

## OBSTETRICS

# Gestational hypertension is associated with increased risk of type 2 diabetes in adult offspring: the Helsinki Birth Cohort Study



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**BACKGROUND:** Women with hypertensive disorders in pregnancy are at an increased risk of cardiovascular disease and type 2 diabetes later in life. Offspring born from these hypertensive pregnancies have increased levels of cardiovascular risk factors; whether they are at an increased risk of type 2 diabetes is not known.

**OBJECTIVE:** The objective of the investigation was to study the risk of type 2 diabetes in the adult offspring exposed to maternal preeclampsia or gestational hypertension in utero.

**STUDY DESIGN:** We studied 5335 members of the Helsinki Birth Cohort Study, who were born between 1934 and 1944 and who lived in Finland in 1995 when the National Medication Purchase Register was initiated. We ascertained gestational hypertension and preeclampsia according to modern criteria by using maternal and birth records. We defined type 2 diabetes through purchases of antidiabetic medication recorded in the comprehensive National Medication Purchase Register, excluding the 31 subjects who had purchased only insulin. We used Cox regression to assess hazard ratios for type 2 diabetes.

**RESULTS:** A total of 590 men (21.6%) and 433 women (16.9%) had purchased medication for diabetes. The hazard ratio for type 2 diabetes for offspring exposed to any maternal hypertension in pregnancy was 1.13 (95% confidence interval, 1.00–1.29;  $n = 1780$ ). For maternal gesta-

tional hypertension, it was 1.15 (95% confidence interval, 1.00–1.33;  $n = 1336$ ) and for preeclampsia 0.98 (95% confidence interval, 0.71–1.34;  $n = 231$ ). For type 2 diabetes with first medication purchase before 62 years, the corresponding hazard ratios were 1.25 (95% confidence interval, 1.04–1.51); 1.28 (95% confidence interval, 1.05–1.58), and 1.18 (95% confidence interval, 0.75–1.84). The hazard ratios were similar when adjusted for birthweight SD score for gestation, length of gestation, maternal body mass index in late pregnancy, height, age, and parity and for childhood or adult socioeconomic position. An increased risk of type 2 diabetes was also associated with low birthweight SD score, independent of the association with gestational hypertension.

**CONCLUSION:** Offspring exposed to maternal gestational hypertension in utero have an increased risk of type 2 diabetes in late adult life. This finding underlines the role of the whole spectrum of hypertensive disorders of pregnancy as risk factors of offspring disease throughout life. It also reinforces previous suggestions that adult health care providers should incorporate birth histories when evaluating an individual's risk to develop type 2 diabetes.

**Key words:** birthweight, cardiovascular disease, cerebrovascular disease, diabetes, gestational age, gestational hypertension, hypertension, ischemic heart disease, premature, preterm, preeclampsia

Hypertensive disorders of pregnancy, including preeclampsia and gestational hypertension, are among the most common pregnancy disorders. Women with these conditions have higher levels of insulin resistance than women with normotensive pregnancy. This difference persists after pregnancy and contributes to a higher risk of type 2 diabetes (T2D) and cardiovascular disease in later life.<sup>1-3</sup>

Offspring born to these women have also increased levels of cardiovascular risk factors such as higher blood pressure<sup>4-6</sup> and body mass index<sup>4,5</sup> and an increased risk of manifest disease including stroke.<sup>7</sup>

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## EDITORS' CHOICE

However, evidence on the offspring risk of diabetes is scanty. Studies on premorbid traits such as glucose metabolism remain inconclusive.<sup>4,8,9</sup> Two studies have assessed T2D as an outcome at mean ages of 47<sup>3</sup> and 45<sup>9</sup> years in offspring of mothers with preeclampsia. The association with T2D did not reach statistical significance in either study alone<sup>3,9</sup> or a combined analysis<sup>5</sup>; neither study assessed other hypertensive disorders of pregnancy.

We used the unique data of the Helsinki Birth Cohort Study, with maternal hypertensive disorders confirmed from pregnancy and birth records using modern criteria,<sup>7</sup> to study their effect on the risk of T2D in offspring born between 1934 and 1944.

