UNIVERSITY of HAWAI'I at MĀNOA
HEALTHY HAWAIʻI
EVALUATION TEAM

Evaluation of a Clinical Algorithm to Identify Undiagnosed Hypertension within the Queen's Clinically Integrated Physician Network (QCIPN)

A Report by the Healthy Hawaiʻi Evaluation Team
for QCIPN and the Hawaii State Department of Health

Mika D. Thompson, MSc
Yan Yan Wu, PhD
Blythe Nett, MPH
Lance K. Ching, PhD, MPH
Mia Taylor, MSN, FNP-BC, APRN-RX
Tiffany Lemmen, DIT, MBA, RT(R)
Meghan McGurk, MPH
Catherine M. Pirkle, PhD

SUMMARY

Background: Automated algorithms are a type of health information technology that often leverage the electronic health records (EHR) of patients to support clinical diagnostic and management decisions; these algorithms may be important tools to identify patients with undiagnosed conditions, such as hypertension, and provide timely intervention to treat and manage those conditions. However, quantitative evidence of the effectiveness of these algorithms to detect undiagnosed conditions in real-world settings, and especially in socioeconomically and racially diverse populations, is insufficient. This evaluation examined patients identified as having hypertension with an automated algorithm and compared the characteristics of those with a diagnosis in their electronic health record to those without such a diagnosis. It further explored differences in the identification of potentially undiagnosed patients by socioeconomic factors, utilizing an ethnically diverse sample of adults within the Queen's Clinically Integrated Physician Network (QCIPN), a large health system in Hawaiʻi.

Methods: We conducted a secondary data analysis of de-identified EHR of patients within the Queen's Health System. To be eligible, patients had to be 18 years of age or older and treated at 1 of 6 clinics in the QCIPN during the period of July 2, 2018 and July 1, 2021 (N=14,497). Patients with resolved hypertension, those diagnosed with hypertension within one year of the end of the data period, those with end-stage renal disease, those taking medication but with no diagnosis for hypertension, and those that expired during the data period were subsequently excluded from further analyses. Included patients were summarized by patient characteristics, including age group, sex, race/ethnicity, categorical body mass index, tobacco use, alcohol use, and comorbid health conditions (N=13,709). Potentially undiagnosed hypertension was based on systolic and diastolic blood pressure measurements; among those meeting the eligibility criteria with two or more consecutive blood pressure readings of ≥140/90 over the past 3 years or one reading of ≥160/100 in the past year. Proportions and Wald 95% confidence intervals were calculated for undiagnosed hypertension compared to all patients with ostensible hypertension (physician-diagnosed and flagged) across patient characteristics.

Results: Our findings suggest that 51.8% of the total 13,709 included patients in our sample had hypertension on record of an active diagnosis and those with high blood pressure readings.

Among the ostensible hypertension cases (N=7,503), 4.9% were flagged as potentially undiagnosed hypertension. The probability of being flagged significantly differed by nearly all factors considered, including age group, ethnicity, clinic, and diabetes status. Patients in the youngest (18-40 years old) age group were significantly more likely to be flagged (18.4%) compared to all other age groups. Relative to White patients (6.8%), Filipino (4.1%), and Japanese (3.7%) patients, along with patients of unspecified ethnicity (3.3%), were less likely to be flagged. Clinic 5 had the greatest proportion of patients flagged with potentially undiagnosed hypertension (14.8%), significantly higher than all other clinics. Patients with ostensible hypertension, who were previously diagnosed with diabetes or prediabetes, had the lowest proportion of potentially undiagnosed hypertension (1.3% and 3.3%, respectively), while those with an unknown diabetes status (11.4%) or any A1C value recorded had a significantly greater proportion of potentially undiagnosed hypertension cases. A significantly greater percent of patients on Medicaid were flagged (11.1%) compared to Medicare patients (3.3%). Lastly, a substantially greater proportion of patients with diagnosed pre-hypertension had ostensible hypertension without a formal diagnosis (42.2%).

Conclusion: The algorithm examined in this evaluation indicated that QCIPN is aptly identifying patients with hypertension. Younger patients with elevated blood pressure are not being diagnosed with hypertension as frequently as older patients despite the large impact on future health. Clinics that have strong physician champions and panel management had a lower proportion of potentially undiagnosed hypertension. Clinic 5 had high physician turnover during the COVID-19 pandemic, which may have led to a drop in proper hypertension diagnoses. The next steps may include: following up with patients with potentially undiagnosed hypertension to confirm a hypertension diagnosis to further examine the effectiveness of the algorithm, exploring which actions were taken by physicians and clinical staff after a patient was flagged to understand clinical procedures that may be impacting diagnosis of hypertension, and examining whether patients achieved a normotensive status through the actions prompted by the algorithm in order to establish if the algorithm can lead to improved health outcomes for patients.

Key Points:

1. Our evaluation provided evidence that less than 5% of patients with high blood pressure were flagged as a potentially undiagnosed hypertension case.
2. Patients were more likely to be flagged if they were younger, non-Filipino or non-Japanese, a patient at the Clinic 5, had an unknown diabetes status and A1C measurement, on Medicaid, and diagnosed with pre-hypertension.
3. QCIPN should focus on confirming that those flagged are actually undiagnosed hypertension cases, accounting for measurement method, and establishing the effectiveness of algorithm prompted interventions and referrals to lifestyle change interventions at reducing hypertension.

INTRODUCTION

Hypertension affects approximately half of the total adult population in the United States (US),[1] with the worldwide number of adults with hypertension doubling over the last three decades.[2] In the US, hypertension presents a substantial financial burden, with the total associated medical costs estimated at $131 billion USD annually.[3] An influential component to the development of many life-threatening cardiovascular outcomes, such as stroke, coronary heart disease, and heart failure,[4] hypertension is strongly associated with premature mortality.[5] In 2019, the Center for Disease Control (CDC) listed hypertension as a primary or contributing cause of over half a million deaths in the US alone.[6] Despite extant and robust clinical standards in the US for diagnosing and managing hypertension,[7] undiagnosed hypertension remains a significant public health issue in both the US and around the world.[2,8] Given both the substantial economic burden and health risks associated with hypertension, identification of potentially undiagnosed hypertensive patients is needed to reduce the impact hypertension has on both the health care system and those who suffer from the condition.

Health Information Technology (HIT), which encompasses many types of systems and technologies designed to improve outcomes and reduce costs, may provide a crucial opportunity in identifying patients with undiagnosed hypertension.[9] Automated electronic health records (EHR) algorithms are a type of HIT that have been used to identify patients with many potentially undiagnosed chronic conditions, such as diabetes[10-12] and hypertension.[8,13-16] These algorithms may identify potential cases based on abnormal test results found in their EHR, scan a patient's problem list for active diagnoses, and flag patients that fit a clinical definition, but lack record of diagnosis or management of the condition. Not only can such technology notify providers regarding patients in need of follow-up, but it may link flagged patients to personalized resources and community-based interventions to further improve management and support.[17] While hypertension is a prevalent issue and one that appears underdiagnosed in many situations, it is also a condition that is highly amenable to clinical algorithms given the ubiquity of blood pressure assessments during routine clinical encounters.

Despite the promising potential, limited empirical research considers the application of HIT in practice and if, or how, innovations actually improve health outcomes or reduce health disparities. Implementation failures and unintended consequences are significant concerns of HIT, as are the technology's impact on operational workflows and those engaged with it.[18] These areas are deeply understudied, despite HIT's extraordinary growth.[19] Of the published HIT interventions, many are complex and/or resource intensive, casting doubt on their long-term sustainability in routine practice.[20] New HIT is not necessarily designed or implemented using evidence-based protocols, nor rigorously evaluated with the findings translated across research or practice communities.[19,21,22] Moreover, some critics of HIT algorithms have expressed concerns regarding poor performance in minority groups, data security concerns, and low provider satisfaction.[23] Impact on populations with significant health disparities is particularly understudied. Consequently, it is important to evaluate EHR algorithms aimed at identifying undiagnosed hypertension within disparate and understudied groups across multiple sociodemographic determinants to elucidate their utility more fully in identifying patients and supporting interventions.

Hawaiʻi-based health systems offer a unique opportunity to assess the use of these algorithms within a population largely comprised of substantially understudied and underrepresented groups, including Native Hawaiians, Other Pacific Islanders, and diverse Asian groups.[24] Adults in Hawaiʻi have the highest predicted prevalence of undiagnosed hypertension in the US, with some groups experiencing a disproportionate burden of cardiometabolic conditions.[18,25] These findings point to disparities in healthcare access, delivery, utilization and quality, highlighting the urgent need to detect undiagnosed conditions, such as hypertension, and evaluate whether currently implemented, HIT-facilitated, detection methods are being applied equitably and effectively across disparate groups. To address the critical research gaps regarding the implementation and effectiveness of automated algorithms in clinical practice on health disparities within understudied populations, as well as provide important lessons that may be generalized to other health systems serving diverse peoples, we examined an algorithm designed to identify patients with undiagnosed hypertension implemented within the Queen's Clinically Integrated Physician Network (QCIPN), a physician organization within the Queen's Health System (QHS), the largest healthcare system in Hawaiʻi. The current evaluation aims to identify how many patients are potentially undiagnosed with hypertension among patients with evidence of hypertension in their EHR. This evaluation additionally compares the sociodemographic characteristics of potentially undiagnosed patients with diagnosed patients identified by an automated algorithm. Through this work, we hope to provide important lessons that may be generalized to the larger QHS, as well as to other health systems serving diverse populations.

