Estimated prevalence of hypertension and undiagnosed hypertension in a large inpatient population: A cross-sectional observational study

A. Mahdi[1], L.C. Armitage[2], L. Tarassenko[1,4], P. Watkinson[3,4]

[1]Institute of Biomedical Engineering, Department of Engineering Science, University of Oxford

[2]Nuffield Department of Primary Care Health Sciences, University of Oxford

[3]Nuffield Department of Clinical Neurosciences, Oxford University Hospitals NHS Trust, Oxford

[4]Sensyne Health, Schrödinger Building, Heatley Road, Oxford Science Park, Oxford, OX4 4GE

Keywords: blood pressure, hypertension prevalence, undiagnosed hypertension

Abstract

Introduction. Hypertension is a major cause of morbidity and mortality. The prevalence of hypertension, both in diagnosed and undiagnosed states, has been widely reported in community populations. However, comparable estimates for hypertension prevalence in the inpatient setting are lacking. We aimed to estimate the prevalence of diagnosed and undiagnosed hypertension in a UK hospital setting, according to current international guidelines for hypertension diagnosis and management. **Methods**. We performed a retrospective cross-sectional observational study of patients admitted to adult wards in four acute hospitals in Oxford, UK, between March 2014 and April 2018. **Results**. We identified 41,455 eligible admitted patients with a total of 1.7 million blood pressure measurements recorded during their hospital admissions. According to European 2018 ESC/ESH diagnostic criteria for hypertension, 21.4% of patients had a mean blood pressure exceeding the diagnostic threshold for either Stage 1, 2 or 3 hypertension. Excluding those patients with either a pre-existing diagnostic code for hypertension or a prescribed antihypertensive medication during their hospital stay, we report that 14% men and 12% women had a mean blood pressure exceeding the ESC/ESH diagnostic criteria for hypertension, indicating these patients have undiagnosed hypertension. **Conclusion**. We identified notable proportions of hospital inpatients whose mean in-hospital blood pressure exceeded diagnostic thresholds for hypertension, with a marked proportion of these appearing to have undiagnosed hypertension. The inpatient setting, in which blood pressure is routinely measured throughout admission, may therefore provide an opportunity to improve detection of hypertension in the adult population.

INTRODUCTION

Background.

Hypertension is a major cause of morbidity and mortality linked with congestive heart failure, kidney disease and coronary artery disease (1). Early detection and management of hypertension are key in prevention of these diseases. However, in the early stages, hypertension is usually asymptomatic and thus many people are unaware of their condition. In the UK healthcare setting, hypertension is typically identified either opportunistically or through the National Health Service Health Check in primary care (2). This is a free check-up of overall health including blood pressure (BP). All adults aged between 40 and 74 years who do not have history of cardiovascular disease and are registered with a GP are invited for a health check every five years (3). However, only half of those invited attend these health checks (4) and 12% of the English adult population have undiagnosed hypertension (5). Therefore, current approaches to identifying people with hypertension in England are not adequate and innovative approaches need to be considered to improve the detection of hypertension.

The inpatient hospital setting, in which multiple BP measurements are performed for each admitted patient provides an opportunity to detect people with undiagnosed hypertension. However, research in this field has so far, focussed on the prevalence of hypertension in the emergency department setting and has largely excluded patients admitted to hospital (6).

Objectives.

The objective of this study is to estimate the prevalence of hypertension and undiagnosed hypertension in a UK hospital inpatient setting using a large hospital database of 1.7 million BP measurements. We also identify and discuss patient characteristics of those who appear to

be at greatest risk of undiagnosed hypertension and potential opportunities for improved detection of undiagnosed hypertension in the adult population.

METHODS

Study design

This study is a retrospective cross-sectional analysis of in-hospital BP for adult hospital patients meeting the eligibility criteria described below.

Study setting

Patients were admitted between March 2014 and April 2018 to adult wards in three Tertiary and one Secondary referral centres in the Oxford University Hospitals NHS Foundation Trust, UK.

Participants

We included patients from all adult wards, with the exception of the intensive care units, of four acute hospitals in the Oxford University Hospitals (OUH) NHS Foundation Trust. We included the first admission of each patient during which at least 3 BP measurements were recorded, with at least one being recorded during the nighttime (midnight-5:59 am) and at least one recorded during the daytime (10:00 am – 7:59 pm) with 2 of these observations being at least 24 hours apart. Hospital day and night periods were defined in accordance with standard practice in the literature (7).

Data analysis

24-hour blood pressure profile in the hospital setting

Each patient's BP data were averaged by hour of the day over their whole admission period, such that each individual only contributed averaged data for a maximum of 24 individual hourly periods. The computational details of this procedure have been described in our previous article (8).

Clinic, ambulatory and undiagnosed hypertension

Classification of clinic and ambulatory (daytime, nighttime and 24-hour) hypertension follows recently published European 2018 ESC/ESH (9) and American 2017 ACC/AHA (10) guidelines for hypertension management. For the definition of the corresponding BP threshold see Supplementary Tables ST-1 and ST-2. Undiagnosed hypertension was defined as mean BP above the diagnostic thresholds and no previous ICD-10 codes for hypertension (Supplementary Table ST-8) nor any of the prescribed antihypertensive drugs listed by British National Formulary (11) (Supplementary Table ST-7).

Isolated hypertension

Definitions of isolated (systolic, diastolic, daytime and nighttime) hypertension categories are derived from the corresponding European 2018 ESC/ESH and American 2017 ACC/AHA thresholds for clinic, ambulatory daytime and nighttime thresholds (see Supplementary Table ST-4 for definitions). As a proxy for the ambulatory BP, we applied 24-hour BP signature described above, with computational details explained in (8).

