INVITED COMMENTARY

Best Practices for Managing Postpartum Hypertension

Natasha Raj Kumar[1] · Adi Hirshberg[1] · Sindhu K. Srinivas[1]

Abstract

Purpose of Review Patients remain at risk for persistent and de novo postpartum hypertension related to pregnancy. This review aims to summarize the current definitions, clinical practices, and novel systems innovations and therapies for postpartum hypertension.

Recent Findings Recent changes to the definitions of hypertension outside of pregnancy have not yet impacted definitions or management of hypertensive disorders of pregnancy (HDP), though research examining the implications of these new definitions on risks of developing HDP and the resultant sequelae is ongoing. The administration of diuretics has been shown to reduce postpartum hypertension among women with HDP. Widespread implementation of telemedicine models and remote assessment of ambulatory blood pressures has increased data available on postpartum blood pressure trajectories, which may impact clinical management. Additionally, policy changes such as postpartum Medicaid extension and an increasing emphasis on building bridges to primary care in the postpartum period may improve long-term outcomes for women with postpartum hypertension. Prediction models utilizing machine learning are an area of ongoing research to assist with risk assessment in the postpartum period.

Summary The clinical management of postpartum hypertension remains focused on blood pressure control and primary care transition for cardiovascular disease risk reduction. In recent years, systemic innovations have improved access through implementation of new care delivery models. However, the implications of changing definitions of hypertension outside of pregnancy, increased data assessing blood pressure trajectories in the postpartum period, and the creation of new risk prediction models utilizing machine learning remain areas of ongoing research.

Introduction

Hypertensive disorders of pregnancy (HDP) affect approximately 10% of pregnancies in the USA and are one of the leading causes of maternal morbidity and mortality [1, 2•] and poor perinatal outcomes. They are also a leading cause of postpartum readmissions and associated healthcare costs [3•, 4•, 5, 6].

Theories regarding the pathophysiology of HDP include chronic uteroplacental ischemia, immune maladaptation and genetic imprinting leading to imbalances of angiogenic factors [7••, 8•, 9]. Definitive treatment of antenatal HDP requires delivery. It is now well known that patients with HDP subsequently are at increased risk of chronic hypertension and cardiovascular disease long term [10••, 11, 12]. Prevalence of long-term complications may potentially be related to timing of onset of HDP, as small studies have shown increased prevalence of chronic hypertension among patients with early onset preeclampsia compared with late onset preeclampsia or gestational hypertension [13•].

Postpartum hypertension, which affects approximately 2% of pregnancies, typically refers to hypertension occurring after delivery through 6 weeks postpartum [14, 15••]. This includes patients with both persistent or worsening hypertension following a pregnancy complicated by antenatal HDP and de novo disease following a normotensive pregnancy and delivery. Gestational hypertension and preeclampsia account for the majority of these cases, while

✉ Natasha Raj Kumar
  natasha.kumar@pennmedicine.upenn.edu

1 Department of Obstetrics and Gynecology, University of Pennsylvania Health System, 3400 Spruce Street, Philadelphia, PA 19104, USA

worsening chronic hypertension and superimposed preeclampsia account for the remainder [16]. Postpartum hypertension due to worsening antenatal HDP is typically easier to diagnose because antenatal disease is a clear risk factor for postpartum disease and patients with antenatal HDP are typically subject to increased surveillance postpartum. Other risk factors for postpartum readmission for hypertension include advanced maternal age, multiparity, elevated body mass index, and longer length of labor [17–19]. While more challenging to diagnose, patients with de novo postpartum hypertension have similar clinical risk factors and antepartum plasma angiogenic profiles to patients with antenatal HDP [20•]. Most cases of de novo postpartum hypertension occur within 5–7 days after delivery, when blood pressures peak during the postpartum period and up to 80% of these cases resolve by 6 weeks postpartum [21, 22].

For patients with persistent hypertension past 6 weeks postpartum, small studies have indicated a variety of disease phenotypes. Notably, in an ambulatory blood pressure monitoring study of 115 patients with preeclampsia, 11.6% had masked hypertension after 6 weeks postpartum compared with none of the patients in control groups [23•]. Among women with either a blood pressure available from a postpartum visit or a reported home blood pressure measurement after 3 weeks postpartum, 53.9% met the criteria for stage 1 hypertension and 19.9% met the criteria for stage 2 hypertension. Though race is a social rather than biologic construct–and thus examination of differences by race demonstrate the impact of racism upon health outcomes rather than any biologic factors–one study has also shown that persistence of higher blood pressures postpartum was more common in Black women compared to White women [24]. These differences in phenotype and trajectory illustrate potential opportunities for population-based interventions in the postpartum period.

Current Definitions of Hypertensive Disorders of Pregnancy

The definitions of hypertensive disorders of pregnancy (HDP) have evolved rapidly in the past decade. Historically, the term "preeclampsia" was used when patients had elevated blood pressures during pregnancy as well as evidence of end organ damage, specifically proteinuria. Since 2013, HDP has been separated into disease without severe features (i.e., elevated systolic blood pressures 140–159 mm Hg or diastolic blood pressures below 90–109 mm Hg) and disease with severe features (i.e., systolic blood pressures above or equal to 160 mm Hg or diastolic blood pressures above or equal to 110 mm Hg or evidence of significant organ damage such as pulmonary edema, neurologic signs or symptoms, or severe laboratory derangements demonstrating

acute kidney or hepatic injury or thrombocytopenia) [25••]. The most recent guidelines developed by the American College of Obstetricians and Gynecologists (ACOG) in 2019 no longer require proteinuria to be part of the definition of preeclampsia [26••]. In addition, severe range blood pressures alone can constitute preeclampsia with severe features without other evidence of end organ damage.

It is also important to note that outside of pregnancy, definitions of hypertension have also been changing. In 2017, the American College of Cardiology (ACC) and the American Heart Association (AHA) published stricter guidelines defining class I hypertension, where systolic blood pressures range 130 to 139 mm Hg or diastolic blood pressures range 80–89 mm Hg [27••]. In 2019, updated guidelines from ACOG on chronic hypertension in pregnancy noted that it was reasonable to continue blood pressure treatment for patients previously diagnosed with chronic hypertension outside of pregnancy based on the stricter parameters for class I hypertension but did not redefine the parameters for HDP [28••]. Several studies including a large retrospective cohort of more than 18,000 patients demonstrated an association between class I hypertension and increased risk of HDP, preterm birth, and adverse perinatal outcomes [29•, 30]. Unsurprisingly, a larger proportion – up to 20% – of pregnant patients previously considered normotensive in the postpartum period by older guidelines would be diagnosed with postpartum hypertension if the stricter ACC/AHA guidelines were applied, though the long-term implications of class I hypertension in the postpartum period are not known [31].

