN and antihypertensive	1.04	(0.98-1.10)	1.04	(0.98-1.10)	1.06	(0.97-1.15)	1.05	(0.96-1.14)	1.11	(1.02-1.21)	1.11	(1.02-1.21)	1.33	(1.18-1.50)	1.33 (1.18-1.50)

Body mass index (BMI), total cholesterol (TC), cardiovascular disease (CVD), systolic blood pressure (SBP), diastolic blood pressure (DBP), atrial fibrillation (AF), chronic kidney disease (CKD), hypertension (HTN)

Table 4 shows demographics of participants in cohort 4 that were eligible at the beginning of their invitation year stratified according to national IMD quintile. There was a disproportionately high number of participants in the least deprived quintile, which reflected the affluence of the study area compared to the national average. The proportion attending a HC was also highest in this quintile. Table 5 shows ORs for outcomes in invited cohort 4, with reference to uninvited cohort 5, stratified according to national IMD quintile. The effects of IMD were significant (at the p=0.05 level) between IMD and detection of: 10 year CVD risk >10%, SBP >140 or DBP > 90 mmHg, BMI >30 kg/m^2, TC >5.5 mmol/L and TC >7.5 mmol/L as well as weight advice / referral.

Table 4. Numbers of participants and proportions of males and HC attendees in cohort 4 according to national IMD quintile, wherein quintile 5 is the least deprived.

	Q1	Q2	Q3	Q4	Q5
n	3775	9083	10792	15098	30238
% male	50.8	49.5	47.5	46.4	45.8
% attended HC	24.1	26.7	32.9	37.2	40.7

Quintile (Q – 1 = most deprived, 5 = least deprived), n (number of participants), HC (health check)

Table 5 Age and gender adjusted odds ratios with 95% confidence intervals for associations between invitation for an NHS health check and the detection of CVD risk factors, new diagnoses and interventions. Results are shown for invited cohort 4, with reference to uninvited cohort 5, stratified according to IMD quintile, wherein quintile 5 is the least deprived. The outcomes with a significant interaction (p<0.05) with IMD are shown in bold.

DETECTION	Q1	Q2	Q3	Q4	Q5
CVD risk >10%	**3.02 (2.14-4.28)**	**6.15 (4.78-7.90)**	**7.82 (6.21-9.84)**	**7.99 (6.67-9.58)**	**9.67 (8.49-11.03)**
CVD risk >20%	3.99 (1.88-8.48)	5.30 (3.11-9.01)	6.96 (4.05-11.96)	7.21 (4.63-11.21)	5.56 (4.22-7.33)

SBP >140 or DBP > 90 mmHg	**1.36 (1.13-1.63)**	**1.45 (1.30-1.63)**	**1.57 (1.42-1.74)**	**1.70 (1.56-1.85)**	**1.71 (1.61-1.82)**
Current smoker	1.17 (1.06-1.30)	1.16 (1.08-1.25)	1.25 (1.16-1.35)	1.25 (1.17-1.35)	1.25 (1.18-1.33)
BMI >30 kg/m^2	**1.59 (1.36-1.86)**	**1.96 (1.75-2.20)**	**2.12 (1.91-2.36)**	**1.93 (1.75-2.12)**	**2.24 (2.08-2.41)**
TC >5.5 mmol/L	**2.41 (2.02-2.87)**	**3.01 (2.67-3.39)**	**3.37 (3.04-3.74)**	**3.76 (3.43-4.11)**	**4.30 (4.03-4.59)**
TC >7.5 mmol/L	**1.10 (0.63-1.93)**	**3.47 (2.10-5.75)**	**2.09 (1.44-3.03)**	**3.55 (2.44-5.16)**	**3.39 (2.66-4.34)**
DIAGNOSES					
HTN	1.65 (1.04-2.62)	1.22 (0.92-1.61)	1.43 (1.12-1.82)	1.23 (0.99-1.54)	1.34 (1.14-1.57)
AF	1.77 (0.29-10.65)	0.56 (0.19-1.64)	1.08 (0.50-2.30)	0.98 (0.50-1.92)	1.08 (0.65-1.79)
CKD	NA*	3.36 (0.35-32.44)	0.67 (0.20-2.31)	0.48 (0.12-1.86)	0.37 (0.10-1.36)
Diabetes	1.32 (0.72-2.45)	1.29 (0.83-2.01)	1.02 (0.67-1.55)	1.15 (0.74-1.78)	1.74 (1.27-2.37)
INTERVENTIONS					
Statin	1.46 (1.00-2.12)	1.39 (1.06-1.82)	1.37 (1.06-1.77)	1.50 (1.19-1.89)	1.76 (1.48-2.09)
Anti-hypertensive	1.20 (0.90-1.60)	1.17 (0.95-1.43)	1.19 (0.99-1.43)	1.14 (0.96-1.35)	1.13 (1.00-1.27)
Antiglycaemics	1.15 (0.60-2.22)	1.05 (0.65-1.69)	1.04 (0.66-1.63)	1.04 (0.63-1.70)	1.44 (1.03-2.00)
Nicotine replace	1.54 (0.75-3.17)	0.54 (0.28-1.03)	1.14 (0.63-2.08)	0.63 (0.36-1.09)	1.31 (0.75-2.28)
Stop smoking advice	1.84 (1.33-2.54)	1.46 (1.18-1.81)	1.48 (1.23-1.79)	1.62 (1.34-1.95)	1.82 (1.58-2.10)
Weight advice/referral	**4.48 (3.60-5.59)**	**6.42 (5.47-7.53)**	**7.68 (6.63-8.89)**	**8.17 (7.21-9.25)**	**10.21 (9.32-11.18)**
Anti-obesity	0.82 (0.29-2.32)	0.56 (0.21-1.48)	0.95 (0.44-2.05)	1.09 (0.45-2.62)	2.16 (0.87-5.36)
CVD risk >10% and statin	1.14 (0.48-2.70)	3.32 (1.94-5.66)	2.53 (1.52-4.20)	3.00 (1.90-4.71)	3.24 (2.34-4.49)
CVD risk >20% and statin	1.49 (0.45-4.96)	3.12 (1.52-6.41)	2.20 (1.00-4.85)	3.25 (1.55-6.81)	2.57 (1.63-4.05)
HTN and anti-hypertensive	1.35 (0.77-2.35)	1.35 (0.97-1.87)	1.21 (0.91-1.60)	1.26 (0.96-1.65)	1.41 (1.17-1.70)

*Insufficient data, Quintile (Q – 1 = most deprived, 5 = least deprived), body mass index (BMI), total cholesterol (TC), cardiovascular disease (CVD), systolic blood pressure (SBP), diastolic blood pressure (DBP), atrial fibrillation (AF), chronic kidney disease (CKD), hypertension (HTN)

DISCUSSION

This study evaluated the NHS HC programme in Hampshire from its implementation in April 2011 until March 2015. HC attendance following invitation increased year on year and as of 2015 was 30%. Attendees were older, from less deprived backgrounds and less likely to be male than those who were invited but chose not to attend. A significant finding was the large increase of up to 17.5% in the proportion of patients with measurements of TC among HC invited cohorts compared to non-invited. As might be expected, this led to large increases in detection of elevated TC >5.5 mmol/L and CVD risk >10%, as well as TC >7.5 mmol/L and CVD risk >20%. Notwithstanding, there were only modest increases in detection plus treatment with statins. Explanations for this might include guidance during the study period recommending statins for CVD risk >20%, whereas the largest increased was in detection of CVD risk > 10%. Nonetheless, even among those with CVD risk >20% only 36.5%-40.7% (range for the invited cohorts) of participants were prescribed statins. This is substantially lower than the 85% used in modelling studies by the Department of Health.[5] In the uninvited group, rates of statin prescriptions following identification of CVD risk >20% were slightly higher (41.9%), but still lower than expected. Accordingly, there may be a more general issue relating to the step up from risk factor identification to diagnosis, and from diagnosis to treatment across general practice that would represent a missed opportunity at a population level for primary prevention of CVD. More specifically to the HC, there is a lack of a defined follow-up pathway following identification of increased 10-year CVD risk. Public Health England commissions and pays for the HC itself but follow-up is then a cost to General Practices which maybe a barrier.

Statin prescription rates may have increased since the study period, as updated National Institute for Health and Care Excellence (NICE) guidance now recommends statins for CVD risk >10% and a recent large and well-publicised review reported a more favourable risk / benefit profile of statins than thought previously.[21] Statin prescription rates resulting from a HC may also be higher outside of Hampshire, as they are known to vary locally.[22]

Other notable findings of this study included increased detection of elevated BP among HC invited cohorts, as well as modest increases in new diagnoses of hypertension and treatment. Those attending HCs were more likely to be diagnosed with diabetes, but the corresponding increase in prescriptions of antiglycaemics did not reach significance. According to HC guidance, diabetes screening is performed only in those deemed “at risk” with BMI ≥ 30 kg/m^2 (≥ 25 kg/m^2 in non-white ethnic groups) or SBP or DBP above ≥ 140 mmHg or 90 mmHg. Data regarding the sensitivity of these criteria are limited, but one study in the United States reported that a BMI cut off of ≥ 25 kg/m^2 “would miss 36% of Asian Americans with newly diagnosed type 2 diabetes”,[23] so the HC may also have missed cases.

There was no significant increase in new diagnoses of CKD. This was likely because kidney function tests were performed only in HC patients with SBP or DBP ≥ 140 mmHg or 90 mmHg. A formal diagnoses of CKD would have required a repeat blood test, something which would need to have been organised by the GP and agreed to by the patient.

The HC did not result in any significant increase in new diagnoses of AF. NICE Hypertension clinical guideline 127 states that practitioners should manually palpate the pulse before measuring blood pressure.[24] However, this may not have been performed consistently or reliably during the HC. Manual palpation is not necessary with electronic sphygmomanometers, and any patient with an irregular pulse would have further required an electrocardiogram (ECG) to diagnose AF.

There were increases in detection of smokers and BMI >30 kg/m^2, as well as corresponding increases in lifestyle advice / referrals, particularly for high BMI. However, there was no significant difference in NRT or anti-obesity medications.

The HC had lower positive predictive values (or yield) for detection of risk factors than checks performed opportunistically. Most notably, lower proportions of CVD risk scores measured during the HC were >10% (–11.5% - –2.8%) and >20% (–6.1% - –1.8%). This may have been because GPs targeted opportunistic checks at those who were already symptomatic or because HC attendees were healthier with a lower prevalence of risk factors. A recent cohort study of 18 general practices in South London also found that participants taking up an opportunistic HC were at higher CVD risk (17% of invited HC and 22% of opportunistic HC with CVD risk score ≥10%), and that in younger adults in more deprived areas the opportunistic HC constituted a higher proportion of all HC performed. It was concluded that GPs were successfully targeting groups at higher risk who may otherwise face barriers to attendance at a pre-arranged HC.[25]

In the final year of this study, uptake of the HC was highest among participants in the least deprived national IMD quintile (40.7%) and lowest in the most deprived (24.1%). There was evidence of better performance of the HC among less deprived participants for detection of 10-year CVD risk >10%, SBP >140 mmHg or DBP > 90 mmHg, BMI, TC >5.5 mmol/L and TC >7.5 mmol/L and weight advice / referral. However, the precise effect of deprivation was difficult to estimate given the competing effects of differences in HC uptake (lowest in the most deprived quintile), the frequency of risk variable (highest in the most deprived quintile) and differing sample sizes (i.e. power to test / reject the null hypothesis). Primary care management may also have played a role, but the lack of difference by deprivation in prescribing rates in those detected suggests this was not a key factor.

Our findings build on existing evidence that attendees tend to be older, female and non-smokers.[16,26] The observation in this study that HC attendees were from less deprived socioeconomic groups is reflected by some studies[27] though not others.[16,26]. Reasons for an inconsistent effect on deprivation are unclear, but may relate to targeting of at risk groups, which has been shown to improve uptake and is likely to vary locally.[22]

Earlier studies report associations between HC attendance and increased recording and detection of CVD risk factors and use of interventions[17]. It has also been shown that a year after completing a HC, attendees have modest but significant reductions in CVD risk scores, diastolic blood pressure, TC levels and lipid ratios.[18] However, Chang et al. [26] found that only a third of HC attendees with CVD risk scores > 20% go on to be prescribed statins, slightly lower

than that observed in the present study (36.5%-40.7%). Reasons for low prescription rates among high-risk groups are unclear, but patient refusal might be important and requires further research. Similar to this study, Smith et al.[28] reported a limited effect of HC attendance on detection rates and treatment of diabetes which, as is explained above, is likely because measuring blood glucose or HBA1c is not a standard part of the HC.

The increases in proportions of new prescriptions we observed were smaller than those found in two large previous matched studies.[17,26] This is to be expected given that those studies compared attendees vs. non-attendees, whereas we considered invitees vs. non-invitees. Given that not everybody invited for a HC will attend, out approach is more likely to be representative of the effect of the HC programme overall.

