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Maternal risk of hypertension 7-15 Years after pregnancy: clues from the placenta

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Abstract

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Contribution to Authorship

CBH, PS, GLD, KLS, JMC originated the idea for this specific project, and CBH, PS, GLD, KLS, JMC designed this project. CBH, PS, BLB and JMC contributed to the design of the POUCH and POUCHmoms Studies and the acquisition of the data. CBH, PS, GLD, KLS, YT, JX, ME, JMC contributed to the development of the analytical plan and interpretation of results. JX and YT analyzed the data. CBH, PS, and ME drafted the article. All authors reviewed and revised the drafts and approved the final version of the manuscript.

Disclosure of Interests

None declared. Completed disclosure of interest forms are available to view online as supporting information.

Details of Ethics Approval

The POUCH Study has maintained continuous approval by the institutional review boards at Michigan State University (IRB# 95-590) since January, 1996, and at the Michigan Department of Health and Human Services (IRB# 44-LHAS) since February, 1998. The POUCHmoms Study has also maintained continuous approval by the institutional review boards at Michigan State University (IRB# 10-161) since January, 2011, and at the University of Pittsburgh (IRB# REN15070264) since December, 2011.

Objective—To assess if pre-eclampsia (PE)-related placental/extraplacental membrane findings are linked to moderately-elevated blood pressure (BP) in pregnancy and later-life hypertension.

Design—Prospective Cohort

Setting—52 prenatal clinics, 5 Michigan communities

Sample—The POUCH Study recruited women at 16–27 weeks' gestation (1998–2004) and studied a sub-cohort in-depth. This sample (n=490) includes sub-cohort women with detailed placental assessments and cardiovascular health evaluations 7–15 years later in the POUCHmoms follow-up study.

Methods—PE-related placental/extraplacental membrane findings (i.e. mural hyperplasia, unaltered/abnormal vessels, or atherosis in decidua; infarcts) were evaluated in relation to pregnancy BP and odds of Stage 2 hypertension at follow-up using weighted polytomous regression. Follow-up hypertension odds also were compared in 3 pregnancy BP groups, i.e. normotensives (referent), and moderately-elevated BP with or without PE-related placental/extraplacental membrane findings.

Main Outcome Measures—Stage 2 hypertension (SBP ≥140 mmHg and/or DBP ≥90 mmHg, or using antihypertensive medications) at follow-up.

Results—After removing women with pregnancy hypertension (i.e. chronic, PE, gestational), mural hyperplasia and unaltered/abnormal decidual vessels were each associated with Stage 2 hypertension at follow-up, adjusted odds ratio (aOR)= 2.7 (95% CI 1.1,6.6), and 1.7 (95% CI 0.8, 3.4) respectively. Women with moderately-elevated BP in pregnancy and evidence of mural hyperplasia or unaltered/abnormal decidual vessels had greater odds of Stage 2 hypertension at follow-up, aOR= 4.5 (95% CI 1.6, 12.5) and 2.6 (95% CI 1.1, 5.9) respectively.

Conclusions—PE-related placental/extraplacental membrane findings help risk stratify women with moderately-elevated BP in pregnancy for later development of hypertension.

Tweetable Abstract

Placental findings associated with mother's risk of later-life hypertension

Keywords

Epidemiology: General Obstetrics; Maternal Physiology; Medical Disorders in Pregnancy; Placental Pathology; Risk Management; Translational Research

Introduction

Among women, a larger percentage of cardiovascular disease (CVD) is attributable to hypertension as compared to men[(1)], and women experience blood pressure (BP) increases at a younger age.[(2)] Early identification of women at increased risk of hypertension, close monitoring and timely interventions could mitigate diseases such as CVD and chronic kidney disease. Studies consistently observe a positive link between pre-eclampsia (PE) in pregnancy and a woman's risk of later-life hypertension and CVD[(3–6)]. Investigators hypothesize that PE and later-life hypertension share underlying risk factors that pre-date

pregnancy[7], and the physiological experience of PE might contribute to later hypertension and CVD[8]. Currently, the American Heart Association and the American College of Obstetricians and Gynecologists recommend using history of PE for CVD risk stratification and targeted medical care management.[9]

Recently we reported on blood pressure (BP) among women in the Pregnancy Outcomes and Community Health (POUCH) Study who were re-evaluated in the POUCHmoms Study 7–15 years later. Those with even moderately-elevated BP during the POUCH Study pregnancy (defined by 2015 criteria for 'pre-hypertension' in non-pregnant populations) were more likely to have hypertension at follow-up with an odds ratio of 2.6 compared to normotensive in pregnancy.[10] A considerable proportion of POUCH Study women, 64%, met the criteria for moderately-elevated BP in pregnancy. We hypothesized that within this large group a subset carried the greatest risk for later-life hypertension, potentially with underlying pathology similar to that of women with hypertensive disorders of pregnancy.