Clinical Management of Postpartum Hypertension

The clinical management of postpartum hypertension focuses primarily on blood pressure control via use of antihypertensive medications both prior to discharge and after discharge, risk reduction for patients with antenatal HDP via use of diuretics postpartum, consideration of magnesium administration for seizure prophylaxis, and clinical surveillance to improve diagnosis during the postpartum period, particularly after discharge.

Postpartum hypertension is diagnostically challenging as it can be quite difficult to predict which patients will develop either worsening hypertension following antenatal HDP or de novo postpartum hypertension, though multiple studies have sought to identify risk factors for postpartum hypertension [5, 32, 33]. Given the challenge in predicting at-risk patients, it is prudent for all patients to receive blood pressure monitoring during the early postpartum period when most cases of postpartum hypertension occur. Innovative healthcare delivery models for remote blood pressure

monitoring, which will be discussed more extensively later in this review, provide a cost-effective solution for widespread surveillance to optimize diagnosis and timely management of postpartum hypertension [34].

Among patients with antenatal HDP, who have a known risk of worsening hypertension in the postpartum period, effective therapies for risk reduction have been an area of ongoing research. Several studies have found that administration of diuretics postpartum can reduce the prevalence of postpartum hypertension among patients with antenatal HDP [35, 36•, 37]. In particular, among patients with antenatal HDP who received a 5-day course of 20 mg furosemide daily, there was a 60% reduction in the prevalence of persistently elevated blood pressure at 7 days, though no difference in postpartum readmissions or need for antihypertensive medications compared to patients who received placebo [36•]. Data from this same trial demonstrates that there were significant differences in blood pressure trajectories among patients who received furosemide compared to placebo; peak blood pressures were noted 3 to 4 days postpartum among patients with severe HDP and 6 to 8 days postpartum among patients with HDP without severe features. We administer 20 mg of oral furosemide nearly universally among patients with HDP, unless there are absolute or relative contraindications which include, but are not limited to allergy to furosemide, specific cardiac lesions, creatinine > 1.2, advanced diabetes (White class C or higher), hypokalemia (K < 3 mEq/L), or preexisting diuretic use. This 5-day postpartum course is usually initiated on the day after delivery.

Acute onset hypertension during pregnancy and postpartum significantly increases the risk of severe maternal morbidity [2•]. In 2019, ACOG published guidelines for the emergent treatment of acute onset, severe hypertension, based on the safety bundle established by the National Partnership on Maternal Safety through the Alliance for Innovation on Maternal Health [38•, 39••]. Both intravenous hydralazine and labetalol are reasonable choices for treatment of severe hypertension in both the antepartum and postpartum period; randomized controlled trials have demonstrated similar efficacy for both agents in terms of resolution of hypertension [40]. When intravenous access is not available or is unlikely to be available in a timely fashion, immediate release oral nifedipine is an effective choice [41, 42]. Ensuring timely treatment, particularly in the postpartum period where patients remain at high risk of cerebrovascular complications though they are no longer pregnant, has been a focus of significant efforts by perinatal quality collaboratives in the USA in the past decade [43]. In 2021, the Society of Maternal Fetal Medicine proposed a hospital-level quality improvement metric for time to treatment of acute onset severe maternal hypertension with target treatment time of less than 60 min [44]. This metric applies to severe hypertension that presents both before and after delivery.

Recommendations regarding initiation of oral medications for management of elevated, but not severe range blood pressures, are more varied. Generally, the goal for blood pressure management with oral medications is to reduce or eliminate the incidence of severe range blood pressures requiring rapid, intravenous treatment, thus reducing risk of severe maternal morbidity and preventable postpartum readmission for blood pressure management and medication titration. ACOG's Taskforce on Hypertension in Pregnancy recommends initiation of oral medications with systolic blood pressures greater than or equal to 150 mm Hg or diastolic blood pressures greater than or equal to 100 mm Hg. This lower target for the postpartum period is recommended, as there are no fetal concerns of growth with aggressive hypertension treatment after delivery. The choice of oral agent can also be challenging in the postpartum period (Table 1). Typically, obstetricians are comfortable with calcium channel blockers such as nifedipine or amlodipine or beta blockers such as labetalol, which are commonly used in pregnancy. These drugs vary widely in the dosing frequency, where the calcium channel blockers are typically administered once daily and the beta blockers

Table 1 Summary of oral medications used for postpartum blood pressure management

Medication	Mechanism of action	Advantages	Disadvantages
Labetalol	Dual alpha (α1) and beta (β1/β2) blocker	• Safe for lactation, low levels in breast milk	• Frequent dosing
Nifedipine or amlodipine	Calcium channel blocker	• Safe for lactation, low levels in breast milk	• Once daily dosing
Enalapril	Angiotensin converting enzyme (ACE) inhibitor	• First line medication in non-pregnant adults • Safe for lactation, low levels in breast milk	• Can only be initiated postpartum
Hydrochlorothiazide	Thiazide diuretic	• Acceptable for lactation at doses 50 mg or less	• Can only be initiated postpartum • Higher doses may decrease breast milk production

