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# Hypertensive Disorders of Pregnancy Subtypes and Long-Term Cardiovascular Risk

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**IMPORTANCE** Hypertensive disorders of pregnancy (HDPs) are associated with an increased long-term risk of cardiovascular disease, but the risks across different HDP subtypes, particularly those other than preeclampsia, remain unclear.

**OBJECTIVE** To examine whether the risk and distribution of specific cardiovascular outcomes differ across HDP subtypes.

**DESIGN, SETTING, AND PARTICIPANTS** This nationwide cohort study retrospectively analyzed women with deliveries in South Korea from 2010 to 2018 using the National Health Insurance Service database. HDPs were classified into 5 subtypes: chronic hypertension, gestational hypertension, superimposed preeclampsia, preeclampsia/eclampsia, and unspecified hypertension. Events were verified through December 2022. Data were analyzed from June 1 to October 31, 2025.

**EXPOSURES** HDPs and their subtypes.

**MAIN OUTCOMES AND MEASURES** The primary outcome was a composite of cardiovascular events, including cardiovascular death, heart failure, myocardial infarction, stroke, and atrial fibrillation. Adjusted hazard ratios (AHRs) were estimated using Cox models accounting for age, cardiovascular comorbidities, demographic, lifestyle, and pregnancy-related factors.

**RESULTS** Among 570 843 women (mean [SD] age, 32.7 [4.0] years), 22 876 (4.0%) had HDPs. HDPs were associated with a higher incidence of cardiovascular events compared with women without HDPs (AHR, 1.62; 95% CI, 1.49-1.76; $P < .001$). The absolute risk increase was approximately 2.10 additional cardiovascular events per 1000 person-years over a median follow-up of 6.5 years (IQR, 4.7-8.7 years; incidence rate, 4.39 vs 2.29 per 1000 person-years). Among those with HDPs, 34.8% had gestational hypertension, 32.4% had preeclampsia or eclampsia, 17.7% had unspecified hypertension, 12.3% had chronic hypertension, and 2.8% had superimposed preeclampsia. All subtypes were independently associated with higher cardiovascular risk, with the highest risk observed in superimposed preeclampsia compared with women without HDPs (AHR, 2.93; 95% CI, 2.15-3.99; $P < .001$). All subtypes were associated with increased risks of heart failure and stroke, and most subtypes were associated with higher cardiovascular mortality. Unspecified hypertension was associated with myocardial infarction, and chronic hypertension and unspecified hypertension were associated with atrial fibrillation.

**CONCLUSIONS AND RELEVANCE** In this cohort study, all HDP subtypes were associated with modest increases in long-term cardiovascular risk, except superimposed preeclampsia, which was associated with a markedly higher risk. These findings suggest that women with superimposed preeclampsia may benefit from closer postpartum cardiovascular surveillance.

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Supplemental content

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Hypertensive disorders of pregnancy (HDPs) complicate approximately 5% to 10% of pregnancies.[1,2] Beyond their immediate obstetric implications,[3] a growing body of epidemiologic evidence demonstrates that women with a history of HDPs face an elevated long-term risk of developing chronic hypertension, stroke, ischemic heart disease, atrial fibrillation (AF), heart failure (HF), and cardiovascular mortality.[4-29] HDPs and later-life cardiovascular disease may share underlying pathophysiologic mechanisms, including endothelial dysfunction, chronic inflammation, and metabolic dysregulation.[30]

HDPs comprise a heterogeneous spectrum of conditions, including preeclampsia/eclampsia, gestational hypertension, chronic hypertension, superimposed preeclampsia, and unspecified hypertension.[29,31] Superimposed preeclampsia, defined as the new onset of preeclamptic features in a woman with preexisting chronic hypertension, represents a particularly complex phenotype.[31] However, it remains unclear whether specific HDP subtypes confer differential long-term cardiovascular risks. Most existing research has focused on preeclampsia,[14,16,20,21,24,25] with comparatively little attention on other subtypes. Furthermore, most large cohort studies to date have been conducted in Western populations. Given that the prevalence, underlying risk factors, and cardiovascular consequences of HDPs may vary across ethnicities,[32,33] data from Asian populations are needed to enhance generalizability and guide subtype-specific monitoring strategies.

To address these gaps, we conducted a nationwide, population-based cohort study in South Korea to examine the association between HDPs and the long-term risk of adverse cardiovascular outcomes. We further assessed whether the risks of cardiovascular events differ across HDP subtypes to inform tailored postpartum surveillance.

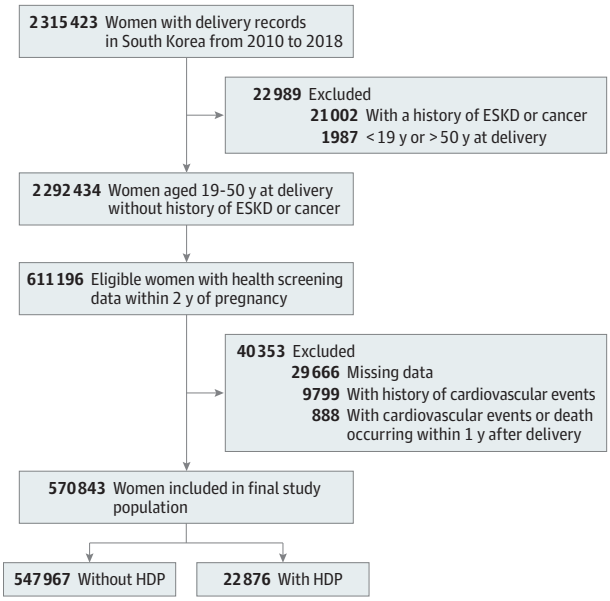
### Key Points

**Question** Do risks and patterns of cardiovascular events differ across hypertensive disorder of pregnancy (HDP) subtypes?