Strengths of this study included the biggest sample size to date for a HC study comprising 277,274 patients invited for a HC and 88,731 patients who were not. It is the first HC study to employ a quasi-randomised method and an intention-to-treat analysis. Specifically, patients were allocated to either HC invited or non-invited groups according to their dates of birth. We were able to evaluate the HC programme at the level of invitation, which is advantageous compared to previous studies which compared attendance vs. non-attendance. There were also weaknesses in our methods. First, our follow-up periods were short, varying from an average of six months (cohort 4) to 3.5 years (cohort 1). Process outcomes may have occurred after the end of follow-up, particularly in the case of new treatments that may have required further appointments and monitoring (e.g. for new prescriptions of antihypertensive). In addition, we were unable to observe clinically important outcomes, such as incident cardiovascular disease. For every 100 people invited for a HC in 2012/13, an extra one person was prescribed a statin. Based on a literature reported number needed to treat (NNT) for primary prevention of cardiovascular events,[29] one event may be prevented for every 560 people invited for a HC, but this estimation does not account for duration of treatment or adherence. Improving NNTs would require greater uptake of the HC and / or greater prescribing among those with identified CVD risk. A second limitation of our study was that we were missing all data including at baseline for an unknown number of patients who died during the follow-up, which was a consequence of how our data source, the HHRA, was organised. These deaths will selectively have reduced numbers of those at highest risk from our population. They will tend to have been in poorer and higher risk groups and, therefore, less likely to attend a HC. The numbers would have been balanced between the cohorts, so should not have affected our between-cohort comparisons. However, they might have reduced the overall risk profile, and differentially within cohorts favour attendance. A third limitation was contamination bias, as some patients in the uninvited group attended a HC. Contamination was largely inevitable given advertising and public awareness of the HC and given that all included GP practices were involved in delivering the programme. Contamination likely led to an underestimation of the effectiveness of the HC programme in our study. Fourth, we had limited details on some factors, including diet and alcohol intake, and non-medical interventions, such as lifestyle advice. Lifestyle advice may have ranged from brief general advice to individually tailored advice with subsequent follow-up. However, such variation likely had a small effect on our results given an earlier study that reported a lack of an association between the intensity of

lifestyle advice as part of a HC and related CVD risk reduction.[30] Fifth, there were potential coding errors or omissions by GPs in recording attendance, measurements, diagnoses and interventions. This may have been particularly problematic for cohort 1 because Read Codes for HC completion were only released in 2012, after the start of the invitation year. Failure of GPs to code attendance retrospectively (i.e. once the Read Codes were available) may, in part, explain, why there was lower recorded HC attendance in cohort 1 compared to the other cohorts. Otherwise, coding errors would have affected the intervention and non-intervention groups equally. Sixth, we missed data on HC undertaken in community pharmacies and other non-GP settings though this was a small minority. Our population was not necessarily representative of the UK, and we had no data on ethnicity. Hampshire does comprise significant urban, suburban and rural populations, but the proportion of ethnic minorities is lower than the national average and this may limit the generalisability of our results. Seventh, we excluded around 35% of the eligible population. This was because of problems with the invitation system, missing DOBs, Read Codes not formatted according to Version 2 and unknown invitation status for some participants (e.g. because of moving into the study area after the start of the follow-up period). However, these exclusions would have been equal across the cohorts. Finally, our study period ended in 2015, and clinical guidance as well as engagement by GPs and patients with the HC programme may have changed since then.

In conclusion, this study evaluated the NHS HC programme and showed that participation increased year on year between 2011 and 2015. The HC programme resulted in large increases in the detection of patients with CVD risk factors, particularly raised cholesterol and 10-year CVD risk scores >10%. There were corresponding, albeit smaller, increases in certain evidence based medical therapies, most notably statins. However, rates of uptake, diagnosis and treatment were well below those expected by the Department of Health.[5] Future work should focus on improving uptake, including through use of non-GP settings (e.g. pharmacy etc.)[31] and by better communication of the programme[32,33] and invitation methods driven by behavioural insights.[34] Further support is also required in decision making for patients and GPs following identification of new risk factors as part of the NHS HC, potentially including incentivisation (e.g. payment by results). Finally, further studies are needed to assess the longer-term effects of the HC on clinical outcomes and health inequalities.

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Figures

Figure 1. Derivation of the study population and five cohorts included in this study. Cohorts 1-4 were invited for HCs in the years beginning 1st April 2011, 12, 13 and 14 respectively, while cohort 5, which was the control group, was not invited.

Figure 2. Histograms showing the distribution of ages within the five cohorts.

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Declaration of competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Ethics approval

This study received ethnical approval from the Research Ethics Committee at the University of Southampton ID: 24358) and approval from the Hampshire Health Record Information Governance Group.

Contributorship

The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. OJK, FS, EW, RP and PR conceived and designed the study; FS performed the data acquisition from the Hampshire Health Record Database and OJK performed the data analysis; OJK and FS drafted the manuscript which was reviewed and amended by all authors. All authors, external and internal, had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. PR is guarantor.

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Transparency declaration

PR 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.

Data sharing

Access to the data used in this study is administrated by the Care and Health Information Exchange (CHIE) Information Governance Group, which is managed by the South, Central and West Commissioning Support Unit on behalf of health and social care organisations in Hampshire, Farnham and the Isle of Wight.

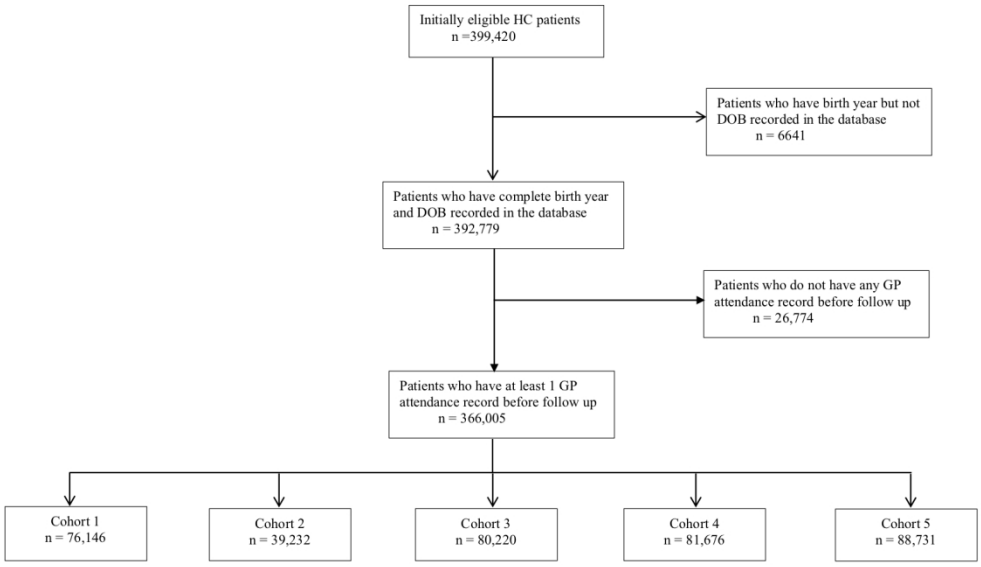

Figure 1. Derivation of the study population and five cohorts included in this study. Cohorts 1-4 were invited for HCs in the years beginning 1st April 2011, 12, 13 and 14 respectively, while cohort 5, which was the control group, was not invited.

146x83mm (300 x 300 DPI)

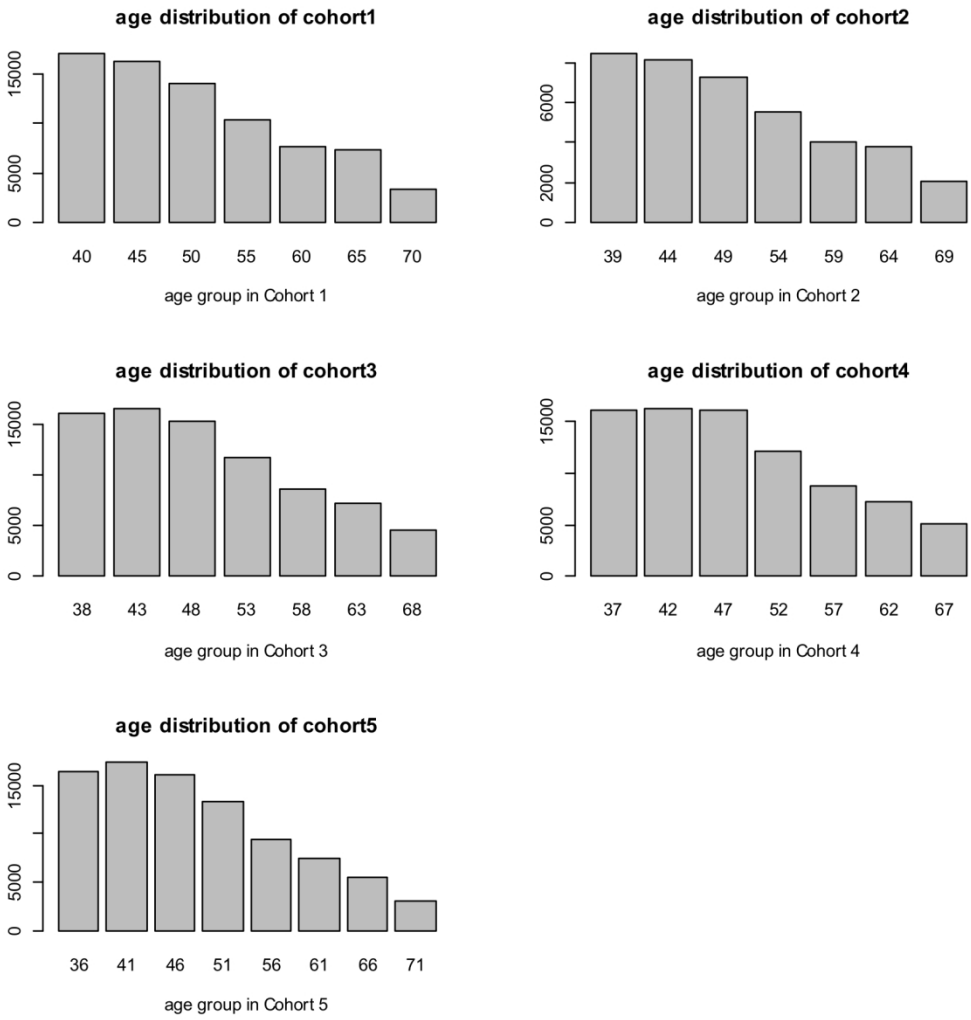

Figure 2. Histograms showing the distribution of ages within the five cohorts.

150x158mm (300 x 300 DPI)

Evaluating the Effectiveness of the NHS Health Check Programme in South England: a Quasi-Randomised Controlled Trial – supplementary materials

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Read codes (5-byte version 2 Read codes, EMIS or BNF)

NHS Health Check codes
8BAg NHS Health Check completed
EMISNQNH6 NHS Health check completed
EMISNQNH7 NHS Health check completed by practice
8BAg0 NHS Health Check completed by third party

Blood pressure
Systolic blood pressure: ReadCode like '2469%' or ReadCode like '246Q%'
Diastolic blood pressure: ReadCode like '246A%' or ReadCode like '246R%'
246.. | O/E - blood pressure reading
246R. | Sitting diastolic blood pressure
246Q. | Sitting systolic blood pressure

Body mass index
'22K2.','22K1.','22K4.','22K5.','22K6.','22K7.','22K8.','22K9.','22K90','22KB.','22K..','22K3.'

Total cholesterol
'44OE.' Plasma total cholesterol level
'44P..' Serum cholesterol
'44P1.' Serum cholesterol normal
'44P2.' Serum cholesterol borderline
'44P3.' Serum cholesterol raised
'44P4.' Serum cholesterol very high
'44PH.' Total cholesterol measurement
'44PJ.' Serum total cholesterol level

10-year risk of CVD disease
'662k%' (JBS CVD risk less than 10% over next ten years)
'662l%' (JBS CVD risk ten percent to 20% over next ten years)
'662m%' (JBS CVD risk greater than 20% up to 30% over next ten years)

'662n%' (JBS CVD risk greater than 30% over next ten years)
'38DP%' (QRISK2 cardiovascular disease 10 year risk score)
'38DF%' (QRISK cardiovascular disease 10 year risk score)
'38DR%' (Framingham 1991 cardiovascular disease 10 year risk score)

Current smoker
'137..','1372.','1373.','1374.','1375.','1376.','137b.','137c.','137C.','137D.','137d.','137e.','137E.','137f.','137G.','137h.','137H.','137J.','137m.','137a.','137X.','137Y.','137Z.','137M.','137n.','137P.','137Q.','137R.','137V.','13p0.','13p5.','67H6.','745H.','8CAg.','8CAL.','8CdB.','8H7i.','8HBM.','8HBP.','8HkQ.','8HTK.','8IAj.','8IEK.','8IEM.','8IEo.','8T08.','9hG..','9hG0.','9hG1.','9kc..','9kc0.','9kf1.','9kf2.','9ko..','9N2k.','9N4M.','9Ndg.','9NdZ.','9OO..','9OO1.','9OO2.','9OO3.','9OO4.','9OO5.','9OO6.','9OO7.','9OO8.','9OO9.','9OOA.','9OOB.','9OOZ.','13p50%','745H0%','745H,%','745H2%','745H3%','745H4%','745Hy%','745Hz%','9NS02%','9OOB0%','9OOB1%','9OOB2%'

Ex smoker
'137K.','137N.','137O.','137S.','137T.','13p4.','1377.','137l.','9km..','137j.','1378.','137F.','137B.','1379.','137A.','137L .','137i.','137K0%'

Non-smoker
'137L.'