METHOD

HDOH Hypertension Algorithm in QCIPN

The evaluation of clinical algorithms that leverage HIT, including EHR, is a national priority, under the CDC's 1815 Cooperative Agreement (CDC-1815) to improve the health of Americans through prevention and management of diabetes, heart disease, and stroke. Through the CDC-1815 Cooperative Agreement, the Hawaiʻi Department of Health (HDOH) collaborated with the QHS to implement an EHR algorithm designed to identify patients with undiagnosed hypertension and prompt management efforts by health providers within QCIPN. Formed in 2014, QCIPN is a physician organization and consists of 800 providers across the 5 inhabited islands in the state of Hawaiʻi. Notably, the current CDC-1815 strategy focused on priority populations with high chronic disease burden, such as Native Hawaiians and Other Pacific Islanders and those of low incomes.

The algorithm was implemented within QCIPN utilizing Epic, a common EHR system that is used by QHS. QHS prepared a de-identified dataset derived from patient EHR with information on which patients were flagged by the algorithm. A de-identified dataset was extracted by QHS using the HDOH-developed algorithm, and delivered to the Healthy Hawaiʻi Evaluation Team (HHET) at the University Hawaiʻi of Mānoa for analysis.

Design

This was a secondary data analysis of de-identified EHR data collected utilizing the hypertension algorithm. Use of these data for evaluation was approved by the University of Hawaiʻi Institutional Review Board (Protocol#: 2019-00128).

Setting

The EHR algorithm was implemented across 7 clinics on the island of Oʻahu within the QCIPN organization. Information from these clinics were limited to data collected from July 2, 2018 to July 1, 2021.

Population

Eligible patients were 18 years or older and had at least one encounter with a physician at one of the 7 selected clinics within QCIPN during the three-year data period. However, one clinic was excluded from the analysis due to their small sample size (N=3). The clinical algorithm was programmed to exclude certain patients from being flagged: (1) those with resolved hypertension (i.e., hypertension that is no longer on the problem list and no elevated reading in the data period to otherwise indicate the patient has potentially undiagnosed hypertension), (2) those with a formal diagnosis that were only screened for hypertension within one year prior to the end of the measurement period, (3) those with an active diagnoses of end-stage renal disease (ascertained through EHR using ICD-9 codes: 585.5, 585.6, V42.0, V45.1, and V56, and ICD-10 codes: N18.5, N18.6, Z49, Z94.0, Z91.15, and Z99.2), (4) those with no hypertension diagnosis but were taking hypertension medication, and (5) those that were deceased by the end of the measurement period.

Measures

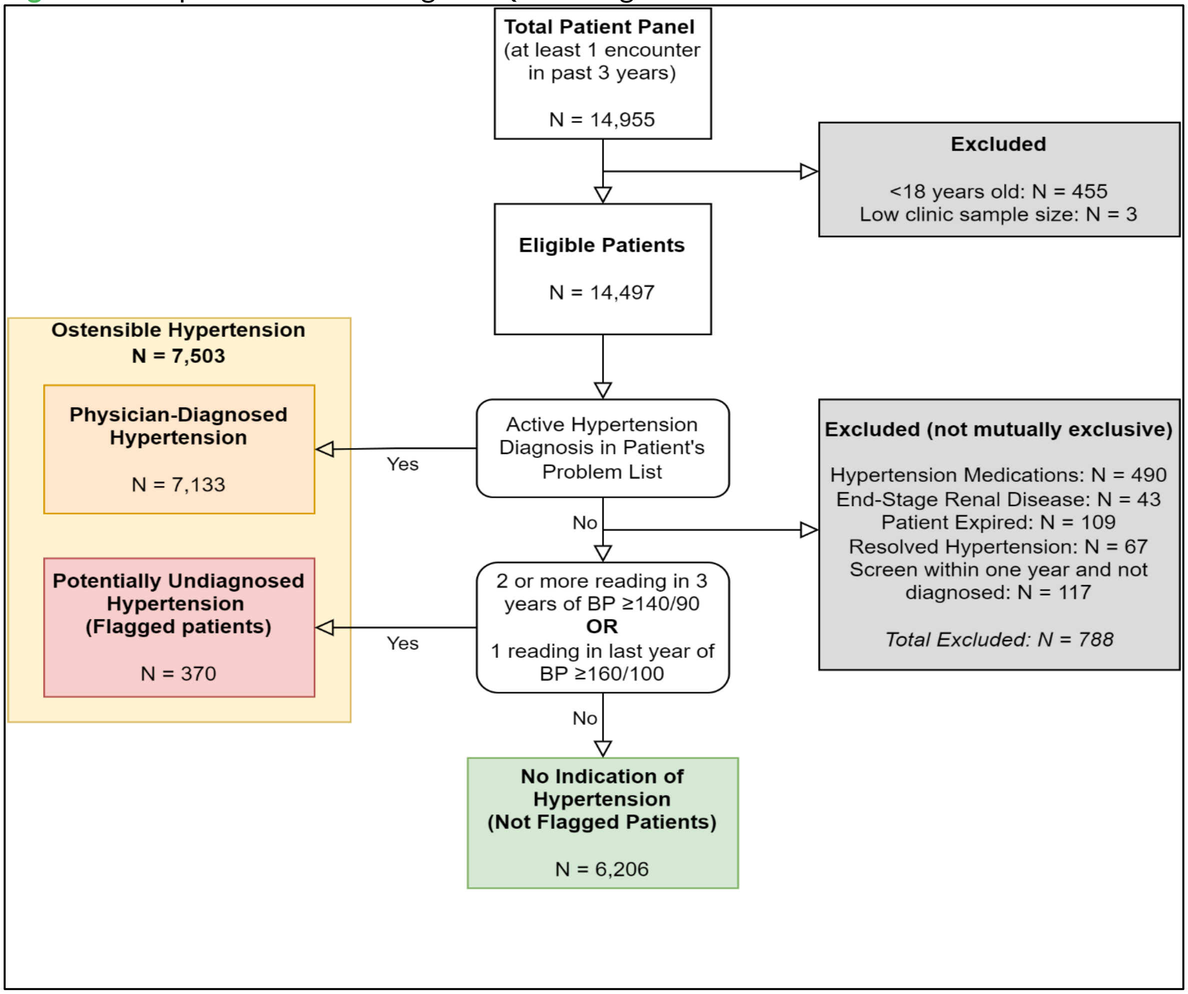
The focus of our evaluation was patients with potentially undiagnosed hypertension, defined by those flagged by the algorithm, but without an active hypertension diagnosis. Three groups were derived from patients EHR: 1. physician-diagnosed hypertension, 2. potentially undiagnosed hypertension (also referred to as flagged), and 3. no indication of hypertension (also referred to as not flagged). Physician-diagnosed hypertension cases were unresolved cases of hypertension derived from the patients' active problem list identified through ICD-9 codes 401-405 and 410.9, and ICD-10 codes I10-I15 and I21.3. Among patients without a hypertension diagnosis on the patients' active problem list, potentially undiagnosed hypertension was ascertained from EHRs utilizing continuously measured systolic and diastolic blood pressure among those without a prior hypertension diagnosis based on the algorithm's flagging criteria: two measurements ≥140/90 in the past three years, or one measurement ≥160/100 in the past year. Lastly, no indication of hypertension cases were patients that were not flagged by the algorithm based on the above criteria and did not have hypertension based on the ICD-9 and ICD-10 codes on their active problem list. Ostensible hypertension was defined as patients within the physician-diagnosed hypertension (number 1 above) and potentially undiagnosed hypertension groups (number 2 above).

Sociodemographic measures were extracted from patients' EHRs problem lists, encounter diagnoses, and/or social histories. The measures included age (at extraction date) group ([18, 39) years; [39, 65) years; [65,85) years; or [85,106] years), sex (male/female), race/ethnicity (White, Native Hawaiian, Other Pacific Islander, Filipino, Japanese, Chinese, Korean, Other Asian, Black, Hispanic, or Other), most recent categorical BMI (underweight, <18.5; normal, [18.5, 25.0); overweight, [25.0, 30.0); or obese, ≥30.0), any mental health conditions (yes/no; ICD-10 codes F20-F29, F30-F39, F40-F48, and F60-F69), any tobacco use (yes/no; ICD-10 codes F17, F17.20-F17.22, F17.29, Z72.0, Z57.31, Z72.0, Z77.22, and Z87.891), any alcohol use (yes/no; extracted from social history), diabetes/prediabetes status (ICD-10 codes E08, E09, E10, E11, E13, and R73.03) or most recently available hemoglobin A1C from laboratory tests (diagnosed diabetes, diagnosed prediabetes, potentially undiagnosed diabetes [A1C: 6.5 or greater with no diagnosis], potentially undiagnosed prediabetes [A1C: 5.7-6.5 with no diagnosis], or missing information [no diabetes diagnosis, prediabetes diagnosis, and A1C]), and pre-hypertension on the patient's problem list (yes/no; ICD-10 code R03.0). Coding for the multiple response race/ethnicity variable was derived using the following rules: 1) if Native Hawaiian was one of the multiple ethnicities listed, "Native Hawaiian" was coded,

2) if a non-White ethnicity was listed with a White ethnicity, the non-White ethnicity was coded, and 3) if there was more than one non-White ethnicity listed, “Other Asian” was coded; all patients endorsing more than one non-White ethnicity (N = 4) were multiple Asian ethnicities (e.g., Japanese and Korean). Hispanic was considered an exception to the above rule, such that patients identifying their race as Hispanic were maintained in the analysis. That is, Hispanic patients that were mixed with a non-Hispanic ethnicity (e.g., Mexican and Filipino, Puerto Rican and Portuguese, etc.) were categorized as Hispanic; only seven Hispanic patients were mixed, none of which violated rule 1 above (i.e., no Hispanic patient in the sample were also Native Hawaiian by ethnicity). All sociodemographic measures were selected for their known or hypothesized associations with hypertension.