To examine this hypothesis we used placental/extraplacental membrane pathology data and pregnancy BP data from the original POUCH Study in combination with BP data from the POUCHmoms follow-up. We focused on placental/extraplacental membrane maternal vessel findings frequently associated with PE, i.e. unusually thick maternal vessel walls (mural hyperplasia), decreased remodeling of maternal vessels, placental disc infarcts, and decidual blood vessel 'atherosis'. We also considered placental evidence of chorioamnionitis, a pathology not typically linked to PE, to make sure our findings were specific to PE-related placental pathology. Our main goals were to answer the following questions: 1) Is PE-associated placental/extraplacental membrane pathology related to an increased risk of moderately-elevated BP in pregnancy? 2) After excluding women with hypertensive disorders of pregnancy, is PE-associated placental/extraplacental membrane pathology linked to an increased risk of later-life hypertension? and 3) Does the presence/absence of PE-associated placental/extraplacental membrane modify the relation between moderately-elevated BP in pregnancy and risk of later-life hypertension?

Materials and Methods

Study design

This prospective cohort includes a pregnancy study, the POUCH Study, and a maternal follow-up component, the POUCHmoms Study[11]. The POUCH Study enrolled 3,019 pregnant women at 16–27 weeks' gestation (1998–2004) from 52 clinics in five Michigan communities[12] with the aim of studying biological and social factors affecting adverse pregnancy outcomes. Inclusion criteria were singleton pregnancy with no known congenital anomaly, maternal age ≥ 15, maternal serum alpha-fetoprotein (MSAFP) screening, no pre-pregnancy diabetes mellitus, and English speaking. Approval for this study was obtained from institutional review boards at MSU, Michigan Department of Community Health, and nine community hospitals. This study did not include core outcome sets and participants were not directly involved in shaping the research.

To conserve resources, a sub-cohort of 1,371 POUCH Study participants was studied in greater depth (e.g. medical records abstracted, biological samples analyzed, placental

pathology). The sub-cohort was constructed by oversampling women with preterm delivery (PTD) and women with a higher risk of pregnancy complications (i.e. African Americans, women with high MSAFP). To account for the cohort and sub-cohort sampling strategy, inverse-probability sampling weights are used in all POUCH and POUCHmoms Study analyses. For example, African-American women, women with high MSAFP and women with PTD who were oversampled into the sub-cohort are assigned a 'smaller weight' so that they represent their proportion in the eligible population agreeing to participate in the original POUCH Study.

Of the 1,371 sub-cohort women, 1,280 did not decline future study participation and were presumed alive at the initiation of the POUCHmoms Study (Figure S1), which was designed primarily to assess risk factors for early evidence of CVD at 7–15 years post-POUCH Study pregnancy. Between 2011 and 2014, 678 POUCHmoms Study participants completed interviews and CVD-related assessments, i.e. BP, carotid ultrasounds, anthropometrics, heart rate variability and blood biomarkers. Women's age at follow-up ranged from 25 to 58 years. For the current analyses we removed women if they lacked complete placenta information, i.e. placentas not saved at delivery or insufficient decidual tissue for assessment (n=160), had chronic hypertension before/during the POUCH Study pregnancy (n=22), or were missing prenatal records (n=6), which led to a final sample of 490 women.

Measures

Blood pressure in pregnancy—Eight pregnancy BP measures were abstracted from the medical records, i.e. the two highest systolic blood pressures (SBP) and diastolic blood pressures (DBP) recorded *before* 20 weeks' gestation, and the two highest SBP and DBP recorded *at or after* 20 weeks' gestation. Women were categorized into four groups: 1) normal BP, i.e. SBP < 120 mmHg and DBP < 80 mmHg or can exceed this only one time; 2) moderately-elevated BP, i.e. at least two SBP ≥ 120 mmHg or at least two DBP ≥ 80 mmHg but no hypertensive disorder of pregnancy; 3) gestational hypertension (GH), i.e. explicit diagnosis of GH in medical records and/SBP ≥140 mmHg or DBP ≥ 90 mmHg on two occasions after 20 weeks' gestation without proteinuria; and 4) PE, i.e. the criteria of group 3 plus proteinuria. Groups 3 and 4 criteria were standard at the time of the POUCH Study[13] and details of the data/process used for group assignment appear in a previous POUCH Study publication.[14]

Placental pathology findings

The POUCH Study developed a detailed protocol for placental evaluation.[12] Briefly, formalin-fixed placentas were examined grossly and nine tissue samples were embedded in paraffin blocks for microscopic assessment: two extra-placental membrane (membrane roll) samples; two umbilical cord samples (one proximal and one distal to disc insertion); and five full-thickness disc samples, one at the cord insertion, one in central tissue that appeared normal on gross exam, two from central tissue and one at the margin (these latter three were representative of grossly visible abnormalities if present). The study pathologist (PKS) was blinded to all clinical data and to gross examination findings when performing microscopic examinations.