**Findings** In this cohort study of 570 843 women, HDPs were associated with increased cardiovascular risk, with 2.10 additional cardiovascular events per 1000 person-years over a median of 6.5 years; among subtypes, superimposed preeclampsia was associated with the highest risk. All subtypes were associated with increased risk of heart failure and stroke and most with cardiovascular death, whereas associations for myocardial infarction and atrial fibrillation varied across subtypes.

**Meaning** These findings suggest that HDP subtypes are associated with heterogeneous long-term cardiovascular risks, underscoring the need for tailored postpartum surveillance strategies.

Figure 1. Flowchart of Participant Selection




ESKD indicates end-stage kidney disease; HDP, hypertensive disorder of pregnancy.

## Methods

### Data Source and Study Population

This study used the National Health Insurance Service (NHIS) database of South Korea. The NHIS is a nationwide claims database that includes detailed demographic information, medical diagnoses coded using the *International Statistical Classification of Diseases, Tenth Revision, Clinical Modification* (*ICD-10-CM*), prescription records, hospitalization data, surgical procedures, and results from biennial national health screening programs. It is administered by a single public insurer that provides mandatory universal health coverage for the entire Korean population. A detailed description of the NHIS database has been published previously,[34] and it has been widely used in epidemiologic studies of cardiovascular disease.[35,36]

We identified women with delivery records between January 2010 and December 2018 (n = 2 315 423) (**Figure 1**). The last delivery during this period was defined as the index delivery to minimize bias from successive pregnancies. After excluding those younger than 19 years or older than 50 years and those with end-stage kidney disease or cancer, 2 292 434 women remained. Among them, 611 196 had a general health screening within 2 years before pregnancy and were included. We further excluded women with missing data, prior cardiovascular events (HF, myocardial infarction [MI], stroke, or AF), or events occurring within 1 year postpartum to ensure a washout period. The final cohort comprised 570 843 women.

This study was approved by the ethics committee of Seoul National University Hospital and adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline for cohort studies. Written informed consent was waived by the ethics committee because only anonymized, unidentifiable data were used.

### Exposure Definition

HDPs were identified using *ICD-10-CM* codes and prescription records. Participants were classified as having HDPs if they

Table 1. Baseline Characteristics by HDP

| Variable | Women, No. (%) | | *P* value | ASD |
|---|---|---|---|---|
| | Without HDP (n = 547 967) | With HDP (n = 22 876) | | |
| Clinical characteristics at delivery | | | | |
| Age, mean (SD), y | 32.7 (4.0) | 33.5 (4.4) | <.001 | 0.210 |
| Age categories, y | | | | |
| <25 | 8183 (1.5) | 305 (1.3) | <.001 | 0.014 |
| 25-29 | 103 160 (18.8) | 3621 (15.8) | | 0.079 |
| 30-34 | 277 651 (50.7) | 10 297 (45.0) | | 0.113 |
| 35-39 | 126 726 (23.1) | 6254 (27.3) | | 0.097 |
| ≥40 | 32 247 (5.9) | 2399 (10.5) | | 0.168 |
| Low income | 71 962 (13.1) | 3437 (15.0) | <.001 | 0.054 |
| Metropolitan area residence | 264 319 (48.2) | 10 491 (45.9) | <.001 | 0.048 |
| Pregnancy characteristics | | | | |
| Nulliparity | 343 130 (62.6) | 16 762 (73.3) | <.001 | 0.228 |
| Multiple gestation | 11 786 (2.2) | 1510 (6.6) | <.001 | 0.218 |
| Mode of delivery | | | | |
| Spontaneous vaginal delivery | 149 564 (27.3) | 2875 (12.6) | <.001 | 0.368 |
| Induced labor | 131 179 (23.9) | 3884 (17.0) | | 0.173 |
| Forceps or vacuum-assisted delivery | 34 329 (6.3) | 902 (3.9) | | 0.105 |
| Breech delivery | 120 (0.02) | 6 (0.03) | | 0.006 |
| Cesarean section | 230 684 (42.1) | 15 139 (66.2) | | 0.483 |
| Mixed delivery type | 2091 (0.4) | 70 (0.3) | | 0.012 |
| Gestational diabetes | 86 656 (15.8) | 5713 (25.0) | <.001 | 0.227 |
| HDP subtype | | | | |
| Chronic hypertension | 0 | 2810 (12.3) | NA | NA |
| Gestational hypertension | 0 | 7954 (34.8) | NA | NA |
| Superimposed preeclampsia | 0 | 644 (2.8) | NA | NA |
| Preeclampsia or eclampsia | 0 | 7411 (32.4) | NA | NA |
| Unspecified hypertension | 0 | 4057 (17.7) | NA | NA |
| Prepregnancy gynecologic and reproductive history | | | | |
| Uterine fibroids | 33 318 (6.1) | 1946 (8.5) | <.001 | 0.093 |
| Adenomyosis | 6610 (1.2) | 470 (2.1) | <.001 | 0.066 |
| Endometriosis | 10 993 (2.0) | 551 (2.4) | <.001 | 0.027 |
| Polycystic ovary syndrome | 19 518 (3.6) | 1204 (5.3) | <.001 | 0.083 |
| History of abortion | 113 322 (20.7) | 4941 (21.6) | <.001 | 0.023 |