Figure 1 presents the derivation of the final analytic sample after applying the algorithm. Of the 14,497 eligible patients, 49.2% had active hypertension in their problem list (physician-diagnosed hypertension). Of the 7,364 patients without a hypertension diagnosis, 788 (10%) were excluded for meeting one or more of the five exclusions (on hypertension medications: n=490, end-stage renal disease: n=43, patient deceased by end of measurement period: n=109, hypertension resolved: n=67, and/or screened for hypertension recently with no diagnosis: n=117). In total, the algorithm identified 6,206 patients in the no indication of hypertension (not flagged) group, 7,133 physician-diagnosed hypertension cases, and 370 potentially undiagnosed hypertension (flagged) cases. Based on the combination of physician-diagnosed and flagged cases, a total of 7,503 cases of ostensible hypertension were identified in the sample.

Figure 1. Sample Derivation using the QCIPN Algorithm



Acronyms: BP = blood pressure

Statistical Methods

All analyses were conducted using R version 4.1.2 with integrated development environment RStudio version 1.4.1106. Sample characteristics were summarized using descriptive proportions within groups (i.e., age, sex, race/ethnicity, etc.) across all patients and among the following subsamples: physician-diagnosed hypertension, potentially undiagnosed hypertension (flagged), no indication of hypertension (not flagged), and patients excluded from the sample. Proportions of patients by sample characteristics were summarized by frequency and column-percentage to compare the distribution of patients between each subsample. Next, we limited the sample to patients with ostensible hypertension (i.e., flagged and physician-diagnosed patients). We compared the percent, and 95% confidence intervals (95%CI) for the percent, of patients flagged by the algorithm among ostensible hypertension cases across sample characteristics, including age group, sex, ethnicity, insurance provider, categorical BMI, clinic, mental health conditions, tobacco use, alcohol use, pre-hypertension, diabetes status, and A1C. Lastly, to further explore the effect of the COVID-19 pandemic on risk of potentially undiagnosed hypertension, we compared the percent flagged among patients with potential hypertension across QCIPN clinics before and after the first statewide Stay-At-Home order, which took effect on March 25, 2020, in Hawai‘i.

RESULTS

Patient Characteristics by Hypertension Status

Table 1 presents the distribution of sociodemographic characteristics of included patients (N = 13,709) stratified by potentially undiagnosed hypertension (N = 370), physician-diagnosed hypertension (N = 7, 133), and no indication of hypertension (N = 6,206). Furthermore, Table 1 presents the distribution of those excluded by the algorithm (N = 788) and the number of missing by each factor. Overall, a greater proportion of the sample were between 40 to 65 years in age (40.8%) and female (55.7%). White was the most prevalent racial/ethnic group among the included patients (26.7%); however, Asian subgroups combined accounted for nearly half of patients (48.8%). A third (33.8%) of patients were of normal BMI compared to overweight (32.0%) and obese (31.1%), while only 3.1% were classified as underweight. Most patients were primarily sampled from Clinic 1 (37.5%) and used commercial HMSA (42.7%) or Medicare (33.7%) as their health insurance provider. Across the total patient sample, 25.2% had a record of some mental health-related condition, 9.4% had a record of tobacco use, and 45.7% had a record of alcohol use. Many patients lacked information on diabetes status (38.0%); however, 21.3% had diagnosed diabetes and 17.6% had diagnosed prediabetes recorded on their problem list. Only 3.7% of the patient sample had pre-hypertension on their problem list. Excluded patients did not differ significantly from the overall sample across most factors except age.

Patients with physician-diagnosed hypertension were proportionally older, male, Native Hawaiian or Asian (including Filipino, Japanese, and Chinese), and overweight or obese relative to patients without hypertension. Most patients with no indication of hypertension used commercial HMSA (55.3%) as their health insurance provider, while a slight majority of diagnosed patients were on Medicare (51.9%). Mental health and tobacco use were similarly distributed among the physician-diagnosed and the no indication of hypertension groups; however, most patients in the latter had a record of alcohol use (52.8%), while only 39.6% of patients with physician-diagnosed hypertension used alcohol. Similarly, the proportions of both diagnosed diabetes (36.3%) and prediabetes (22.7%) were greater in the physician-diagnosed hypertension group compared to patients with potentially undiagnosed hypertension or no indication of hypertension; most patients with no indication of hypertension had an unknown diabetes status and A1C (61.9%)

Patients with no indication of hypertension derived more frequently from Clinic 1 (45.5% versus 30.7%). Approximately 20% of diagnosed patients, and only about 6.5% of the undiagnosed or no hypertension groups, came from Clinic 3. More patients with potentially undiagnosed hypertension saw providers practicing at Clinic 5 (37.8%) than any other QCIPN clinic.

Table 1. Sample Characteristics by Potentially Undiagnosed Hypertension, Physician-Diagnosed Hypertension, No Indication of Hypertension, and Excluded Patients (N = 13,709)

	Total Sample† N = 13,709 N (column-%)	Potentially Undiagnosed Hypertension (Flagged) N = 370 N (column-%)	Physician-Diagnosed Hypertension N = 7,133 N (column-%)	No Indication of Hypertension (Not Flagged) N = 6,206 N (column-%)	Excluded N = 788 N (column-%)	Missing
Age Group						
[18,40) years	2,879 (21.0)	57 (15.4)	253 (3.6)	2,569 (41.4)	100 (12.7)	0
[40,65) years	5,588 (40.8)	167 (45.1)	2,724 (38.2)	2,697 (43.5)	341 (43.3)	
[65,85) years	4,155 (30.3)	124 (33.5)	3,165 (44.4)	866 (14.0)	262 (33.3)	
[85+] years	1,087 (7.9)	22 (6.0)	991 (13.9)	74 (1.2)	85 (10.8)	
Sex						
Female	7,639 (55.7)	194 (52.4)	3,587 (50.3)	3,858 (62.2)	448 (56.9)	0
Male	6,070 (44.3)	176 (47.6)	3,546 (49.7)	2,348 (37.8)	340 (43.2)	
Race/Ethnicity						
White	3,666 (26.7)	115 (31.1)	1,569 (22.0)	1,982 (31.9)	255 (32.4)	0
Native Hawaiian	1,227 (9.0)	38 (10.3)	663 (9.3)	526 (8.5)	80 (10.2)	
Other Pacific Islander	367 (2.7)	10 (2.7)	192 (2.7)	165 (2.7)	27 (3.4)	
Filipino	2,351 (17.1)	56 (15.1)	1,326 (18.6)	969 (15.6)	103 (13.1)	
Japanese	2,839 (20.7)	71 (19.2)	1,851 (26.0)	917 (14.8)	155 (19.7)	
Chinese	875 (6.4)	24 (6.5)	512 (7.2)	339 (5.5)	52 (6.6)	
Korean	274 (2.0)	7 (1.9)	140 (2.0)	127 (2.1)	18 (2.3)	
Other Asian	353 (2.6)	12 (3.2)	140 (2.0)	201 (3.2)	28 (3.6)	
Black	228 (1.7)	8 (2.2)	84 (1.2)	136 (2.2)	10 (1.3)	
Hispanic	271 (2.0)	10 (2.7)	97 (1.4)	164 (2.6)	15 (1.9)	
Other	1,258 (9.2)	19 (5.1)	559 (7.8)	680 (11.0)	45 (5.7)	
Categorical BMI						
Normal	4,572 (33.8)	115 (31.1)	1,979 (28.0)	2,478 (40.9)	253 (32.6)	205
Overweight	4,326 (32.0)	132 (35.7)	2,372 (33.5)	1,822 (30.0)	234 (30.1)	