Of particular interest for these analyses, the pathologist recorded two groups of placental/extra-placental membrane findings often linked to PE. The first group, known as ‘maternal vascular-developmental,’ included mural hyperplasia and unaltered/abnormal decidual (meaning inadequately remodeled or otherwise abnormal) vessels (Figure S2a, b, c, d).[15] Mural hyperplasia, defined as an increased thickening of the decidual vessel wall with three or more visible muscle cell layers and decreased luminal diameter, was not common in POUCH Study placentas. Only 15% of placentas showed evidence of mural hyperplasia in one or more of the seven decidual samples examined per placenta. Therefore, one positive decidual sample was the cut-point for a positive placenta. By contrast, unaltered/abnormal decidual vessels often appeared in a single decidual sample but less often were observed in two or more decidual samples (about 38% of placentas), therefore the latter was used as the cut-point for positive. Previous POUCH Study results showed these placental findings, using the aforementioned cut-points, were associated with an increased risk of both medically indicated and spontaneous PTD at < 35 weeks’ gestation.[15]

A second group of PE-related placental findings, ‘maternal vascular obstructive,’ included infarcts and decidual blood vessel ‘atherosis’.[15] (Figure S2e) Some pathologists consider placenta margin infarcts as less important/informative than central disc infarcts,[16, 17] motivating us to evaluate the two locations separately. We categorized ‘atherosis’, margin infarcts, and central disc infarcts as present if observed in any one placental/extra-placental membrane sample. In our previous work ‘atherosis’ and infarcts were associated with increased risk of medically indicated PTD.[15]

As a test of specificity, we also considered histologic chorioamnionitis (HCA) which typically is not associated with PE. HCA, defined as an advanced maternal inflammatory response or fetal inflammatory response in the chorion/amnion, was linked to increased risk of spontaneous PTD at < 35 weeks’ gestation in the POUCH Study.[12]

Blood pressure at follow-up—BP measures in the POUCHmoms Study were obtained by study nurses or ultrasonographers who followed the Joint National Committee (JNC) guidelines[18]. Women sat with the arm extended level to the heart and three consecutive BPs were recorded one minute apart using either a Panasonic EW3109W (Panasonic Corp., Newark, NJ) or an Omron Hem-907 (Omron Healthcare, Inc., Lake Forest, IL) with a small, medium, or large cuff as indicated by arm size. Digital monitors were compared with manual readings to ensure accuracy. The second and third BP measures were averaged to create a final SBP and DBP. According to JNC-8 Guidelines, women were categorized as either normotensive/slightly elevated BP (SBP < 130 mmHg and DBP <80 mmHg), Stage I hypertension (SBP between 130–139 mmHg and/or DBP between 80–89 mmHg), or Stage 2 hypertension (SBP ≥140 mmHg and/or DBP ≥90 mmHg or using antihypertensive medications). The normal BP and the slightly elevated BP were combined due to the small number of the latter.

Covariates—Women’s age (continuous) and body mass index (BMI, continuous) at enrollment in the POUCH Study, number of years to the follow-up visit (continuous 7–15 years), race/ethnicity (binary: White/other and African American), and smoking status during pregnancy (yes, no) were each evaluated as potential confounding variables in our

analyses. Pregnancy BMI was highly correlated with BMI at follow-up; we chose to use the former given that follow-up BMI can't directly influence previous placental findings (and therefore is not a direct confounder).

Analytic Strategy

Analyses were performed with survey procedures in SAS v9.3 (SAS Institute Inc., Cary, NC) to account for the original POUCH Study sampling design and weighting. Maternal characteristics were compared between the POUCHmoms Study follow-up sample with our inclusion criteria (n=490) and the remaining sub-cohort POUCH Study mothers (Chi-square test). We first evaluated placental findings (positive and negative cut-points described above) as 'exposure variables' with a four-level 'outcome variable' of maternal BP in pregnancy, i.e. normal BP, moderately-elevated BP, GH, PE (Chi-square test). Next we used weighted polytomous regression models, unadjusted and adjusted with all the previously described covariates, to assess associations between the 'exposure variable, ' placental findings, and our three-level 'outcome variable' of BP at follow-up after removing women with GH and PE.

In a final set of analyses we considered whether placental findings could help identify which women with moderately-elevated BP in pregnancy were at greatest risk of hypertension at follow-up. We created a three-group 'exposure' variable for BP in pregnancy and each placental finding, i.e. group 1 normal BP (ref), group 2 moderately-elevated BP and (−) placental finding, and group 3 moderately-elevated BP and (+) placental finding. We used this exposure variable and in relation to the 'outcome variable', BP at follow-up, in the polytomous regression models

Results

Maternal characteristics at the time of enrollment in the original POUCH Study and at the follow-up POUCHmoms Study are described in Table 1 for our analytic sample; we provide absolute percentages and percentages weighted for the POUCH Study sampling scheme. We compared these characteristics among three groups (data not shown); 1) women in the current analyses (n=490); 2) women in the POUCHmoms follow-up study who were removed from these analyses because of incomplete placenta assessments, chronic hypertension, or incomplete pregnancy BP data (188); and 3) women eligible for the POUCHmoms Study but not followed-up (n=693). Groups one and two are similar on all variables listed in Table 1. Group three, those not followed, had lower levels of education and were more likely to be insured by Medicaid at entry to the POUCH Study. In addition, African-American women were less likely to be in the follow-up study (unweighted 35% of the current study, 47% of those not followed). Other variables, i.e. pre-pregnancy BMI, hypertension disorders of pregnancy and PTD were comparable across all three groups.