may be administered up to three times per day. Studies have shown that both beta blockers and calcium channel blockers can effectively control blood pressures postpartum [45]. However, first-line medications outside of pregnancy typically include angiotensin converting enzyme inhibitors and angiotensin receptor blockers, for which there are generally limited data for breastfeeding mothers. Of these drugs, the secretion of enalapril may be selectively restricted in breast milk and is not thought to be harmful [46]. Thiazide diuretics are also widely used outside of pregnancy. They do not seem to have adverse neonatal effects but may suppress lactation when used at high doses [47].
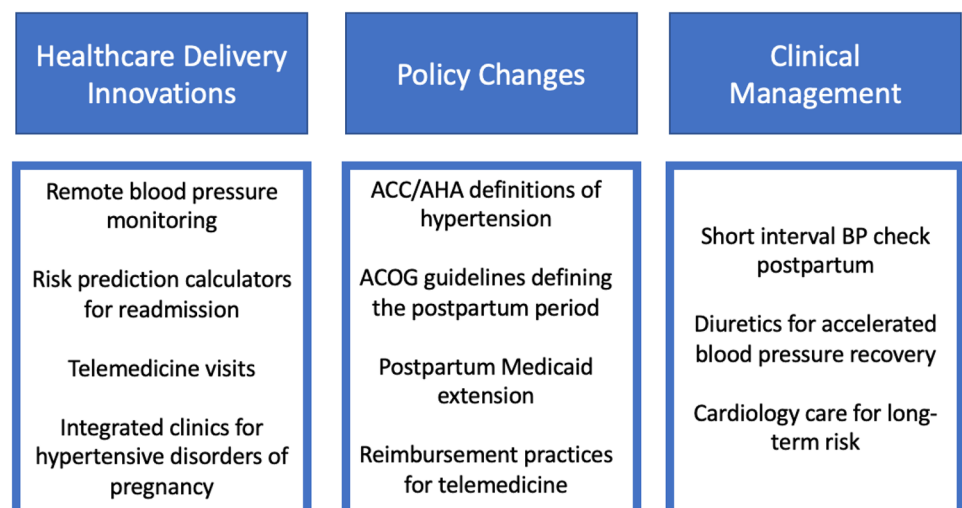
Intravenous magnesium is recommended for seizure prophylaxis among patients with antenatal HDP with severe features, but there are limited guidelines dictating administration during the postpartum period in patients with persistent or worsening hypertension or de novo HDP, both in terms of indications and duration of treatment. Specifically, the seizure risk, in patients with de novo postpartum HDP, is unclear. Does a patient with new onset severe blood pressure 7 days from delivery carry the same seizure risk warranting magnesium that a patient with antenatal HDP with severe features does? The answer to this question is unknown thereby leading to significant management variation in patient with presenting with either de novo postpartum hypertension or representing with persistent or worsening severe postpartum hypertension. There is limited data examining the impact of magnesium administration on the incidence of eclampsia among patients with postpartum hypertension [48]. In a meta-analysis of seven randomized controlled trials including 1124 participants and two eclampsia events, a shortened duration of magnesium postpartum was as effective for seizure prophylaxis as the traditional 24-h administration [49]. There is scant data to guide magnesium administration for patients with antenatal disease that demonstrate worsening postpartum hypertension,

though the utility is likely limited. Postpartum hypertension in these patients is a worsening of antecedent disease and thus the risk of eclampsia in the postpartum period is likely reduced from the time of their initial diagnosis and peri-delivery, thereby not warranting magnesium prophylaxis. This is in clear contrast to patients with de novo postpartum hypertension, as noted above, whose seizure risk at time of new postpartum presentation is unknown. At our institution, we typically initiate magnesium for 12 h for patients with de novo postpartum hypertension with severe features, extending to 24 h if there are other concerning features such as laboratory derangements or persistent neurologic symptoms, as there is data associating prodromal neurologic symptoms with eclampsia [50]. Magnesium dosing should be adjusted based on renal function as the medication is renally cleared; strategies for adjustment include but are not limited to utilizing intermittent serial boluses or decreasing the infusion rate as well as serial magnesium levels.

Paradigm Shifts in Management of Postpartum Hypertension

Recently, the clinical management and research surrounding HDP has shifted drastically in response to several key factors (Fig. 1). The advent of the COVID-19 pandemic has accelerated changes in blood pressure monitoring and outpatient management of HDP [51••]. Novel research techniques such as machine learning also demonstrate promise in helping clinicians to better understand patients' risks related to HDP in the postpartum period [52••]. The prioritization of work aiming to reduce disparities in maternal morbidity and mortality in the USA has shifted policy and clinical paradigms governing the postpartum period along with an increased focus on improving interpregnancy health by augmenting bridges to primary care following pregnancy.

Fig. 1 Recent developments in management of postpartum hypertension

Healthcare Delivery Innovations	Policy Changes	Clinical Management
Remote blood pressure monitoring Risk prediction calculators for readmission Telemedicine visits Integrated clinics for hypertensive disorders of pregnancy	ACC/AHA definitions of hypertension ACOG guidelines defining the postpartum period Postpartum Medicaid extension Reimbursement practices for telemedicine	Short interval BP check postpartum Diuretics for accelerated blood pressure recovery Cardiology care for long-term risk

The COVID-19 pandemic augmented ongoing efforts to integrate telemedicine into prenatal and postpartum care [53, 54]. For HDP in particular, the practice of remote blood pressure monitoring either via home blood pressure monitoring – where patients check blood pressures at prescribed intervals themselves and keep a log- or ambulatory blood pressure monitoring – where a machine automatically obtains blood pressures, usually at much shorter intervals, for a 24–48 h period – has been proven to be safe, efficacious, and cost-effective even before the pandemic [55•, 56]. As previously discussed, it can be challenging to identify or predict patients who may develop postpartum hypertension. In the postpartum period, remote blood pressure monitoring holds significant promise for improving rapid diagnosis and effective, low-cost intervention (Table 2). Use of remote blood pressure monitoring increases engagement with postpartum care and reduces racial disparities in postpartum blood pressure ascertainment [57, 58••, 59]. Essential aspects of ensuring an efficacious intervention include (1) utilization of a validated blood pressure cuff, and (2) patient education prior to discharge regarding critical parameters for communication or intervention. At our institution, all patients with antenatal HDP are enrolled in a remote blood pressure monitoring program, where patients submit blood pressures via text messaging for review by providers during the postpartum period [58••]. We have also recently started enrolling low

risk patients without antenatal HDP in a separate remote blood pressure monitoring program, with less frequent requests for blood pressure measurements. In addition, postpartum follow-up visits for HDP are predominantly performed via telehealth to maximize access to care. Finally, data on the incidence of postpartum hypertension and trajectories of blood pressures postpartum have historically been limited by loss to follow-up in the postpartum period [60]. Remote blood pressure monitoring serves as a rich new source of data on blood pressure trajectories postpartum, which may facilitate more nuanced research on the true incidence, phenotypes, and management of postpartum hypertension [24, 32].