(continued)

had (1) 1 diagnosis or more of hypertension (codes I10-I13, I15, O10, O11, O13, O14, O15, or O16) within 280 days before delivery (ie, during pregnancy) or (2) hypertension (codes I10-I13 or code I15) before pregnancy (>280 days before the delivery date) within the 5 years preceding pregnancy, accompanied by antihypertensive medication use for 6 months or more during this period. The latter was defined as prepregnancy hypertension, indicating chronic disease. Hypertension was defined as systolic blood pressure of 140 mm Hg or higher or diastolic blood pressure of 90 mm Hg or higher per Korean Society of Hypertension guidelines.[37]

Participants with HDPs were further classified into 5 mutually exclusive subtypes using a hierarchical algorithm: (1) preeclampsia or eclampsia (codes O14 or O15 without prepregnancy hypertension), (2) superimposed preeclampsia (code O11, codes O14 or O15 with prepregnancy hypertension), (3) gestational hypertension (code O13 without prepregnancy hypertension), (4) chronic hypertension (code O10 or prepregnancy hypertension), and (5) unspecified HDPs (code O16, isolated codes I10-I13 or I15 during pregnancy not meeting other criteria). To preserve generalizability to clinical data and minimize misclassification bias, unspecified hypertension was retained as a prespecified subtype.

The validity of *ICD-10*–based definitions for HDPs and their subtypes was assessed in 100 randomly selected deliveries at Seoul National University Hospital (January to June 2018), showing excellent agreement with clinical diagnoses (overall accuracies of 99% for HDPs and 98% for subtypes) (eTable 1 in Supplement 1).

Table 1. Baseline Characteristics by HDP (continued)

| Variable | Women, No. (%) | | *P* value | ASD |
|---|---|---|---|---|
| | Without HDP (n = 547 967) | With HDP (n = 22 876) | | |
| Characteristics at prepregnancy health screening | | | | |
| BMI, mean (SD) | 21.3 (3.1) | 23.4 (4.5) | <.001 | 0.549 |
| BMI ≥25 | 60 988 (11.1) | 6728 (29.4) | <.001 | 0.455 |
| WC, mean (SD), cm | 71.0 (8.0) | 75.4 (10.6) | <.001 | 0.467 |
| Abdominal obesity[a] | 34 636 (6.3) | 4200 (18.4) | <.001 | 0.366 |
| Blood pressure, mean (SD), mm Hg | | | | |
| Systolic | 110.1 (10.7) | 119.3 (14.9) | <.001 | 0.709 |
| Diastolic | 69.1 (8.1) | 75.5 (10.9) | <.001 | 0.666 |
| Current smoker | 22 171 (4.0) | 1269 (5.5) | <.001 | 0.070 |
| Heavy alcohol use | 25 310 (4.6) | 1258 (5.5) | <.001 | 0.040 |
| Regular physical activity | 56 895 (10.4) | 2898 (12.7) | <.001 | 0.072 |
| Diabetes | 3694 (0.7) | 819 (3.6) | <.001 | 0.202 |
| Dyslipidemia | 23 257 (4.2) | 1899 (8.3) | <.001 | 0.167 |
| Chronic kidney disease | 3813 (0.7) | 171 (0.7) | .36 | 0.006 |
| Fasting glucose, mean (SD), mg/dL | 88.5 (11.5) | 92.6 (20.5) | <.001 | 0.246 |
| Total cholesterol, mean (SD), mg/dL | 180.1 (31.5) | 186.7 (33.9) | <.001 | 0.201 |
| HDL-C, mean (SD), mg/dL | 63.7 (18.1) | 61.4 (19.9) | <.001 | 0.122 |
| LDL-C, mean (SD), mg/dL | 100.3 (29.1) | 106.0 (31.4) | <.001 | 0.188 |
| Estimated GFR, mean (SD), mL/min/1.73 $m^2$ | 109.1 (17.7) | 108.2 (17.7) | <.001 | 0.049 |
| Follow-up duration, median (IQR), y[b] | 6.5 (4.8-8.7) | 5.9 (4.3-8.1) | <.001 | NA |

Abbreviations: ASD, absolute standardized difference; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); GFR, glomerular filtration rate; HDL-C, high-density lipoprotein cholesterol; HDP, hypertensive disorder of pregnancy; LDL-C, low-density lipoprotein cholesterol; NA, not applicable; WC, waist circumference.