First, we examined placental pathology and BP in pregnancy. The prevalence of PE appeared higher in women with PE-associated placental pathology findings, i.e. mural hyperplasia, unaltered/abnormal decidual vessels, infarcts and decidual blood vessel atherosis, as compare to women without these placental findings. However, the small numbers of women with PE made estimates and comparisons imprecise (Table 2). Two of the PE-associated

placental findings, mural hyperplasia and unaltered/abnormal decidual vessels, also were linked to a higher prevalence of moderately-elevated BP in pregnancy. Placental infarcts were positively associated with GH. By contrast, histologic chorioamnionitis did not raise the risk of elevated BP in pregnancy.

Next, we assessed placental pathology and BP at follow-up after excluding women with PE and GH. The odds of Stage 2 hypertension 7–15 years after the POUCH Study pregnancy was elevated among women with placental evidence of mural hyperplasia during the POUCH Study, adjusted odds ratio (aOR)= 2.7 (95% CI 1.1, 6.6) Table 3. In an unadjusted model, a twofold increased odds of Stage 2 hypertension at follow-up was observed among women with unaltered/abnormal decidual vessels, though in the adjusted model the confidence interval included one, aOR=1.7 (95% CI 0.8, 3.4). Placental infarcts, 'atherosis' and HCA were not associated with blood pressure at follow-up, however, the number of women with decidual blood vessel 'atherosis' was too small to adequately assess their risk.

A final set of analyses used findings in POUCH Study placentas to stratify women with moderately-elevated BP during the POUCH Study pregnancy. The focus was on two placental findings associated with follow-up hypertension in the previous analyses, i.e. mural hyperplasia or unaltered/abnormal decidual vessels. Odds of Stage 2 hypertension in the placenta pathology-stratified, moderately-elevated BP groups were compared to that of women with normal BP in pregnancy. Approximately one third of women with both moderately-elevated BP in pregnancy and placental mural hyperplasia went on to have Stage 2 hypertension at follow-up; aOR= 4.5 (95% CI 1.6, 12.5) (Table 4). A similar pattern was observed for women with both moderately-elevated BP in pregnancy and unaltered/abnormal decidual vessels, aOR=2.6 (95% CI 1.1, 5.9). Women with moderately-elevated BP in pregnancy but no mural hyperplasia or unaltered/abnormal decidual vessels were not at increased risk of Stage 2 hypertension at follow-up.

Discussion

Main Findings

We assessed BP and placental/extraplacental membrane findings among pregnant women who later were evaluated (7–15 years after the pregnancy) for CVD risk factors including hypertension. We observed that women who did not meet the definition of hypertensive disorders of pregnancy but whose placentas showed evidence of decidual vessel mural hyperplasia and/or unaltered/abnormal vessels were at increased risk of Stage 2 hypertension at follow-up. In addition, these same decidual vessel findings helped risk stratify women with moderately-elevated BP in pregnancy, i.e. those with mural hyperplasia and/or unaltered/abnormal vessels had a 2–5 fold increased odds of Stage 2 hypertension at follow-up while those without these vessel findings showed no significant elevated risk.

Strengths and limitations

There are several major strengths of this study. Participants were diverse in socioeconomic indicators and sampled from multiple prenatal clinics situated within multiple communities,

thereby enhancing the generalizability of our findings. We looked at prevalence of 'normal BP' in pregnancy, hypertensive disorders (PE, GH), and an understudied group, i.e. women with moderately-elevated BP in pregnancy, in relation to placental pathology findings. The placental findings were identified through a rigorous, unbiased protocol (pathologist blinded to pregnancy outcome, clinical complications, gross placental examination data) applied equally to placentas from routine and complicated pregnancies. Many studies rely on placentas selected for examination at inner city, teaching hospitals and rarely are placentas analyzed without knowledge of clinical information. We showed specificity of the positive association between decidual vessel findings and later risk of hypertension by demonstrating no link with the placental complication HCA. Trained study professionals obtained BP measures at follow-up by using a standard protocol. Often women's health from pregnancy to later life is studied with extant data and considerable variability in measures of BP documented later in life.