Novel research utilizing machine learning has led to the development of risk prediction models for women with HDP that may help individualize care in the postpartum period. Risk factors for postpartum readmission for HDP have previously been identified using a variety of retrospective study designs; these include antecedent HDP, advanced maternal age, multiparity, elevated body mass index, and longer length of labor [17–19, 61]. More recently, researchers have produced risk prediction models using machine learning that identify readmissions for complications of HDP with reasonable accuracy [52••]. These prediction models have reinforced existing knowledge regarding risk factors for HDP and also identified new predictive factors. Specifically, systolic blood pressure trend, mean diastolic blood pressure

Table 2 Summary of recent studies examining remote blood pressure monitoring programs for hypertensive disorders of pregnancy

Article	Findings
Hirshberg et al. [58••]	• 92.2% of patients reported a blood pressure postpartum when using a text-based program compared to 43.7% using office-based care • 84% of patients enrolled in the text-based program met ACOG recommendations for reporting blood pressures at specific postpartum timepoints • There was a statistically significant increase in postpartum readmissions for patients utilizing office-based care
Hauspurg [24]	• 83% continued the program beyond 3 weeks postpartum and 74% continued the program beyond 4 weeks postpartum 88% of patients enrolled in the program attended a 6-week postpartum visit, compared with 66% attendance among women with a hypertensive disorder of pregnancy in the year before implementation • 94% of patients were satisfied with their experience in the remote monitoring program • 93% would recommend the program to others • 96% reported they were comfortable using new technology • 88% did not worry about their privacy • 82% expressed feeling more comfortable knowing a nurse was checking their health daily
Hoppe et al. [59]	• Patients enrolled in a telehealth model with remote blood pressure monitoring had significantly fewer postpartum readmissions than patients enrolled in office-based care • More patients in the telehealth model reported at least one blood pressure in the first 10 days postpartum
Quinn and McLaughlin [57]	• 90% of patients returned for their postpartum visit • More than 30% of enrolled patients received outpatient management of medications, resulting in decreased readmissions • Coordination of care beyond the episode of pregnancy to primary care providers doubled for enrolled patients
Niu et al. [34]	• Telehealth monitoring significantly reduced postpartum readmissions, 3.7% (8/214) versus 0.5% (1/214), and resulted in higher quality-adjusted life years • Average cost of telehealth per patient was $309 and was cost-effective up to a cost of $420 per patient Telehealth monitoring remained cost-effective down to a readmission cost of $10,999 (compared to baseline estimate of $14,401)

after delivery, and having antenatal HDP are all predictive of postpartum readmission.

Increased attention to maternal morbidity and pregnancy-related mortality, in which more than half of maternal deaths occur past 42 days postpartum, has led to increased public health campaigns around postpartum health issues and the reconceptualization of the postpartum period by professional organizations and policymakers. These significant changes to the postpartum care paradigm will expand care for patients with postpartum hypertension. Healthcare organizations such as the Preeclampsia Foundation have run national public health campaigns ("Still at Risk") emphasizing the warning signs and risk factors for postpartum hypertension, recognizing the importance of patient education and advocacy in reducing maternal morbidity. In 2018, ACOG published a committee opinion formally redefining the postpartum period from an arbitrary 6 weeks to an ongoing, individualized process over the fourth trimester [62•]. Attention has also been paid to improving the quality of postpartum care via health system interventions such as the use of patient navigators [63•]. Supplementing the changing definition of postpartum care, ACOG and SMFM have dedicated sustained political support to efforts to extend Medicaid coverage to 12 months postpartum; an increasing number of states, including some Southern states that did not support Medicaid expansion through the Patient Protection and Affordable Care Act, have passed legislation or applied for Centers for Medicare and Medicaid Services waivers for postpartum Medicaid extension [64, 65]. This extended coverage will significantly improve ongoing care beyond the early postpartum period to ensure prioritization on improving long-term health.

Growing understanding of the long-term implications of HDP and other medical complications of pregnancy have led to an increasing focus on building transitions from postpartum care to primary care, which will be essential for the long-term wellbeing of women with postpartum hypertension [66•, 67]. For HDP specifically, researchers have identified risk factors for loss to follow-up postpartum [33] and for persistent hypertension, as previously described. Implementation of transition clinics, where patients with HDP are followed for a longer period of time with services tailored to their specific clinical problem, may significantly improve patients' acquisition of resources such as home blood pressure monitors [68•]. Generally, populations in these clinics demonstrated high completion of preventive measures such as nutritionist referrals and primary care follow-up appointments, though their rate of triage visits and postpartum readmissions may be higher due to increased engagement with care [68•, 69]. These data highlight the importance of utilizing caution when choosing quality metrics for postpartum care; while postpartum readmissions are a frequently reported metric

in health services research, readmissions for HDP are not necessarily all preventable and therefore are not always an indicator of poor quality of care. In fact, heightened surveillance, leading to a necessary readmission, may reflect improved quality of care. Though the long-term cardiovascular disease (CVD) risks associated with HDP are now well known, research has identified significant gaps in postpartum cardiology care for these women [70]. At our institution, we refer all patients with severe preeclampsia in pregnancy who were delivered preterm or were started on an antihypertensive agent to cardiology for follow-up to facilitate more detailed counseling and additional workup given the significantly elevated long-term cardiovascular risk in these patients. While a cardiology referral may not be feasible at all institutions, a referral to primary care with deliberate CVD surveillance and prevention strategies for women with HDP, particularly those with severe disease, should be considered. Use of telemedicine may improve postpartum visit attendance rates, transition to primary care, cardiology follow-up rates as well.

Conclusions

Postpartum hypertension, which affects approximately 2% of pregnancies, typically refers to hypertension occurring after delivery through 6 weeks postpartum, which includes patients with worsening hypertension after antenatal diagnosis of HDP and patients with de novo postpartum hypertension after a normotensive pregnancy and intrapartum course. As of now, changing definitions of hypertension outside of pregnancy has not impacted definitions of hypertensive disorders of pregnancy (HDP). The clinical management of postpartum hypertension remains focused on accelerated diuresis, blood pressure control, and seizure prophylaxis when appropriate. In recent years, systemic innovations have improved access to postpartum blood pressure monitoring through implementation of new care delivery models and new research utilizing machine learning has led to the development of new risk prediction models for postpartum hypertension. The long-term risks of cardiovascular disease related to HDP are now well understood, and legislation expanding insurance coverage has allowed for an increasing focus on postpartum transitions to primary care. Overall, these recent developments in healthcare delivery models, policy reform, and novel therapeutics have significantly improved care for hypertensive disorders of pregnancy in the postpartum period. Continued efforts in this area hold the potential to significantly reduce maternal morbidity and mortality in the USA.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