SI conversion factors: To convert HDL-C, LDL-C, and total cholesterol to millimoles per liter, multiply by 0.0259; to convert fasting glucose to millimoles per liter, multiply by 0.0555.

[a] Defined as WC of 90 cm or more for men and 85 cm or more for women.

[b] Follow-up duration for composite cardiovascular events.

## Definitions of Covariates

Covariates were grouped into 3 domains: (1) clinical characteristics at delivery, (2) prepregnancy gynecologic and reproductive history (>280 days before delivery, within a 5-year window), and (3) health examination results within 2 years before pregnancy. More details are provided in the eMethods in Supplement 1.

## Outcome Definition

Participants were followed up from 1 year after the index delivery, to allow for a washout period, until December 2022. Follow-up data were available for all participants. The primary outcome was a composite of cardiovascular events, including cardiovascular death, HF, MI, stroke, and AF. Secondary outcomes were the individual components. Outcomes were identified using *ICD-10-CM* codes with additional operational criteria: HF (≥1 hospitalization with code I50), MI (≥1 hospitalization with codes I21-I22), stroke (≥1 hospitalization with codes I63-I64 plus a claim for brain computed tomography or magnetic resonance imaging), and AF (≥1 inpatient or ≥2 outpatient diagnoses of code I48). Cardiovascular death was defined as death attributed to any cardiovascular cause (*ICD-10* codes I00-I99).

## Statistical Analysis

Baseline characteristics were summarized as frequencies and percentages for categorical variables and as mean (SD) values for continuous variables. There were no missing values for the variables used in the study. Group comparisons were conducted using the $\chi^2$ test for categorical variables and the *t* test or analysis of variance for continuous variables. Absolute standardized differences (ASDs) were also calculated to assess between-group balance. Incidence rates were calculated as events per 1000 person-years. Kaplan-Meier curves estimated cumulative incidence, and group differences were assessed with the log-rank test. Cox proportional hazards models were applied to estimate adjusted hazard ratios (HRs) and 95% CIs for the association between HDPs (and their subtypes) and outcomes. Multivariable models were adjusted for age, income, residential area, parity, delivery mode, abortion history, gestational diabetes, prepregnancy comorbidities, and lifestyle factors. The assumed causal structure involving these variables is visualized using a directed acyclic graph (eFigure 1 in Supplement 1). Subgroup analyses were performed according to age, income, region, parity, delivery mode, abortion history, and multiple gestations.

We conducted 3 sensitivity analyses and 1 short-term outcome analysis. First, we excluded the unspecified HDP group to test the robustness of the results. Second, analyses were repeated in nulliparous women to minimize confounding from prior pregnancies. Third, we applied more stringent diagnostic criteria for HDPs, requiring 2 or more outpatient or 1 or more inpatient claims with an HDP-related *ICD-10* code. For the short-term outcome analysis, we conducted an additional evaluation

Table 2. Association Between HDPs and CV Outcomes

| Outcome | Patients, No. | Events, No. | Follow-up duration, PY | Incidence rate, per 1000 PY | Absolute risk difference, per 1000 PY[a] | Age-adjusted HR (95% CI) | *P* value | Adjusted HR (95% CI)[b] | *P* value | Adjusted HR (95% CI)[c] | *P* value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Composite CV events | | | | | | | | | | | |
| Without HDP | 547 967 | 8432 | 3 685 910 | 2.29 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| With HDP | 22 876 | 629 | 143 232 | 4.39 | 2.10 | 1.92 (1.77-2.08) | <.001 | 1.70 (1.57-1.85) | <.001 | 1.62 (1.49-1.76) | <.001 |
| CV death | | | | | | | | | | | |
| Without HDP | 547 967 | 77 | 3 707 084 | 0.02 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| With HDP | 22 876 | 12 | 144 883 | 0.08 | 0.06 | 3.70 (2.01-6.82) | <.001 | 2.76 (1.46-5.23) | .002 | 2.58 (1.35-4.91) | .004 |
| Heart failure | | | | | | | | | | | |
| Without HDP | 547 967 | 5688 | 3 694 169 | 1.54 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| With HDP | 22 876 | 426 | 143 862 | 2.96 | 1.42 | 1.94 (1.76-2.15) | <.001 | 1.71 (1.54-1.89) | <.001 | 1.61 (1.45-1.78) | <.001 |
| Myocardial infarction | | | | | | | | | | | |
| Without HDP | 547 967 | 1554 | 3 702 470 | 0.42 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| With HDP | 22 876 | 96 | 144 589 | 0.66 | 0.24 | 1.55 (1.26-1.91) | <.001 | 1.37 (1.11-1.68) | .004 | 1.33 (1.08-1.65) | .008 |
| Stroke | | | | | | | | | | | |
| Without HDP | 547 967 | 935 | 3 704 284 | 0.25 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| With HDP | 22 876 | 109 | 144 543 | 0.75 | 0.50 | 2.83 (2.32-3.45) | <.001 | 2.46 (2.00-3.01) | <.001 | 2.38 (1.94-2.92) | <.001 |
| Atrial fibrillation | | | | | | | | | | | |
| Without HDP | 547 967 | 1013 | 3 703 400 | 0.27 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| With HDP | 22 876 | 66 | 144 646 | 0.46 | 0.19 | 1.62 (1.26-2.08) | <.001 | 1.53 (1.19-1.97) | .001 | 1.51 (1.17-1.94) | .002 |

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CV, cardiovascular; HDP, hypertensive disorder of pregnancy; HR, hazard ratio; NA, not applicable; PY, person-years.