Limitations of our study include small sample sizes for some placental findings, e.g. 'atherosis'. The study sample was not entirely comparable to the original POUCH Study sub-cohort, e.g. the latter had a larger proportion of African-American women. Race/ethnicity was a POUCH Study sampling strata, therefore sampling weights used in our analytic models provide some adjustment for this discrepancy. Still, we recognize that within a sampling stratum those followed-up may not be completely representative. It seems unlikely, however, that follow-up would be biased according to placental findings, and the proportions of women with PTD or hypertensive disorders of pregnancy in our study sample (weighted 11% and 7% respectively), and in the remaining sub-cohort women (weighted 11% and 7% respectively) were the same. Women in the follow-up POUCHmoms Study were 25–58 years of age with a modest prevalence of hypertension consistent with this age range; our results may be most applicable to women who become hypertensive at these earlier ages. While the placentas/extraplacental membranes offered compelling information on women's future health, clinically it may be challenging to identify these decidual vessel findings in large groups of deliveries, e.g. all women with moderately-elevated BP in pregnancy. Thus, our results also motivate future research to identify biomarkers that correlate with placental vessel findings and, along with other co-factors, can be used to predict later-life hypertension.

Interpretation

For decades studies repeatedly demonstrated that women with PE are more likely to develop CVD[4, 19] including hypertension[20] later in life. More recent reports extended this increased risk to include women with GH.[21, 22] As a result, clinicians are encouraged to query woman about their history of hypertensive disorders of pregnancy and manage these patients accordingly. Thus, pregnancy is unique in offering a window into future CVD risk before overt, persistent clinical signs begin.

The clinical convention of BP cutoffs to define hypertensive disorders of pregnancy is guided by risks to mother and fetus during pregnancy and not by mother's future risk of hypertension. We have been interested in moderately-elevated BP in pregnancy because in non-pregnant populations future risk of CVD increases across the BP spectrum[23] and

cutoffs for intervention have been shifting downward.[24] While many factors influence BP during pregnancy, our previous report of increased risk for later-life hypertension among women with moderately-elevated BP in pregnancy[10] motivated further consideration of this group. Here we showed that the addition of placental/extraplacental membrane findings associated with PE can help further risk-stratify women with moderately-elevated BP in pregnancy.

Among the few reports of placental findings and later maternal health, most include women with clinical complications such as PE[25] or preterm birth[25, 26] as added risk factors. One Swedish study reported a positive association between history of placental abruption and higher maternal BP at age 40.[27] Another study observed a link between delivery of an SGA infant (a possible proxy for placental vascular pathology) and maternal endothelial dysfunction six months after delivery, even in the absence of PE.[28] Among women in our study with moderately-elevated BP in pregnancy and evidence of placental vascular pathology (mural hyperplasia and/or unaltered/abnormal vessels in the decidua) who went on to have hypertension at follow-up, most (two-thirds) had neither a preterm birth or an SGA infant during the POUCH Study pregnancy.

In POUCH Study placentas, mural hyperplasia in decidual vessels occurred less frequently than unaltered/abnormal vessels, and these two findings were strongly correlated, i.e. 94% of placentas with mural hyperplasia in decidual vessels showed evidence of unaltered/abnormal vessels while 31% of women with at least two of seven decidual samples showing unaltered/abnormal vessels had evidence of mural hyperplasia. Mural hyperplasia may represent an extreme of unaltered/abnormal vessels, with inability of the trophoblasts to remodel vessel walls and atypical vessel response to pregnancy. Of note, about 18% of POUCH Study women with PE in our initial analysis showed evidence of mural hyperplasia in decidual vessels and 52% showed unaltered/abnormal vessels in two more decidual vessel samples. While we excluded 22 POUCH Study sub-cohort women with chronic hypertension (CH) from this analysis, a look back at their placental findings indicate their prevalence of mural hyperplasia in decidual vessels (8%) was similar to that of women with normal BP in pregnancy. Their prevalence of unaltered/abnormal vessels was high (54%) and similar to that of women with PE, but the small number of women with CH and placental data preclude any strong inferences. Interestingly, while placental infarcts were more common in women with GH and PE, they were not associated with hypertension 7–15 years post-delivery.