Obese	4,204 (31.1)	109 (29.5)	2,529 (35.7)	1,566 (25.8)	246 (31.7)	
Underweight	413 (3.1)	14 (3.8)	200 (2.8)	199 (3.3)	44 (5.7)	
Clinic						
Clinic 1	5,136 (37.5)	122 (33.0)	2,190 (30.7)	2,824 (45.5)	304 (38.6)	0
Clinic 2	2,148 (15.7)	19 (5.1)	1,002 (14.1)	1,127 (18.2)	233 (29.6)	
Clinic 3	1,938 (14.1)	24 (6.5)	1,497 (21.0)	417 (6.7)	50 (6.4)	
Clinic 4	1,808 (13.2)	45 (12.2)	1,017 (14.3)	746 (12.0)	51 (6.5)	
Clinic 5	1,706 (12.4)	140 (37.8)	806 (11.3)	760 (12.3)	106 (13.5)	
Clinic 6	973 (7.1)	20 (5.4)	621 (8.7)	332 (5.4)	44 (5.6)	
Payer						
Commercial (other)	1,756 (12.9)	44 (11.9)	720 (10.1)	992 (16.1)	95 (12.1)	73
HMSA Commercial	5,825 (42.7)	150 (40.7)	2,268 (31.9)	3,407 (55.3)	287 (36.6)	
Medicaid	1,039 (7.6)	42 (11.4)	338 (4.8)	659 (10.7)	62 (7.9)	
Medicare	4,594 (33.7)	124 (33.6)	3,685 (51.9)	785 (12.7)	324 (41.3)	
Military	365 (2.7)	7 (1.9)	75 (1.1)	283 (4.6)	14 (1.8)	
Other	61 (0.4)	2 (0.5)	21 (0.3)	38 (0.6)	2 (0.3)	
Mental Health						
No	10,255 (74.8)	257 (69.5)	5,433 (76.2)	4,565 (73.6)	535 (67.9)	0
Yes	3,454 (25.2)	113 (30.5)	1,700 (23.8)	1,641 (26.4)	253 (32.1)	
Tobacco Use						
No	12,376 (90.6)	338 (91.4)	6,487 (91.1)	5,551 (90.1)	687 (87.5)	55
Yes	1,281 (9.4)	32 (8.7)	637 (8.9)	612 (9.9)	98 (12.5)	
Alcohol Use						
No	7,366 (54.3)	197 (53.7)	4,289 (60.4)	2,880 (47.2)	441 (56.7)	150
Yes	6,203 (45.7)	170 (46.3)	2,812 (39.6)	3,221 (52.8)	337 (43.3)	
Diabetes Status & A1C‡						
Diagnosed Diabetes	2,913 (21.3)	33 (8.9)	2,592 (36.3)	288 (4.6)	216 (27.4)	0
Diagnosed Prediabetes	2,414 (17.6)	56 (15.1)	1,617 (22.7)	741 (11.9)	142 (18.0)	
A1C [4.3,5.7)%	2,144 (15.6)	82 (22.2)	992 (13.9)	1,070 (17.2)	140 (17.8)	
A1C [5.7,6.5)%	1,006 (7.3)	41 (11.1)	702 (9.8)	263 (4.2)	48 (6.1)	

A1C [6.5,17]%	18 (0.1)	2 (0.5)	12 (0.2)	4 (0.1)	2 (0.3)	
Unknown	5,214 (38.0)	156 (42.2)	1,218 (17.1)	3,840 (61.9)	240 (30.5)	
Pre-Hypertension						
No	13,198 (96.3)	289 (78.1)	7,022 (98.4)	5,887 (94.9)	746 (94.7)	0
Yes	511 (3.7)	81 (21.9)	111 (1.6)	319 (5.1)	42 (5.3)	

Acronyms: BMI = Body mass index; HMSA = Hawaii Medical Service Association
†Patients in the total sample does not include patients reported in the “Excluded” or missing columns
‡Patients in the A1c categories did not have a diagnosis for either Prediabetes or Diabetes

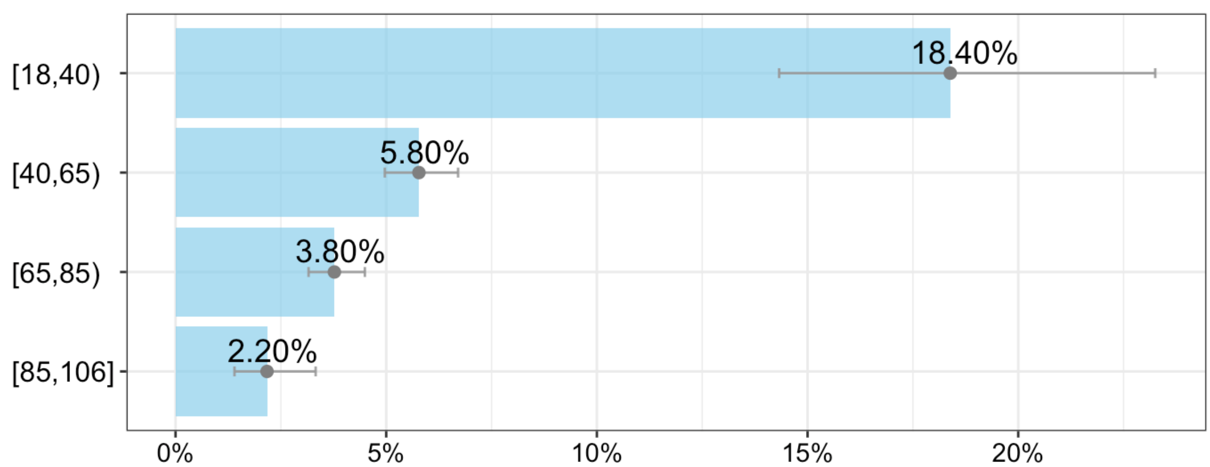
Potentially Undiagnosed Hypertension by Patient Characteristics

Figures 2-8 present the percent of potentially undiagnosed hypertension (flagged) patients by select patient characteristics: age, race/ethnicity, QCIPN clinic, diabetes status, health insurance provider, pre-hypertension status, and other patient factors. In all figures, the displayed percentages are calculated by the number of potentially undiagnosed hypertension cases over the total number of ostensible hypertension cases (physician-diagnosed hypertension and potentially undiagnosed hypertension) across each group. Additionally, 95% confidence intervals are displayed graphically in each bar chart to illustrate groups that significantly differed from one another.

Age

Younger patients were more frequently flagged with potentially undiagnosed hypertension relative to older patients (Figure 2). Patients in the youngest (18-40 years old) age group were significantly more likely to be flagged (18.4%) compared to all other age groups. Similarly, 5.8% of patients with potentially undiagnosed hypertension were in 40-65 years group, which was significantly greater than those in the 65-85 years group (3.8% flagged) and the 85-106 years group (2.2% flagged).

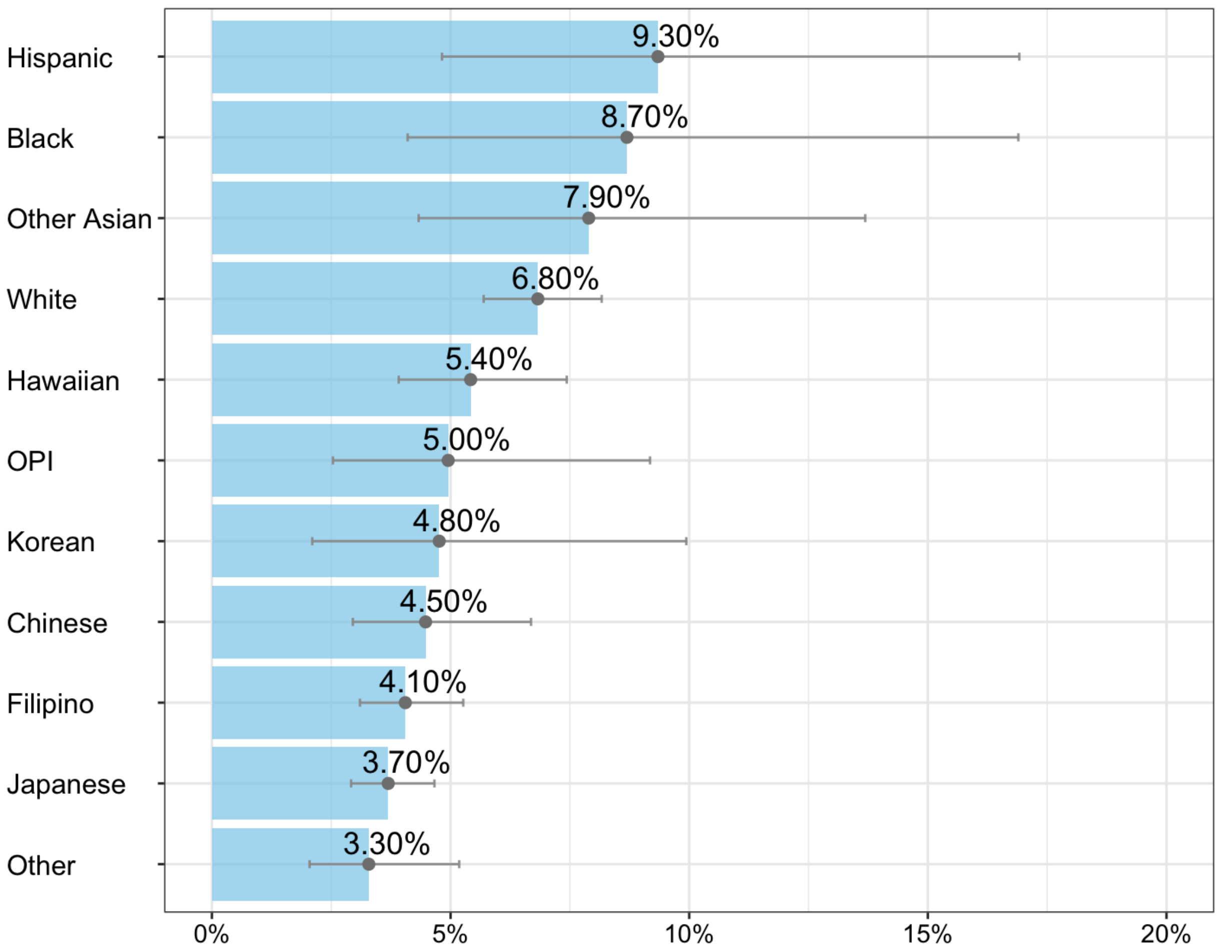
Figure 2. Percent of Potentially Undiagnosed Hypertension (Flagged) Cases across all Ostensible Hypertension Cases by Age in Years