[a] Absolute risk difference compared with the no HDP group.

[b] Adjusted for age, BMI (≥25 vs <25), diabetes, dyslipidemia, and chronic kidney disease.

[c] Adjusted for age, BMI (≥25 vs <25), diabetes, dyslipidemia, chronic kidney disease, low income, metropolitan area residence, nulliparity, spontaneous vaginal delivery, history of abortion, gestational diabetes, current smoker, heavy alcohol use, and regular physical activity.

that did not exclude women who experienced cardiovascular events within the first postpartum year and examined the association between HDPs and outcomes during this 1-year period. This analysis included a total of 571 731 women.

All analyses were conducted using SAS, version 9.4 (SAS Institute Inc). Two-sided $P < .05$ was considered statistically significant. Data were analyzed from June 1 to October 31, 2025.

## Results

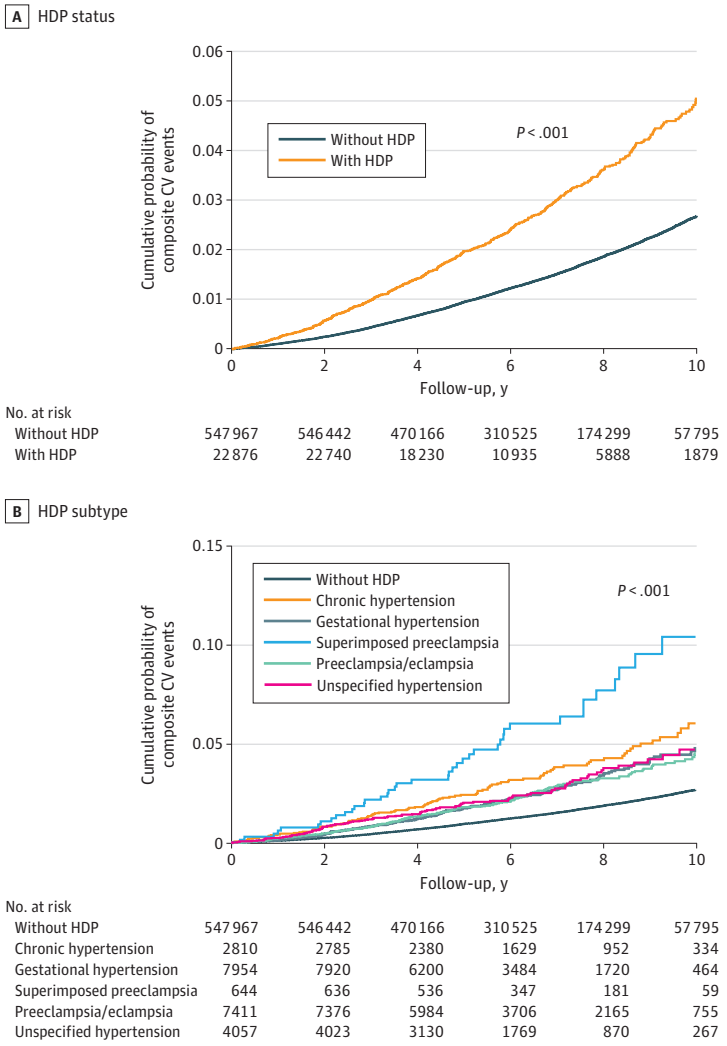
### Baseline Characteristics According to HDPs

Among the 570 843 women (mean [SD] age, 32.7 [4.0] years), 22 876 (4.0%) were identified as having HDPs. Women with HDPs were significantly older at delivery (mean [SD] age, 33.5 [4.4] vs 32.7 [4.0] years; ASD, 0.210) and were more likely to be nulliparous (73.3% vs 62.6%; ASD, 0.228) or have multiple gestations (6.6% vs 2.2%; ASD, 0.218) (**Table 1**). Cesarean delivery was frequent in both groups (66.2% vs 42.1%). Women with HDPs also showed a higher prevalence of cardiovascular risk factors, including higher body mass index, elevated blood pressure, diabetes, and dyslipidemia.

### Cardiovascular Events According to HDP Status

During a median follow-up of 6.5 years (IQR, 4.7-8.7 years), 629 of 22 876 women with HDPs (2.7%) and 8432 of 547 967 women without HDPs (1.5%) experienced cardiovascular events, corresponding to incidence rates of 4.39 and 2.29 per 1000 person-years, respectively ($P < .001$) (**Table 2** and **Figure 2**A). The absolute risk increase was 2.10 additional cardiovascular events per 1000 person-years. Cox regression showed that HDPs were associated with nearly a 2-fold increased risk of cardiovascular events (age-adjusted HR, 1.92; 95% CI, 1.77-2.08; $P < .001$), which remained significant after multivariable adjustment (adjusted HR, 1.62; 95% CI, 1.49-1.76; $P < .001$) (Table 2). Similar findings were observed in the sensitivity analysis excluding the unspecified HDP subtype (eTable 2 in Supplement 1). Subgroup analyses showed that this association was generally consistent across subgroups, except among women with multiple gestations, in whom the association was not significant

Figure 2. Cumulative Incidence of Composite Cardiovascular (CV) Events by Hypertensive Disorder of Pregnancy (HDP) Status and Subtype




Cumulative incidence curves are shown for composite CV events by HDP status (A) and HDP subtypes (B).