Never smoking
'1371.'

Hypertension
QOFv28 - Hypertension
G2...
G20..%
G24.. - G2z.. (Excluding G24z1, G2400, G2410, G27..)
Gyu2.
Gyu20

Ischaemic heart disease
QOF v28 - Secondary Prevention of Coronary Heart Disease
G3... – G309.
G30B. - G330z (excluding G310.)
G33z. - G3401
G342. – G35X.
G38.. – G3z..
Gyu3.% (excluding Gyu31)

Diabetes
QOF v28 – Diabetes
C10.., C109J, C109K, C10C.,C10D., C10E.%, C10F.% (Excluding C10F8), C10G.%, C10H.%, C10M.%, C10N.%,PKyP.,C10P.%

CKD
QOF v28 – CKD
1Z12.
1Z13.
1Z14.
1Z15.
1Z16.
1Z1B. – 1Z1L.
K053.
K054.
K055.

AF
QOF v28 – AF

G573.% (excluding G5731, G5736)

Heart Failure
QOF v28 – HF
G58..%
G1yz1
662f. – 662i.

Atherosclerosis and other peripheral vascular disease
G70% Atherosclerosis
G73 Other peripheral vascular disease
G7310 Buerger's disease
G7311 Presenile gangrene
G731z Thromboangiitis obliterans NOS
G732% Peripheral gangrene
G733 Ischaemic foot
G73y Other specified peripheral vascular disease
G73y0 Diabetic peripheral angiopathy
G73yz Other specified peripheral vascular disease NOS
G73z Peripheral vascular disease NOS
G73z0 Intermittent claudication
G73zz Peripheral vascular disease NOS

Stroke and TIA
QOF v28 – Stroke and TIA
G61..% (excluding G617.)
G63y0 - G63y1
G64..%
G66..% (excluding G669.)
G6760
G6W..
G6X..
G65..- G654.
G656.- G65zz
Gyu62 – Gyu66
Gyu6F
Gyu6G
ZV12D
Fyu55
G619.

Additional circulatory system disease.
Gyu% Additional circulatory system disease classification terms
NOT Gyu0% Acute rheumatic fever
NOT Gyu1% Chronic rheumatic heart disease
NOT Gyu2% Hypertensive diseases
NOT Gyu8% Diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified
NOT Gyu9% Other and unspecified disorders of the circulatory system

STATINS
bx% LIPID-LOWERING DRUGS
2.12 Lipid-regulating drugs (BNF)

Antihypertensive
BNF_Code 02.02.01.00, 02.02.02.00, 02.02.03.00, 02.04.00.00, 02.04.01.00, 02.05.04.00, 02.05.05.00, 02.05.05.01, 02.05.05.02, 02.06.02.00, TitleofGroup in ('Angiotensin-Converting Enzyme Inhibitors','Calcium Channel Blockers','Angiotensin-II Receptor Antagonists','Potassium Sparing Diuretics','Thiazides And Related Diuretics','Loop Diuretics','Alpha-Adrenoceptor Blocking

Drugs','Beta-Adrenoceptor Blocking Drugs','Compound Beta-Adrenoceptor Blocking Drugs','Drugs Affecting The Renin-Angiotensin System')

Anti-obesity
aw...

Anti-diabetes
BNF code 06.01.00.00, and titleofGroup is : Drugs Used In Diabetes

Nicotine replacement
BNF_Code 04.10.00.00, 04.10.02.00

K: Palliative care

1Z01	Terminal illness - late stage
2JE	Last days of life
8BA2	Terminal care
8BAP	Specialist palliative care
8BAS	Specialist palliative care treatment - daycare
8BAT	Specialist palliative care treatment - outpatient
8BAe	Anticipatory palliative care
8BJ1	Palliative treatment
8CM1%	On gold standards palliative care framework
8CM4	Liverpool care pathway for the dying
8CME	Has end of life advanced care plan
8H6A	Refer to terminal care consult
8H7L	Refer for terminal care
8H7g	Referral to palliative care service
8HH7	Referred to community specialist palliative care team
9EB5	DS 1500 Disability living allowance (terminal care) completed
9Ng7	On end of life care register
ZV57C	Palliative care

Previous health checks and CVD risk assessments

38B1 Vascular disease risk assessment
38B10 CVD (cardiovascular disease) risk assessment by third party
66f Cardiovascular disease monitoring
66f0 Cardiovascular disease annual review
66f1 Cardiovascular disease interim monitoring
66f2 Cardiovascular disease high risk review
8BAg NHS Health Check completed
9OhA Cardiovascular disease risk assessment done
8BAg0 NHS Health Check completed by third party

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Evaluating the Effectiveness of the NHS Health Check Programme in South England: a Quasi-Randomised Controlled Trial

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Secondary Subject Heading:	General practice / Family practice
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Evaluating the Effectiveness of the NHS Health Check Programme in South England: a Quasi-Randomised Controlled Trial

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ABSTRACT

Objectives: Evaluate uptake, risk factor detection and management from the National Health Service (NHS) Health Check (HC).

Design: Quasi-randomised controlled trial wherein participants were allocated to five cohorts based on birth year. Four cohorts were invited for an NHS HC between April 2011 and March 2015.

Setting: 151 General Practices in Hampshire, England, United Kingdom.

Participants: 366,005 participants born 1/4/1940 – 31/3/1976 eligible for an NHS HC.

Intervention: NHS HC invitation.

Main outcome measures: HC attendance and absolute percentage changes and odds ratios (ORs) of (i) detecting cardiovascular (CVD) 10-year risk >10% and >20%, smokers, total cholesterol (TC) >5.5 mmol/L and >7.5 mmol/L; (ii) diagnosing hypertension, type 2 diabetes mellitus (T2DM), chronic kidney disease (CKD) and atrial fibrillation (AF); and (iii) new interventions with statins, antihypertensives, antiglycaemics and nicotine replacement therapy (NRT).

Results: HC attendance rose from 12% to 30% between 2011/12 and 2014/15 (p <0.001). HC invitation increased detection of CVD risk >10% (2.0%-3.6, p<0.001) and >20% (0.1%-0.6%, p<0.001-0.392), TC >5.5 mmol/L (4.1%-7.0%, p<0.001) and >7.5 mmol/L (0.3%-0.4% p<0.001), hypertension (0.3%-0.6%, p<0.001-0.003), and interventions with statins (0.2%-0.9%, p<0.001-0.017) and antihypertensives (0.1%-0.6%, p <0.001-0.205). There were no consistent differences in detection of smokers, NRT, or diabetes, AF or CKD. Multivariate analyses showed associations between HC invitation and detecting CVD risk >10% (OR 8.01, 95% CI 7.34-8.73), >20% (5.86, 4.83-7.10), TC >5.5 mmol/L (3.72, 3.57-3.89), >7.5 mmol/L (2.89, 2.46-3.38), and diagnoses of hypertension (1.33, 1.20-1.47) and diabetes (1.34, 1.12-1.61). ORs of CVD risk >10% plus statin and >20% plus statin, respectively, were 2.90 (2.36-3.57) and 2.60 (1.92-3.52), and hypertension plus antihypertensive was 1.33 (1.18-1.50). There were no associations with AF, CKD, antiglycaemics or NRT. Detection of several risk factors varied inversely by deprivation.

Conclusions: HC invitation increased detection of cardiovascular risk factors, but corresponding increases in evidence-based interventions were modest.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This is the first study to investigate outcomes associated with invitation for a National Health Service Health Check using a quasi-randomised method together with an intention-to-treat analysis.
- This study included a large population of 366,005 participants in a mixture of urban, semi-urban and rural settings.
- Invitation for a Health Check increased detection of cardiovascular risk factors, but this translated into only modest increases in evidence-based interventions.
- The follow-up of 6 months to 3.5 years limited assessment of patient relevant outcomes (e.g. incident cardiovascular disease).
- There was insufficient information to consider outcomes related to alcohol consumption and diet.

INTRODUCTION

Cardiovascular disease (CVD) is a significant cause of mortality and morbidity worldwide,[1] and results in substantial global healthcare expenditure.[2] In 2009, the National Health Service (NHS) in England began a Health Check (HC) programme with the intention of identifying and managing individuals at higher risk of CVD or related conditions, such as diabetes mellitus and kidney disease, and preventing such conditions. This is similar to national programmes in other countries including in Canada[3] and the United States.[4] Modelling by the UK Department of Health suggested that the NHS HC programme could prevent 1,600 strokes and heart attacks each year, although the modelling assumptions, particularly with regard to uptake, may have overestimated effectiveness.[5] More recent estimation of the health benefits from microsimulation modelling using existing programme data suggest that the NHS HC programme results in approximately 300 fewer deaths and 1,000 people living free from disease (ischaemic heart disease, stroke, dementia and lung cancer) each year in England.[6]

Patients that are eligible to participate in the NHS HC programme are invited for HCs every five years. Patients are eligible if they are aged 40-74 and have no known CVD, diabetes, kidney disease or previous treatment with statins. The HC itself is performed in primary care, largely in general practice, and comprises an assessment of smoking status, diet, exercise, family history and more recently alcohol intake. Measurements are taken of body mass index (BMI), waist circumference, blood pressure (BP) and cholesterol, and a 10 year CVD risk score is calculated. Patients with systolic BP (SBP) or diastolic BP (DBP) ≥ 140 mmHg or 90 mmHg, respectively, have additional blood tests to measure kidney function. If impaired kidney function is detected, that is an estimated glomerular filtration rate (eGFR) < 60 ml/min/1.73 m^2, the blood test is repeated within two weeks to confirm a diagnosis of chronic kidney disease (CKD).[7] Any HC attendee with BMI ≥ 30 kg/m^2 (≥ 25 kg/m^2 in non-white ethnic groups) or SBP or DBP above ≥ 140 mmHg or 90 mmHg, respectively, are also screened for type 2 diabetes mellitus (T2DM) by measuring glycated hemoglobin (HbA1c) or fasting glucose. If CVD risk factors are newly identified or conditions newly diagnosed during the HC, patients are offered appropriate management, including lifestyle advice, treatments and referrals to local services.

The HC programme has been contentious from its inception. There have been concerns of a lack of proven effectiveness to justify the yearly expenditure,[8] which is thought to be around £450 million.[9] A systematic review of randomised controlled trials found that general health checks provide no overall

reduction in CVD or cancer mortality, only an increase in risk factor recording and diagnoses.[10] The initial implementation of the NHS HC programme suffered early problems, such as low uptake,[11] variable implementation,[12] and poor understanding of the aims and purpose of the HC among some invitees.[13] In addition, there were concerns about inequitable distribution of the HC and a resultant widening of health inequalities.[9] Proponents of the NHS HC programme argue that existing randomised trials, the most recent of which started in 1999, are not representative of more effective modern HCs and intervention strategies.[14] In addition, since the early years, participation has increased, with a 2018 study reporting that 48.2% of those invited for a HC have now attended.[15] Strategies have also increased uptake among some deprived and ethnic minority populations to or above the average.[16]

A number of studies have evaluated the effectiveness of the NHS HC programme.[16,17] HC attendance has been associated with increased CVD risk factor recording, detection of hypercholesterolaemia and hypertension, and increased prescribing of statins comparing attendees and matched non-attendees (hazard ratio [HR] 1.58, 95% 1.53–1.63) and antihypertensives (HR 1.06, 95% 1.03–1.10).[17] HC attendees have also been shown to have reduced CVD risk scores, blood pressures and serum lipids a year afterwards.[18] However, a significant limitation of existing studies is that they have used observational data comparing HC attendees and non-attendees. Only a proportion of those invited for a HC actually attend, and those attending are not representative of the eligible population.[16,17] This study aims to evaluate the effect of invitation for a HC (i.e. not just attendance) in terms of uptake and risk factor detection and management in eligible participants.