Data sources

Patients had their vital observations, including heart rate and systolic and diastolic BP recorded using the System for Electronic Notification and Documentation (SEND). SEND is a software application that links vital sign monitoring devices including BP monitors, with a tablet computer for the manual recording of vital signs in patients (12). All vital-sign equipment used within the study was purchased and maintained (including regular calibration) in accordance with the Oxford University Hospitals NHS Foundation Trust Medical Devices Management Policy. Other data (date of birth, sex, ICD-10 codes and prescription information) were obtained from the Patient Administration System (PAS) in the hospitals' electronic patient record (EPR) system, Cerner Millennium (https://www.cerner.com/, North Kansas City, MO, USA).

Sample size

We examined all patients aged 16 years of age and over who were admitted between March 2014 and April 2018 with observations recorded electronically using the SEND system for eligibility.

Quantitative variables

We investigated the prevalence of elevated BP in pre-defined patient subgroups according to (i) sex as recorded in the EPR, (ii) age, (iii) elective versus emergency admission and (iv) medical versus surgical admission.

RESULTS

Descriptive data

Between March 2014 and April 2018, 208,948 patients 16 years of age and over were admitted to Oxford University Hospitals NHS Foundation Trust. After excluding patients with no nighttime observations (113,012), those with no daytime observation (6,161), those in whom the time between first and last observation was less than 24 hours (13,899) and any subsequent admissions of the same patient (34,421), 41,455 patients were eligible for inclusion in the study (see Figure 1 for an inclusion/exclusion criteria flowchart). A total of 1,701,812 BP measurements were recorded for these patients. Mean age of patients was 64 years (SD 19) and 51% were female. Median length of stay was 4.7 days (IQR 7.4) and 63% were admitted as an emergency, whilst 33% were admitted electively and 4% classified as 'other' (e.g. maternity admissions or transfer from other hospital provider other than in an emergency). See Table 1 for a summary including number of patients, age, length of stay, number vital sign observation sets and mean systolic and diastolic BP stratified by sex, age group, NHS Admission Method and NHS Specialty.

Estimated prevalence of hypertension

According to the European ESC/ESH diagnostic criteria for hypertension, 79% patients had a mean BP within normal limits, whilst 18% had a mean BP equal to or greater than the diagnostic thresholds for Stage 1 hypertension, 3% had a mean BP equal to or greater than the diagnostic thresholds for Stage 2 hypertension and 0.4% equal to or greater than the thresholds for Stage 3 hypertension (Table 2). Using the American ACC/AHA guidelines, the proportions of patients meeting the diagnostic thresholds for Stage 1, 2 and 3 hypertensions were higher, at 26%, 18% and 3%, respectively (Table 2).

Estimated age-dependent trends of hypertension

The estimated age-dependent prevalence of hypertension trends for men and women and according to the European ESC/ESH and American ACC/AHA definitions of thresholds are shown in Figure 2 and Table 3. The analogous estimated prevalence trends for undiagnosed hypertension are shown in Figure 3 and Table 4.

Estimated prevalence of isolated hypertension

There was 19% of those meeting the criteria for isolated systolic hypertension according to ESC/ESH thresholds (31% according to ACC/AHA thresholds). The prevalence for those meeting the criteria for isolated nighttime hypertension was 39% according to ESC/ESH (45% according to ACC/AHA). The prevalence for isolated diastolic and daytime hypertension was very small (Supplementary Table ST-5).

The analogous prevalence for those meeting the criteria for isolated systolic hypertension but undiagnosed (i.e. those with no previous ICD-10 codes for hypertension nor any of the prescribed anti-hypertensive drugs listed by the British Natinal Formulary) was lower at 5% according to ESC/ESH (9% according to ACC/AHA). Again, the prevalence for those meeting the criterial for isolated nightime hypertension was 17% according to ESC/ESH (22% according to ACC/AHA). The prevalence for undiagnosed isolated diastolic and daytime hypertension was nearly zero (Supplementary Table ST-6).

DISCUSSION

Key results

This study estimated prevalence of hypertension and undiagnosed hypertension in an inpatient setting using a large hospital database of 1.7 million BP measurements, according to the European 2018 ESC/ESH guidelines (9) and American 2017 ACC/AHA guidelines (10).

Interpretation

Although the prevalence of hypertension and specifically undiagnosed hypertension in the community has been well established, it is rarely reported in the hospital setting. Literature regarding the prevalence of elevated in-hospital BP in the absence of a diagnosis of hypertension and its diagnostic ability and association with the future development of hypertension is also lacking.

Prevalence of hypertension

The prevalence of undiagnosed hypertension in emergency departments has been reported to be about 3% to 15% of adult patients, of which nearly 50% being categorised as having Stage 1 hypertension, 25% to 36% Stage 2 and 12% to 30% Stage 3 hypertension (13). In comparison, the current study shows that elevated BP was observed in nearly 21% patients according to ESC/ESH (47% according to ACC/AHA), of which 18%, 3% and 0.4% using ESC/ESH (26%, 18% 3% using ACC/AHA) were categorized as having Stage 1, 2 and 3 hypertension, respectively.

Screening for hypertension in hospital

Hospital admission allows for an opportunistic screening of BP and potential identification of undiagnosed hypertension. The accumulation of multiple measurements during hospital admission may also allow more accurate detection of patients who have hypertension in the community, for whom a single normotensive screening measurement obtained in a primary care appointment might mean they are inappropriately classified as being normotensive.

Figure 2 shows that the prevalence of elevated BP (irrespective of the presence of an ICD-10 code or medication prescription for hypertension) increases with age. As this patient group includes those with and without an existing diagnosis of hypertension, this might be considered to most accurately reflect the prevalence of uncontrolled hypertension in each of the hypertension diagnostic categories of night, day, clinic and 24-hour, as categorised according to the ESC/ESH and ACC/AHA guidelines.