1.• Hitti J, Sienas L, Walker S, Benedetti TJ, Easterling T. Contribution of hypertension to severe maternal morbidity. Am J Obstet Gynecol. 2018;219(4):405. **This is a retrospective cohort examining rates of SMM among participants with HDP (n=7025, single tertiary care center in Pacific Northwest, 2013–2017).**

2.• Kilpatrick SJ, Abreo A, Greene N, Melsop K, Peterson N, Shields LE, et al. Severe maternal morbidity in a large cohort of women with acute severe intrapartum hypertension. Am J Obstet Gynecol. 2016;215(1):91. **This is a retrospective cohort examining rates of SMM among participants with and without HDP (n=>95,000, California state, 2012–2014).**

3.• Mogos MF, Salemi JL, Spooner KK, McFarlin BL, Salihu HH. Hypertensive disorders of pregnancy and postpartum readmission in the United States: national surveillance of the revolving door. J Hypertens. 2018;36(3):608–18. **This is a registry-based study examining the cost associated with postpartum readmissions due to HDP in 2013–2014 from the Nationwide Readmissions Database, which includes approximately half of the US population.**

4.• Clapp MA, Little SE, Zheng J, Robinson JN. A multi-state analysis of postpartum readmissions in the United States. Am J Obstet Gynecol. 2016;215(1):113. **This is a registry-based study examining the postpartum readmission rate, indication and timing for nearly 6 million deliveries in California, Florida and New York between 2004 and 2011.**

5.• Hirshberg A, Levine L, Srinivas S. Clinical factors associated with readmission for postpartum hypertension in women with pregnancy-related hypertension: a nested case control study. J Perinatol. 2016;36(5):405–9. **This is a nested case control study of 99 participants between 2005 and 2009, examining factors associated with postpartum readmission for HDP.**

6.• Wen T, Wright JD, Goffman D, D'Alton ME, Attenello FJ, Mack WJ, et al. Hypertensive postpartum admissions among women without a history of hypertension or preeclampsia. Obstet Gynecol. 2019;133(4):712–9. **This is a registry-based study examining postpartum readmission rates for HDP among participants who did not have an HDP diagnosis during their delivery hospitalization.**

7.•• Lane-Cordova AD, Khan SS, Grobman WA, Greenland P, Shah SJ. Long-term cardiovascular risks associated with adverse pregnancy outcomes: JACC review topic of the week. J Am Coll Cardiol. 2019;73(16):2106–16. **This is a review article summarizing the associations between adverse pregnancy outcomes such as preeclampsia and long-term risk for CVD and theorized mechanisms for these relationships.**

8.• Karumanchi SA. Angiogenic factors in preeclampsia: from diagnosis to therapy. Hypertension. 2016;67(6):1072–9. **This is a review article summarizing angiogenic factors associated with preeclampsia.**

9.• Verlohren S, Dröge L-A. The diagnostic value of angiogenic/anti-angiogenic factors in differential diagnosis of preeclampsia. Am J Obstet Gynecol. 2020;226(2):S1048–58. **This is a review article summarizing diagnostic value of angiogenic factors as biomarkers for preeclampsia.**

10.•• Leon LJ, McCarthy FP, Direk K, Gonzalez-Izquierdo A, Prieto-Merino D, Casas JP, et al. Preeclampsia and cardiovascular disease in a large UK pregnancy cohort of linked electronic health records: a CALIBER study. Circulation. 2019;140(13):1050–60. **This is a large cohort study establishing the association between preeclampsia and long-term CVD risk (n=1.3 million, UK population).**

11.• Wilkins-Haug L, Celi A, Thomas A, Frolkis J, Seely EW. Recognition by women's health care providers of long-term cardiovascular disease risk after preeclampsia. Obstet Gynecol. 2015;125(6):1287–92. **This is a survey-based study assessing health care providers' knowledge regarding pregnancy outcome as a risk factor for CVD.**

12.• Seely EW, Tsigas E, Rich-Edwards JW. Preeclampsia and future cardiovascular disease in women: how good are the data and how can we manage our patients? Semin Perinatol. 2015;39(4):276–83. **This is a review summarizing patient, provider and systems level barriers and solutions to promoting CVD prevention among participants with history of HDP.**

13.• Veerbeek JH, Hermes W, Breimer AY, Van Rijn BB, Koenen SV, Mol BW, et al. Cardiovascular disease risk factors after early-onset preeclampsia, late-onset preeclampsia, and pregnancy-induced hypertension. Hypertension. 2015;65(3):600–6. **This prospective cohort examined whether patients with HDP had common, modifiable CVD risk factors postpartum. Their findings indicate that CVD prevention strategies could be stratified according to HDP severity and gestational age of onset.**

14.• Sharma KJ, Kilpatrick SJ. Postpartum hypertension: etiology, diagnosis, and management. Obstet Gynecol Surv. 2017;72(4):248–52. **This review also discusses the etiology and diagnosis of postpartum hypertension.**

15.•• Sibai BM. Etiology and management of postpartum hypertension-preeclampsia. Am J Obstet Gynecol. 2012;206(6):470–5. **This review is one of the sentinel articles summarizing the etiology and management of postpartum hypertension.**

16.• Al-Safi Z, Imudia AN, Filetti LC, Hobson DT, Bahado-Singh RO, Awonuga AO. Delayed postpartum preeclampsia and eclampsia: demographics, clinical course, and complications. Obstet Gynecol. 2011;118(5):1102–7. **This article reviews phenotypes of postpartum hypertension.**

17.• Glover AV, Tita A, Biggio JR, Anderson SB, Harper LM. Incidence and risk factors for postpartum severe hypertension in women with underlying chronic hypertension. Am J Perinatol. 2019;36(7):737–41. **This is a retrospective cohort of 235 women with chronic hypertension, of whom 30 (12.8%) developed postpartum hypertension. Median time to diagnosis of postpartum hypertension was 10 days. Risk factors included number of antihypertensive medications and SBP>135 at discharge.**

18.• Smithson SD, Greene NH, Esakoff TF. Risk factors for re-presentation for postpartum hypertension in patients without a history of hypertension or preeclampsia. Am J Obstet Gynecol MFM. 2021;3(2):100297. **This retrospective cohort of 99 patients without history of hypertension in pregnancy who re-presented to the hospital (but may not necessarily have been readmitted) for hypertension postpartum found that**

age of > 40 years, black race, body mass index of > 30, and antenatal prescription of low-dose aspirin were all associated with risk for re-presentation to the hospital.