(eFigure 2 in Supplement 1). The association between HDPs and cardiovascular events was stronger among multiparous than nulliparous women ($P$ = .02 for interaction).

With respect to individual cardiovascular outcomes, women with HDPs experienced 12 cardiovascular deaths, 426 cases of HF, 96 of MI, 109 of strokes, and 66 of AF, corresponding to incidence rates of 0.08, 2.96, 0.66, 0.75, and 0.46 per 1000 patient-years, respectively (Table 2). These rates were significantly higher than those in women without HDPs (eFigure 3 in Supplement 1). In multivariable Cox analysis, HDPs remained independently associated with increased risks of each outcome (Table 2).

## HDP Subtypes and Their Association With Cardiovascular Events

Of the 22 876 women with HDPs, 7954 (34.8%) had gestational hypertension, 7411 (32.4%) had preeclampsia or eclampsia, 4057 (17.7%) had unspecified hypertension, 2810 (12.3%) had chronic hypertension, and 644 (2.8%) had superimposed preeclampsia. Baseline characteristics across HDP subtypes are shown in eTable 3 in Supplement 1.

The cumulative incidence of composite cardiovascular events was highest in women with superimposed preeclampsia (9.83 per 1000 person-years), followed by chronic hypertension (5.51 per 1000 person-years), unspecified hypertension (4.22 per 1000 person-years), preeclampsia or eclampsia (4.01 per 1000 person-years), and gestational hypertension (3.94 per 1000 person-years) (**Table 3** and Figure 2B). In multivariable Cox analysis, all HDP subtypes were significantly associated with an increased risk of cardiovascular events compared with women without HDPs, with the highest HR observed in superimposed preeclampsia (adjusted HR, 2.93; 95% CI, 2.15-3.99; $P$ < .001).

With respect to individual cardiovascular outcomes, all HDP subtypes were significantly associated with higher risks of HF and stroke, and most were associated with higher risk of cardiovascular death, compared with women without HDPs (Table 3). For MI, an association was not

Table 3. Association Between HDP Subtypes and CV Outcomes[a]

| Outcome | Patients, No. | Events, No. | Follow-up duration, PY | Incidence rate, per 1000 PY | Absolute risk difference, per 1000 PY[b] | Age-adjusted HR (95% CI) | *P* value | Adjusted HR (95% CI)[c] | *P* value | Adjusted HR (95% CI)[d] | *P* value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Composite CV events | | | | | | | | | | | |
| Without HDP | 547 967 | 8432 | 3 685 910 | 2.29 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| Chronic hypertension | 2810 | 105 | 19 050 | 5.51 | 3.22 | 2.24 (1.85-2.71) | <.001 | 1.89 (1.56-2.30) | <.001 | 1.81 (1.49-2.20) | <.001 |
| Gestational hypertension | 7954 | 189 | 47 939 | 3.94 | 1.65 | 1.79 (1.55-2.06) | <.001 | 1.60 (1.39-1.85) | <.001 | 1.53 (1.32-1.77) | <.001 |
| Superimposed preeclampsia | 644 | 41 | 4172 | 9.83 | 7.54 | 4.03 (2.96-5.47) | <.001 | 3.14 (2.31-4.28) | <.001 | 2.93 (2.15-3.99) | <.001 |
| Preeclampsia or eclampsia | 7411 | 191 | 47 664 | 4.01 | 1.72 | 1.73 (1.50-2.00) | <.001 | 1.58 (1.37-1.83) | <.001 | 1.50 (1.30-1.74) | <.001 |
| Unspecified hypertension | 4057 | 103 | 24 408 | 4.22 | 1.93 | 1.87 (1.54-2.27) | <.001 | 1.67 (1.38-2.03) | <.001 | 1.61 (1.33-1.96) | <.001 |
| CV death | | | | | | | | | | | |
| Without HDP | 547 967 | 77 | 3 707 084 | 0.02 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| Chronic hypertension | 2810 | 3 | 19 375 | 0.15 | 0.13 | 5.71 (1.79-18.22) | .003 | 3.64 (1.10-12.03) | .03 | 3.44 (1.04-11.36) | .04 |
| Gestational hypertension | 7954 | 4 | 48 385 | 0.08 | 0.06 | 4.08 (1.49-11.16) | .006 | 3.16 (1.14-8.75) | .03 | 2.92 (1.05-8.10) | .04 |
| Superimposed preeclampsia | 644 | 0 | 4286 | 0 | NA | NA | NA | NA | NA | NA | NA |
| Preeclampsia or eclampsia | 7411 | 5 | 48 136 | 0.10 | 0.08 | 4.59 (1.86-11.36) | .001 | 3.70 (1.48-9.25) | .005 | 3.48 (1.38-8.77) | .008 |
| Unspecified hypertension | 4057 | 0 | 24 702 | 0 | NA | NA | NA | NA | NA | NA | NA |
| Heart failure | | | | | | | | | | | |
| Without HDP | 547 967 | 5688 | 3 694 169 | 1.54 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| Chronic hypertension | 2810 | 74 | 19 155 | 3.86 | 2.32 | 2.38 (1.89-2.99) | <.001 | 1.98 (1.57-2.50) | <.001 | 1.88 (1.49-2.37) | <.001 |
| Gestational hypertension | 7954 | 129 | 48 113 | 2.68 | 1.14 | 1.82 (1.53-2.17) | <.001 | 1.62 (1.36-1.93) | <.001 | 1.52 (1.28-1.81) | <.001 |
| Superimposed preeclampsia | 644 | 27 | 4215 | 6.41 | 4.87 | 4.00 (2.74-5.84) | <.001 | 3.05 (2.08-4.46) | <.001 | 2.80 (1.91-4.09) | <.001 |
| Preeclampsia or eclampsia | 7411 | 131 | 47 830 | 2.74 | 1.20 | 1.77 (1.49-2.11) | <.001 | 1.60 (1.35-1.91) | <.001 | 1.50 (1.26-1.79) | <.001 |
| Unspecified hypertension | 4057 | 65 | 24 549 | 2.65 | 1.11 | 1.77 (1.39-2.26) | <.001 | 1.56 (1.22-2.00) | <.001 | 1.50 (1.17-1.91) | .001 |
| Myocardial infarction | | | | | | | | | | | |
| Without HDP | 547 967 | 1554 | 3 702 470 | 0.42 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| Chronic hypertension | 2810 | 15 | 19 328 | 0.78 | 0.36 | 1.67 (1.00-2.77) | .049 | 1.37 (0.82-2.29) | .23 | 1.32 (0.79-2.21) | .29 |
| Gestational hypertension | 7954 | 32 | 48 292 | 0.66 | 0.24 | 1.62 (1.14-2.30) | .007 | 1.45 (1.02-2.06) | .04 | 1.42 (0.99-2.02) | .051 |
| Superimposed preeclampsia | 644 | 5 | 4270 | 1.17 | 0.75 | 2.51 (1.04-6.05) | .04 | 1.89 (0.78-4.57) | .16 | 1.79 (0.74-4.33) | .19 |