There are two significant clinical deductions which can be drawn from Figure 2. Firstly, the marked prevalence of uncontrolled hypertension in all of these categories when either guideline is applied indicate that hospital admission may provide an opportunity for improvement of hypertension control or at a minimum to prompt post-discharge follow up of BP in primary care. Secondly is the high rate of isolated nocturnal hypertension. The fact that BP is measured in hospital outside traditional clinic hours, when patients might usually present to a health professional provides opportunity to increase the detection of patients with isolated nocturnal hypertension. Whilst clinicians may commonly attribute elevated or labile BP in hospital to stress and anxiety, previous studies have suggested increased BP lability under stress is a predictor of future cardiovascular events (14).

Figure 3 illustrates that there is a decrease in prevalence of undiagnosed hypertension with advancing age. It is unlikely that this is solely attributable to physiological aging and may

reflect the success of the UK's NHS Health Check in identifying a proportion of those aged over 40 years who have hypertension. The marked prevalence of undiagnosed hypertension which can be seen in both men and women below this age may indicate that a reduction in the age at which the health check is offered could increase detection of hypertension and improve preventative cardiovascular medicine in the UK.

Using more conservative ESC/ESH thresholds, there was a high prevalence of those with elevated BP 21.4% (47% ACC/AHA) out of which 5% (13% ACC/AHA) were undiagnosed with hypertension. Furthermore there were 17% of those meeting the ESC/ESH (22% ACC/AHA) criteria for undiagnosed isolated nighttime hypertension. These patients would not be identified by office measurements, but may have increased cardiovascular risk (15).

Present guidelines on the management of elevated BP in hospital are only applicable to patients who have markedly elevated BP in the emergency department setting (16). Internationally, hypertension guidelines provide diagnostic criteria for the clinic, home or ambulatory setting (Supplementary Tables ST-1 and ST2) but do not suggest diagnostic thresholds for the in-hospital setting (10,17–19). This may be owing to a lack of studies upon which hospital thresholds could be defined. Indeed, the emergency department guidelines draw on evidence from few studies which are limited in sample size and representativeness. Further research investigating the diagnostic performance of in-hospital BP measurements for reliably detecting hypertension is required.

Study limitations

This was a retrospective study with inherent limitations. The study used measurements recorded on the wards by nursing staff as part of their regular observations of in-hospital patients. This poses two potential limitations. Firstly, patients who have longer hospital stays

will contribute more data to a hospital database of vital-sign observations. We compensated for this by generating one 24-hour BP profile per patient, regardless of their length of hospital stay with details of this procedure described in (8). Secondly, the question of selection bias arises. The patients who are clinically less stable may have their BP taken more frequently during nighttime hours. However, observations may also be measured at night as a result of admission time or clinical protocols. Our pre-defined inclusion criteria based on earlier work in which we defined a method for 24-hour BP profiling of patients meant we excluded the majority of patients admitted to hospital. The greatest number of patients were excluded due to having no nighttime BP measurements. This may have caused us to underestimate the prevalence of daytime hypertension.

This study included patients from four hospitals (three tertiary and one secondary) within a single University Hospital Trust in the UK. Generalisability of the estimates of hypertension prevalence to other hospital patient populations in non-university hospital trusts and those out with the UK healthcare setting is therefore limited.

ETHICS

This study was approved by the Oxfordshire Research Ethics Committee (reference: 16/SC/0264), with Confidential Advisory Group approval to process patient data without consent (reference: 16/CAG/0066).

DISCLOSURES

PW works part-time for Sensyne Health and has share options in Sensyne Health. LT is a non-executive Director of Sensyne Health and holds share options in the company.

ACKNOWLEDGEMENTS

The views expressed are those of the authors and not necessarily those of the National Health Service (NHS), the National Institute for Health Research or the Department of Health. This research would not have been possible without the help of Dr Marco Pimentel, who was instrumental in compiling the anonymised patient data.

SOURCES OF FUNDING

The research described in this paper is supported by the NIHR Biomedical Research Centre, Oxford, and by an EPSRC grant (EP/EP/N024966/1 – Intelligent Wearable Sensors for Predictive Patient Monitoring).

REFERENCES

1. Lewington S, Clarke R, Qizilbash N, Peto R, Collins R PRLSCRQN, Collaboration PS. Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. Lancet. 2002;360(9349):1903–13.

2. Fleming S, Atherton H, Mccartney D, Hodgkinson J, Greenfield S, Hobbs FDR, et al. Self-screening and non-physician screening for hypertension in communities: A systematic review. Am J Hypertens. 2015;28(11):1316–24.

3. Public Health England. NHS Health Check: our approach to the evidence. 2016.

4. Martin A, Saunders CL, Harte E, Griffin SJ, MacLure C, Mant J, et al. Delivery and impact of the NHS Health Check in the first 8 years: a systematic review. Br J Gen Pract. 2018 Jul;68(672):e449–59.

5. Public Health England. Hypertension prevalence estimates in England for local

populations. 2016.

6. Armitage LC, Whelan ME, Watkinson PJ, Farmer AJ. Screening for hypertension using emergency department blood pressure measurements can identify patients with undiagnosed hypertension: A systematic review with meta-analysis. J Clin Hypertens. 2019;21(9):1415–25.

7. Staessen JA, Bieniaszewski L, O'Brien E, Gosse P, Hayashi H, Imai Y, et al. Nocturnal blood pressure fall on ambulatory monitoring in a large international database. The "Ad Hoc'' Working Group." Hypertension. 1997;29:30–9.

8. Mahdi A, Watkinson P, McManus R, Tarassenko L. Circadian blood pressure vriations computed from 1.7 million measurements in an acute hospital setting. Am J Hypertens. 2019;32:1154–61.

9. Williams B, Mancia G, Spiering W, Agabiti Rosei E, Azizi M, Burnier M, et al. 2018 ESC/ESH Guidelines for the management of arterial hypertension. Eur Heart J. 2018;39(33):3021–104.

10. Whelton PK, Carey RM, Aronow WS, Casey DE, Collins KJ, Dennison Himmelfarb C, et al. 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the Prevention, Detection, Evaluation, and Management of High Blood Pressure in Adults. J Am Coll Cardiol. 2018;71(19):e127–248.