19.• Chornock R, Iqbal SN, Kawakita T. Racial disparity in postpartum readmission due to hypertension among women with pregnancy-associated hypertension. Am J Perinatol. 2021;38(12):1297–302. This retrospective cohort study of 4,317 women with pregnancy-associated hypertension before initial discharge and 66 (1.5%) who postpartum readmission due to hypertension found that older maternal age and non-Hispanic black race were associated with increased risk of readmission.

20.• Goel A, Maski MR, Bajracharya S, Wenger JB, Zhang D, Salahuddin S, et al. Epidemiology and mechanisms of de novo and persistent hypertension in the postpartum period. Circulation. 2015;132(18):1726–33. This prospective cohort assess levels of angiogenic factors among participants who ultimately developed postpartum hypertension, showing that participants with postpartum hypertension have similar biomarker profiles to participants with antenatal HDP.

21.• Berks D, Steegers EA, Molas M, Visser W. Resolution of hypertension and proteinuria after preeclampsia. Obstet Gynecol. 2009;114(6):1307–14. This prospective cohort examines the time required for hypertension to resolve after incidence of HDP.

22.• Suzuki H, Watanabe Y, Arima H, Kobayashi K, Ohno Y, Kanno Y. Short-and long-term prognosis of blood pressure and kidney disease in women with a past history of preeclampsia. Clin Exp Nephrol. 2008;12(2):102–9. This review summarizes three separate studies, the first of which examined blood pressure trajectories after HDP.

23.• Ditisheim A, Wuerzner G, Ponte B, Vial Y, Irion O, Burnier M, et al. Prevalence of hypertensive phenotypes after preeclampsia: a prospective cohort study. Hypertension. 2018;71(1):103–9. This prospective cohort examined postpartum hypertension phenotypes among patients with antenatal HDP, finding high rates of masked hypertension on ambulatory blood pressure monitoring (which otherwise would be missed in routine clinical evaluations).

24.• Hauspurg A, Lemon L, Cabrera C, Javaid A, Binstock A, Quinn B, et al. Racial differences in postpartum blood pressure trajectories among women after a hypertensive disorder of pregnancy. JAMA Netw Open. 2020;3(12):e2030815. This prospective cohort examined postpartum blood pressure trajectories after HDP.

25.•• Obstetricians ACo, Gynecologists. Hypertension in pregnancy. Report of the American College of Obstetricians and Gynecologists' task force on hypertension in pregnancy. Obstet Gynecol. 2013;122(5):1122–31. This is one of the sentinel practice documents governing hypertension in pregnancy.

26.•• Obstetricians ACo, Gynecologists. ACOG practice bulletin no. 202: gestational hypertension and preeclampsia. Obstet Gynecol. 2019;133(1):e1–25. This is one of the sentinel practice documents governing hypertension in pregnancy.

27.•• Levine G, Bates E, Bittl J, Brindis R, Fihn S, Fleisher L. A report of the American college of cardiology/American heart association task force on clinical practice guidelines. An update of the 2011 ACCF/AHA/SCAI guideline for percutaneous coronary intervention, 2011 ACCF/AHA guideline for coronary artery bypass graft surgery, 2012 ACC/AHA/ACP/AATS/PCNA/SCAI/STS guideline for the diagnosis and management of patients with stable ischemic heart disease, 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction, 2014 AHA/ACC guideline for the management of patients with non-ST-elevation acute coronary syndromes, and 2014 ACC/AHA guideline on perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery. Circulation. 2016;134:e123–55. This is one of the sentinel practice documents governing hypertension outside of pregnancy.

28.•• Obstetricians ACo, Gynecologists. ACOG Practice Bulletin No. 203: chronic hypertension in pregnancy. Obstet Gynecol. 2019;133(1):e26–50. This is one of the sentinel practice documents governing hypertension in pregnancy.

29.• Reddy M, Rolnik DL, Harris K, Li W, Mol BW, Costa FDS, et al. Challenging the definition of hypertension in pregnancy: a retrospective cohort study. Am J Obstet Gynecol. 2020;222(6):606. This large retrospective cohort of more than 18,000 patients found that patients who met criteria for class I hypertension were at increased risk of preeclampsia, preterm birth and other adverse perinatal outcomes compared to patients with normal blood pressures and at decreased risk of preeclampsia relative to patients with class 2 hypertension (i.e. ACOG's definition of hypertension).

30.• Norton E, Shofer F, Schwartz H, Dugoff L. Adverse perinatal outcomes associated with stage 1 hypertension in pregnancy: a retrospective cohort study. Am J Perinatol. 2021. This article characterizes adverse perinatal outcomes associated with class 1 hypertension.

31.• Smith GN, Pudwell J, Saade GR. Impact of the new American hypertension guidelines on the prevalence of postpartum hypertension. Am J Perinatol. 2019;36(4):440–2. This retrospective cohort demonstrated that up to 56–67% of patients with HDP would be classified as having postpartum hypertension at 6–12 months postpartum if ACC/AHA guidelines were used compared to only 21–31% with ACOG guidelines.

32.• Perdigao JL, Hirshberg A, Koelper N, Srinivas SK, Sammel MD, Levine LD. Postpartum blood pressure trends are impacted by race and BMI. Pregnancy Hypertens. 2020;20:14–8. This article utilizes data from a home blood pressure monitoring program to assess risk factors for postpartum hypertension.

33.• Levine LD, Nkonde-Price C, Limaye M, Srinivas SK. Factors associated with postpartum follow-up and persistent hypertension among women with severe preeclampsia. J Perinatol. 2016;36(12):1079–82. This was a secondary analysis of a retrospective cohort of 193 patients with severe preeclampsia assessing factors associated with persistent hypertension and postpartum visit attendance.

34.• Niu B, Mukhtarova N, Alagoz O, Hoppe K. Cost-effectiveness of telehealth with remote patient monitoring for postpartum hypertension. J Matern-Fetal Neonatal Med. 2021. This is a cost-effectiveness analysis of a home blood pressure monitoring program in the postpartum period.