(continued)

Table 3. Association Between HDP Subtypes and CV Outcomes[a] (continued)

| Outcome | Patients, No. | Events, No. | Follow-up duration, PY | Incidence rate, per 1000 PY | Absolute risk difference, per 1000 PY[b] | Age-adjusted HR (95% CI) | *P* value | Adjusted HR (95% CI)[c] | *P* value | Adjusted HR (95% CI)[d] | *P* value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Preeclampsia or eclampsia | 7411 | 25 | 48 069 | 0.52 | 0.10 | 1.21 (0.81-1.80) | .35 | 1.10 (0.74-1.63) | .65 | 1.07 (0.72-1.60) | .73 |
| Unspecified hypertension | 4057 | 19 | 24 630 | 0.77 | 0.35 | 1.83 (1.16-2.88) | .009 | 1.62 (1.03-2.55) | .04 | 1.58 (1.00-2.49) | .048 |
| Stroke | | | | | | | | | | | |
| Without HDP | 547 967 | 935 | 3 704 284 | 0.25 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| Chronic hypertension | 2810 | 15 | 19 315 | 0.78 | 0.53 | 2.51 (1.51-4.19) | <.001 | 2.03 (1.21-3.41) | .007 | 1.98 (1.18-3.32) | .01 |
| Gestational hypertension | 7954 | 29 | 48 292 | 0.60 | 0.35 | 2.43 (1.68-3.51) | <.001 | 2.15 (1.48-3.11) | <.001 | 2.07 (1.42-3.00) | <.001 |
| Superimposed preeclampsia | 644 | 9 | 4259 | 2.11 | 1.86 | 6.79 (3.52-13.11) | <.001 | 4.98 (2.56-9.70) | <.001 | 4.75 (2.44-9.27) | <.001 |
| Preeclampsia or eclampsia | 7411 | 33 | 48 052 | 0.69 | 0.44 | 2.57 (1.82-3.64) | <.001 | 2.32 (1.64-3.29) | <.001 | 2.26 (1.59-3.22) | <.001 |
| Unspecified hypertension | 4057 | 23 | 24 625 | 0.93 | 0.68 | 3.58 (2.37-5.42) | <.001 | 3.13 (2.06-4.75) | <.001 | 3.03 (2.00-4.60) | <.001 |
| Atrial fibrillation | | | | | | | | | | | |
| Without HDP | 547 967 | 1013 | 3 703 400 | 0.27 | Reference | 1 [Reference] | NA | 1 [Reference] | NA | 1 [Reference] | NA |
| Chronic hypertension | 2810 | 15 | 19 308 | 0.78 | 0.51 | 2.57 (1.54-4.28) | <.001 | 2.37 (1.41-3.96) | .001 | 2.33 (1.39-3.90) | .001 |
| Gestational hypertension | 7954 | 16 | 48 332 | 0.33 | 0.06 | 1.22 (0.74-1.99) | .44 | 1.16 (0.71-1.90) | .56 | 1.14 (0.69-1.87) | .62 |
| Superimposed preeclampsia | 644 | 4 | 4268 | 0.94 | 0.67 | 3.09 (1.16-8.24) | .02 | 2.73 (1.02-7.33) | .045 | 2.67 (0.99-7.17) | .051 |
| Preeclampsia or eclampsia | 7411 | 18 | 48 079 | 0.37 | 0.10 | 1.33 (0.83-2.12) | .23 | 1.28 (0.80-2.04) | .31 | 1.25 (0.78-2.00) | .35 |
| Unspecified hypertension | 4057 | 13 | 24 660 | 0.53 | 0.26 | 1.89 (1.09-3.26) | .02 | 1.79 (1.04-3.10) | .04 | 1.79 (1.03-3.10) | .04 |