Conclusion

Our findings suggest the ‘window of pregnancy’ contains clues, beyond the obvious complications of PE, GH, PTD, or SGA, to mothers’ future vascular health. Maternal vessel placental/extraplacental membrane findings typically associated with PE help risk stratify women with moderately-elevated BP in pregnancy who are at greater risk of later-life hypertension.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. Cheng S, Claggett B, Correia AW, Shah AM, Gupta DK, Skali H, et al. Temporal trends in the population attributable risk for cardiovascular disease: the Atherosclerosis Risk in Communities Study. Circulation. 2014;130(10):820–8. [PubMed: 25210095]
2. Ji H, Kim A, Ebinger JE, Niiranen TJ, Claggett BL, Bairey Merz CN, et al. Sex Differences in Blood Pressure Trajectories Over the Life Course. JAMA Cardiol. 2020.
3. Behrens I, Basit S, Melbye M, Lykke JA, Wohlfahrt J, Bundgaard H, et al. Risk of post-pregnancy hypertension in women with a history of hypertensive disorders of pregnancy: nationwide cohort study. BMJ. 2017;358:j3078. [PubMed: 28701333]
4. Brown MC, Best KE, Pearce MS, Waugh J, Robson SC, Bell R. Cardiovascular disease risk in women with pre-eclampsia: systematic review and meta-analysis. Eur J Epidemiol. 2013;28(1):1–19. [PubMed: 23397514]
5. Garovic VD, Bailey KR, Boerwinkle E, Hunt SC, Weder AB, Curb D, et al. Hypertension in pregnancy as a risk factor for cardiovascular disease later in life. J Hypertens. 2010;28(4):826–33. [PubMed: 20087214]
6. Rich-Edwards JW, Fraser A, Lawlor DA, Catov JM. Pregnancy characteristics and women's future cardiovascular health: an underused opportunity to improve women's health? Epidemiol Rev. 2014;36:57–70. [PubMed: 24025350]
7. Romundstad PR, Magnussen EB, Smith GD, Vatten LJ. Hypertension in pregnancy and later cardiovascular risk: common antecedents? Circulation. 2010;122(6):579–84. [PubMed: 20660802]
8. Staff AC, Dechend R, Pijnenborg R. Learning from the placenta: acute atherosis and vascular remodeling in preeclampsia-novel aspects for atherosclerosis and future cardiovascular health. Hypertension. 2010;56(6):1026–34. [PubMed: 20956732]
9. ACOG Practice Bulletin No. 202 Summary: Gestational Hypertension and Preeclampsia. Obstet Gynecol. 2019;133(1):211–4.
10. Dunietz GL, Strutz KL, Holzman C, Tian Y, Todem D, Bullen BL, et al. Moderately elevated blood pressure during pregnancy and odds of hypertension later in life: the POUCHmoms longitudinal study. BJOG. 2017;124(10):1606–13. [PubMed: 28074637]
11. Holzman C, Bullen B, Fisher R, Paneth N, Reuss L, Prematurity Study G. Pregnancy outcomes and community health: the POUCH study of preterm delivery. Paediatr Perinat Epidemiol. 2001;15 Suppl 2:136–58. [PubMed: 11520406]

12. Holzman C, Lin X, Senagore P, Chung H. Histologic chorioamnionitis and preterm delivery. Am J Epidemiol. 2007;166(7):786–94. [PubMed: 17625222]
13. Report of the National High Blood Pressure Education Program Working Group on High Blood Pressure in Pregnancy. Am J Obstet Gynecol. 2000;183(1):S1–S22.
14. Mijal RS, Holzman CB, Rana S, Karumanchi SA, Wang J, Sikorskii A. Midpregnancy levels of angiogenic markers in relation to maternal characteristics. Am J Obstet Gynecol. 2011;204(3):244 e1–12.
15. Kelly R, Holzman C, Senagore P, Wang J, Tian Y, Rahbar MH, et al. Placental vascular pathology findings and pathways to preterm delivery. Am J Epidemiol. 2009;170(2):148–58. [PubMed: 19509320]
16. Benirschke KK P; Baergen RN. Legal Considerations. Pathology of the Human Placenta. Fifth ed. New York, New York: Springer Science+Business Media, Inc.; 2006. p. 1050.
17. Redline R Disorders of the Placental Parenchyma. In: Lewis SP, E, editor. Pathology of the Placenta. 2nd ed. Philadelphia, PA: Churchill Livingstone; 1999. p. 411.
18. Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, Izzo JL Jr., et al. The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure: the JNC 7 report. JAMA. 2003;289(19):2560–72. [PubMed: 12748199]
19. Wu P, Haththotuwa R, Kwok CS, Babu A, Kotronias RA, Rushton C, et al. Preeclampsia and Future Cardiovascular Health: A Systematic Review and Meta-Analysis. Circ Cardiovasc Qual Outcomes. 2017;10(2).
20. Groenhof TKJ, van Rijn BB, Franx A, Roeters van Lennep JE, Bots ML, Lely AT. Preventing cardiovascular disease after hypertensive disorders of pregnancy: Searching for the how and when. Eur J Prev Cardiol. 2017;24(16):1735–45. [PubMed: 28895439]
21. Haug EB, Horn J, Markovitz AR, Fraser A, Vatten LJ, Macdonald-Wallis C, et al. Life Course Trajectories of Cardiovascular Risk Factors in Women With and Without Hypertensive Disorders in First Pregnancy: The HUNT Study in Norway. J Am Heart Assoc. 2018;7(15):e009250. [PubMed: 30371249]
22. Sia WW, Pertman SM, Yan RM, Tsuyuki RT. Are Preeclampsia and Adverse Obstetrical Outcomes Predictors of Cardiovascular Disease? A Case-Control Study of Women With Heart Disease. J Obstet Gynaecol Can. 2019;41(12):1760–7. [PubMed: 31279766]
23. Yano Y, Reis JP, Colangelo LA, Shimbo D, Viera AJ, Allen NB, et al. Association of Blood Pressure Classification in Young Adults Using the 2017 American College of Cardiology/American Heart Association Blood Pressure Guideline With Cardiovascular Events Later in Life. JAMA. 2018;320(17):1774–82. [PubMed: 30398601]
24. Whelton PK, Carey RM, Aronow WS, Casey DE Jr., Collins KJ, Dennison Himmelfarb C, et al. 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the Prevention, Detection, Evaluation, and Management of High Blood Pressure in Adults: Executive Summary: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. Hypertension. 2018;71(6):1269–324. [PubMed: 29133354]
25. Cain MA, Salemi JL, Tanner JP, Kirby RS, Salihu HM, Louis JM. Pregnancy as a window to future health: maternal placental syndromes and short-term cardiovascular outcomes. Am J Obstet Gynecol. 2016;215(4):484 e1–e14.
26. Catov JM, Muldoon MF, Reis SE, Ness RB, Nguyen LN, Yamal JM, et al. Preterm birth with placental evidence of malperfusion is associated with cardiovascular risk factors after pregnancy: a prospective cohort study. BJOG. 2018;125(8):1009–17. [PubMed: 29193660]
27. Parikh NI, Norberg M, Ingelsson E, Cnattingius S, Vasan RS, Domellof M, et al. Association of Pregnancy Complications and Characteristics With Future Risk of Elevated Blood Pressure: The Vasterbotten Intervention Program. Hypertension. 2017;69(3):475–83. [PubMed: 28137991]
28. Hillman SL, Kubba T, Williams DJ. Delivery of small-for-gestational-age neonate and association with early-onset impaired maternal endothelial function. Ultrasound Obstet Gynecol. 2017;49(1):150–4. [PubMed: 27800643]

