Blood Pressure and the Electronic Health Record: A Work in Progress

Amier Ahmad, MD; Suzanne Oparil, MD

In this issue of the *Journal of the American Heart Association* (*JAHA*), Ayala Solares et al used data from linked primary care electronic health records (EHRs) in the United Kingdom to test whether multiple blood pressure (BP) measurements over time are better predictors of future cardiovascular disease (CVD) events and death than single current baseline BP measurements.[1] The authors identified 80 964 men and women at the age of 50 years who had at least one systolic BP (SBP) recorded within 1 year of baseline, at least 10 years of registration with their clinic before baseline, and no prior CVD or antihypertensive or lipid-lowering prescriptions. Associations between past SBP values recorded in the EHRs up to 10 years before baseline, usual SBP values corrected by taking prior BP fluctuations into account, and baseline SBP (a single current SBP value) were then used to determine the relationship between SBP and incident CVD, defined as first hospitalization for or death from coronary heart disease or stroke/transient ischemic attack. The major finding was that elevated past, baseline, and usual SBP measurements were separately and independently associated with increased incident CVD risk. The associations with CVD risk were stronger for past and usual SBP measurements (hazard ratio, 1.39–1.45) than for single current baseline SBP (hazard ratio, 1.18–1.30). The authors concluded that although extracting multiple prior SBP measurements from the EHRs yielded stronger associations with incident CVD than use of a single SBP recording, adding multiple prior SBP values to multivariate risk prediction models did not significantly improve risk prediction.

The failure to find improvement in risk prediction when including long-term exposure to prior BP is consistent with prior studies.[2,3] Paige et al conducted a pooled analysis of 191 445 adults with no history of CVD from 38 longitudinal cohort studies to assess the benefit of including repeated measurements of SBP and cholesterol compared with single baseline measurements in predicting absolute 5-year risk of CVD.[2] They demonstrated a modest ≈1% improvement in the specificity of risk prediction models when repeated measurements were included. Similarly, Paynter et al estimated usual SBP and cholesterol levels using repeated measurements over 3 years before baseline.[3] When incorporated into risk prediction models, there was no statistically significant improvement in C-indexes compared with single baseline measurements. The growing availability of EHRs and self-monitoring tools will make repeated SBP measurements more accessible to the practicing clinician. However, the findings of Ayala Solares et al[1] temper the expectation that these values by themselves will significantly improve the predicative performance of risk stratification tools.

While acknowledging the correlations between past and current SBP with CVD outcomes, it is important to recognize the inherent limitations of in-office BP measurement for diagnosing hypertension and predicting CVD risk. Out-of-office BP measurement is needed to identify BP patterns that cannot be detected with in-office BP measurement alone.[4] These phenotypes, which include white coat hypertension (BP elevated in office, normal out of office) and masked hypertension (BP normal in office, elevated out of office), are highly prevalent and have different prognoses.

White coat hypertension has been reported in 19% to 30% of untreated hypertensive patients in recent studies.[5–7] Whether white coat hypertension is associated with increased CVD and mortality remains a matter of debate.[8] White coat hypertension has traditionally been considered benign, as early studies did not show differences in long-term CVD outcomes in patients with white coat hypertension compared with normotensive controls. However, more recent findings have raised concerns that people with white coat hypertension are at increased risk of developing sustained hypertension and resultant CVD events over time.[9] If, in fact, white coat hypertension has a relatively benign prognosis, risk models using SBP based on EHRs would overestimate CVD risk in these patients, likely resulting in unnecessary treatment with antihypertensive therapy.

The opinions expressed in this article are not necessarily those of the editors or of the American Heart Association.

From the Division of Cardiology, New York University School of Medicine, New York, NY (A.A.); and Vascular Biology and Hypertension Program, Division of Cardiovascular Disease, University of Alabama at Birmingham, AL (S.O.).

Correspondence to: Amier Ahmad, MD, New York University School of Medicine, 550 First Ave, New York, NY. E-mail: amier.ahmad@nyulangone.org

J Am Heart Assoc. 2019;8:e012960. DOI: 10.1161/JAHA.119.012960.

In contrast, masked hypertension, which has been reported in 15% to 25% of untreated hypertensive patients in recent studies, has been associated with a 2-fold increased risk of CVD compared with normotension.[5–7,10,11] Masked hypertension is not captured using in-office EHRs data, and use of risk prediction tools guided by EHRs data would leave these high-risk patients untreated.[4,12]

The study by Ayala Solares et al[1] has several strengths. It is the first to compare past, current, and usual SBP values obtained from EHRs from primary care practices. It identified a large sample size of ≈80 000 individuals at the age of 50 years, representative of the UK general population, using EHRs from the UK Clinical Practice Research Database. The UK Clinical Practice Research Database is one of the largest databases in the world, providing clinical information from ≈7% of primary care practices in the United Kingdom.[13,14] The analysis was restricted to data from participants of a single age (50 years) at enrollment, thus eliminating confounding by age, which has a major effect on BP over time. Exclusion of data from people with prevalent CVD or use of antihypertensive medications also adds rigor to the analysis of BP over time. The EHRs in the UK Clinical Practice Research Database is linked to the National Health Service databases on mortality and hospitalizations, thus ensuring complete capture of clinical data and CVD outcomes. Data used in the analysis were obtained from practices that met research quality standards, and the quality and validity of diagnoses recorded in the UK Clinical Practice Research Database have been reported previously.[14] The authors recognized that EHRs often lack important data about risk factors and confounding factors and accounted for this using a statistical computational method. Real-world risk prediction models were also used to make the results generalizable; and repeated SBP measurements, derived from EHRs, had long-term predictive value similar to repeated SBP measurements in research data sets.