35.• Viteri OA, Alrais MA, Pedroza C, Hutchinson M, Chauhan SP, Blackwell SC, et al. Torsemide for prevention of persistent postpartum hypertension in women with preeclampsia: a randomized controlled Trial. Obstet Gynecol. 2018;132(5):1185–91. This was a randomized controlled trial of 118 participants examining the efficacy of oral torsemide in postpartum blood pressure control for participants with HDP (August 2016-September 2017).

36.• Lopes Perdigao J, Lewey J, Hirshberg A, Koelper N, Srinivas SK, Elovitz MA, et al. Furosemide for accelerated recovery of blood pressure postpartum in women with a hypertensive disorder of pregnancy: a randomized controlled trial. Hypertension. 2021;77(5):1517–24. This was a randomized controlled trial of 384 participants examining the efficacy of oral furosemide in postpartum blood pressure control for participants with HDP (June 2018-October 2019).

37.• Veena P, Perivela L, Raghavan SS. Furosemide in postpartum management of severe preeclampsia: a randomized controlled trial. Hypertens Pregnancy. 2017;36(1):84–9. This was a randomized controlled trial of 108 participants examining the

efficacy of oral furosemide in postpartum blood pressure control for participants with HDP (September 2011-August 2013).

38.• ACOG Committee Opinion No. 767. Emergent therapy for acute-onset, severe hypertension during pregnancy and the postpartum period. Obstet Gynecol. 2019;133(2):e174–80. **This is one of the sentinel practice guidelines dictating management of severe hypertension in pregnancy and postpartum.**

39.•• Bernstein PS, Martin JN, Jr., Barton JR, Shields LE, Druzin ML, Scavone BM, et al. National partnership for maternal safety: consensus bundle on severe hypertension during pregnancy and the postpartum period. Obstet Gynecol. 2017;130(2). **This is one of the sentinel documents dictating practices that ensure quality and safety in management of severe maternal hypertension.**

40.• Vigil-De Gracia P, Ruiz E, López JC, de Jaramillo IA, Vega-Maleck JC, Pinzón J. Management of severe hypertension in the postpartum period with intravenous hydralazine or labetalol: a randomized clinical trial. Hypertens Pregnancy. 2007;26(2):163–71. **This is a randomized controlled trial of 82 participants with severe postpartum hypertension comparing the efficacy of IV hydralazine or IV labetalol for treatment.**

41.• Brown MA, Buddle ML, Farrell T, Davis GK. Efficacy and safety of nifedipine tablets for the acute treatment of severe hypertension in pregnancy. Am J Obstet Gynecol. 2002;187(4):1046–50. **This study examines the efficacy and safety of immediate release nifedipine in pregnancy.**

42.• Easterling T, Mundle S, Bracken H, Parvekar S, Mool S, Magee LA, et al. Oral antihypertensive regimens (nifedipine retard, labetalol, and methyldopa) for management of severe hypertension in pregnancy: an open-label, randomised controlled trial. Lancet. 2019;394(10203):1011–21. **This study compares the efficacy of various oral antihypertensive regimens in pregnancy.**

43.• Schneider P, King PAL, Keenan-Devlin L, Borders AE. Improving the timely delivery of antihypertensive medication for severe perinatal hypertension in pregnancy and postpartum. Am J Perinatol. 2021. **This is a retrospective cohort examined changes in rate of timely treatment of severe maternal hypertension after implementation of a hospital based quality improvement initiative.**

44.• Combs CA, Allbert JR, Hameed AB, Main E, Taylor I, Allen C, et al. Society for maternal-fetal medicine special statement: a quality metric for evaluating timely treatment of severe hypertension. Am J Obstet Gynecol. 2021. **This is a statement from the Society of Maternal Fetal Medicine's Patient Safety and Quality Committee discussing the utility of time to treatment of severe maternal hypertension as a hospital or system quality metric.**

45.• Sharma KJ, Greene N, Kilpatrick SJ. Oral labetalol compared to oral nifedipine for postpartum hypertension: a randomized controlled trial. Hypertens Pregnancy. 2017;36(1):44–7. **This is a randomized controlled trial of 50 participants comparing the efficacy of oral labetalol vs nifedipine in controlling blood pressures postpartum.**

46.• Tosounidou S, Gordon C. Medications in pregnancy and breast-feeding. Best Pract Res Clin Obstet Gynaecol. 2020;64:68–76. **This review cites the safety data on enalapril during breastfeeding.**

47.• Anderson PO. Treating hypertension during breastfeeding. Breastfeed Med. 2018;13(2):95–6. **This is a review article summarizing the known data for antihypertensive medications and lactation.**

48.• Vigil-De Gracia P, Ludmir J. The use of magnesium sulfate for women with severe preeclampsia or eclampsia diagnosed during the postpartum period. J Matern Fetal Neonatal Med.

2015;28(18):2207–9. **This is a systematic review of magnesium use in the postpartum period, for which only sub-groups of two randomized controlled trials met inclusion criteria.**

49.• Yifu P, Lei Y, Yujin G, Xingwang Z, Shaoming L. Shortened postpartum magnesium sulfate treatment vs traditional 24h for severe preeclampsia: a systematic review and meta-analysis of randomized trials. Hypertens Pregnancy. 2020;39(2):186–95. **This was a systemic review and meta-analysis including 7 RCTs examining the appropriate duration of postpartum magnesium sulfate treatment for seizure prophylaxis in the setting of HDP.**

50.• Cooray SD, Edmonds SM, Tong S, Samarasekera SP, Whitehead CL. Characterization of symptoms immediately preceding eclampsia. Obstet Gynecol. 2011;118(5):995–9. **This is a prospective observational study of 3,267 patients in Tanzania, examining patients' symptoms preceding eclamptic seizures. Neurologic symptoms with or without visual disturbance were the most common prodromal symptom, regardless of degree of hypertension.**

51.•• Koonin LM, Hoots B, Tsang CA, Leroy Z, Farris K, Jolly B, et al. Trends in the use of telehealth during the emergence of the COVID-19 pandemic–United States, January–March 2020. Morb Mortal Wkly Rep. 2020;69(43):1595. **This CDC MMWR reported a 154% increase in use of telehealth between the last week in March in 2020 compared with the same time period one year prior and proposes that this change may be due to pandemic-related changes in telehealth policies and public health guidance.**