METHODS

Study population and data source

This study took place in Hampshire, a region in the south of England comprising over 1.5 million residents in a mixture of urban, suburban and rural settings. In Hampshire, the HC is commissioned by three Local Authorities: Southampton City Council, Portsmouth City Council and Hampshire County Council. The two largest urban areas in Hampshire are the cities of Southampton and Portsmouth, each with a population of around 200,000-250,000. There were 151 General Practices that contributed data to this study, around 80% of the total in the region. The organisation of the HC programme in Hampshire involved assigning eligible patients into five separate cohorts. Cohort assignment was based on date

of birth (DOB), although the cohorts had comparable means and distributions of ages. This method of assignment (i.e. based on birth year) constituted a form of "quasi-randomisation".[19] Specifically, patients with years of birth ending in "0" or "5" were assigned to one cohort, "1" or "6" to another cohort, "2" or "7" to another and so forth, mirroring the quinquennial invitation system used for NHS breast cancer screening. The first cohort (cohort 1) was invited for a HC in the year 1st April 2011 to 31st March 2012, while the subsequent cohorts (cohorts 2-5) were invited in the years beginning 1st April 2012-15. The study period was from 1st April 2011 to 31st March 2015. During this time, cohorts 1-4 were invited for HCs. Cohort 5 was eligible for a HC but not invited (i.e. until after the follow-up period ended) and was our control group. We compared outcomes in each of the invited cohorts 1-4 separately against those in cohort 5. The exact follow-up periods depended on the cohorts being compared and are described below.

The population for this study were eligible for a HC on 1st April 2011. This required a DOB between 1st April 1940 - 31st March 1976 and (as of 1st April 2011) (i) no history of vascular disease (e.g. coronary artery disease, cerebrovascular disease, atherosclerosis, peripheral vascular disease (PVD) or circulatory system disease); (ii) no previous diagnosis of hypertension, diabetes, CKD, atrial fibrillation (AF), heart failure (HF), stroke or transient ischaemic attack (TIA); and (iii) no pre-existing records of receiving statins prescription, palliative care, a health check, or CVD risk assessment. These medical eligibility criteria matched the criteria used locally by general practices (GPs) to identify and invite participants to participate in the HC programme. The Read Codes for eligibility and outcomes are included as supplementary information. Using the participants DOBs, we assigned them into cohorts 1-5 to identify the years they were invited for a HC between 1st April 2011 and 31st March 2015 (or not invited in the case of cohort 5). As is explained below, for some analyses, we reapplied the eligibility criteria to identify participants still eligible for a HC at the start of each invitation year.

As there was a temporary pause in sending out HC invitations during the first half of the year beginning 1st April 2012 in the Hampshire County Council Local Authority, we excluded patients belonging to cohort 2 living in that area (~40,000 participants). We excluded patients with no recorded DOB (6,641) or no GP attendance record before 1st April 2011 (26,774), as we assumed that those patients had moved into the area after the start of the follow-up. We excluded patients with medical records not formatted according to Read Codes Version 2 (~70,000). In total, we excluded around 35% of the population.

We acquired data for this study from the Hampshire Health Record Analytical database (HHRA). At the time of the study, the HHRA linked anonymised clinical records from 151 primary care practices, secondary care (e.g. inpatient, outpatient, and accident and emergency) from 3 acute (hospital) NHS trusts, and laboratory and pathology tests. The HHRA also contained deprivation indices for the populations served by the included GP practices. The HHRA covers a registered population of around 1.5 million patients. Unfortunately, the organisation or the HHRA is such that some patients who die are removed from the database. As such, we did not use mortality or CVD events, which frequently result in death, as outcomes.

Information extracted and outcome measures

For each participant, we extracted from HHRA data concerning HC attendance, age, gender and individual level deprivation (IMD) at baseline. Ethnicity was poorly recorded (50% missing) and, in any case, this information was not released for analysis due to concerns about identifiability. We extracted data for the following outcomes: (i) recording of BP, total serum cholesterol (TC), smoking status (i.e., "current smoker", "ex-smoker", and "never smoker"), BMI, and 10-year CVD risk score (e.g. Framingham and QRISK); (ii) detection of CVD risk score >10%, CVD risk score >20%, current smoker, TC >5.5 mmol/L, TC >7.5 mmol/L, and BMI >30 kg/m^2; (iii) new diagnoses of hypertension, AF, diabetes and CKD (≥ stage 3); and (iv) new interventions with statins, antihypertensives, antiglycaemic medication, nicotine replacement therapy (NRT), anti-obesity medication, stop-smoking advice/referral and weight management advice/referral. We identified outcomes only where corresponding Read Codes had been recorded (e.g. we did not assume that BMI had been measured just because a weight management referral had been made). Data were extracted from the HHRA in January 2017.

Follow-up periods and statistical analysis

For each cohort overall and for HC attendees / non-attendees within each cohort separately, we calculated baseline means and standard deviations of age, gender and IMD. We calculated proportions (%) with outcomes occurring between 1st April 2011 and 31st March 2015. We calculated absolute differences in these proportions for each of cohorts 1-4 vs. 5 (i.e. invited vs non-invited) as well as the range (i.e. of absolute differences for cohorts 1-4 vs. 5). We also compared proportions with outcomes among attendees and non-attendees. A chi-square test was used to test for equality between proportions. .

In the second stage of our analysis, we calculated odds ratios (ORs) for each outcome. We employed multivariable logistic regression models adjusted for age and gender. We calculated ORs for each invited cohort (i.e. cohorts 1-4) separately, with the reference being uninvited cohort 5. The rationale for this approach was to capture changes in performance over a time period when awareness and experience among patients and providers was increasing. Evaluation of earlier years (e.g. cohort 1) is still of interest because of longer follow-up, but the most recently invited cohort (i.e. cohort 4) may be most reflective of current practice. Finally, to examine whether the impact of the programme differed by deprivation, we re-ran the regression analysis for the most recently invited cohort (i.e. cohort 4) vs. uninvited cohort 5 while including an interaction term for IMD.

All analyses were by intention-to-treat. We did sensitivity analysis by excluding those who attended opportunistically. In these analyses, follow-up was from the start of the invitation year of the invited cohort until 31st March 2015. Specifically, for cohorts 1-4 vs. 5, follow-up periods were from 1st April 2011, 1st April 2012, 1st April 2013, 1st April 2014, respectively, until 31st March 2015. We included only participants still eligible at the start of the invitation year. As invitations were sent out throughout each year rather than all at the start, participants were invited on average six months from the start of their invitation years. This corresponds to follow-up periods for comparisons of cohorts 1-4 vs. 5, respectively, of 3.5, 2.5, 1.5 and 0.5 years. This study received ethical approval from the Research Ethics Committee at the University of Southampton ID: 24358) and approval from the Hampshire Health Record Information Governance Group. Data extraction was implemented using SQL server 2008 R2, and statistical analyses were conducted using R (Version 3.5.1, R Foundation for Statistical Computing, Vienna, Austria).[20]

Patient and public involvement

There were no patients directly involved in the planning or design of this study.

RESULTS

Study sample and baseline characteristics

The derivation of the study population and five cohorts is shown in figure 1. 399,420 met our inclusion criteria and had medical records formatted as Read Codes Version 2. From those, we excluded 6,641 without a recorded DOB and a further 26,774 patients without entries in their health records from before 1st April 2011 who likely moved into Hampshire after the start of the follow-up period. The remaining

366,005 participants formed our study population. Table 1 summarises their baseline characteristics broken down into cohorts 1-5. The cohorts had similar proportions of male gender (within 1%) and mean deprivation scores (within one centile). The cohorts differed more markedly in mean age, although the maximum difference was just 3 years between cohorts 1 and 5. The age differences reflected the HC invitation system in Hampshire which, as is described above, is based on DOB. However, figure 2 comprises histograms showing broadly similar distributions of ages within each cohort.

Table 1. Demographic information of the five cohorts overall and broken down into HC attendees and non-attendees within each cohort.

	Cohort 1			Cohort 2			Cohort 3			Cohort 4			Cohort 5		
	All	Att	DNA	All	Att	DNA	All	Att	DNA	All	Att	DNA	All	Att*	DNA
n	**76146**	9464	66682	**39232**	9868	29364	**80220**	19991	60229	**81676**	21188	60488	**88731**	4232	84499
% male	**47.5**	45.6	47.8	**46.5**	40.7	48.3	**47.0**	41.0	49.0	**47.4**	41.9	49.3	**47.2**	48.0	47.1
Age range	**(40, 70)**	(40, 70)	(40, 70)	**(39, 69)**	(39, 69)	(39, 69)	**(38, 68)**	(38, 68)	(38, 68)	**(37, 67)**	(37, 67)	(37, 67)	**(36, 71)**	(36, 71)	(36, 71)
Mean age (SD)	**51(9.0)**	54(9.9)	50(8.7)	**50(9.1)**	53(9.5)	49(8.7)	**49(9.0)**	52(9.6)	48(8.6)	**48(9.9)**	51(9.4)	47(8.8)	**48(9.5)**	59(10.4)	48(9.5)
Mean IMD decile (SD)	**7.3(2.6)**	7.8(2.4)	7.3(2.6)	**7.3(2.6)**	7.9(2.3)	7.2(2.7)	**7.3(2.6)**	7.7(2.4)	7.2(2.7)	**7.3(2.6)**	7.7(2.4)	7.2(2.7)	**7.3(2.6)**	7.5(2.6)	7.3(2.6)

Attended (Att), number (n), did not attend (DNA), standard deviation (SD), Index of Multiple Deprivation (IMD - 1 = most deprived decile, 10 = least deprived), *some participants in cohort 5 attended a HC opportunistically (i.e. without receiving a formal invitation)

HC attendees in all cohorts were more likely to be female, older and less deprived compared to those who did not attend (Table 1). Proportions within each invited cohort (i.e. cohorts 1-4) attending HCs increased year on year during the follow-up, and for cohorts 1-4 were 12%, 27%, 28% and 30%, respectively. Despite not being formally invited, a number of patients in cohort 5 attended a HC during the follow-up period. These patients had likely responded to local or national advertising for the HC programme or had been offered HCs opportunistically by their GPs.

Proportions of risk factor recording, detection, diagnoses and interventions

Table 2 summarises the proportions of patients with recording and detection of risk factors, new diagnoses, and new interventions during the follow-up period, which varied by cohort. The results are shown for each cohort overall and separately for attendees and non-attendees within each cohort. Given the large sample size, even small differences in proportions between cohorts were frequently highly significant (see supplementary information for p-values). Proportions generally increased year on year for cohorts 1-4, reflecting increasing attendance, and were lowest in the uninvited cohort 5. There were significant ($p < 0.001$) increases in absolute proportions in invited cohorts 1-4 with recorded BP (range for cohorts 1-4 vs. 5 = 4.9%-7.9%), BMI (5.0%-13.4%), TC (8.4%-17.4%), CVD risk (7.4%-19.6%) and smoking status (2.8%-7.0%). There were also significant increases in detection of CVD risk >10% (2.0%-3.6%), SBP >140 / DBP >90 (1.0%-2.1%), BMI >30 kg/m^2 (0.9%-2.5%), TC >5.5 mmol/L (4.1%-7.0%) and TC >7.5 mmol/L (0.3%-0.4%). There were more modest or not consistently significant differences in proportions with detected CVD risk >20% (0.1%-0.6%) and current smoking (–0.3%-0.5%).

The proportions with detection of risk factors among those with recordings were lower in the invited cohorts (i.e. 1-4) compared to uninvited cohort 5, particularly for CVD risk >10% (–11.5% - –2.9%), >20% (–6.1% - –1.8%) and BMI >30 kg/m^2 (–2.8% - –1.0%). Even though smaller absolute numbers of high-risk patients were identified by opportunistic testing, these data suggest a higher positive predictive value of opportunistic testing compared to the HC, which may reflect different risk profiles of patients.

HC resulted in minor or no increases in proportions with new diagnoses of hypertension (0.3%-0.6%), AF (0.0%-0.1%), CKD (0.0%-0.1%) or diabetes (0.0%-0.1%). There were minor increases in proportions receiving statins (0.2%-0.9%), antihypertensives (0.2%-0.6%) and stop smoking advice (0.4%-0.9%),

but no consistent difference in antiglycaemics (-0.1%-0.0%), NRT (0.0%) or anti-obesity medications (0.0%). There was an increase in weight advice / referrals (4.6%-10.5%).

Table 2. Proportions of participants with risk factor recording / detection, new diagnoses and new interventions in each of the five cohorts overall and for HC attendees and non-attendees within each cohort separately.