11. Joint Formulary Committee. British National Formulary (BNF) No. 72. Pharmaceutical Press; 2016. 1424 p.

12. Wong D, Bonnici T, Knight J, Morgan L, Coombes P, Watkinson P. SEND: a system for electronic notification and documentation of vital sign observations. BMC Med

Inform Decis Mak. 2015 Dec;15(1):68.

13. Svenson JE, Repplinger M. Hypertension in the ED: still an unrecognized problem. Am J Emerg Med [Internet]. 2008 Oct [cited 2018 Aug 2];26(8):913–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18926352

14. Chida Y, Steptoe A. Greater Cardiovascular Responses to Laboratory Mental Stress Are Associated With Poor Subsequent Cardiovascular Risk Status. Hypertension. 2010;55:1026–32.

15. Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: A systematic analysis for the Global Burden of Disease Study 2010. Lancet. 2012;380(9859):2224–60.

16. Wolf SJ, Lo B, Shih RD, Smith MD, Fesmire FM. Clinical Policy: Critical Issues in the Evaluation and Management of Adult Patients in the Emergency Department With Asymptomatic Elevated Blood Pressure. Ann Emerg Med. 2013 Jul;62(1):59–68.

17. Williams B, Mancia G, Spiering W, Agabiti Rosei E, Azizi M, Burnier M, et al. 2018 ESC/ESH Guidelines for the management of arterial hypertension. J Hypertens. 2018 Oct;36(10):1953–2041.

18. National Institute for Health and Care Excellence. Hypertension in adults: diagnosis and management.

19. National Heart Foundation of Australia, – National Blood Pressure and Vascular, Disease Advisory Committee. Guideline for the diagnosis and management of hypertension in adults. 2016.

Table 1. Number of patients and percentage relative to the total (41,455), mean age (years), median length of stay (days), median number of BP observations and mean systolic and diastolic blood pressure (mmHg) stratified by sex, age groups, NHS Admission Method and NHS Specialty.

	Patients	**Age**	**LOS**	**Number of BP measurements**	**SBP**	**DBP**
	Percentage of total	Mean (SD)	Median (IQR)	Median (IQR)	Mean (SD)	Mean (SD)
All	41,455 (100 %)	64 (19)	4.7 (7.4)	27 (34)	127 (16)	69 (9)
Sex						
Men	20,169 (49 %)	64 (19)	4.9 (7.5)	28 (34)	128 (15)	70 (9)
Women	21,286 (51 %)	65 (20)	4.6 (7.2)	26 (33)	126 (17)	67 (9)
Age groups						
18-29	2,833 (7 %)	24 (4)	2.8 (3.9)	17 (19)	118 (12)	66 (8)
30-39	2,722 (7 %)	35 (3)	3.2 (4.5)	19 (23)	119 (14)	69 (9)
40-49	3,714 (9 %)	45 (3)	3.6 (5.1)	22 (26)	122 (14)	71 (10)
50-59	5,674 (14 %)	55 (3)	4.1 (5.8)	25 (28)	125 (15)	71 (9)
60-69	7,071 (17 %)	65 (3)	4.5 (6.4)	27 (32)	127 (15)	69 (9)
70-79	8,680 (21 %)	74 (3)	5.2 (7.9)	30 (35)	130 (16)	68 (8)
80-89	7,861 (19 %)	84 (3)	6.8 (10.9)	34 (44)	132 (17)	68 (9)
90+	2,714 (7 %)	91 (1)	7.5 (12)	34 (45)	133 (18)	68 (9)
NHS Admission Method						
Emergency	26,290 (63 %)	66 (21)	5.1 (8.9)	26 (37)	125 (14)	67 (8)
Elective	13,490 (33 %)	61 (17)	3.9 (4.7)	27 (26)	128 (17)	69 (9)
Other	1,675 (4 %)	64 (18)	9.8 (11.9)	46 (48)	126 (16)	68 (9)
NHS Specialty						
Medical	18,113 (44 %)	69 (19)	4.9 (8.9)	25 (36)	127 (18)	69 (10)
Surgical	22,543 (54 %)	60 (19)	4.6 (6.3)	28 (31)	127 (15)	68 (8)
Other	792 (2 %)	66 (15)	5.5 (9.8)	27 (41)	125 (16)	68 (9)

* BP – blood pressure, SBP – systolic blood pressure, DBP – diastolic BP, LOS – length of stay, SD – standard deviation, IQR – interquartile range; "other" in NHS Admission Method refers to any admission method, that is not Emergency or Elective (e.g. maternity admissions or transfer from other hospital provider other than in an emergency); "other" in NHS Specialty refers to any specialty that is not Medical or Surgical.

Table 2. Estimated prevalence (%) of normotension and hypertension (see Supplementary Table ST-1 for definition of thresholds) stratified by age (years), median length of stay (days), median number of blood pressure observations according to European ESC/ESH and American ACC/AHA guidelines.

	Patients	**Age**	**LOS**	**Number of BP measurements**
	% of total	Mean (SD)	Median (IQR)	Median (IQR)
Hypertension category (2018 ESC/ESH)				
Normotensive	32,788 (79 %)	62 (20)	5 (7)	27 (34)
Stage 1	7,504 (18 %)	72 (15)	5 (8)	27 (35)
Stage 2	1,297 (3 %)	74 (15)	4 (6)	23 (29)
Stage 3	144 (0.4 %)	72 (18)	2 (3)	19 (15)
Hypertension category (2017 ACC/AHA)				
Normotensive	24,158 (58 %)	60 (20)	5 (7)	27 (34)
Stage 1	10,858 (26 %)	68 (17)	5 (8)	27 (34)
Stage 2	7,504 (18 %)	72 (15)	5 (8)	28 (35)
Stage 3	1,417 (3 %)	74 (15)	4 (6)	23 (28)

* BP – blood pressure, LOS – length of stay, SD – standard deviation, IQR – interquartile range.