Table 1.

Characteristics of study sample during the POUCH Study and 7–15 years later at follow-up POUCHmoms Study

	POUCH Study			At POUCHmoms Follow-up 7–15 yrs later		
	N	%	Weighted %*	N	%	Weighted %*
Maternal Age (years)						
< 30	355	72	72	38	8	8
30–39	134	27	28	277	56	54
≥ 40	1	0.2	0.04	175	36	38
Maternal Education (years)						
< 12	92	19	18	32	7	6
= 12	124	25	24	66	13	12
> 12	274	56	58	392	80	82
Maternal Race/Ethnicity						
White/Other	318	65	75			
African American	172	35	25			
Medicaid Insurance						
No	251	51	56	317	65	69
Yes	239	49	44	173	35	31
Pre-pregnancy BMI						
Underweight	26	5	4			
Normal	222	45	47			
Overweight	102	21	22			
Obese	140	29	27			
Parity						
0	215	44	44	0	0	0
1	31	6	4	44	9	8
≥2	244	50	52	446	91	92
Smoking during pregnancy						
Yes	137	28	28			
No	353	72	72			
Preterm						
Yes	118	24	11			
No	372	76	89			
Blood pressure during pregnancy						
Normal Blood Pressure	152	31	28			
Moderately-elevated blood pressure	298	61	65			
Gestational hypertension	25	5	4			
PE	15	3	3			
Blood pressure at follow up						
Normal Blood Pressure				287	58	59
Elevated Blood Pressure				21	4	5

	POUCH Study			At POUCHmoms Follow-up 7–15 yrs later		
	N	%	Weighted %*	N	%	Weighted %*
Stage I hypertension				96	20	20
Stage II hypertension				86	18	16

*Weighted for POUCH Study sampling protocol of cohort and subcohort; these percentages approximate prevalences in eligible population agreeing to participate in the POUCH Study

Table 2.

Placental/extraplacental membrane findings and maternal blood pressure in the POUCH Study pregnancy (n=490)

		Normal Blood Pressure (n=152)	Moderately-elevated Blood Pressure (n=298)	Gestational Hypertension (n=25)	Pre-eclampsia (n=15)
Placental/Extraplacental Membrane Findings	N (percentage *)	N (percentage *)	N (percentage *)	N (percentage *)	N (percentage *)
Mural Hyperplasia					
No (0/7)	413 (84%)	139 (34%)	237 (57%)	25 (6%)	12 (3%)
Yes (≥1/7)	77 (16%)	13 (17%)	61 (79%) p=.05#	0	3 (4%) p=0.36#
Unaltered/Abnormal Decidual Vessels					
None or one (0/7 or 1/7)	261 (53%)	91 (35%)	145 (56%)	19 (7%)	6 (2%)
Two or more (≥2/7)	229 (47%)	61 (27%)	153 (67%) p=.08#	6 (2%) p=0.15#	9 (4%) p=0.32#
Atherosis					
No	464 (95%)	145 (31%)	282 (61%)	25 (5%)	12 (3%)
Yes	26 (5%)	7 (27%)	16 (61%) p=0.79#	0	3 (12%) p=0.66#
Infarct					
None	324 (66%)	108 (33%)	200 (62%) p=0.32#	11 (3%) p<0.05#	5 (2%) p<0.05#
Disc Margin only	108 (22%)	27 (25%)	64 (59%)	9 (9%)	8 (7%)
Central Disc	58 (12%)	17 (29%)	34 (59%)	5 (9%)	2 (3%)
Histologic Chorioamnionitis					
No	437 (89%)	126 (29%)	272 (62%)	25 (100%)	14 (88%)
Yes	53 (11%)	26 (49%)	26 (44%) p <0.05#	0	1 (2%) p=0.92#

*Weighted for the sub-cohort sampling scheme.