It is important to recognize the deficiencies of in-office BP, the only form of BP measurement commonly reported in EHRs. In-office BP measurements often misdiagnose hypertension.[15] Accordingly, the 2015 US Preventive Services Task Force recommended use of ambulatory BP monitoring to diagnose hypertension[16]; and more recent guidelines have reinforced the importance of out-of-office BP measurement, including both ambulatory BP monitoring and home or self measurement for both diagnosis of hypertension and monitoring treatment.[12,17] Ambulatory BP monitoring and home BP measurements are superior to in-office readings in predicting CVD outcomes. However, use of ambulatory BP monitoring remains infrequent because of limited access, excessive cost, and concerns over the accuracy and benefits of testing.[18] For these reasons, many clinicians rely on in-office BP measures recorded in EHRs for clinical decision making.

EHRs represent a vast repository of patient data that are easily accessible and can be used to improve patient care. Although the current study did not show significant improvement in risk prediction using repeated measurements of BP recorded in EHRs over single clinic BP measurements, it helps lay the groundwork for future integration of machine learning to assist in patient care. Digital programs are currently being used to aid in BP management. For example, Milani et al evaluated BP control in 156 patients with uncontrolled hypertension using a home-based BP program in which commercially available BP monitors transmitted recordings directly to EHRs.[19] Patients then received medication titration and lifestyle recommendations on the basis of their home readings. A total of 71% of participants achieved target BP levels (versus 31% of matched controls). Incorporating machine learning algorithms with currently used telemedicine practices and EHRs represents an exciting new avenue that could potentially improve how hypertension is treated and controlled.

Disclosures

Dr Oparil reports personal fees from Actelion Clinical Research, Novo Nordisk, Inc, 98point6, Inc, Pfizer, Inc, and Idorsia Pharmaceuticals Ltd, outside of the submitted work; has received research grants from George Clinical Pty Ltd, Bayer, and Idorsia Pharmaceuticals Ltd, outside the submitted work; and serves as Editor-in-Chief of *Current Hypertension Reports*. Dr Ahmad has no disclosures to report.

References

1. Ayala Solares JR, Canoy D, Raimondi FED, Zhu Y, Hassaine A, Salimi-Khorshidi G, Tran J, Copland E, Zottoli M, Pinho-Gomes A-C, Nazarzadeh M, Rahimi K. Long-term exposure to elevated systolic blood pressure in predicting incident cardiovascular disease: evidence from large-scale routine electronic health records. *J Am Heart Assoc*. 2019;8:e012129. DOI: 10.1161/JAHA.119.012129.
2. Paige E, Barrett J, Pennells L, Sweeting M, Willeit P, Di Angelantonio E, Gudnason V, Nordestgaard BG, Psaty BM, Goldbourt U, Best LG, Assmann G, Salonen JT, Nietert PJ, Verschuren WMM, Brunner EJ, Kronmal RA, Salomaa V, Bakker SJL, Dagenais GR, Sato S, Jansson JH, Willeit J, Onat A, de la Camara AG, Roussel R, Volzke H, Dankner R, Tipping RW, Meade TW, Donfrancesco C, Kuller LH, Peters A, Gallacher J, Kromhout D, Iso H, Knuiman M, Casiglia E, Kavousi M, Palmieri L, Sundstrom J, Davis BR, Njolstad I, Couper D, Danesh J, Thompson SG, Wood A. Use of repeated blood pressure and cholesterol measurements to improve cardiovascular disease risk prediction: an individual-participant-data meta-analysis. *Am J Epidemiol*. 2017;186:899–907.
3. Paynter NP, Crainiceanu CM, Sharrett AR, Chambless LE, Coresh J. Effect of correcting for long-term variation in major coronary heart disease risk factors: relative hazard estimation and risk prediction in the Atherosclerosis Risk in Communities study. *Ann Epidemiol*. 2012;22:191–197.
4. Muntner P, Einhorn PT, Cushman WC, Whelton PK, Bello NA, Drawz PE, Green BB, Jones DW, Juraschek SP, Margolis KL, Miller ER III, Navar AM, Ostchega Y, Rakotz MK, Rosner B, Schwartz JE, Shimbo D, Stergiou GS, Townsend RR, Williamson JD, Wright JT Jr, Appel LJ; 2017 National Heart, Lung, and Blood Institute Working Group. Blood pressure assessment in adults in clinical practice and clinic-based research: *Journal of the American College of Cardiology* Scientific Expert Panel. *J Am Coll Cardiol*. 2019;73:317–335.
5. Schwartz JE, Burg MM, Shimbo D, Broderick JE, Stone AA, Ishikawa J, Sloan R, Yurgel T, Grossman S, Pickering TG. Clinic blood pressure underestimates ambulatory blood pressure in an untreated employer-based US population:

results from the Masked Hypertension Study. *Circulation*. 2016;134:1794–1807.