Table 3. **Estimated daytime, nighttime and 24-hour hypertension.** Estimated prevalence (%) of hypertension in hospital population stratified by age groups, NHS Admission Method and NHS Specialty according to the European ESC/ESH and American ACC/AHA guidelines (Supplementary Table ST-2).

	2018 ESC/ESH								**2017 ACC/AHA**							
ABPM	"Clinic"		Daytime		Nighttime		24-h		"Clinic"		Daytime		Nighttime		24-h	
SBP/DBP ≥	140/90		135/85		120/70		130/80		130/80		130/80		110/65		125/75	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Overall	21	21	29	28	73	65	43	40	43	40	42	38	95	90	59	53
Age groups																
18-29	6	2	15	4	55	31	23	8	23	8	28	10	93	79	44	17
30-39	11	4	20	8	65	36	30	12	30	12	33	13	95	81	48	21
40-49	15	8	26	15	74	47	37	20	37	20	39	22	97	87	55	33
50-59	19	14	29	22	76	59	43	31	43	31	43	33	97	91	60	45
60-69	21	20	31	29	74	66	45	41	45	41	44	40	97	91	60	55
70-79	23	27	31	35	76	74	47	50	47	50	43	47	96	92	62	64
80-89	28	34	34	39	76	80	51	58	51	58	46	51	94	95	64	70
90+	26	36	31	41	77	82	49	61	49	61	43	52	94	95	62	72
NHS Admission Method																
Elective	17	14	26	22	71	55	41	32	41	32	40	32	96	87	57	45
Emergency	22	25	30	31	74	70	45	45	45	45	43	41	95	92	60	57
Other	21	24	26	29	70	65	40	41	40	41	38	38	94	91	56	51
NHS Specialty																
Medical	22	25	29	31	72	69	43	45	43	45	40	41	94	91	57	56
Surgical	19	18	29	25	74	61	43	37	43	37	43	35	96	90	60	50
Other	19	17	28	23	72	60	41	36	41	36	40	34	95	88	54	49

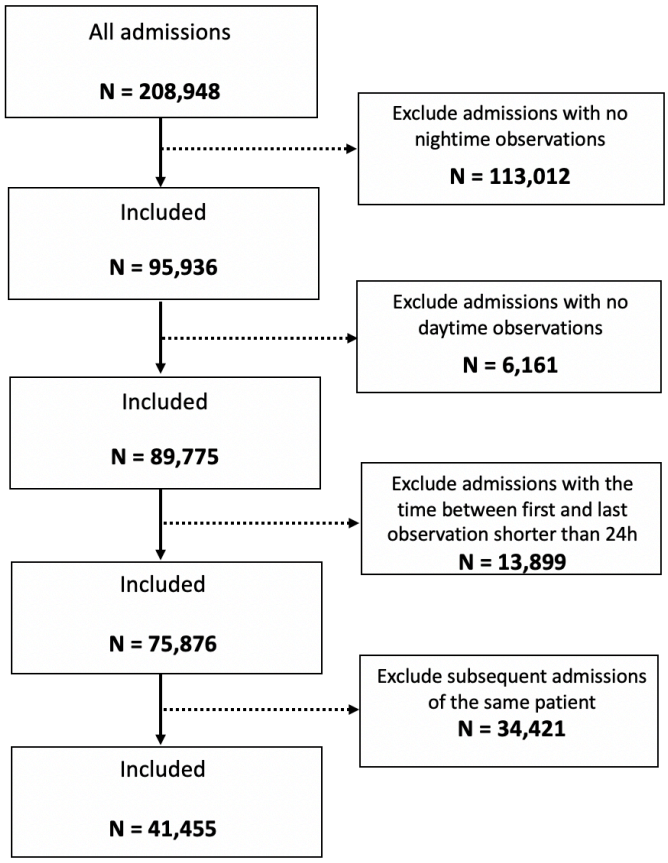
* SBP – systolic blood pressure, DBP – diastolic blood pressure.

Table 4. **Estimated undiagnosed clinic, daytime, nighttime and 24-hour hypertension.** Estimated undiagnosed hypertension prevalence (%) in hospital population stratified by age category, NHS Admission Method and NHS Specialty according to the European ESC/ESH and American ACC/AHA guidelines (Supplementary Table ST-2).

	2018 ESC/ESH								**2017 ACC/AHA**							
ABPM	"Clinic"		Daytime		Nighttime		24-h		"Clinic"		Daytime		Nighttime		24-h	
SBP/DBP ≥	140/90		135/85		120/70		130/80		130/80		130/80		110/65		125/75	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Overall	5	5	9	8	29	25	14	12	14	12	15	12	42	42	22	18
Age groups																
18-29	4	1	13	3	50	28	20	6	20	6	25	8	86	74	39	15
30-39	6	2	13	5	52	30	22	8	22	8	25	9	79	71	37	16
40-49	7	4	14	9	50	34	22	12	22	12	23	14	69	67	35	22
50-59	6	6	12	11	36	34	18	16	18	16	20	18	50	58	28	25
60-69	5	6	9	10	26	28	14	16	14	16	14	16	36	43	20	23
70-79	4	5	7	8	19	21	10	14	10	14	10	12	25	29	15	18
80-89	5	5	6	7	16	17	10	11	10	11	9	10	21	21	13	14
90+	4	6	6	7	19	17	11	11	11	11	10	9	25	20	15	15
NHS Admission Method																
Elective	4	4	8	8	29	24	14	11	14	11	15	12	42	46	22	18
Emergency	6	6	10	8	30	26	15	13	15	13	16	14	42	41	23	19
Other	4	4	*6*	6	20	19	9	9	9	9	9	9	28	32	15	13
NHS Specialty																
Medical	5	5	8	8	24	24	12	12	12	12	12	12	35	38	18	18
Surgical	5	5	10	8	33	26	16	12	16	12	17	13	46	46	25	19
Other	7	7	11	11	34	28	17	15	17	15	17	16	49	49	24	21

* SBP – systolic blood pressure, DBP – diastolic blood pressure.