## Materials and Methods

We studied 6410 singleton members of the Helsinki Birth Cohort Study,

born between 1934 and 1944, who had adequate antenatal clinic and birth hospital data to confirm diagnoses of maternal pregnancy disorders by modern criteria as described.<sup>7</sup> The specific criteria are shown in [Table 1](#). Birthweight SD score, adjusted for gestational age and sex, was based on Finnish standards.<sup>10</sup>

Of the 6410 cohort members, 5335 lived in Finland in 1995, when the National Medication Reimbursement Database was initiated. Based on this database, we defined T2D as at least 1 purchase of medication for diabetes between 1995 and 2011. Because the early-life origins of type 1 diabetes are likely to be distinct from those of T2D, we excluded the 31 subjects who had purchased only insulin, who are likely to have type 1 diabetes. This left us with 5304 subjects.

Comparisons of these subjects with those who had died or emigrated from

TABLE 1

**Definition of maternal hypertension in pregnancy according to the International Society for the Study of Hypertension in Pregnancy criteria, modified based on data available<sup>7</sup>**

Variables	Blood pressure	Proteinuria
Normotension	All systolic measurements <140 mm Hg and diastolic <90 mm Hg	No
Gestational hypertension	At least 1 systolic measurement $\geq$ 140 mm Hg or diastolic $\geq$ 90 mm Hg after 20 wks of gestation, no chronic hypertension	No
Nonsevere preeclampsia	At least 1 systolic measurement $\geq$ 140 mm Hg or diastolic $\geq$ 90 mm Hg after 20 wks of gestation, all systolic measurements <160 mm Hg, and diastolic <110 mm Hg	Yes <sup>a</sup>
Severe preeclampsia	At least 1 systolic measurement $\geq$ 160 mm Hg or diastolic $\geq$ 110 mm Hg after 20 wks of gestation	Yes <sup>a</sup>
Chronic hypertension or superimposed preeclampsia	At least 1 systolic measurement $\geq$ 140 mm Hg or diastolic $\geq$ 90 mm Hg before 20 wks of gestation <sup>b</sup>	Yes/No
Any hypertension in pregnancy	Any of the previously cited hypertensive conditions	

<sup>a</sup> Definition of proteinuria was based on a qualitative measurement, the cutoff of which approximates to 1 mg/mL of albumin; <sup>b</sup> A total of 816 of the 6410 mothers (12.7%) had blood pressure recordings before 20 weeks' gestation and could be classified in relation to chronic hypertension/superimposed preeclampsia. Therefore, we do not present chronic hypertension/superimposed preeclampsia as a separate exposure group but include the offspring of these mothers in the any hypertension category.

Kajantie et al. Hypertension in pregnancy and type 2 diabetes in adult offspring. *Am J Obstet Gynecol* 2017.

Finland before 1995 are shown in [Supplemental Table 1](#). Those who had died or emigrated were more likely to be men, were born to younger mothers, and had lower and more frequently unknown adult socioeconomic position. There was no difference in the frequency of hypertensive disorders of pregnancy or in childhood socioeconomic position.

The study was approved by the Ethics Committee at Helsinki and Uusimaa Hospital District, and data were linked with permission from the Ministry of Social and Health Affairs, the National Institute for Health and Welfare, and the National Social Insurance Institution. We used Cox regression, stratified for offspring sex and year of birth, to calculate hazard ratios for offspring T2D. Other censoring events were death and migration from Finland, whichever occurred first.

To allow for nonlinear associations with covariates, values of categorical covariates with more than 2 categories (childhood and adulthood socioeconomic position) were contrasted against an indicator category (lowest socioeconomic position). Continuous covariates were first entered as first-,

second-, and third-degree polynomials. Because this had virtually no effect on the association between hypertensive pregnancy disorders and offspring T2D, we report the result adjusted for linear effects of the continuous covariates.