**Number of positive samples among the seven decidual samples examined per placenta.

#Chi-square comparison with no placental abnormality and normal blood pressure as referents

Table 3.

Associations between placental/extraplacental membrane findings and maternal blood pressure at follow-up (7–15 years after POUCH Study pregnancy) among women with no hypertensive disorders during the POUCH Study pregnancy (N=450)

	Blood Pressure at follow-up						
	Normal/Slightly Elevated (ref)	Stage 1 Hypertension			Stage 2 Hypertension		
	<130 Systolic BP and <80 Diastolic BP	130–139 Systolic BP and /or 80–89 Diastolic BP			≥ 140 Systolic BP and /or ≥ 90 Diastolic BP or currently taking medications		
	N (ref)	N	OR*	aOR#	N	OR*	aOR#
Placental/extraplacental Membrane Findings							
Mural Hyperplasia							
No (0/7) **	253	71	1.0	1.0	52	1.0	1.0
Yes (≥1/7) **	42	12	0.8 (0.4, 1.8)	0.8 (0.3, 2.0)	20	**2.9 (1.4, 5.8)**	**2.7 (1.1, 6.6)**
Unaltered/Abnormal Decidual Vessels							
None or one (0–1/7) **	167	42	1.0	1.0	27	1.0	1.0
Two or more (≥2/7) **	128	41	1.1 (0.6, 1.9)	0.9 (0.5, 1.8)	45	**2.1 (1.1, 3.9)**	1.7 (0.8, 3.4)
Atherosis							
No	284	78	1.0	1.0	65	1.0	1.0
Yes	11	5	1.0 (0.3, 3.3)	0.8 (0.2, 3.1)	7	1.9 (0.7, 5.6)	1.3 (0.4, 4.7)
Infarct							
None	200	55	1.0	1.0	53	1.0	1.0
Disc Margin only	60	21	1.2 (0.6, 2.5)	1.4 (0.7, 2.8)	10	0.8 (0.3, 1.8)	0.9 (0.4, 2.4)
Central Disc	35	7	0.8 (0.3, 2.1)	0.8 (0.3, 2.0)	9	1.0 (0.4, 2.4)	0.8 (0.3, 2.1)
Histologic Chorioamnionitis							
No	264	72	1.0	1.0	62	1.0	1.0
Yes	31	11	0.9 (0.4, 2.2)	0.9 (0.3, 2.3)	10	1.3 (0.5, 3.2)	1.1 (0.5, 2.5)

*Weighted for the POUCH Study sub-cohort sampling scheme.

**Number of positive samples among the seven decidual samples examined per placenta.

#Adjusted for maternal race, maternal age at enrollment, interval of follow-up, smoking before pregnancy, and pre-pregnancy BMI at POUCH Study.

Table 4.

Associations between moderately-elevated blood pressure during pregnancy, stratified by placental/placental membrane findings, and maternal blood pressure at follow-up (7–15 years after POUCH Study pregnancy) among women with no hypertensive disorders during the POUCH Study pregnancy (N=450)

	Blood Pressure (BP)at follow-up (n=450)						
	Normal/Slightly Elevated BP (ref)	Stage 1 Hypertension			Stage 2 Hypertension		
	<130 Systolic BP and <80 Diastolic BP	130–139 Systolic BP and /or 80–89 Diastolic BP			≥ 140 Systolic BP and /or ≥ 90 Diastolic BP or currently taking medications		
	N (ref)	N	OR*	aOR#	N	OR*	aOR#
Blood Pressure in pregnancy and placental/extraplacental membrane findings							
Normal BP (ref)	106	30	1.0	1.0	16	1.0	1.0
Moderately-elevated BP/ − Mural hyperplasia (0/7)	155	46	1.1 (0.6, 2.0)	1.0 (0.5, 2.1)	36	1.5 (0.7, 3.2)	1.6 (0.7, 3.6)
Moderately-elevated BP/ + Mural hyperplasia (≥1/7)	34	7	0.6 (0.2, 1.9)	0.6 (0.2, 2.0)	**20**	**5.1 (2.1, 12.4)**	**4.5 (1.6, 12.5)**
Normal BP (ref)	106	30	1.0	1.0	16	1.0	1.0
Moderately-elevated BP/None or one (0–1/7) unaltered/abnormal decidual vessels	99	27	1.0 (0.5, 2.0)	1.0 (0.4, 2.2)	19	1.3 (0.6, 3.1)	1.6 (0.6, 4.1)
Moderately-elevated BP/Two or more (≥2/7) unaltered/abnormal decidual vessels	90	26	1.0 (0.5, 2.1)	0.9 (0.4, 2.0)	37	**2.9 (1.3, 6.2)**	**2.6 (1.1, 5.9)**

*Weighted for the POUCH Study sub-cohort sampling scheme.

#Adjusted for maternal race, maternal age at enrollment, interval of follow-up, smoking before pregnancy, and pre-pregnancy BMI at POUCH Study.