Figure 1. Inclusion/exclusion criteria flowchart.



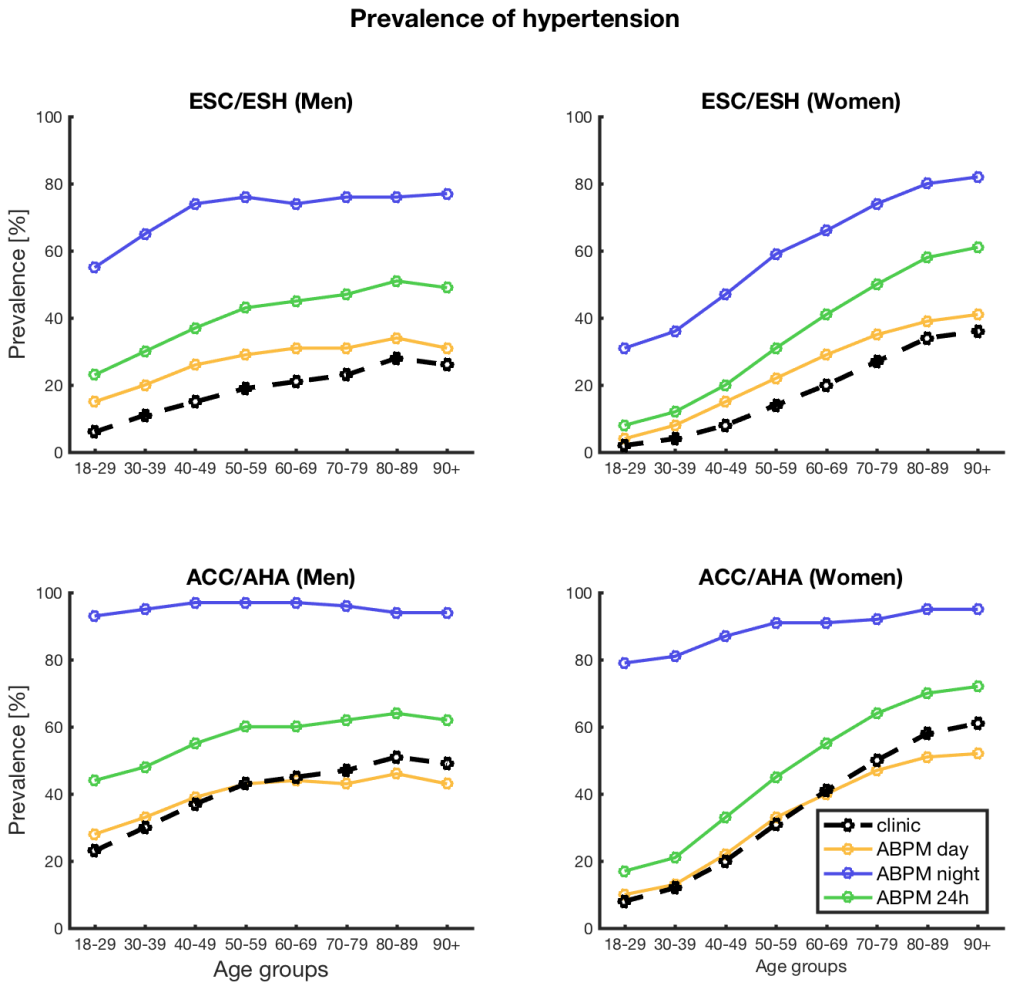


Figure 2. **Estimated age-dependent hypertension trends**. Estimated prevalence of hypertension trends for different age groups according to the European ESC/ESH (top panel) and American ACC/AHA (bottom panel) guidelines.