## Results

Clinical characteristics are shown in [Table 2](#). A total of 590 men (21.6%) and 433 women (16.9%) had purchased medication for diabetes. The mean age at the first registered purchase was 61.7 years (SD 6.0) for men and 63.0 years (SD 6.0) for women. Because there was no difference in the association between maternal hypertension in pregnancy and T2D between male and female offspring (*P* for interaction > .3), we report the results pooled for both sexes, stratified for sex and year of birth.

### Hypertension in pregnancy and T2D in adult offspring

Offspring of mothers with hypertension in pregnancy had a higher risk of developing T2D in adult life, compared with offspring of normotensive women ([Figure](#)). The risk was due to an increased risk

in offspring of women with gestational hypertension. We then assessed these associations separately among those whose first medication purchase for T2D occurred before and after age 62 years, the approximate mean age of first purchase. We selected this cutoff because the medication purchase register started in 1995, when the subjects were aged 50–61 years. The increased risk of T2D was confined to those with first medication purchase before age 62 years ([Figure](#)).

There was no association between the risk of T2D and maternal nonsevere or severe preeclampsia ([Figure](#)). A post hoc analysis with any maternal preeclampsia combined showed hazard ratios of 0.98 (95% confidence interval [CI], 0.71–1.34) for T2D, 1.18 (95% CI, 0.75–1.84) for onset before and 0.83 (95% CI, 0.53–1.29) after 62 years.

### Prenatal factors and socioeconomic status

A 1 SD higher birthweight SD score was associated with a hazard ratio of 0.87 for T2D (95% CI, 0.81–0.93). The risk of T2D was not associated with length of gestation or preterm

**TABLE 2**  
**Characteristics of the mothers and their offspring according to maternal hypertensive disorders**

Characteristics	Normotensive (n = 3524)	Any hypertension in pregnancy (n = 1780) <sup>a</sup>	Gestational hypertension (n = 1336)	Preeclampsia, nonsevere (n = 97)	Preeclampsia, severe (n = 134)	Missing
Men	1836 (52.1%)	899 (50.5%)	677 (50.7%)	54 (55.7%)	71 (53.0%)	0
<b>Maternal</b>						
Age at delivery, y	27.9 (5.3)	28.9 (5.7)	28.9 (5.8)	27.8 (4.9)	29.2 (6.1)	5
Height	159.5 (5.6)	159.7 (5.8)	159.6 (5.8)	160.0 (5.8)	160.2 (5.6)	266
Body mass index before delivery	26.0 (2.8)	26.8 (3.2)	26.8 (3.2)	27.0 (3.5)	26.8 (3.0)	339
Primiparous	1731 (49.1%)	1000 (56.2%)	731 (54.7%)	66 (68.0%)	101 (75.4%)	0
<b>Birth</b>						
Length of gestation, wks	40.0 (1.6)	39.9 (1.7)	40.0 (1.7)	39.7 (1.9)	39.3 (2.0)	285
Birthweight, g	3430 (467)	3345 (518)	3379 (495)	3227 (514)	2881 (590)	0
Birthweight SD score	-0.3 (0.9)	-0.4 (1.1)	-0.4 (1.0)	-0.6 (1.0)	-1.3 (1.1)	285
<b>Father's occupational status</b>						0
Unknown	211 (6.0%)	116 (6.5%)	88 (6.6%)	6 (6.2%)	9 (6.7%)	
Manual worker	2385 (67.7%)	1201 (67.5%)	903 (67.6%)	58 (59.8%)	81 (60.4%)	
Lower official	697 (19.8%)	339 (19.0%)	254 (19.0%)	21 (21.6%)	31 (23.1%)	
Higher official	231 (6.6%)	124 (7.0%)	91 (6.8%)	12 (12.4%)	13 (9.7%)	
<b>Own adult occupational status</b>						0
Unknown	62 (1.8%)	32 (1.8%)	25 (1.9%)	1 (1.1%)	1 (0.7%)	
Manual worker	1416 (40.2%)	744 (41.8%)	563 (42.1%)	35 (36.1%)	56 (41.8%)	
Self-employed	330 (9.4%)	163 (9.2%)	121 (9.1%)	10 (10.3%)	12 (9.0%)	
Lower official	1327 (37.7%)	662 (37.2%)	500 (37.4%)	39 (40.2%)	46 (34.3%)	
Higher official	389 (11.0%)	179 (10.1%)	127 (9.5%)	12 (12.4%)	19 (14.2%)	
<b>Adult</b>						
Ever purchased medication for diabetes, n, %	660 (18.7%)	363 (20.4%)	277 (20.7%)	17 (17.5%)	25 (18.7%)	0
Mean age at first purchase, y	62.5 (6.1)	61.7 (6.0)	61.8 (6.1)	62.6 (6.2)	61.4 (6.0)	0

Numbers are mean (SD) or n (percentage).