Race/Ethnicity

Across race/ethnicity, the risk of potentially undiagnosed hypertension differed between some groups (Figure 3). Hispanic patients with ostensible hypertension appeared to have the highest risk of being flagged (9.3%). However, this estimate only significantly differed from flagged Japanese patients (3.7%). Relative to White patients (6.8%), Filipino (4.10%), and Japanese (3.7%) patients, along with patients of unspecified ethnicity (3.3%), were less likely to be flagged, but these differences were not statistically significant

Figure 3. Percent of Potentially Undiagnosed Hypertension (Flagged) Cases across all Ostensible Hypertension by Race/Ethnicity

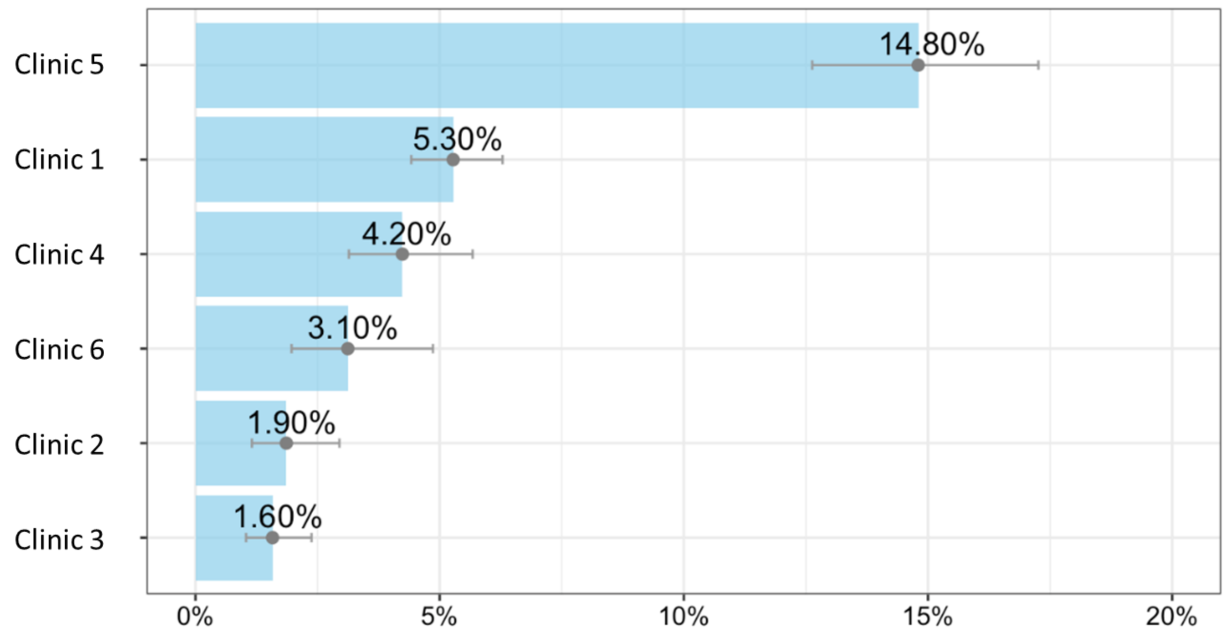


Acronyms: OPI = Other Pacific Islander

QCIPN Clinic

The proportion of potentially undiagnosed hypertension differed across QCIPN clinics (Figure 4). Clinic 5 had the greatest proportion of patients with potentially undiagnosed hypertension (14.8%), significantly higher than all other performing locations, followed by: Clinic 1 (5.3%), Clinic 4 (4.2%), Clinic 6 (3.1%), Clinic 2 (1.9%), and Clinic 3 (1.6%). Clinic 1 and Clinic 4 had a significantly greater proportion of potentially undiagnosed hypertension relative to the three remaining performing locations.

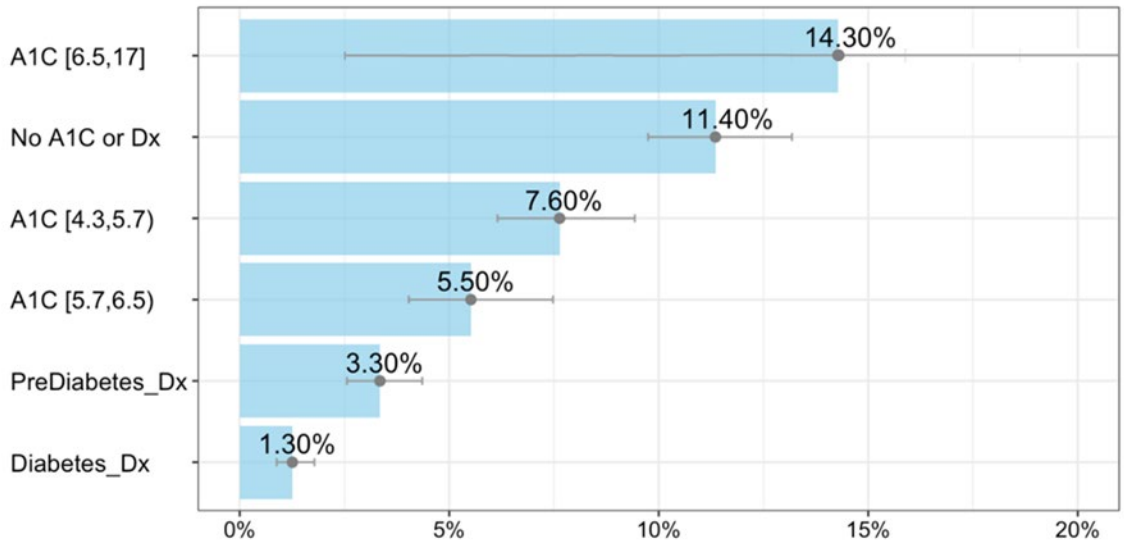
Figure 4. Percent of Potentially Undiagnosed Hypertension (Flagged) Cases across all Ostensible Hypertension by QCIPN Clinic



Diabetes Status

Figure 5 presents the proportions of potentially undiagnosed hypertension cases by diabetes status and A1C among patients with hypertension. Patients with hypertension previously diagnosed with diabetes or prediabetes had the lowest proportion of potentially undiagnosed hypertension (1.3% and 3.3%, respectively). The proportion of patients flagged as potentially undiagnosed hypertension cases was significantly greatest among those with missing diabetes and A1C information (11.4%). While patients without a formal diagnosis for either prediabetes or diabetes with an A1C of 6.5 or greater had a proportionally greater number of flagged cases (14.3%) than other diabetes statuses, it was not significantly different than the overall average. However, the proportion of patients with potentially undiagnosed hypertension was significantly greater among patients with an A1C between 4.3 and 5.7 than those with diabetes or prediabetes diagnosis.

Figure 5. Percent of Potentially Undiagnosed Hypertension (Flagged) Cases across all Ostensible Hypertension by Diabetes, Prediabetes, and A1C

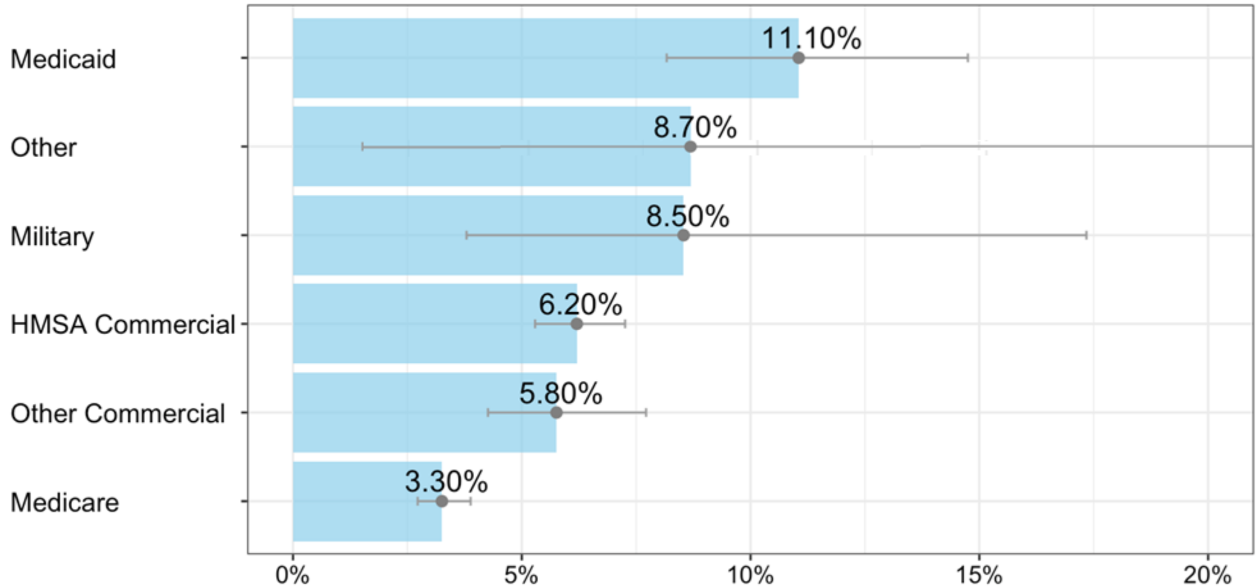


Acronyms: Dx = diagnosis
Patients in the A1c categories did not have a diagnosis for either Prediabetes or Diabetes

Health Insurance Provider

Figure 6 presents the proportion of potentially undiagnosed hypertension by health insurance provider. Patients on Medicaid had the highest proportion of flagged cases (11.1%) across the different health insurance categories, while those on Medicare had the lowest proportion of patients with potentially undiagnosed hypertension (3.3%). HMSA Commercial, the second largest category of insurance provider (second to Medicare) among hypertension cases, had a significantly greater proportion of patients with potentially undiagnosed hypertension (6.2%) than the overall average rate of ostensible hypertension in the total sample (4.9%), whereas the proportion of potentially undiagnosed hypertension using other insurance providers (i.e., Military, Other Commercial, Other) did not differ from the average.