	C1			C2			C3			C4			C5		
	All	Att	DNA	**All**	Att	DNA	**All**	Att	DNA	**All**	Att	DNA	**All**	Att	DNA
RECORDING %															
BP	**72.3**	98.6	68.5	**75.2**	98.6	67.3	**74.3**	98.7	66.3	**73.3**	98.6	64.4	**67.3**	99.1	65.7
BMI	**48.4**	97.7	41.4	**56.5**	98.5	42.3	**56.5**	98.5	42.5	**56.8**	98.6	42.2	**43.4**	98.0	40.6
TC	**41.5**	97.6	33.6	**49.5**	97.1	33.6	**49.4**	97.0	33.6	**50.6**	97.2	34.2	**33.1**	96.1	30.0
CVD risk	**23.0**	89.0	13.7	**32.8**	89.4	13.8	**33.2**	89.1	14.7	**35.3**	92.3	15.3	**15.7**	90.2	11.9
Smoking status	**71.8**	98.5	68.1	**75.8**	98.9	68.0	**75.7**	98.7	68.1	**76.0**	98.4	68.2	**69.0**	98.7	67.6
DETECTION %															
CVD risk >10%	**7.7**	29.0	4.7	**9.3**	23.0	4.7	**9.0**	22.2	4.6	**8.8**	20.7	4.6	**5.7**	44.5	3.8
% of CVD risk recorded with >10%	**33.6**	32.6	34.5	**28.4**	25.7	34.3	**27.0**	24.9	31.1	**24.9**	22.5	30.1	**36.4**	49.3	31.5
CVD risk >20%	**2.2**	8.1	1.3	**2.4**	5.2	1.4	**2.1**	4.4	1.3	**1.8**	3.6	1.2	**1.8**	15.0	1.1
% of CVD risk recorded with >20%	**9.4**	9.1	9.6	**7.2**	5.8	10.1	**6.3**	5.0	9.1	**5.1**	3.9	7.8	**11.2**	16.6	9.1
SBP >140 or DBP > 90 mmHg	**17.8**	24.6	16.8	**17.5**	20.1	16.6	**17.3**	20.6	16.3	**16.6**	19.7	15.6	**15.7**	29.9	14.9
% of BP recorded with >140 or >90	**24.6**	25.0	24.5	**23.3**	20.4	24.7	**23.3**	20.8	24.5	**22.7**	20.0	24.2	**23.3**	30.2	22.7
Current smoker	**20.7**	17.0	21.2	**20.8**	14.6	22.8	**20.9**	14.4	23.1	**21.4**	16.3	23.2	**20.9**	18.4	21.1
% of smoking status recorded who currently smoke	**28.8**	17.3	31.1	**27.4**	14.8	33.6	**27.6**	14.6	33.9	**28.2**	16.6	34.1	**30.3**	18.6	31.2
BMI >30 kg/m^2	**12.6**	18.0	11.9	**13.9**	17.6	12.7	**13.8**	17.9	12.4	**14.3**	19.7	12.3	**11.8**	20.1	11.4
% BMI recoded with >30	**26.1**	18.5	28.7	**24.7**	17.9	30.0	**24.4**	18.2	29.1	**25.1**	20.0	29.2	**27.2**	20.5	28.0
TC >5.5 mmol/L	**19.1**	44.1	15.5	**22.0**	43.1	14.9	**21.4**	41.4	14.8	**21.6**	39.8	15.2	**15.0**	48.8	13.3
% of TC recorded with >5.5 mmol/L	**46.0**	45.2	46.2	**44.3**	44.4	44.3	**43.3**	42.7	43.9	**42.7**	40.9	44.4	**45.3**	50.8	44.4
TC >7.5 mmol/L	**1.4**	2.7	1.2	**1.5**	2.4	1.2	**1.5**	2.5	1.1	**1.5**	2.3	1.3	**1.1**	3.3	1.0
% of TC recorded with >7.5 mmol/L	**3.3**	2.8	3.6	**3.1**	2.5	3.6	**3.0**	2.6	3.3	**3.1**	2.4	3.8	**3.4**	3.4	3.4
DIAGNOSES %															
Hypertension	**4.2**	4.7	4.1	**4.1**	3.7	4.3	**3.9**	3.0	4.2	**4.0**	2.5	4.5	**3.6**	6.5	3.5
% of SBP >140 or DBP > 90 with hypertension diagnosis	**18.0**	15.1	18.7	**17.7**	13.6	19.3	**17.5**	11.5	20.1	**17.8**	9.3	21.6	**17.3**	16.4	17.4
AF	**0.5**	0.5	0.5	**0.4**	0.4	0.4	**0.4**	0.4	0.5	**0.4**	0.2	0.4	**0.4**	0.9	0.3
CKD	**0.3**	0.3	0.3	**0.3**	0.4	0.3	**0.3**	0.2	0.3	**0.3**	0.1	0.3	**0.2**	0.6	0.2
Diabetes	**1.3**	0.9	1.3	**1.2**	0.7	1.4	**1.3**	0.6	1.5	**1.3**	0.6	1.6	**1.2**	1.2	1.2
INTERVENTIONS %															
Statin	**4.9**	7.7	4.5	**5.0**	5.6	4.8	**4.4**	4.5	4.4	**4.3**	3.3	4.6	**4.0**	13.0	3.6
% of CVD>10% prescribed statins	**22.5**	16.5	27.8	**18.8**	12.7	28.8	**17.6**	11.4	27.5	**16.2**	9.3	27.0	**23.6**	19.0	26.2
% of CVD>20% prescribed statins	**40.7**	31.5	48.8	**37.9**	28.7	49.4	**38.2**	27.4	50.2	**36.5**	23.0	50.8	**41.9**	33.9	47.5
Antihypertensive	**7.6**	8.0	7.5	**7.7**	6.9	7.9	**7.3**	6.1	7.7	**7.2**	5.8	7.7	**7.1**	10.6	6.9
% of hypertensives prescribed antihypertensive	**78.5**	79.6	78.3	**78.5**	77.7	78.7	**78.4**	79.3	78.2	**77.7**	77.3	77.8	**78.3**	85.0	77.7
Antiglycaemics	**1.1**	0.7	1.2	**1.0**	0.6	1.2	**1.1**	0.5	1.3	**1.2**	0.5	1.4	**1.1**	1.1	1.1
% of diabetics prescribed antiglycaemics	**74.2**	66.7	74.9	**74.4**	66.7	75.7	**74.9**	60.5	76.9	**73.2**	59.2	75.1	**76.7**	73.1	76.9
NRT	**1.1**	0.9	1.1	**1.1**	0.9	1.2	**1.1**	0.8	1.2	**1.1**	0.8	1.2	**1.1**	1.2	1.1
% of current smokers prescribed NRT	**4.6**	4.7	4.5	**4.7**	5.2	4.6	**4.7**	5.1	4.7	**4.6**	4.4	4.6	**4.6**	6.2	4.6
Stop smoking advice	**7.4**	9.9	7.1	**7.9**	8.5	7.8	**7.6**	7.7	7.5	**7.7**	8.4	7.5	**7.0**	10.3	6.9

% of current smokers given advice	**22.8**	26.8	22.4	**23.7**	24.5	23.5	**22.7**	23.5	22.6	**22.7**	23.8	22.5	**22.3**	25.3	22.1
Weight advice/referral	**12.9**	55.5	6.8	**18.3**	52.3	6.8	**18.4**	51.7	7.4	**18.8**	49.6	8.0	**8.3**	55.7	5.9
% of BMI>30 kg/m^2 given advice/referal	**26.8**	63.2	19.0	**31.5**	60.1	18.2	**33.3**	60.0	20.6	**34.4**	57.7	21.3	**20.8**	60.8	17.2
Anti-obesity	**0.3**	0.2	0.3	**0.3**	0.2	0.4	**0.3**	0.3	0.3	**0.3**	0.3	0.3	**0.3**	0.2	0.3
% of BMI>30 kg/m^2 prescribed anti-obesity	**1.8**	1.0	2.0	**2.0**	0.9	2.5	**1.8**	1.2	2.1	**1.8**	1.0	2.2	**2.1**	0.7	2.2

Attended (Att), Blood pressure (BP), body mass index (BMI), total cholesterol (TC), cardiovascular disease (CVD), systolic blood pressure (SBP), diastolic blood pressure (DBP), atrial fibrillation (AF), chronic kidney disease (CKD), Nicotine replacement therapy (NRT)

Proportions receiving statins were lower among HC invited cohorts compared to non-invited following detection of CVD risk >10% (–7.4% - –1.1%) and >20% (–5.5% - –1.2%). Similarly, antiglycaemic interventions among new cases of diabetes were lower (–3.5% - –1.8%), as were new anti-obesity prescriptions following detection of BMI >30 kg/m^2 (–0.3% - –0.1%). Differences in proportions receiving antihypertensives following new hypertension diagnoses were inconsistent (–0.6% - 0.2%), but there was an increase in proportions among HC invitees receiving weight advice / referral following detection of BMI >30 kg/m^2 (6.0%-13.6%).

Odds ratios of risk factor detection, diagnoses and interventions

Table 3 summarises the ORs and 95% confidence intervals from the regression analyses. Compared to uninvited cohort 5 (including and excluding those who attended opportunistically), the odds of detection of risk factors, new diagnoses and interventions were generally higher in invited cohorts 1-4, and they increased year on year throughout the study period. For cohort 4 vs. 5, there were large and significant increases in the odds of detecting CVD risk >10% (OR 8.01, 7.34-8.73), CVD risk >20% (OR 5.86, 4.83-7.10) TC >5.5 mmol/L (OR 3.72, 3.57-3.89), TC >7.5 mmol/L (OR 2.89, 2.46-3.38) and BMI > 30 kg/m^2 (OR 2.05, 1.96-2.14). These may be conservative given that the average follow-up was just 6 months, and for some participants almost none, while many outcomes from the HC would likely take longer to occur. There were significant increases in detection of current smokers (OR 1.22, 1.18-1.26) and elevated BP (OR 1.64, 1.57-1.70). There were modest increases in new diagnoses of hypertension (OR 1.33, 1.20-1.47) and diabetes (OR 1.34, 1.12-1.61), but not AF (OR 1.00, 0.72-1.39) or CKD (OR 0.69, 0.36-1.32). In terms of new interventions, there were increases in weight advice / referrals (OR 8.36, 7.89-8.86), stop smoking advice (OR 1.65, 1.51-1.79), statins (OR 1.54, 1.39-1.71) and antihypertensives (OR 1.15, 1.06-1.24). The ORs of CVD risk >10% plus statin or >20% plus statin, respectively, were 2.90 (2.36-3.57) and 2.60 (1.92-3.52). The OR of hypertension diagnosis plus antihypertensive treatment was 1.33 (1.18-1.50). There were no significant differences in prescriptions of NRT (OR 0.92, 0.71-1.20), antiglycaemics (OR 1.18, 0.97-1.44) or anti-obesity medications (OR 1.00, 0.68-1.48).

Table 3. Age and gender adjusted odds ratios with 95% confidence intervals for associations between invitation for an NHS health check and the detection of CVD risk factors, new diagnoses and interventions. Results are shown for the comparisons of cohorts 1-4 against all of cohort 5 and against patients in cohort 5 who we confirmed did not attend (DNA) a HC incidentally.