<sup>a</sup> The number includes in addition 213 mothers with chronic hypertension.

Kajantie et al. Hypertension in pregnancy and type 2 diabetes in adult offspring. *Am J Obstet Gynecol* 2017.

birth (hazard ratio, 1.18; 95% CI, 0.88–1.58), although the association with preterm birth before 35 weeks of gestation, previously reported in the source cohort,<sup>11</sup> approached statistical significance (hazard ratio, 1.60; 95% CI, 0.94–2.72).

The risk of T2D was also not associated with maternal age, height, body mass index (BMI) before delivery or parity or with childhood socioeconomic position; offspring with lower adult socioeconomic position had higher rates of

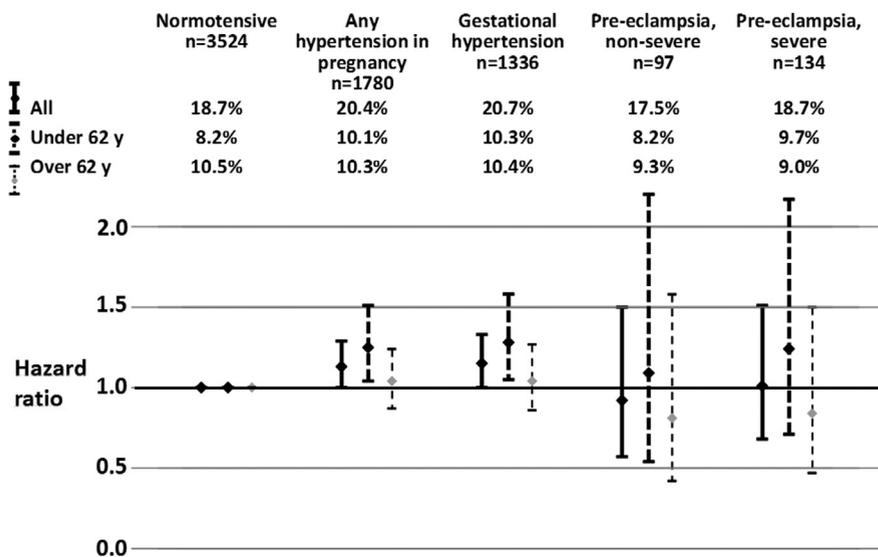
T2D. Adjustment for these variables had a negligible effect on the association between maternal hypertensive disorders and offspring T2D (Table 3).

We then assessed the association between birthweight SD score and adult T2D separately among offspring from normotensive and hypertensive pregnancies (Table 4). The association appeared stronger among normotensive pregnancies, although the interaction was not formally statistically significant. Conversely, the association between

maternal gestational hypertension and offspring adult T2D was strongest among offspring with the highest birthweight SD scores.

### Comment

We found that offspring born to mothers with gestational hypertension have a higher risk of T2D treated by medication than offspring of normotensive mothers. The association was limited to T2D with medication initiated before 62 years of age. It was

**FIGURE**  
**Hazard ratios and 95% confidence intervals for type 2 diabetes**

Hazard ratios and 95% confidence intervals for type 2 diabetes according to exposure to maternal hypertensive disorders in pregnancy. The percentages indicate the proportion of cohort members with type 2 diabetes. Any hypertension in pregnancy includes also 213 mothers with chronic hypertension.

Kajantie et al. Hypertension in pregnancy and type 2 diabetes in adult offspring. *Am J Obstet Gynecol* 2017.

not confounded by maternal age or BMI in pregnancy or by childhood socioeconomic status. We were unable to find any association between maternal preeclampsia and offspring T2D.