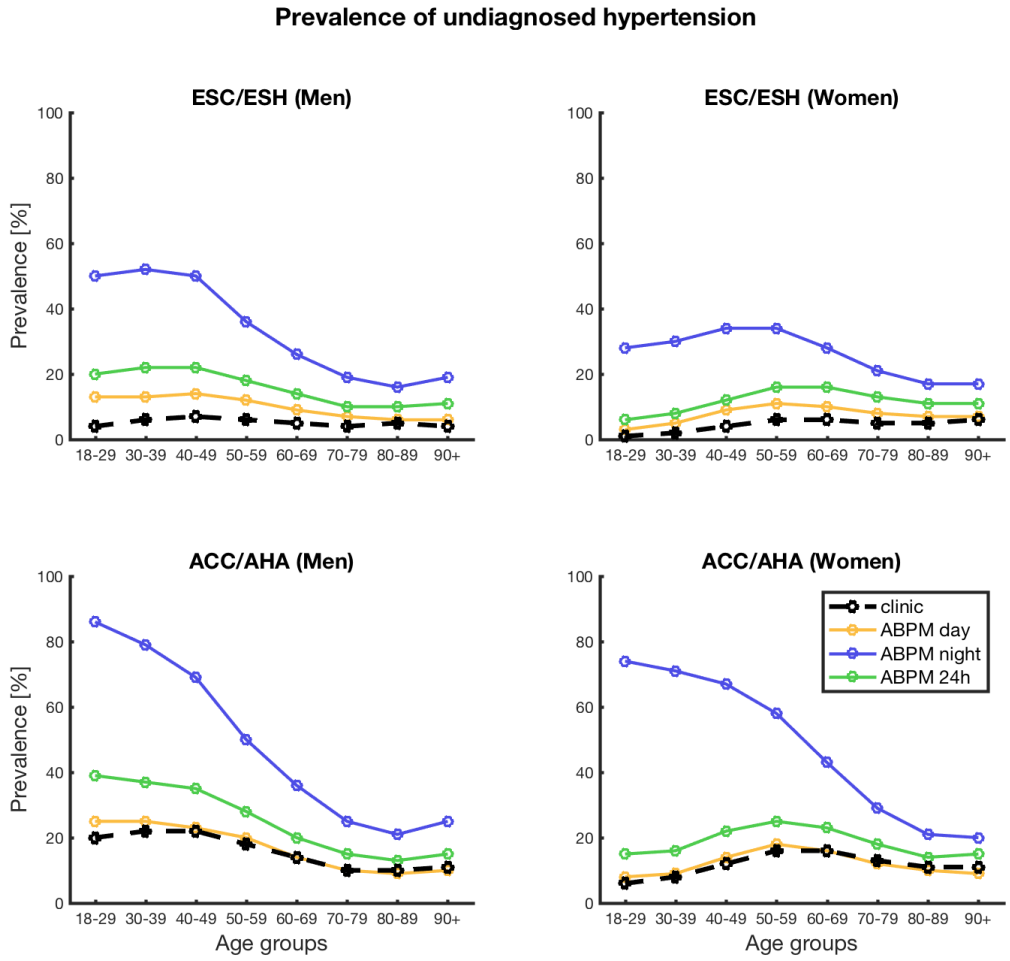


Figure 3. **Estimated undiagnosed age-dependent hypertension trends**. Estimated prevalence of undiagnosed hypertension trends for different age groups according to the European ESC/ESH (top panel) and American ACC/AHA (bottom panel) guidelines.

SUPPLEMENTARY MATERIAL

Estimated prevalence of hypertension and undiagnosed hypertension in a large inpatient population: A cross-sectional observational study

A. Mahdi[1], L.C. Armitage[2], L. Tarassenko[1,4], P. Watkinson[3,4]

Table ST-1. Definitions of clinic hypertension categories according to the European ESC/ESH and American ACC/AHA guidelines for management of arterial hypertension.

BP category	**2018 ESC/ESH**			**2017 ACC/AHA**		
	SBP		DBP	SBP		DBP
Normotension						
Optimal	< 120	*and*	< 80	-		-
Normal	120-129	*or*	80-84	< 120	*and*	< 80
Elevated	130-139	*or*	85-89	120-129	*and*	< 80
Hypertension						
Stage 1	140-159	*or*	90-99	130-139	*or*	80-89
Stage 2	160-179	*or*	100-109	140-159	*or*	90-99
Stage 3	≥ 180	*or*	≥ 110	≥ 160	*or*	≥ 100

* BP – blood pressure, SBP – systolic blood pressure, DBP – diastolic blood pressure. Individuals with systolic and diastolic blood pressure in 2 categories should be designated to the higher blood pressure category.

Table ST-2. Definitions of clinic and ambulatory hypertension according to the European ESC/ESH and American ACC/AHA guidelines.

Measurements	**2018 ESC/ESH**			**2017 ACC/AHA**		
	SBP		DBP	SBP		DBP
Clinic	≥ 140	*or*	≥ 90	≥ 130	*or*	≥ 80
Ambulatory hypertension						
Daytime mean	≥ 135	*or*	≥ 85	≥ 130	*or*	≥ 80
Nighttime mean	≥ 120	*or*	≥ 70	≥ 110	*or*	≥ 65
24-h mean	≥ 130	*or*	≥ 80	≥ 125	*or*	≥ 75

* SBP – systolic blood pressure, DBP – diastolic blood pressure

Table ST-3. Estimated prevalence (%) of normotension and hypertension (see Supplementary Table ST-1 for definition of thresholds) stratified by age (years), median length of stay (days), median number of blood pressure observations according to European ESC/ESH and American ACC/AHA guidelines for patients 18 years of age and older.

	Patients	**Age**	**LOS**	**Number of Obs**
	% of total	Mean (SD)	Median (IQR)	Median (IQR)
Hypertension category (2018 ESC/ESH)				
Normotensive	32,396 (78 %)	62 (19)	5 (7)	27 (33)
Stage 1	7,496 (18 %)	72 (15)	5 (8)	27 (35)
Stage 2	1,297 (3 %)	74 (15)	4 (6)	23 (29)
Stage 3	144 (0.4 %)	72 (18)	2 (3)	19 (15)
Hypertension category (2017 ACC/AHA)				
Normotensive	23,796 (57 %)	61 (20)	5 (7)	27 (34)
Stage 1	10,828 (26 %)	68 (17)	5 (8)	27 (34)
Stage 2	7,496 (18 %)	72 (15)	5 (8)	27 (35)
Stage 3	1,417 (3 %)	74 (15)	4 (6)	23 (28)

* BP – blood pressure, LOS – length of stay, SD – standard deviation, IQR – interquartile range.

Table ST-4. Definitions of isolated hypertension categories based on the European ESC/ESH and American ACC/AHA guidelines. *24-hour SBP (DBP)* is the mean systolic (diastolic) blood pressure during the entire admission. *Daytime SBP* (*DBP*) is the mean systolic (diastolic) blood pressure measurements taken during daytime hours (10:00 am – 7:59 pm). *Nighttime SBP* (*DBP*) is the mean systolic (diastolic) blood pressure measurements taken during night hours (midnight – 5:59 am).

Hypertension category	**2018 ESC/ESH**	**2017 ACC/AHA**
Isolated systolic	24-hour SBP ≥ 140 *and* DBP < 90	24-hour SBP ≥ 130 *and* DBP 80
Isolated diastolic	24-hour SBP < 140 *and* DBP ≥ 90	24-hour SBP < 130 *and* DBP ≥ 80
Isolated daytime	Daytime SBP ≥ 135 or DBP ≥ 85 *and* Nighttime SBP < 120 *and* DBP < 70	Daytime SBP ≥ 130 or DBP ≥ 80 *and* Nighttime SBP < 110 *and* DBP < 65
Isolated nighttime	Daytime SBP < 135 *and* DBP < 85 *and* Nighttime SBP ≥ 120 *or* DBP ≥ 70	Daytime SBP < 130 *and* DBP < 80 *and* Nighttime SBP ≥ 110 *or* DBP ≥ 65

* SBP – systolic blood pressure, DBP – diastolic blood pressure.