Figure 6. Percent of Potentially Undiagnosed Hypertension (Flagged) Cases across all Ostensible Hypertension by Health Insurance Provider

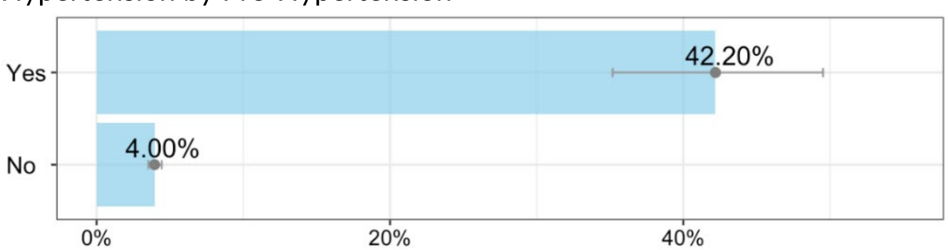


Acronyms: HMSA = Hawaii Medical Service Association

Pre-Hypertension Status

Patients with diagnosed pre-hypertension had a significantly greater proportion of potentially undiagnosed hypertension (42.2%) relative to those without pre-hypertension (4.0%) (Figure 7). The difference in proportion between these group (38.2%) makes pre-hypertension the strongest sociodemographic indicator of potentially undiagnosed hypertension observed in our analysis.

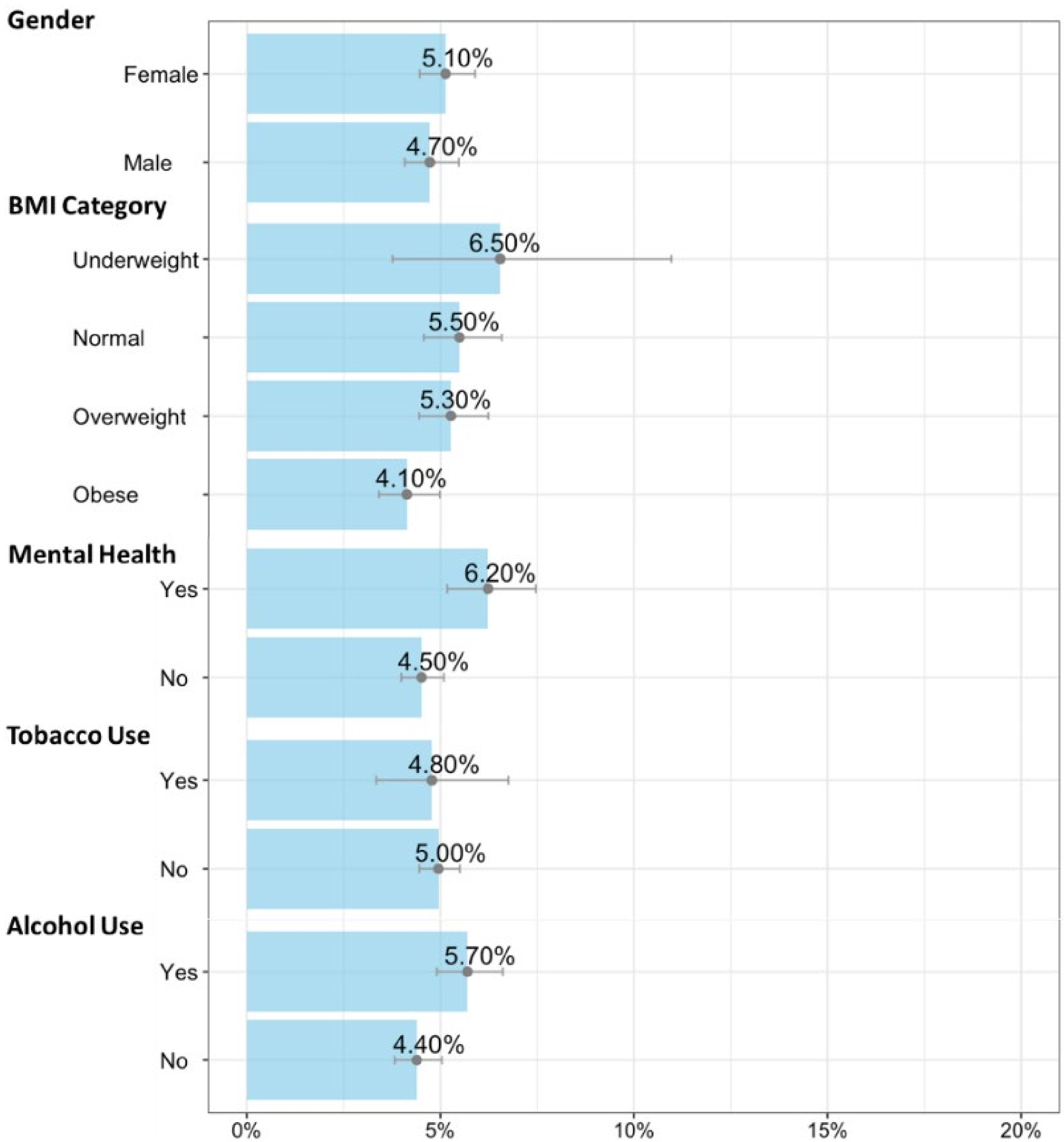
Figure 7. Percent of Potentially Undiagnosed Hypertension (Flagged) Cases across all Ostensible Hypertension by Pre-Hypertension



Other Patient Factors

Figure 8 presents the proportions of potentially undiagnosed hypertension (flagged) cases by all other factors considered in the evaluation, including the patient's gender, BMI category, diagnosed mental health condition(s), record of tobacco use, and record of alcohol use. Only having a record of mental health conditions (6.2%) and alcohol use (5.7%) appear to be associated with hypertension diagnosis status among ostensible hypertension patients, while the proportion of potentially undiagnosed hypertension across the other factors did not significantly differ from overall average.

Figure 8. Percent of Potentially Undiagnosed Hypertension (Flagged) Cases by Gender, BMI Category, Mental Health, Tobacco Use, and Alcohol Use across all Ostensible Hypertension



Acronyms: BMI = Body mass index

Flagging Across Clinics Before and After the COVID-19 Pandemic

Table 2 presents the proportion of potentially undiagnosed hypertension cases by QCIPN clinic before and after the first Stay-At-Home order related to the COVID-19 pandemic took effect in the state of Hawaiʻi. All clinics except Clinic 1 had a greater proportion of patients flagged as potentially undiagnosed hypertension in the period following the Stay-At-Home order, with the largest difference observed in Clinic 5, where the percent of potentially undiagnosed hypertension went from 8.9% before the order to 16.9% in the period after. The difference in the percent of potentially undiagnosed hypertension patients across the remaining clinics was less than half that of Clinic 5 (<4.0% difference).

Table 2. Number of Potentially Undiagnosed Hypertension Cases Before and After the First Stay-At-Home Order in Hawaiʻi by Clinic

QCIPN Clinic	**Percent of Patients Flagged**	**Before Stay-at-Home Order 07/02/2018-03/24/2020**			**After Stay-at-Home Order 03/25/2020-07/01/2021**			**Percent Difference in Flagged before and after**
		Number of Patients Flagged	*Total Number of Patients*	*Percent*	*Number of Patients Flagged*	*Total Number of Patients*	*Percent*	
Clinic 5	14.8%	22	246	8.9%	118	700	16.9%	8.0
Clinic 1	5.3%	32	544	5.9%	90	1768	5.1%	-0.8
Clinic 4	4.2%	4	97	4.1%	41	965	4.2%	0.1
Clinic 6	3.1%	0	78	0.0%	20	563	3.6%	3.6
Clinic 2	1.9%	7	601	1.2%	12	420	2.9%	1.7
Clinic 3	1.6%	1	86	1.2%	23	1435	1.6%	0.4
Total	4.9%	66	1652	4.0%	304	5851	5.2%	1.2

DISCUSSION

This evaluation described the frequency of and factors associated with potentially undiagnosed hypertension as identified by an automated algorithm implemented in a large healthcare system in Hawai'i. We found that as many as 4.9% of the 7,503 patients with ostensible hypertension (physician-diagnosed and flagged) in our sample could potentially have undiagnosed hypertension based on blood pressure measurements found in their EHR. The observed differences by patient characteristics highlighted several groups disproportionately flagged by the algorithm. The probability of patients flagged for potentially undiagnosed hypertension significantly differed by age group, ethnicity, performing location, diabetes status, insurance provider, and pre-hypertension diagnosis. Patients with potentially undiagnosed hypertension tended to be younger, belong to an ethnic group other than Filipino or Japanese, from Clinic 5, had an unknown diabetes status and A1C measurement, on Medicaid, and diagnosed with pre-hypertension. Lastly, the probability of being flagged did not appear to significantly differ by gender, BMI category, or tobacco use.