We have previously discussed the limitations of the maternal hypertension in pregnancy data in the Helsinki Birth Cohort Study.<sup>7</sup> A further limitation is

that we have no information on maternal gestational diabetes or offspring adult BMI, key risk factors of offspring T2D. Adjustment for maternal BMI, however, did not change our findings. Moreover, although the use of medication purchase data enabled us to distinguish between type 1 and type 2 diabetes, we could not identify subjects with diabetes treated by diet only or subjects who died or

emigrated before the register was started in 1995. However, comparisons between those who could not be included because of pre-1995 death or migration and those included raised little concern over bias.

As described,<sup>7</sup> a number of mothers had no blood pressure recorded before 20 weeks of gestation. Thus, the gestational hypertension group is likely also to include mothers that today would be classified as having chronic hypertension.

Whereas gestational hypertension predicts subsequent T2D and other chronic diseases in the mother,<sup>1</sup> our study is to our knowledge the first to assess its effects on diabetes in adult offspring. The hazard ratios, 1.15 for any T2D and 1.34 for T2D before age 62 years, are relatively modest. Yet they compare with associations with established adult risk factors such as the risk ratio of 1.37 for T2D reported for current smoking.<sup>12</sup> For further comparison, previously reported hazard ratios of gestational hypertension in this same cohort include 1.4 for offspring stroke,<sup>7</sup> 1.19 for any severe mental disorder, and 1.44 for severe mood disorder.<sup>13</sup>

The lack of association between maternal preeclampsia and offspring T2D should be interpreted with caution because of the smaller numbers. However, it is consistent with 2 previous studies that have focused on preeclampsia rather than gestational

**TABLE 3**  
**Hazard ratios for type 2 diabetes in the offspring according to maternal hypertension in pregnancy, adjusted for covariates**

Variables	Normotensive (n = 3524)	Any hypertension in pregnancy (n = 1780) <sup>a</sup>	Gestational hypertension (n = 1336)	Preeclampsia, nonsevere (n = 97)	Preeclampsia, severe (n = 134)
Model 1	Referent	1.13 (1.00, 1.29)	1.15 (1.00, 1.33)	0.92 (0.57, 1.50)	1.01 (0.68, 1.51)
Model 2	Referent	1.13 (0.99, 1.29)	1.16 (1.01, 1.35)	0.92 (0.57, 1.50)	0.95 (0.63, 1.44)
Model 3	Referent	1.13 (0.99, 1.30)	1.16 (1.00, 1.35)	0.90 (0.54, 1.51)	0.99 (0.65, 1.52)
Model 4	Referent	1.13 (0.99, 1.28)	1.14 (0.99, 1.32)	0.94 (0.58, 1.53)	1.02 (0.69, 1.53)

Analyses are stratified for offspring sex and year of birth. Model 1 was unadjusted. Model 2 was adjusted for length of gestation and birthweight SD score. Model 3 was adjusted for model 2 plus maternal age, height, body mass index, and whether multiparous. Model 4 was adjusted for childhood and adult socioeconomic position.

<sup>a</sup> The number includes in addition 213 mothers with chronic hypertension.

Kajantie et al. Hypertension in pregnancy and type 2 diabetes in adult offspring. *Am J Obstet Gynecol* 2017.

TABLE 4

**Hazard ratios for type 2 diabetes in the offspring of normotensive mothers and mothers with gestational hypertension, according to birthweight SD in relation to length of gestation**

Birthweight SD score in thirds	Normotensive		Gestational hypertension	
	Diabetes/total, n, %	Hazard ratio (95% CI)	Diabetes/total, n	Hazard ratio (95% CI)
Lowest	232/1043 (22.2%)	1.43 (1.18–1.74)	112/450 (24.9%)	1.71 (1.35–2.17)
Middle	207/1137 (18.2%)	1.16 (0.95–1.41)	79/432 (18.3%)	1.19 (0.91–1.55)
Highest	201/1222 (16.4%)	Referent	78/393 (19.9%)	1.30 (1.00–1.69)
Hazard ratio per one SD birth weight		0.83 (0.76–0.91)		0.91 (0.81–1.03)
<i>P</i> for linear trend		< .0001		.1
<i>P</i> for quadratic trend		.05		.2
<i>P</i> for interaction <sup>a</sup>				.2

Analyses are stratified for offspring sex and year of birth and adjusted for length of gestation.