	Cohort1 vs		Cohort2 vs		Cohort3 vs		Cohort4 vs	
	Cohort5 All	Cohort5 DNA	Cohort5 All	Cohort5 DNA	Cohort5 All	Cohort5 DNA	Cohort5 All	Cohort5 DNA
DETECTION %								
CVD risk >10%	1.20 (1.15-1.25)	1.71 (1.64-1.80)	1.93 (1.82-2.04)	2.66 (2.50-2.83)	3.28 (3.08-3.50)	3.98 (3.71-4.27)	8.01 (7.34-8.73)	11.17 (10.13-12.33)
CVD risk >20%	1.07 (0.99-1.15)	1.49 (1.37-1.63)	1.44 (1.29-1.61)	1.90 (1.69-2.15)	2.83 (2.48-3.23)	3.12 (2.72-3.58)	5.86 (4.83-7.10)	7.18 (5.82-8.85)
SBP >140 or DBP > 90 mmHg	1.04 (1.01-1.07)	1.06 (1.03-1.09)	1.08 (1.05-1.12)	1.10 (1.06-1.14)	1.23 (1.19-1.27)	1.26 (1.21-1.30)	1.64 (1.57-1.70)	1.69 (1.62-1.76)
Current smoker	1.03 (1.01-1.06)	1.03 (1.01-1.06)	1.05 (1.02-1.09)	1.05 (1.02-1.09)	1.05 (1.02-1.08)	1.05 (1.03-1.08)	1.22 (1.18-1.26)	1.23 (1.19-1.27)
BMI >30 kg/m^2	1.09 (1.06-1.12)	1.14 (1.11-1.18)	1.26 (1.21-1.31)	1.31 (1.26-1.36)	1.46 (1.41-1.51)	1.52 (1.47-1.58)	2.05 (1.96-2.14)	2.18 (2.09-2.28)
TC >5.5 mmol/L	1.19 (1.16-1.23)	1.33 (1.29-1.37)	1.67 (1.61-1.72)	1.83 (1.77-1.90)	2.10 (2.03-2.17)	2.27 (2.19-2.34)	3.72 (3.57-3.89)	4.20 (4.02-4.39)
TC >7.5 mmol/L	1.12 (1.02-1.22)	1.19 (1.08-1.30)	1.42 (1.26-1.59)	1.52 (1.35-1.71)	1.66 (1.47-1.87)	1.76 (1.56-1.99)	2.89 (2.46-3.38)	3.15 (2.67-3.72)
DIAGNOSES %								
HTN	1.04 (0.99-1.09)	1.03 (0.98-1.09)	1.06 (0.98-1.14)	1.04 (0.97-1.12)	1.10 (1.02-1.19)	1.10 (1.02-1.19)	1.33 (1.20-1.47)	1.34 (1.20-1.48)
AF	1.14 (0.98-1.32)	1.11 (0.95-1.30)	0.91 (0.72-1.14)	0.89 (0.71-1.13)	1.33 (1.06-1.67)	1.31 (1.05-1.65)	1.00 (0.72-1.39)	1.01 (0.72-1.40)
CKD	1.01 (0.84-1.22)	0.98 (0.81-1.19)	1.22 (0.93-1.61)	1.18 (0.90-1.57)	1.08 (0.77-1.51)	1.06 (0.76-1.49)	0.69 (0.36-1.32)	0.68 (0.36-1.30)
Diabetes	0.99 (0.91-1.08)	0.97 (0.88-1.06)	0.95 (0.84-1.09)	0.94 (0.82-1.07)	1.12 (0.99-1.28)	1.12 (0.98-1.27)	1.34 (1.12-1.61)	1.36 (1.13-1.64)
INTERVENTIONS %								
Statin	1.06 (1.01-1.11)	1.12 (1.06-1.18)	1.17 (1.09-1.25)	1.21 (1.13-1.30)	1.26 (1.16-1.35)	1.27 (1.18-1.37)	1.54 (1.39-1.71)	1.58 (1.42-1.76)
Antihypertensive	0.99 (0.95-1.03)	0.99 (0.95-1.03)	1.04 (0.99-1.10)	1.04 (0.98-1.09)	1.04 (0.98-1.10)	1.04 (0.98-1.10)	1.15 (1.06-1.24)	1.15 (1.07-1.24)
Antiglycaemics	0.93 (0.85-1.02)	0.92 (0.83-1.01)	0.90 (0.79-1.04)	0.90 (0.78-1.03)	1.04 (0.91-1.20)	1.03 (0.90-1.19)	1.18 (0.97-1.44)	1.19 (0.97-1.45)
Nicotine	1.00 (0.91-1.10)	1.01 (0.92-1.11)	1.05 (0.91-1.22)	1.07 (0.92-1.24)	1.04 (0.88-1.22)	1.08 (0.91-1.28)	0.92 (0.71-1.20)	0.96 (0.73-1.25)
Stop smoking advice	1.08 (1.04-1.12)	1.12 (1.08-1.16)	1.19 (1.13-1.26)	1.23 (1.17-1.30)	1.28 (1.20-1.35)	1.32 (1.25-1.40)	1.65 (1.51-1.79)	1.74 (1.60-1.90)
Weight advice/referral	1.50 (1.45-1.55)	2.14 (2.07-2.22)	2.84 (2.73-2.95)	3.98 (3.81-4.16)	4.21 (4.04-4.40)	5.69 (5.42-5.98)	8.36 (7.89-8.86)	14.33 (13.31-15.43)

Anti-obesity	1.06	(0.88-1.26)	1.06	(0.88-1.27)	1.11	(0.85-1.44)	1.11	(0.85-1.44)	1.09	(0.83-1.44)	1.08	(0.82-1.42)	1.00	(0.68-1.48)	1.00 (0.68-1.49)
CVD>10% and statin	1.12	(1.03-1.21)	1.35	(1.24-1.48)	1.27	(1.12-1.43)	1.49	(1.31-1.70)	1.78	(1.54-2.07)	1.90	(1.63-2.21)	2.90	(2.36-3.57)	3.27 (2.63-4.06)
CVD>20% and statin	1.03	(0.92-1.15)	1.25	(1.11-1.42)	1.07	(0.90-1.28)	1.28	(1.06-1.54)	1.58	(1.29-1.94)	1.67	(1.36-2.06)	2.60	(1.92-3.52)	2.95 (2.15-4.04)
HTN and antihypertensive	1.04	(0.98-1.10)	1.04	(0.98-1.10)	1.06	(0.97-1.15)	1.05	(0.96-1.14)	1.11	(1.02-1.21)	1.11	(1.02-1.21)	1.33	(1.18-1.50)	1.33 (1.18-1.50)

Body mass index (BMI), total cholesterol (TC), cardiovascular disease (CVD), systolic blood pressure (SBP), diastolic blood pressure (DBP), atrial fibrillation (AF), chronic kidney disease (CKD), hypertension (HTN)

Table 4 shows demographics of participants in cohort 4 that were eligible at the beginning of their invitation year stratified according to national IMD quintile. There was a disproportionately high number of participants in the least deprived quintile, which reflected the affluence of the study area compared to the national average. The proportion attending a HC was also highest in this quintile. Table 5 shows ORs for outcomes in invited cohort 4, with reference to uninvited cohort 5, stratified according to national IMD quintile. The effects of IMD were significant (at the p=0.05 level) between IMD and detection of: 10 year CVD risk >10%, SBP >140 or DBP > 90 mmHg, BMI >30 kg/m^2, TC >5.5 mmol/L and TC >7.5 mmol/L as well as weight advice / referral.

Table 4. Numbers of participants and proportions of males and HC attendees in cohort 4 according to national IMD quintile, wherein quintile 5 is the least deprived.

	Q1	Q2	Q3	Q4	Q5
n	3775	9083	10792	15098	30238
% male	50.8	49.5	47.5	46.4	45.8
% attended HC	24.1	26.7	32.9	37.2	40.7

Quintile (Q – 1 = most deprived, 5 = least deprived), n (number of participants), HC (health check)

Table 5 Age and gender adjusted odds ratios with 95% confidence intervals for associations between invitation for an NHS health check and the detection of CVD risk factors, new diagnoses and interventions. Results are shown for invited cohort 4, with reference to uninvited cohort 5, stratified according to IMD quintile, wherein quintile 5 is the least deprived. The outcomes with a significant interaction (p<0.05) with IMD are shown in bold.

DETECTION	Q1	Q2	Q3	Q4	Q5
CVD risk >10%	**3.02 (2.14-4.28)**	**6.15 (4.78-7.90)**	**7.82 (6.21-9.84)**	**7.99 (6.67-9.58)**	**9.67 (8.49-11.03)**
CVD risk >20%	3.99 (1.88-8.48)	5.30 (3.11-9.01)	6.96 (4.05-11.96)	7.21 (4.63-11.21)	5.56 (4.22-7.33)

SBP >140 or DBP > 90 mmHg	**1.36 (1.13-1.63)**	**1.45 (1.30-1.63)**	**1.57 (1.42-1.74)**	**1.70 (1.56-1.85)**	**1.71 (1.61-1.82)**
Current smoker	1.17 (1.06-1.30)	1.16 (1.08-1.25)	1.25 (1.16-1.35)	1.25 (1.17-1.35)	1.25 (1.18-1.33)
BMI >30 kg/m^2	**1.59 (1.36-1.86)**	**1.96 (1.75-2.20)**	**2.12 (1.91-2.36)**	**1.93 (1.75-2.12)**	**2.24 (2.08-2.41)**
TC >5.5 mmol/L	**2.41 (2.02-2.87)**	**3.01 (2.67-3.39)**	**3.37 (3.04-3.74)**	**3.76 (3.43-4.11)**	**4.30 (4.03-4.59)**
TC >7.5 mmol/L	**1.10 (0.63-1.93)**	**3.47 (2.10-5.75)**	**2.09 (1.44-3.03)**	**3.55 (2.44-5.16)**	**3.39 (2.66-4.34)**
DIAGNOSES					
HTN	1.65 (1.04-2.62)	1.22 (0.92-1.61)	1.43 (1.12-1.82)	1.23 (0.99-1.54)	1.34 (1.14-1.57)
AF	1.77 (0.29-10.65)	0.56 (0.19-1.64)	1.08 (0.50-2.30)	0.98 (0.50-1.92)	1.08 (0.65-1.79)
CKD	NA*	3.36 (0.35-32.44)	0.67 (0.20-2.31)	0.48 (0.12-1.86)	0.37 (0.10-1.36)
Diabetes	1.32 (0.72-2.45)	1.29 (0.83-2.01)	1.02 (0.67-1.55)	1.15 (0.74-1.78)	1.74 (1.27-2.37)
INTERVENTIONS					
Statin	1.46 (1.00-2.12)	1.39 (1.06-1.82)	1.37 (1.06-1.77)	1.50 (1.19-1.89)	1.76 (1.48-2.09)
Anti-hypertensive	1.20 (0.90-1.60)	1.17 (0.95-1.43)	1.19 (0.99-1.43)	1.14 (0.96-1.35)	1.13 (1.00-1.27)
Antiglycaemics	1.15 (0.60-2.22)	1.05 (0.65-1.69)	1.04 (0.66-1.63)	1.04 (0.63-1.70)	1.44 (1.03-2.00)
Nicotine replace	1.54 (0.75-3.17)	0.54 (0.28-1.03)	1.14 (0.63-2.08)	0.63 (0.36-1.09)	1.31 (0.75-2.28)
Stop smoking advice	1.84 (1.33-2.54)	1.46 (1.18-1.81)	1.48 (1.23-1.79)	1.62 (1.34-1.95)	1.82 (1.58-2.10)
Weight advice/referral	**4.48 (3.60-5.59)**	**6.42 (5.47-7.53)**	**7.68 (6.63-8.89)**	**8.17 (7.21-9.25)**	**10.21 (9.32-11.18)**
Anti-obesity	0.82 (0.29-2.32)	0.56 (0.21-1.48)	0.95 (0.44-2.05)	1.09 (0.45-2.62)	2.16 (0.87-5.36)
CVD risk >10% and statin	1.14 (0.48-2.70)	3.32 (1.94-5.66)	2.53 (1.52-4.20)	3.00 (1.90-4.71)	3.24 (2.34-4.49)
CVD risk >20% and statin	1.49 (0.45-4.96)	3.12 (1.52-6.41)	2.20 (1.00-4.85)	3.25 (1.55-6.81)	2.57 (1.63-4.05)
HTN and anti-hypertensive	1.35 (0.77-2.35)	1.35 (0.97-1.87)	1.21 (0.91-1.60)	1.26 (0.96-1.65)	1.41 (1.17-1.70)

*Insufficient data, Quintile (Q – 1 = most deprived, 5 = least deprived), body mass index (BMI), total cholesterol (TC), cardiovascular disease (CVD), systolic blood pressure (SBP), diastolic blood pressure (DBP), atrial fibrillation (AF), chronic kidney disease (CKD), hypertension (HTN)

DISCUSSION

This study evaluated the NHS HC programme in Hampshire from its implementation in April 2011 until March 2015. HC attendance following invitation increased year on year and as of 2015 was 30%. Attendees were older, from less deprived backgrounds and less likely to be male than those who were invited but chose not to attend. A significant finding was the large increase of up to 17.5% in the proportion of patients with measurements of TC among HC invited cohorts compared to non-invited. As might be expected, this led to large increases in detection of elevated TC >5.5 mmol/L and CVD risk >10%, as well as TC >7.5 mmol/L and CVD risk >20%. Notwithstanding, there were only modest increases in detection plus treatment with statins. Explanations for this might include guidance during the study period recommending statins for CVD risk >20%, whereas the largest increased was in detection of CVD risk > 10%. Nonetheless, even among those with CVD risk >20% only 36.5%-40.7% (range for the invited cohorts) of participants were prescribed statins. This is substantially lower than the 85% used in modelling studies by the Department of Health.[5] In the uninvited group, rates of statin prescriptions following identification of CVD risk >20% were slightly higher (41.9%), but still lower than expected. Accordingly, there may be a more general issue relating to the step up from risk factor identification to diagnosis, and from diagnosis to treatment across general practice that would represent a missed opportunity at a population level for primary prevention of CVD. More specifically to the HC, there is a lack of a defined follow-up pathway following identification of increased 10-year CVD risk. Public Health England commissions and pays for the HC itself but follow-up is then a cost to General Practices which maybe a barrier.

Statin prescription rates may have increased since the study period, as updated National Institute for Health and Care Excellence (NICE) guidance now recommends statins for CVD risk >10% and a recent large and well-publicised review reported a more favourable risk / benefit profile of statins than thought previously.[21] Statin prescription rates resulting from a HC may also be higher outside of Hampshire, as they are known to vary locally.[22]

Other notable findings of this study included increased detection of elevated BP among HC invited cohorts, as well as modest increases in new diagnoses of hypertension and treatment. Those attending HCs were more likely to be diagnosed with diabetes, but the corresponding increase in prescriptions of antiglycaemics did not reach significance. According to HC guidance, diabetes screening is performed only in those deemed “at risk” with BMI ≥ 30 kg/m^2 (≥ 25 kg/m^2 in non-white ethnic groups) or SBP or DBP above ≥ 140 mmHg or 90 mmHg. Data regarding the sensitivity of these criteria are limited, but one study in the United States reported that a BMI cut off of ≥ 25 kg/m^2 “would miss 36% of Asian Americans with newly diagnosed type 2 diabetes”,[23] so the HC may also have missed cases.