We found that less than 5% of patients with ostensible hypertension were flagged as potentially undiagnosed hypertension; this was less than the predicted prevalence of 6.5% undiagnosed hypertension in Hawai'i,[18] suggesting that the clinics in QCIPN may be doing slightly better than expected at identifying patients with hypertension. A study of approximately 9 million US patients comparing the number of observed hypertension cases and the number of predicted cases (utilizing the Million Hearts Hypertension Prevalence Estimator Tool) found that the nearly 13% of patients with hypertension may not be formally diagnosed with the condition.[13] Similarly, utilizing a large sample of patients within the OCHIN, Inc (formally known as the Oregon Community Health Information Network) community health network, a collaboration of community health centers across 14 states in the US, Huguet and colleagues[26] found that 37.3% of patients had undiagnosed hypertension, with 24.9% of cases remaining undiagnosed for the five-year duration of the study period. Despite methodological differences, these estimates far exceed the estimated probability of being flagged observed in our evaluation, suggesting that the algorithm implemented within QCIPN is performing well.

While our data suggest that the overall prevalence of undiagnosed hypertension may be low, approximately 1 in 8 patients in the 18 to 40 years old age group, 1 in 10 patients in the missing diabetes/prediabetes/A1C group, and 1 in 10 patients in the Medicaid group, were flagged as a potentially undiagnosed case. The differences by age are further reflected by the lower proportion of potentially undiagnosed hypertension on Medicare compared to Medicaid recipients. One explanation for these observations may be that patients with hypertension at a younger age are less likely to be assigned a hypertension diagnosed relative to those in older age groups.[27,28] Younger patients may be difficult to reach as they record lower levels of health care service utilization compared to older patients.[29,30] Moreover, differences in health care utilization may provide a cogent explanation for not only the differences by age group but also for the differences in percent flagged by diabetes, prediabetes, and A1C measurement. That is, patients that use health care services more often would be more likely to be diagnosed with other conditions such as diabetes or prediabetes, or have an A1C measurement in their records, compared to those with missing information; patients with missing information on one condition may be more likely to be missing an appropriate hypertension diagnosis as well. Additionally, providers may not view hypertension in young adulthood with the same urgency as in older adults given the older age at which serious hypertension-related outcomes tend to occur.[31] However, with early onset hypertension associated with hypertension in later life and a greater odds of cardiovascular mortality compared to late onset.[28,32] Our findings thus underscore a critical need to improve the recognition of hypertension in young adulthood.

The large proportion of patients with potentially undiagnosed hypertension having been diagnosed with pre-hypertension may have many explanations. For example, providers may consider other patient factors not captured in our data to diagnose hypertension; some providers may be more willing to assign a pre-hypertension diagnosis, while being more cautious when considering a hypertension diagnosis. Therefore, the high proportion of potentially undiagnosed hypertension cases with diagnosed pre-hypertension may not necessarily be due to a lack of care but may reflect a limitation of relying solely on recorded blood pressure measurements to identify undiagnosed patients. Alternatively, given that the algorithm's criteria for flagging a patient was higher than the most recent guidelines (i.e., the cut-point under the American Heart Association 2017 guideline is greater than or equal to 130/80 for stage I hypertension),[7] the higher proportion of pre-hypertension among undiagnosed hypertensive patients may indicate a potential misclassification. A phenomenon known as masked hypertension, or masked uncontrolled hypertension, may offer an explanation for this potential misdiagnosis. Masked hypertension occurs when a patient has normal blood pressure reading in office while having hypertensive readings out of the physician's office (e.g., at-home or ambulatory readings).[33] If certain providers within QCIPN were less likely than others to consider at-home blood pressure measurements in their diagnostic decision-making, this might explain why patients with diagnosed pre-hypertension were more likely to be flagged by the algorithm. Given the strong association between masked hypertension and pre-hypertension, the higher proportion of patients with pre-hypertension among the undiagnosed group may indicate masked hypertension as an underlying driver of missed diagnoses.[34]

The differences by performing location were notable, such that nearly 15% of hypertension patients at Clinic 5 potentially had undiagnosed hypertension, while patients from Clinic 2 and Clinic 3 had markedly few patients flagged by the algorithm. While we are unable to determine the factors contributing to this difference, the high percentage of patients with potentially undiagnosed hypertension at Clinic 5 may be related to a lack of adaptation, or a drastic change in clinical needs of patients served by this clinic, during the COVID-19 pandemic. Telehealth use increased dramatically during the COVID-19 pandemic, yet access to remote care differed by population subgroups.[35] Secondary analyses comparing the proportion of patients flagged as potentially undiagnosed hypertension before and after the Stay-At-Home order was passed in Hawaiʻi (March 25, 2020) revealed that the proportion of potentially undiagnosed hypertension cases at Clinic 5 increased to 16.9% from 8.9%. In addition, Clinic 5 experienced a significant turnover in providers during the data period; specifically, two of the four full-time providers left the clinic. Prior studies demonstrate associations between physician turnover and reductions in timely care,[36] patient satisfaction, and organizational stability.[37] Losing half of the full-time providers may have resulted in delays in new provider workflow orientation and/or a lack of access to care while patients are being turned over to new providers. While one explanation for the lower proportions of potentially undiagnosed hypertension at other locations may similarly relate to a lower provider turnover rate, another potential explanation for the success of sites like Clinic 3 may be that they have physician champions whose care is centered around population health and chronic condition management. Providers at this location are known within the system for their focus on appropriate coding, panel management, and case managers who monitor blood pressure.

Limitations

Our evaluation has several limitations. First, all variables utilized in the analysis were derived from an EHR with no direct evaluator-patient contact; as a result, we were unable to follow up with patients flagged by the algorithm to confirm undiagnosed hypertension. Second, selection bias through both health care access/utilization may affect the generalizability of our findings to the outpatient population of QHS. Individuals that are unable or unwilling to see a health provider may be more likely to have hypertension but lack a formal diagnosis, especially those without other co-occurring conditions that may prompt health services utilization. Therefore, the estimates of potentially undiagnosed hypertension and associated characteristics obtained from this report should not be generalized to those outside of the patient population. Third, the lower sample size in certain variables of interest may have limited our ability to detect significant differences between group (e.g., specific race/ethnicity groups, A1C measurements, and other health insurance provider). Moreover, the race/ethnicity categories utilize the Office of Management and Budget categories used in federal reporting; therefore, the Hispanic category is derived from race rather than ethnicity.[38] Hawaiʻi also utilizes a different race/ethnicity categorization scheme to account for a large proportion of multiracial residents (nearly 25%).[39] Given this categorization scheme, certain race/ethnicity groups (i.e., non-White groups) in this evaluation may include substantial proportions of multiethnic patients. Aside from the multiethnic nature of our sample and Hawaiʻi as a state, the collection of information on race/ethnicity is complex and challenging for several inherent reasons, including a lack of standard definitions, differences between the constructs of race and ethnicity, and the influence of acculturation and assimilation, among others.[40] In addition, our sample was limited to patients with at least one encounter in the last 3 years. Therefore, the implemented algorithm would be unable to flag patients overdue to follow-up; that is, patients with blood pressure measurements from up to 3 years ago may be flagged based on what may now be irrelevant data. Lastly, masked hypertension remains a persistent limitation in studies examining undiagnosed hypertension, with a prevalence reported around 10-17% using daytime measurements; the prevalence of masked hypertension may be far greater when accounting for daytime, nighttime, and ambulatory measurements.[41] Masked hypertension may be especially problematic if some QCIPN providers were less likely to log at-home blood pressure measurements. While we believe that masked hypertension is unlikely to differentially affect participants by patient characteristics, it may offer another potential explanation for the higher proportion of flagged participant at the Clinic 5 location; that is, providers at this clinic may have been less likely to record out-of-office blood pressure relative to the other performing locations during the COVID-19 pandemic or physician turnover.

RECOMMENDATIONS

Our findings warrant further investigative efforts to understand the underlying reasons certain patients lacked a formal hypertension diagnosis despite having blood pressure measurements that clearly indicate hypertension. Next steps for QCIPN could be to further examine the flagged undiagnosed hypertension cases to see whether the algorithm correctly flagged individuals as undiagnosed hypertension cases. That is, one way to assess the specificity and sensitivity of the algorithm (i.e., the algorithm's ability to correctly identify undiagnosed hypertension) would be to identify patients with potentially undiagnosed hypertension that were further examined by their provider and ascertain how many were confirmed to have hypertension. Additionally, QCIPN could explore which actions were taken following a flag, and whether properly flagged patients were able to achieve a normotensive status through these actions; the latter may help to reveal the effectiveness of such automated algorithms in clinical practice. Lastly, record of how the blood pressure was measured (at-home, ambulatory, or in-office) may allow future evaluations to further examine the underlying drivers of flagged cases.

CONCLUSION

Our evaluation underscores the value of leveraging EHR algorithms in identifying patients with potentially undiagnosed hypertension and highlights several sociodemographic factors associated with the lack of diagnosis. The algorithm examined in this evaluation indicated that QCIPN is doing well in identifying patients with hypertension; the proportion of patients with potentially undiagnosed hypertension was far lower than that of studies utilizing larger samples of patients across the United States. QCIPN should continue to deploy the hypertension algorithm and work to capture the groups of patients that seem to be less likely to be diagnosed (e.g., younger patients).