6. Thomas SJ, Booth JN III, Bromfield SG, Seals SR, Spruill TM, Ogedegbe G, Kidambi S, Shimbo D, Calhoun D, Muntner P. Clinic and ambulatory blood pressure in a population-based sample of African Americans: the Jackson Heart Study. *J Am Soc Hypertens*. 2017;11:204–212.
7. Omboni S, Aristizabal D, De la Sierra A, Dolan E, Head G, Kahan T, Kantola I, Kario K, Kawecka-Jaszcz K, Malan L, Narkiewicz K, Octavio JA, Ohkubo T, Palatini P, Siegelova J, Silva E, Stergiou G, Zhang Y, Mancia G, Parati G; ARTEMIS (international Ambulatory blood pressure Registry: TEleMonitoring of hypertension and cardiovascular rISk project) Investigators. Hypertension types defined by clinic and ambulatory blood pressure in 14,143 patients referred to hypertension clinics worldwide: data from the ARTEMIS study. *J Hypertens*. 2016;34:2187–2198.
8. Muntner P, Booth JN III, Shimbo D, Schwartz JE. Is white-coat hypertension associated with increased cardiovascular and mortality risk? *J Hypertens*. 2016;34:1655–1658.
9. Mancia G, Bombelli M, Facchetti R, Madotto F, Quarti-Trevano F, Polo Friz H, Grassi G, Sega R. Long-term risk of sustained hypertension in white-coat or masked hypertension. *Hypertension*. 2009;54:226–232.
10. Booth JN III, Diaz KM, Seals SR, Sims M, Ravenell J, Muntner P, Shimbo D. Masked hypertension and cardiovascular disease events in a prospective cohort of blacks: the Jackson Heart Study. *Hypertension*. 2016;68:501–510.
11. Palla M, Saber H, Konda S, Briasoulis A. Masked hypertension and cardiovascular outcomes: an updated systematic review and meta-analysis. *Integr Blood Press Control*. 2018;11:11–24.
12. Whelton PK, Carey RM, Aronow WS, Casey DE Jr, Collins KJ, Dennison Himmelfarb C, DePalma SM, Gidding S, Jamerson KA, Jones DW, MacLaughlin EJ, Muntner P, Ovbiagele B, Smith SC Jr, Spencer CC, Stafford RS, Taler SJ, Thomas RJ, Williams KA Sr, Williamson JD, Wright JT Jr. 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:e13–e115.
13. Herrett E, Gallagher AM, Bhaskaran K, Forbes H, Mathur R, van Staa T, Smeeth L. Data resource profile: clinical practice research datalink (CPRD). *Int J Epidemiol*. 2015;44:827–836.
14. Herrett E, Thomas SL, Schoonen WM, Smeeth L, Hall AJ. Validation and validity of diagnoses in the general practice research database: a systematic review. *Br J Clin Pharmacol*. 2010;69:4–14.
15. Kronish IM, Kent S, Moise N, Shimbo D, Safford MM, Kynerd RE, O'Beirne R, Sullivan A, Muntner P. Barriers to conducting ambulatory and home blood pressure monitoring during hypertension screening in the United States. *J Am Soc Hypertens*. 2017;11:573–580.
16. Siu AL; U.S. Preventive Services Task Force. Screening for high blood pressure in adults: U.S. Preventive Services Task Force recommendation statement. *Ann Intern Med*. 2015;163:778–786.
17. Williams B, Mancia G, Spiering W, Agabiti Rosei E, Azizi M, Burnier M, Clement DL, Coca A, de Simone G, Dominiczak A, Kahan T, Mahfoud F, Redon J, Ruilope L, Zanchetti A, Kerins M, Kjeldsen SE, Kreutz R, Laurent S, Lip GYH, McManus R, Narkiewicz K, Ruschitzka F, Schmieder RE, Shlyakhto E, Tsioufis C, Aboyans V, Desormais I. 2018 ESC/ESH guidelines for the management of arterial hypertension: the Task Force for the management of arterial hypertension of the European Society of Cardiology and the European Society of Hypertension. *J Hypertens*. 2018;36:1953–2041.
18. Shimbo D, Abdalla M, Falzon L, Townsend RR, Muntner P. Role of ambulatory and home blood pressure monitoring in clinical practice: a narrative review. *Ann Intern Med*. 2015;163:691–700.
19. Milani RV, Lavie CJ, Bober RM, Milani AR, Ventura HO. Improving hypertension control and patient engagement using digital tools. *Am J Med*. 2017;130:14–20.

Key Words: Editorials • blood pressure • electronic health record • hypertension