There was no significant increase in new diagnoses of CKD. This was likely because kidney function tests were performed only in HC patients with SBP or DBP ≥ 140 mmHg or 90 mmHg. A formal diagnoses of CKD would have required a repeat blood test, something which would need to have been organised by the GP and agreed to by the patient.

The HC did not result in any significant increase in new diagnoses of AF. NICE Hypertension clinical guideline 127 states that practitioners should manually palpate the pulse before measuring blood pressure.[24] However, this may not have been performed consistently or reliably during the HC. Manual palpation is not necessary with electronic sphygmomanometers, and any patient with an irregular pulse would have further required an electrocardiogram (ECG) to diagnose AF.

There were increases in detection of smokers and BMI >30 kg/m^2, as well as corresponding increases in lifestyle advice / referrals, particularly for high BMI. However, there was no significant difference in NRT or anti-obesity medications.

The HC had lower positive predictive values (or yield) for detection of risk factors than checks performed opportunistically. Most notably, lower proportions of CVD risk scores measured during the HC were >10% (–11.5% - –2.9%) and >20% (–6.1% - –1.8%). This may have been because GPs targeted opportunistic checks at those who were already symptomatic or because HC attendees were healthier with a lower prevalence of risk factors. A recent cohort study of 18 general practices in South London also found that participants taking up an opportunistic HC were at higher CVD risk (17% of invited HC and 22% of opportunistic HC with CVD risk score ≥10%), and that in younger adults in more deprived areas the opportunistic HC constituted a higher proportion of all HC performed. It was concluded that GPs were successfully targeting groups at higher risk who may otherwise face barriers to attendance at a pre-arranged HC.[25]

In the final year of this study, uptake of the HC was highest among participants in the least deprived national IMD quintile (40.7%) and lowest in the most deprived (24.1%). There was evidence of better performance of the HC among less deprived participants for detection of 10-year CVD risk >10%, SBP >140 mmHg or DBP > 90 mmHg, BMI, TC >5.5 mmol/L and TC >7.5 mmol/L and weight advice / referral. However, the precise effect of deprivation was difficult to estimate given the competing effects of differences in HC uptake (lowest in the most deprived quintile), the frequency of risk variable (highest in the most deprived quintile) and differing sample sizes (i.e. power to test / reject the null hypothesis). Primary care management may also have played a role, but the lack of difference by deprivation in prescribing rates in those detected suggests this was not a key factor.

Our findings build on existing evidence that attendees tend to be older, female and non-smokers.[16,26] The observation in this study that HC attendees were less likely to come from more deprived socioeconomic groups is reflected by some studies[27] though not others.[16,26]. Reasons for an inconsistent effect of deprivation are unclear, but may relate to local variation in targeting of high CVD risk individuals, who are overrepresented in more deprived groups. An example of such targeting was reported by a study in East London, which found no effect of deprivation, where GP practices were paid more for HCs that involved detection of higher CVD risk scores.[22] In Hampshire, including the cities of Southampton and Portsmouth, there was no clear incentive to detect high CVD risk nor specific targeting of deprived communities.

Earlier studies report associations between HC attendance and increased recording and detection of CVD risk factors and use of interventions[17]. It has also been shown that a year after completing a HC, attendees have modest but significant reductions in CVD risk scores, diastolic blood pressure, TC levels and lipid ratios.[18] However, Chang et al. [26] found that only a third of HC attendees with CVD risk scores > 20% go on to be prescribed statins, slightly lower than that observed in the present study (36.5%-40.7%). Reasons for low prescription rates among high-risk groups are unclear, but patient refusal might be important and requires further research. Similar to this study, Smith et al.[28] reported a limited effect of HC attendance on detection rates and treatment of diabetes which, as is explained above, is likely because measuring blood glucose or HBA1c is not a standard part of the HC.

The increases in proportions of new prescriptions we observed were smaller than those found in two large previous matched studies.[17,26] This is to be expected given that those studies compared attendees vs. non-attendees, whereas we considered invitees vs. non-invitees. Given that not everybody invited for a HC will attend, out approach is more likely to be representative of the effect of the HC programme overall.

Strengths of this study included the biggest sample size to date for a HC study comprising 277,274 patients invited for a HC and 88,731 patients who were not. It is the first HC study to employ a quasi-randomised method and an intention-to-treat analysis. Specifically, patients were allocated to either HC invited or non-invited groups according to their dates of birth. We were able to evaluate the HC programme at the level of invitation, which is advantageous compared to previous studies which compared attendance vs. non-attendance. There were also weaknesses in our methods. First, our follow-up periods were short, varying from an average of six months (cohort 4) to 3.5 years (cohort 1). Process outcomes may have occurred after the end of follow-up, particularly in the case of new treatments that may have required further appointments and monitoring (e.g. for new prescriptions of antihypertensive). In addition, we were unable to observe clinically important outcomes, such as incident cardiovascular disease. For every 100 people invited for a HC in 2012/13, an extra one person was prescribed a statin. Based on a literature reported number needed to treat (NNT) for primary prevention of cardiovascular events,[29] one event may be prevented for every 560 people invited for a HC, but this estimation does not account for duration of treatment or adherence. Improving NNTs would require greater uptake of the HC and / or greater prescribing among those with identified CVD risk. A second limitation of our study was that we were missing all data including at baseline for an unknown number of patients who died during the follow-up, which was a consequence of how our data source, the HHRA, was organised. These deaths will selectively have reduced numbers of those at highest risk from our population. They will tend to have been in poorer and higher risk groups and, therefore, less likely to attend a HC. The numbers would have been balanced between the cohorts, so should not have affected our between-cohort comparisons. However, they might have reduced the overall risk profile, and differentially within cohorts favour attendance. A third limitation was contamination bias, as some patients in the uninvited group attended a HC. Contamination was largely inevitable given advertising and public awareness of the HC and given that all included GP practices were involved in delivering the programme. Contamination likely led to an

underestimation of the effectiveness of the HC programme in our study. Fourth, we had limited details on some factors, including diet and alcohol intake, and non-medical interventions, such as lifestyle advice. Lifestyle advice may have ranged from brief general advice to individually tailored advice with subsequent follow-up. However, such variation likely had a small effect on our results given an earlier study that reported a lack of an association between the intensity of lifestyle advice as part of a HC and related CVD risk reduction.[30] Fifth, there were potential coding errors or omissions by GPs in recording attendance, measurements, diagnoses and interventions. This may have been particularly problematic for cohort 1 because Read Codes for HC completion were only released in 2012, after the start of the invitation year. Failure of GPs to code attendance retrospectively (i.e. once the Read Codes were available) may, in part, explain, why there was lower recorded HC attendance in cohort 1 compared to the other cohorts. Otherwise, coding errors would have affected the intervention and non-intervention groups equally. Sixth, we missed data on HC undertaken in community pharmacies and other non-GP settings though this was a small minority. Our population was not necessarily representative of the UK, and we had no data on ethnicity. Hampshire does comprise significant urban, suburban and rural populations, but the proportion of ethnic minorities is lower than the national average and this may limit the generalisability of our results. Seventh, we excluded around 35% of the eligible population. This was because of problems with the invitation system, missing DOBs, Read Codes not formatted according to Version 2 and unknown invitation status for some participants (e.g. because of moving into the study area after the start of the follow-up period). However, these exclusions would have been equal across the cohorts. Finally, our study period ended in 2015, and clinical guidance as well as engagement by GPs and patients with the HC programme may have changed since then.

In conclusion, this study evaluated the NHS HC programme and showed that participation increased year on year between 2011 and 2015. The HC programme resulted in large increases in the detection of patients with CVD risk factors, particularly raised cholesterol and 10-year CVD risk scores >10%. There were corresponding, albeit smaller, increases in certain evidence based medical therapies, most notably statins. However, rates of uptake, diagnosis and treatment were well below those expected by the Department of Health.[5] Future work should focus on improving uptake, including through use of non-GP settings (e.g. pharmacy etc.)[31] and by better communication of the programme[32,33] and invitation methods driven by behavioural insights.[34] Further support is also required in decision making for patients and GPs following identification of new risk factors as part of the NHS HC, potentially including incentivisation (e.g. payment by results). Finally, further studies are needed to assess the longer-term effects of the HC on clinical outcomes and health inequalities.

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Figures

Figure 1. Derivation of the study population and five cohorts included in this study. Cohorts 1-4 were invited for HCs in the years beginning 1st April 2011, 12, 13 and 14 respectively, while cohort 5, which was the control group, was not invited.

Figure 2. Histograms showing the distribution of ages within the five cohorts.

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Declaration of competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Ethics approval

This study received ethnical approval from the Research Ethics Committee at the University of Southampton ID: 24358) and approval from the Hampshire Health Record Information Governance Group.

Contributorship

The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. OJK, FS, EW, RP and PR conceived and designed the study; FS performed the data acquisition from the Hampshire Health Record Database and OJK performed the data analysis; OJK and FS drafted the manuscript

which was reviewed and amended by all authors. All authors, external and internal, had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. PR is guarantor.

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Transparency declaration

PR 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.

Data sharing

Access to the data used in this study is administrated by the Care and Health Information Exchange (CHIE) Information Governance Group, which is managed by the South, Central and West Commissioning Support Unit on behalf of health and social care organisations in Hampshire, Farnham and the Isle of Wight.

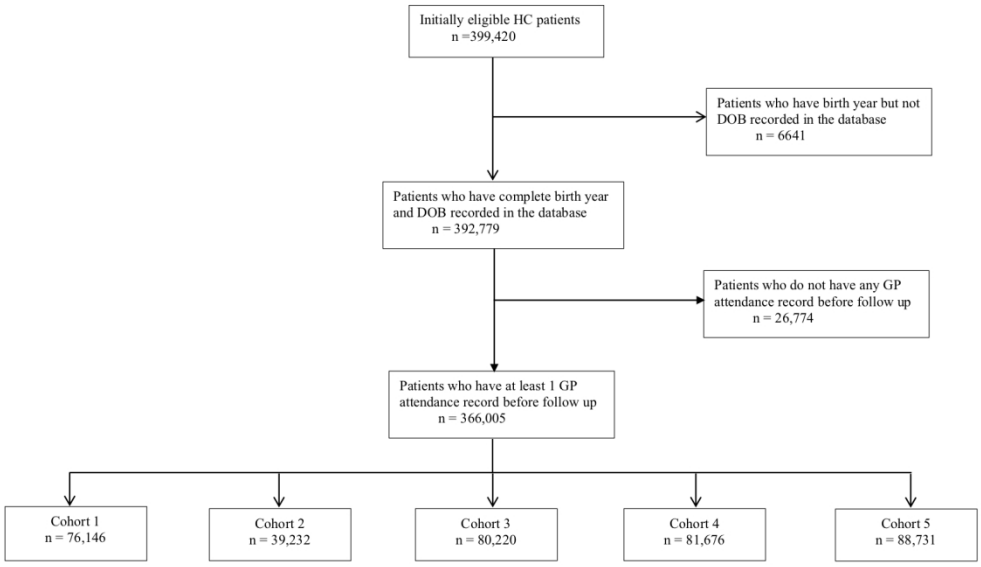

Figure 1. Derivation of the study population and five cohorts included in this study. Cohorts 1-4 were invited for HCs in the years beginning 1st April 2011, 12, 13 and 14 respectively, while cohort 5, which was the control group, was not invited.