A major strength in integrating algorithms designed to identify patients with undiagnosed hypertension is their potential to not only prompt provider follow-up but to link patients with potentially undiagnosed hypertension to personalized referral services. For instance, with smoking being an important risk factor in hypertension development,[42] patients flagged by the algorithm who smoke may be automatically linked to programs like the Hawaii Tobacco Quitline services. Similarly, algorithms may link some patients with potentially undiagnosed hypertension to behavioral change programs tailored to their needs based on factors such as BMI and age. QCIPN should continue to refer patients into treatment or lifestyle change programs, within the QHS system and the surrounding community, and ensure that providers are knowledgeable about programs to refer patients flagged with potentially undiagnosed hypertension. This evaluation provides evidence that QCIPN and other health systems should continue to leverage HIT in identifying, preventing, and managing patients with hypertension.

REFERENCES

1. Ostchega Y, Fryar CD, Nwankwo T, Nguyen DT. Hypertension prevalence among adults aged 18 and over: United States, 2017–2018. 2020.

2. Zhou B, Carrillo-Larco RM, Danaei G, et al. Worldwide trends in hypertension prevalence and progress in treatment and control from 1990 to 2019: a pooled analysis of 1201 population-representative studies with 104 million participants. *The Lancet.* 2021;398(10304):957-980.

3. Kirkland EB, Heincelman M, Bishu KG, et al. Trends in Healthcare Expenditures Among US Adults With Hypertension: National Estimates, 2003-2014. *Journal of the American Heart Association.* 2018;7(11).

4. Fuchs FD, Whelton PK. High Blood Pressure and Cardiovascular Disease. *Hypertension.* 2020;75(2):285-292.

5. Mills KT, Stefanescu A, He J. The global epidemiology of hypertension. *Nature Reviews Nephrology.* 2020;16(4):223-237.

6. About Multiple Cause of Death, 1999-2019. Centers for Disease Control and Prevention; 2019. Accessed 01/03/2022.

7. Whelton PK, Carey RM, Aronow WS, 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: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Hypertension.* 2018;71(6):e13-e115.

8. Meador M, Lewis JH, Bay RC, Wall HK, Jackson C. Who are the undiagnosed? Disparities in hypertension diagnoses in vulnerable populations. *Family & community health.* 2020;43(1):35.

9. Yen PY, McAlearney AS, Sieck CJ, Hefner JL, Huerta TR. Health Information Technology (HIT) Adaptation: Refocusing on the Journey to Successful HIT Implementation. *JMIR medical informatics.* 2017;5(3):e28.

10. Teltsch DY, Fazeli Farsani S, Swain RS, et al. Development and validation of algorithms to identify newly diagnosed type 1 and type 2 diabetes in pediatric population using electronic medical records and claims data. *Pharmacoepidemiology and drug safety.* 2019;28(2):234-243.

11. Makam AN, Nguyen OK, Moore B, Ma Y, Amarasingham R. Identifying patients with diabetes and the earliest date of diagnosis in real time: an electronic health record case-finding algorithm. *BMC Medical Informatics and Decision Making.* 2013;13(1):81.

12. Holt TA, Gunnarsson CL, Cload PA, Ross SD. Identification of undiagnosed diabetes and quality of diabetes care in the United States: cross-sectional study of 11.5 million primary care electronic records. *CMAJ Open.* 2014;2(4):E248-E255.

13. Ciemins EL, Ritchey MD, Joshi VV, Loustalot F, Hannan J, Cuddeback JK. Application of a Tool to Identify Undiagnosed Hypertension - United States, 2016. *MMWR Morbidity and mortality weekly report.* 2018;67(29):798-802.

14. Meador M, Osheroff JA, Reisler B. Improving Identification and Diagnosis of Hypertensive Patients Hiding in Plain Sight (HIPS) in Health Centers. *Joint Commission journal on quality and patient safety.* 2018;44(3):117-129.

15. Rakotz MK, Ewigman BG, Sarav M, et al. A technology-based quality innovation to identify undiagnosed hypertension among active primary care patients. *The Annals of Family Medicine.* 2014;12(4):352-358.

16. Wall HK, Hannan JA, Wright JS. Patients with undiagnosed hypertension: hiding in plain sight. *Jama.* 2014;312(19):1973-1974.

17. Buitron de la Vega P, Losi S, Sprague Martinez L, et al. Implementing an EHR-based Screening and Referral System to Address Social Determinants of Health in Primary Care. *Medical care.* 2019;57 Suppl 6 Suppl 2:S133-s139.

18. Park S, Gillespie C, Baumgardner J, et al. Modeled state-level estimates of hypertension prevalence and undiagnosed hypertension among US adults during 2013-2015. *Journal of clinical hypertension (Greenwich, Conn).* 2018;20(10):1395-1410.

19. Cantor MN, Thorpe L. Integrating Data On Social Determinants Of Health Into Electronic Health Records. *Health Aff (Millwood).* 2018;37(4):585-590.

20. McGowan JJ, Cusack CM, Bloomrosen M. The future of health IT innovation and informatics: a report from AMIA's 2010 policy meeting. *Journal of the American Medical Informatics Association : JAMIA.* 2012;19(3):460-467.

21. Casey JA, Schwartz BS, Stewart WF, Adler NE. Using Electronic Health Records for Population Health Research: A Review of Methods and Applications. *Annual review of public health.* 2016;37:61-81.

22. Black AD, Car J, Pagliari C, et al. The impact of eHealth on the quality and safety of health care: a systematic overview. *PLoS medicine.* 2011;8(1):e1000387.

23. Panch T, Mattie H, Celi LA. The "inconvenient truth" about AI in healthcare. *NPJ digital medicine.* 2019;2:77.

24. QuickFacts Hawaii. US Department of Commerce; 2021. Accessed 02/21/2022.

25. Đoàn LN, Takata Y, Hooker K, Mendez-Luck C, Irvin VL. Trends in Cardiovascular Disease by Asian American, Native Hawaiian, and Pacific Islander Ethnicity, Medicare Health Outcomes Survey 2011–2015. *The Journals of Gerontology: Series A.* 2021;77(2):299-309.

26. Huguet N, Larson A, Angier H, et al. Rates of Undiagnosed Hypertension and Diagnosed Hypertension Without Anti-hypertensive Medication Following the Affordable Care Act. *American journal of hypertension.* 2021;34(9):989-998.

27. Johnson HM, Thorpe CT, Bartels CM, et al. Undiagnosed hypertension among young adults with regular primary care use. *Journal of hypertension.* 2014;32(1):65-74.

28. Hinton TC, Adams ZH, Baker RP, et al. Investigation and Treatment of High Blood Pressure in Young People. *Hypertension.* 2020;75(1):16-22.

29. Tillmann BW, Fu L, Hill AD, et al. Acute healthcare resource utilization by age: A cohort study. *PLOS ONE.* 2021;16(5):e0251877.

30. King CC, Bartels CM, Magnan EM, Fink JT, Smith MA, Johnson HM. The importance of frequent return visits and hypertension control among US young adults: a multidisciplinary group practice observational study. *The Journal of Clinical Hypertension.* 2017;19(12):1288-1297.

31. Rodgers JL, Jones J, Bolleddu SI, et al. Cardiovascular Risks Associated with Gender and Aging. *Journal of cardiovascular development and disease.* 2019;6(2).

32. Niiranen TJ, McCabe EL, Larson MG, et al. Heritability and risks associated with early onset hypertension: multigenerational, prospective analysis in the Framingham Heart Study. *BMJ (Clinical research ed).* 2017;357:j1949.

33. Thakkar HV, Pope A, Anpalahan M. Masked Hypertension: A Systematic Review. *Heart, Lung and Circulation.* 2020;29(1):102-111.

34. Franklin SS, O'Brien E, Staessen JA. Masked hypertension: understanding its complexity. *European Heart Journal.* 2016;38(15):1112-1118.

35. Karimi M, Lee EC, Couture SJ, et al. National survey trends in telehealth use in 2021: disparities in utilization and audio vs. video services. Department of Health and Human Services, Office of the Assistant Secretary ...; 2022.

36. Reddy A, Pollack CE, Asch DA, Canamucio A, Werner RM. The Effect of Primary Care Provider Turnover on Patient Experience of Care and Ambulatory Quality of Care. *JAMA internal medicine.* 2015;175(7):1157-1162.

37. Misra-Hebert AD, Kay R, Stoller JK. A review of physician turnover: rates, causes, and consequences. *American journal of medical quality : the official journal of the American College of Medical Quality.* 2004;19(2):56-66.

38. Management Oo, Budget. Revisions to the standards for the classification of federal data on race and ethnicity. *Federal Register.* 1997;62(210):58782-58790.

39. Bureau USC. QuickFacts Hawaii. 2021; https://www.census.gov/quickfacts/HI. Accessed 6/30/2022, 2022.

40. Kaneshiro B, Geling O, Gellert K, Millar L. The challenges of collecting data on race and ethnicity in a diverse, multiethnic state. *Hawaii medical journal.* 2011;70(8):168-171.

41. Anstey DE, Shimbo D. Masked hypertension—what lies ahead? *Journal of Human Hypertension.* 2017;31(9):545-546.

42. Gao K, Shi X, Wang W. The life-course impact of smoking on hypertension, myocardial infarction and respiratory diseases. *Scientific reports.* 2017;7(1):4330.