<sup>a</sup> Interaction between gestational hypertension and birthweight SD score as a continuous variable.

Kajantie et al. Hypertension in pregnancy and type 2 diabetes in adult offspring. *Am J Obstet Gynecol* 2017.

hypertension as an exposure.<sup>3,5,9</sup> One of these studies was based on the UK 1958 Birth Cohort and reported a hazard ratio of 1.19 (95% CI, 0.48–2.96), when the outcome was self-reported T2D at age 45 years.<sup>5,9</sup> Another study assessed the offspring of mothers who had had preeclampsia in any of their pregnancies identified T2D cases from medical records in a population followed up to 22–62 years and reported a hazard ratio of 1.38 (95% CI, 0.89–2.14).<sup>3</sup> In the present study, the confidence interval of the 0.98 hazard ratio was 0.71–1.34; it excludes any moderate or large effects with reasonable certainty.

Both low birthweight and gestational hypertension seemed to be independent, additive risk factors for offspring T2D. There was, however, some suggestion that the risk associated with gestational hypertension might be strongest among those born at high birthweight for gestation. This would be consistent with a role of maternal gestational diabetes or subthreshold hyperglycemia, which are associated with gestational hypertension and high birthweight.

We conclude that intrauterine exposure maternal gestational hypertension is a novel risk factor of T2D in adult life. This finding underlines the role of the whole spectrum of hypertensive disorders of pregnancy as risk factors of offspring disease throughout life.

Furthermore, it reinforces previous suggestions that adult health care providers should incorporate birth histories when evaluating of an individual's risk to develop T2D. ■

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SUPPLEMENTAL TABLE 1

**Characteristics of subjects who were excluded because of having died or emigrated before the follow-up was started in 1995, as compared with study participants**

Characteristics	Dead or emigrated before 1995 (n = 1075)	Available for follow-up in 1995 (n = 5304)	Pvalue <sup>a</sup>
Men	599 (55.7%)	2735 (51.5%)	.01
<b>Maternal</b>			
Age at delivery, y	27.8 (5.3)	28.2 (5.4)	.01
Height	159.8 (5.8)	159.6 (5.7)	.20
Body mass index before delivery	26.3 (3.0)	26.2 (2.9)	.40
Primiparous	520 (48.5%)	2573 (51.5%)	.07
<b>Hypertension in pregnancy</b>			
			.60
Normotensive	727 (67.6%)	3524 (66.4%)	
Gestational hypertension	248 (23.1%)	1336 (25.2%)	
Preeclampsia, nonsevere	23 (2.1%)	97 (1.8%)	
Preeclampsia, severe	30 (2.8%)	134 (2.5%)	
<b>Birth</b>			
Length of gestation, wks	40.0 (1.6)	39.9 (1.6)	.60
Birthweight, g	3428 (502)	3401 (486)	.10
Birthweight SD score	−0.30 (1.02)	−0.33 (0.98)	.40
<b>Father's occupational status</b>			
			.20
Unknown	80 (7.6%)	327 (6.2%)	
Manual worker	724 (67.3%)	3586 (67.6%)	
Lower official	207 (19.3%)	1036 (19.5%)	
Higher official	62 (5.8%)	355 (6.7%)	
<b>Own adult occupational status</b>			
			< .0001
Unknown	521 (48.5%)	94 (1.8%)	
Manual worker	253 (23.5%)	2160 (40.7%)	
Self-employed	48 (4.5%)	493 (9.3%)	
Lower official	179 (16.7%)	1989 (37.5%)	
Higher official	74 (6.5%)	568 (10.7%)	

<sup>a</sup>  $\chi^2$  test or *t* test.

Kajantie et al. Hypertension in pregnancy and type 2 diabetes in adult offspring. *Am J Obstet Gynecol* 2017.