146x83mm (300 x 300 DPI)

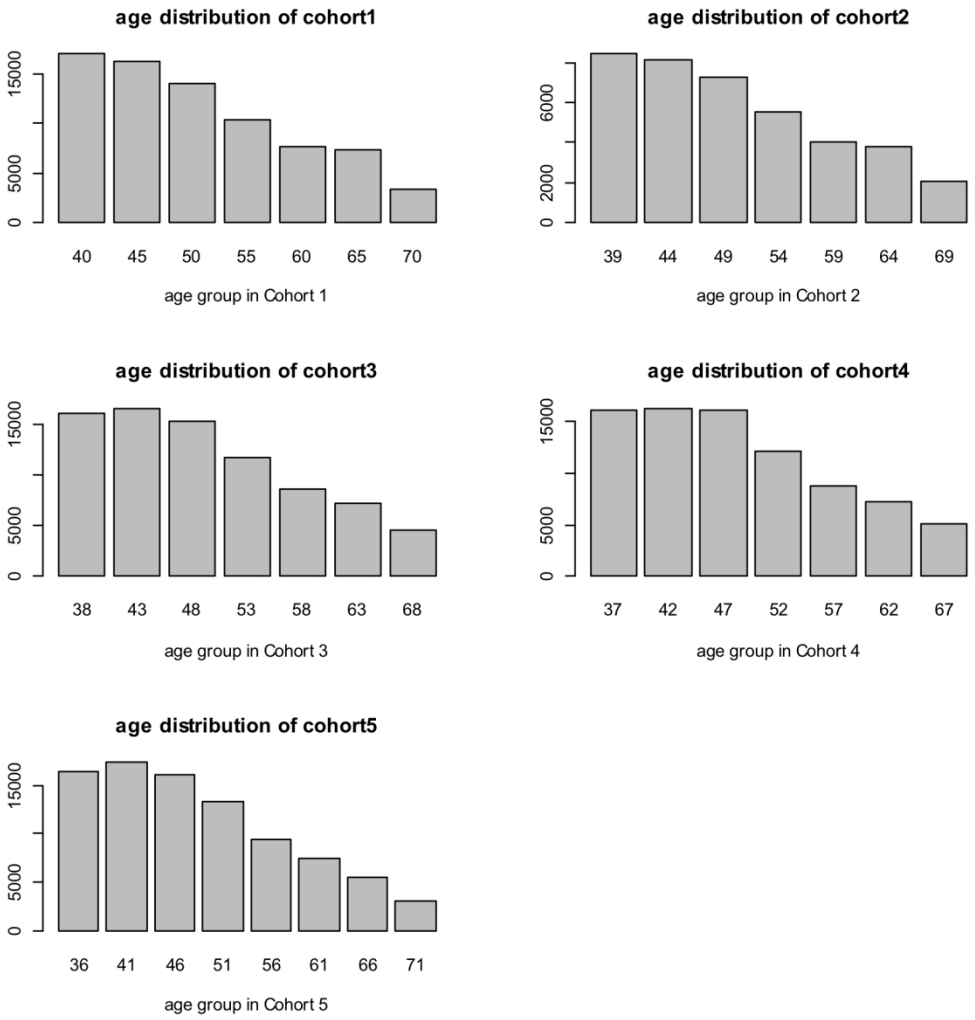

Figure 2. Histograms showing the distribution of ages within the five cohorts.

150x158mm (300 x 300 DPI)

Evaluating the Effectiveness of the NHS Health Check Programme in South England: a Quasi-Randomised Controlled Trial – supplementary materials

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Read codes (5-byte version 2 Read codes, EMIS or BNF)

NHS Health Check codes
8BAg NHS Health Check completed
EMISNQNH6 NHS Health check completed
EMISNQNH7 NHS Health check completed by practice
8BAg0 NHS Health Check completed by third party

Blood pressure
Systolic blood pressure: ReadCode like '2469%' or ReadCode like '246Q%'
Diastolic blood pressure: ReadCode like '246A%' or ReadCode like '246R%'
246.. | O/E - blood pressure reading
246R. | Sitting diastolic blood pressure
246Q. | Sitting systolic blood pressure

Body mass index
'22K2.','22K1.','22K4.','22K5.','22K6.','22K7.','22K8.','22K9.','22K90','22KB.','22K..','22K3.'

Total cholesterol
'44OE.' Plasma total cholesterol level
'44P..' Serum cholesterol
'44P1.' Serum cholesterol normal
'44P2.' Serum cholesterol borderline
'44P3.' Serum cholesterol raised
'44P4.' Serum cholesterol very high
'44PH.' Total cholesterol measurement
'44PJ.' Serum total cholesterol level

10-year risk of CVD disease
'662k%' (JBS CVD risk less than 10% over next ten years)
'662l%' (JBS CVD risk ten percent to 20% over next ten years)
'662m%' (JBS CVD risk greater than 20% up to 30% over next ten years)

'662n%' (JBS CVD risk greater than 30% over next ten years)
'38DP%' (QRISK2 cardiovascular disease 10 year risk score)
'38DF%' (QRISK cardiovascular disease 10 year risk score)
'38DR%' (Framingham 1991 cardiovascular disease 10 year risk score)

Current smoker
'137..','1372.','1373.','1374.','1375.','1376.','137b.','137c.','137C.','137D.','137d.','137e.','137E.','137f.','137G.','137h.','137H.','137J.','137m.','137a.','137X.','137Y.','137Z.','137M.','137n.','137P.','137Q.','137R.','137V.','13p0.','13p5.','67H6.','745H.','8CAg.','8CAL.','8CdB.','8H7i.','8HBM.','8HBP.','8HkQ.','8HTK.','8IAj.','8IEK.','8IEM.','8IEo.','8T08.','9hG..','9hG0.','9hG1.','9kc..','9kc0.','9kf1.','9kf2.','9ko..','9N2k.','9N4M.','9Ndg.','9NdZ.','9OO..','9OO1.','9OO2.','9OO3.','9OO4.','9OO5.','9OO6.','9OO7.','9OO8.','9OO9.','9OOA.','9OOB.','9OOZ.','13p50%','745H0%','745H,%','745H2%','745H3%','745H4%','745Hy%','745Hz%','9NS02%','9OOB0%','9OOB1%','9OOB2%'

Ex smoker
'137K.','137N.','137O.','137S.','137T.','13p4.','1377.','137l.','9km..','137j.','1378.','137F.','137B.','1379.','137A.','137L .','137i.','137K0%'

Non-smoker
'137L.'

Never smoking
'1371.'

Hypertension
QOFv28 - Hypertension
G2...
G20..%
G24.. - G2z.. (Excluding G24z1, G2400, G2410, G27..)
Gyu2.
Gyu20

Ischaemic heart disease
QOF v28 - Secondary Prevention of Coronary Heart Disease
G3... – G309.
G30B. - G330z (excluding G310.)
G33z. - G3401
G342. – G35X.
G38.. – G3z..
Gyu3.% (excluding Gyu31)

Diabetes
QOF v28 – Diabetes
C10.., C109J, C109K, C10C.,C10D., C10E.%, C10F.% (Excluding C10F8), C10G.%, C10H.%, C10M.%, C10N.%,PKyP.,C10P.%

CKD
QOF v28 – CKD
1Z12.
1Z13.
1Z14.
1Z15.
1Z16.
1Z1B. – 1Z1L.
K053.
K054.
K055.

AF
QOF v28 – AF

G573.% (excluding G5731, G5736)

Heart Failure
QOF v28 – HF
G58..%
G1yz1
662f. – 662i.

Atherosclerosis and other peripheral vascular disease
G70% Atherosclerosis
G73 Other peripheral vascular disease
G7310 Buerger's disease
G7311 Presenile gangrene
G731z Thromboangiitis obliterans NOS
G732% Peripheral gangrene
G733 Ischaemic foot
G73y Other specified peripheral vascular disease
G73y0 Diabetic peripheral angiopathy
G73yz Other specified peripheral vascular disease NOS
G73z Peripheral vascular disease NOS
G73z0 Intermittent claudication
G73zz Peripheral vascular disease NOS

Stroke and TIA
QOF v28 – Stroke and TIA
G61..% (excluding G617.)
G63y0 - G63y1
G64..%
G66..% (excluding G669.)
G6760
G6W..
G6X..
G65..- G654.
G656.- G65zz
Gyu62 – Gyu66
Gyu6F
Gyu6G
ZV12D
Fyu55
G619.

Additional circulatory system disease.
Gyu% Additional circulatory system disease classification terms
NOT Gyu0% Acute rheumatic fever
NOT Gyu1% Chronic rheumatic heart disease
NOT Gyu2% Hypertensive diseases
NOT Gyu8% Diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified
NOT Gyu9% Other and unspecified disorders of the circulatory system

STATINS
bx% LIPID-LOWERING DRUGS
2.12 Lipid-regulating drugs (BNF)

Antihypertensive
BNF_Code 02.02.01.00, 02.02.02.00, 02.02.03.00, 02.04.00.00, 02.04.01.00, 02.05.04.00, 02.05.05.00, 02.05.05.01, 02.05.05.02, 02.06.02.00, TitleofGroup in ('Angiotensin-Converting Enzyme Inhibitors','Calcium Channel Blockers','Angiotensin-II Receptor Antagonists','Potassium Sparing Diuretics','Thiazides And Related Diuretics','Loop Diuretics','Alpha-Adrenoceptor Blocking

Drugs','Beta-Adrenoceptor Blocking Drugs','Compound Beta-Adrenoceptor Blocking Drugs','Drugs Affecting The Renin-Angiotensin System')

Anti-obesity
aw...

Anti-diabetes
BNF code 06.01.00.00, and titleofGroup is : Drugs Used In Diabetes

Nicotine replacement
BNF_Code 04.10.00.00, 04.10.02.00

K: Palliative care

1Z01	Terminal illness - late stage
2JE	Last days of life
8BA2	Terminal care
8BAP	Specialist palliative care
8BAS	Specialist palliative care treatment - daycare
8BAT	Specialist palliative care treatment - outpatient
8BAe	Anticipatory palliative care
8BJ1	Palliative treatment
8CM1%	On gold standards palliative care framework
8CM4	Liverpool care pathway for the dying
8CME	Has end of life advanced care plan
8H6A	Refer to terminal care consult
8H7L	Refer for terminal care
8H7g	Referral to palliative care service
8HH7	Referred to community specialist palliative care team
9EB5	DS 1500 Disability living allowance (terminal care) completed
9Ng7	On end of life care register
ZV57C	Palliative care

Previous health checks and CVD risk assessments

38B1 Vascular disease risk assessment
38B10 CVD (cardiovascular disease) risk assessment by third party
66f Cardiovascular disease monitoring
66f0 Cardiovascular disease annual review
66f1 Cardiovascular disease interim monitoring
66f2 Cardiovascular disease high risk review
8BAg NHS Health Check completed
9OhA Cardiovascular disease risk assessment done
8BAg0 NHS Health Check completed by third party

Table 1. Comparison of proportions of participants with risk factor recording / detection, new diagnoses and new interventions in each of the four invited cohorts vs. uninvited cohort 5.

	C1 vs C5 (p-value)	C2 vs C5 (p-value)	C3 vs C5 (p-value)	C4 vs C5 (p-value)
RECORDING %				
BP	<0.001	<0.001	<0.001	<0.001
BMI	<0.001	<0.001	<0.001	<0.001
TC	<0.001	<0.001	<0.001	<0.001
CVD risk	<0.001	<0.001	<0.001	<0.001
Smoking status	<0.001	<0.001	<0.001	<0.001
DETECTION %				
CVD risk >10%	<0.001	<0.001	<0.001	<0.001
% of CVD risk recorded with >10%	<0.001	<0.001	<0.001	<0.001
CVD risk >20%	<0.001	<0.001	<0.001	0.392
% of CVD risk recorded with >20%	<0.001	<0.001	<0.001	<0.001
SBP >140 or DBP > 90 mmHg	<0.001	<0.001	<0.001	<0.001
% of BP recorded with >140 or >90	<0.001	0.911	0.804	0.009
Current smoker	0.170	0.475	0.826	0.013
% of smoking status recorded who currently smoke	<0.001	<0.001	<0.001	<0.001
BMI >30 kg/m^2	<0.001	<0.001	<0.001	<0.001
% BMI recoded with >30	<0.001	<0.001	<0.001	<0.001
TC >5.5 mmol/L	<0.001	<0.001	<0.001	<0.001
% of TC recorded with >5.5 mmol/L	0.005	0.002	<0.001	<0.001
TC >7.5 mmol/L	<0.001	<0.001	<0.001	<0.001
% of TC recorded with >7.5 mmol/L	0.584	0.005	<0.001	<0.001
DIAGNOSES %				
Hypertension	<0.001	<0.001	0.003	<0.001

% of SBP >140 or DBP > 90 with hypertension diagnosis	<0.001	0.148	0.271	0.007
AF	<0.001	0.855	0.012	0.783
CKD	0.118	0.040	0.443	0.741
Diabetes	0.129	0.624	0.065	0.015
INTERVENTIONS %				
Statin	<0.001	<0.001	<0.001	0.017
% of CVD>10% prescribed statins	<0.001	<0.001	<0.001	<0.001
% of CVD>20% prescribed statins	<0.001	<0.001	<0.001	<0.001
Antihypertensive	<0.001	<0.001	0.077	0.205
% of hypertensives prescribed antihypertensive	0.450	0.415	0.711	0.003
Antiglycaemics	0.515	0.192	0.957	0.481
% of diabetics prescribed antiglycaemics	<0.001	<0.001	<0.001	<0.001
NRT	0.405	0.757	0.789	0.881
% of current smokers prescribed NRT	0.400	0.552	0.370	0.397
Stop smoking advice	0.003	<0.001	<0.001	<0.001
% of current smokers given advice	0.010	<0.001	0.035	0.024
Weight advice/referral	<0.001	<0.001	<0.001	<0.001
% of BMI>30 kg/m^2 given advice/referal	<0.001	<0.001	<0.001	<0.001
Anti-obesity	0.503	0.491	0.893	0.708
% of BMI>30 kg/m^2 prescribed anti-obesity	0.002	0.398	<0.001	<0.001

Attended (Att), Blood pressure (BP), body mass index (BMI), total cholesterol (TC), cardiovascular disease (CVD), systolic blood pressure (SBP), diastolic blood pressure (DBP), atrial fibrillation (AF), chronic kidney disease (CKD), Nicotine replacement therapy (NRT)