Table ST-5. Estimated prevalence for isolated (systolic, diastolic, daytime and nighttime) hypertension using thresholds defined in the Supplementary Table ST-4.

	Patients	**Age**	**LOS**	**Number of BP measurements**
	% of total	Mean (SD)	Median (IQR)	Median (IQR)
Isolated hypertension type (derivided from 2018 ESC/ESH thresholds)				
Systolic	7,807 (19 %)	74 (14)	5 (8)	27 (35)
Diastolic	76 (0.001 %)	58 (18)	3 (5)	18 (23)
Daytime	486 (0.01 %)	66 (17)	3 (3)	19 (20)
Nighttime	16,139 (39 %)	66 (19)	5 (9)	29 (36)
Isolated hypertension type (derived form 2017 ACC/AHA thresholds)				
Systolic	12,693 (31 %)	72 (15)	5 (8)	29 (35)
Diastolic	474 (0.01 %)	57 (17)	5 (6)	23 (27)
Daytime	279 (0.007 %)	63 (18)	3 (3)	20 (20)
Nighttime	18,499 (45 %)	63 (20)	5 (8)	28 (35)

* BP – blood pressure, LOS – length of stay, SD – standard deviation, IQR – interquartile range.

Table ST-6. Estimated prevalence for undiagnosed isolated (systolic, diastolic, daytime and tighttime) hypertension using thresholds defined in the Supplementary Table ST-4. Here *undiagnosed* are those with no ICD-10 codes for hypertension or anti-hypertensive drugs prescribed.

	Patients	**Age**	**LOS**	**Number of BP measurements**
	% of total	Mean (SD)	Median (IQR)	Median (IQR)
Undiagnosed Isolated hypertension type (derivided from 2018 ESC/ESH thresholds)				
Systolic	1,866 (5 %)	67 (17)	4 (5)	21 (24)
Diastolic	26 (0 %)	49 (17)	2 (2)	17 (9)
Daytime	239 (0.006 %)	59 (18)	2 (2)	15 (16)
Nighttime	6,999 (17 %)	57 (20)	5 (7)	25 (30)
Undiagnosed isolated hypertension type (derived form 2017 ACC/AHA thresholds)				
Systolic	3,936 (9 %)	65 (19)	4 (6)	24 (28)
Diastolic	229 (0.006 %)	50 (16)	4 (6)	20 (24)
Daytime	158 (0.004 %)	57 (19)	2 (2)	16 (16)
Nighttime	9,213 (22 %)	54 (20)	4 (6)	24 (29)

* BP – blood pressure, LOS – length of stay, SD – standard deviation, IQR – interquartile range.

Table ST-7. Anti-hypertensive drugs listed in the British National Formulary, March 2017.

Beta blockers	**Renin-angiotensin ACE inhibit**	**Renin angiotensin angio2receptor antagonist**
Carvedilol	Captopril	Azilsartan medoxomil
Labetalol hydrochloride	Co-zidocapt	Candesartan cilexetil
Nadolol	Enalapril maleate	Eprosartan
Oxprenolol hydrochloride	Enalapril with hydrochlorothiazide	Irbesartan
Pindolol	Fosinopril sodium	Irbesartan with hydrochlorothiazide
Propranolol hydrochloride	Imidapril hydrochloride	Losartan potassium
Timolol maleate	Lisinopril	Losartan with hydrochlorothiazide
Acebutolol	Lisinopril with hydrochlorothiazide	Olmesartan medoxomil
Atenolol	Moexipril hydrochloride	Olmesartan with amlodipine
Bisoprolol	Perindopril arginine	Telmisartan
Celiprolol hydrochloride	Perindopril arginine with indapamide	Telmisartan with hydrochlorothiazide
Co-tenidone	Perindopril erbumine	Valsartan with hydrochlorothiazide
Esmolol hydrochloride	Quinapril	
Metoprolol tartrate	Quinapril with hydrochlorothiazide	
Nebivolol	Ramipril with felodipine	
	Trandolapril	

Calcium-channel blockers	**Diuretics**
Amlodipine	Amiloride with cyclopenthiazide
Diltiazem hydrochloride	Bendroflumethiazide
Felodipine	Co-amilozide
Isradipine	Hydrochlorothiazide
Lacidipine	Indapamide
Lercanidipine hydrochloride	
Nicardipine nydrochloride	
Nifedipine	
Verapamil hydrochloride	

Vasodilators Antihypertensives	**Vasodilators Peripheral**	**Central Acting**
Hydralazine hydrochloride	phenoxybenzamine hydrochloride	Clonidine hydrochloride
Minoxidil	phentolamine mesilate	Methyldopa
Sodium nitroprusside		Moxonidine

Renin angiotensin renin inhibit	**Antiadrenergic**	
Aliskiren	Guanethidine monosulfate	

Table ST-8. ICD-10 codes for hypertension.

I10: Essential (primary) hypertension	

I11: Hypertensive heart disease	
I11.0	Hypertensive heart disease with (congestive) heart failure
I11.9	Hypertensive heart disease without (congestive) heart failure

I12: Hypertensive renal disease	
I12.0	Hypertensive renal disease with renal failure
I12.9	Hypertensive renal disease without renal failure

I13: Hypertensive heart and renal disease	
I13.0	Hypertensive heart and renal disease with (congestive) heart failure
I13.1	Hypertensive heart and renal disease with renal failure
I13.2	Hypertensive heart and renal disease with both (congestive) heart failure and renal failure.
I13.9	Hypertensive heart and renal disease, unspecified

I15: Secondary hypertension	
I15.0	Renovascular hypertension
I15.1	Hypertension secondary to other renal disorders
I15.2	Hypertension secondary to endocrine disorders
I15.8	Other secondary hypertension
I15.9	Secondary hypertension, unspecified