52.•• Hoffman MK, Ma N, Roberts A. A machine learning algorithm for predicting maternal readmission for hypertensive disorders of pregnancy. Am J Obstet Gynecol MFM. 2021;3(1):100250. **This study documents the machine learning process based on a prospective cohort of more than 20,000 patients that was used to develop a risk prediction model for postpartum readmission for HDP.**

53.• Anthony Jnr B. Implications of telehealth and digital care solutions during COVID-19 pandemic: a qualitative literature review. Inform Health Soc Care. 2021;46(1):68–83. **This systematic review assessed the types of telehealth being employed ruing the pandemic, the various applications of telehealth in the pandemic, policies supporting telehealth globally during the COVID pandemic, and determinants of adoption of telehealth solutions during the pandemic.**

54.• Krenitsky NM, Spiegelman J, Sutton D, Syeda S, Moroz L. Primed for a pandemic: implementation of telehealth outpatient monitoring for women with mild COVID-19. Semin Perinatol. 2020;44(7):151285. **This narrative piece described the experience creating a telehealth clinic for pregnant patients with COVID at a single institution.**

55.• Bello NA, Woolley JJ, Cleary KL, Falzon L, Alpert BS, Oparil S, et al. Accuracy of blood pressure measurement devices in pregnancy: a systematic review of validation studies. Hypertension. 2018;71(2):326–35. **This is a systematic review examining the accuracy of blood pressure measurement devices in pregnancy.**

56.• Tremonti C, Beddoe J, Brown MA. Reliability of home blood pressure monitoring devices in pregnancy. Pregnancy Hypertens. 2017;8:9–14. **This paper assesses the reliability of home blood pressure monitors.**

57.• Quinn B, McLaughlin M. Engaging postpartum women through implementation of a remote monitoring protocol for hypertensive disorders of pregnancy. J Obstet Gynecol Neonatal Nurs. 2020;49(6):S1. **This was a program evaluation of a quality improvement initiative where patients with HDP were enrolled in remote blood pressure monitoring postpartum.**

58.•• Hirshberg A, Downes K, Srinivas S. Comparing standard office-based follow-up with text-based remote monitoring in the management of postpartum hypertension: a randomised clinical trial. BMJ Qual Saf. 2018;27(11):871. **This randomized controlled trial of 206 participants with HDP during delivery admission examined the efficacy of remote blood pressure monitoring postpartum.**

59.• Hoppe KK, Thomas N, Zernick M, Zella JB, Havighurst T, Kim K, et al. Telehealth with remote blood pressure monitoring compared with standard care for postpartum hypertension. Am J Obstet Gynecol. 2020;223(4):585–8. **This nonrandomized controlled trial examined hospital readmission rates for patients assigned to telehealth and remote blood pressure monitoring compared to standard outpatient care, where telehealth was associated with decreased postpartum readmissions.**

60.• Walters BN, Walters T. Hypertension in the puerperium. Lancet. 1987;2(8554):330. **This is one of the earliest studies of patients examining blood pressure trajectories postpartum.**

61.• Stamilio DM, Beckham AJ, Boggess KA, Jelovsek JE, Venkatesh KK. Risk factors for postpartum readmission for preeclampsia or hypertension before delivery discharge among low-risk women: a case-control study. Am J Obstet Gynecol MFM. 2021;3(3):100317. **This case control study of 135 participants identified risk factors associated with postpartum readmission for HDP.**

62.• McKinney J, Keyser L, Clinton S, Pagliano C. ACOG Committee Opinion No. 736. Optimizing Postpartum Care. Obstet Gynecol. 2018;132(3). **This is a sentinel practice guideline dictating the postpartum care paradigm.**

63.• Yee LM, Martinez NG, Nguyen AT, Hajjar N, Chen MJ, Simon MA. Using a patient navigator to improve postpartum care in an urban women's health clinic. Obstet Gynecol. 2017;129(5):925. **This is a prospective observational study examining the impact of a postpartum care navigation program on achievement of postpartum milestones such as postpartum visit attendance, postpartum depression screening, and contraception planning.**

64.• Kumar NR, Borders A, Simon MA. Postpartum Medicaid extension to address racial inequity in maternal mortality. Am J Public Health. 2021;111(2):202–4. **This is a commentary discussing the potential impact of postpartum Medicaid extension on racial disparities in maternal morbidity and mortality.**

65.• Stuebe A, Moore JE, Mittal P, Reddy L, Low LK, Brown H. Extending Medicaid coverage for postpartum moms. Health Aff Blog. 2019. **This is a commentary discussing the importance of Medicaid extension postpartum.**

66.• McCloskey L, Bernstein J, The Bridging the Chasm C, Amutah-Onukagha N, Anthony J, Barger M, et al. Bridging the chasm between pregnancy and health over the life course: a national agenda for research and action. Women's Health Issues. 2021;31(3):204–18. **This is a summary of a 2-day workshop held by experts to examine the critical areas for improvement to facilitate transitions from postpartum care to primary care.**

67.• Seely EW, Celi AC, Chausmer J, Graves C, Kilpatrick S, Nicklas JM, et al. Cardiovascular health after preeclampsia: patient and provider perspective. J Women's Health. 2020;30(3):305–13. **This is a summary of a patient and provider workshop that sought to identify patient perspectives on barriers and facilitators to CVD risk reduction, clinical programs specialized in post-preeclampsia care, recommendations by national organizations for risk reduction and next steps to improve care for these patients.**

68.• Celi AC, Seely EW, Wang P, Thomas AM, Wilkins-Haug LE. Caring for women after hypertensive pregnancies and beyond: implementation and integration of a postpartum transition clinic. Matern Child Health J. 2019;23(11):1459–66. **This is a program evaluation of a specialized clinic for patients with history of HDP, which showed implementation of this clinic improved completion of recommended primary care measures.**

69.• Bibbo C, Celi A, Thomas AM, Blake-Lamb TL, Wilkins-Haug L. Does the addition of a specialized postpartum clinic improve the care of women with preeclampsia? Obstet Gynecol. 2014;123:39S This is a retrospective cohort examining primary care follow up among patients who were enrolled in a specialized postpartum clinic for patients compared to patients who were not.

70.• Gladstone RA, Pudwell J, Pal RS, Smith GN. Referral to cardiology following postpartum cardiovascular risk screening at the maternal health clinic in Kingston, Ontario. Can J Cardiol. 2019;35(6):761–9. **This was a retrospective cohort examining rates of cardiology referral among patients with HDP at a single institution.**

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.