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CV, cardiovascular; HDP, hypertensive disorder of pregnancy; HR, hazard ratio; NA, not applicable; PY, person-years.

[a] Absolute risk difference and HR were not calculated for groups with no events.

[b] Absolute risk difference compared with the no HDP group.

[c] Adjusted for age, BMI (≥25 vs <25), diabetes, dyslipidemia, and chronic kidney disease.

[d] Adjusted for age, BMI (≥25 vs <25), diabetes, dyslipidemia, chronic kidney disease, low income, metropolitan area residence, nulliparity, spontaneous vaginal delivery, history of abortion, gestational diabetes, current smoker, heavy alcohol use, and regular physical activity.

observed for gestational hypertension (adjusted HR, 1.42; 95% CI, 0.99-2.02; *P* = .051) but was for unspecified hypertension (adjusted HR, 1.58; 95% CI, 1.00-2.49; *P* = .048). For AF, associations were observed for chronic hypertension (adjusted HR, 2.33; 95% CI, 1.39-3.90; *P* = .001) and unspecified hypertension (adjusted HR, 1.79; 95% CI, 1.03-3.10; *P* = .04) but not superimposed preeclampsia (adjusted HR, 2.67; 95% CI, 0.99-7.17; *P* = .051).

### Sensitivity Analyses in Nulliparous Women and Using Stringent HDP Criteria

Findings were materially unchanged when analyses were limited to nulliparous women (n = 359 892): HDPs remained associated with a higher risk of the primary composite outcome (eTable 4 in Supplement 1), with the highest risk noted for superimposed preeclampsia (adjusted HR, 2.56; 95% CI, 1.66-3.95; *P* < .001) (eTable 5 in Supplement 1). Most HDP subtypes were associated with increased risks of HF and stroke. Associations between chronic hypertension or superimposed preeclampsia and AF were also observed.

When applying more stringent criteria for HDP diagnosis, 6388 (1.1%) were classified as having HDPs. Any HDP was again associated with increased risks of composite cardiovascular events and individual outcomes (eTable 6 in Supplement 1). All HDP subtypes were associated with the risk of composite cardiovascular events, HF, and stroke, and most subtypes with cardiovascular death (eTable 7 in Supplement 1). Associations of unspecified hypertension with MI and of chronic hypertension and superimposed preeclampsia with AF were consistently observed.

### Short-Term Outcome Analysis

In the short-term outcome analysis (n = 571 731), HDPs were associated with a markedly higher risk of 1-year cardiovascular events (adjusted HR, 4.04; 95% CI, 3.33-4.89; *P* < .001) (eFigure 4A and eTable 8 in Supplement 1). Increased risks were also observed for individual outcomes. Among HDP subtypes, superimposed preeclampsia showed the highest 1-year incidence of cardiovascular events (eFigure 4B and eTable 9 in Supplement 1) and was consistently associated with increased risks of each individual outcome.

## Discussion

In this large, nationwide cohort of more than half a million women with delivery records, HDPs were independently associated with an increased long-term risk of major cardiovascular events. The magnitude of risk varied by HDP subtype, with the highest risk of composite cardiovascular events observed in women with superimposed preeclampsia. For individual outcomes, the risks of HF and stroke were consistently elevated across all subtypes, and most subtypes were also associated with cardiovascular death, whereas associations with MI were observed for unspecified hypertension. The risk of AF was increased in the chronic hypertension and unspecified hypertension subgroups. These findings extend the existing literature by delineating subtype-specific cardiovascular risk profiles and highlight the need for tailored postpartum surveillance.

HDPs affect 5% to 10% of pregnancies and remain a leading cause of maternal morbidity and mortality. Although prevalence varies by ethnicity, with relatively lower rates observed among Asian individuals,[32] the incidence has increased markedly in recent decades across populations.[38] The underlying pathophysiology is multifactorial, involving abnormal placentation, placental ischemia, angiogenic imbalance, and endothelial dysfunction.[30,39] HDPs are also associated with diverse adverse maternal and fetal or neonatal outcomes, including preterm birth, placental abruption, postpartum hemorrhage, stillbirth, and short-term cardiovascular complications during the peripartum period.[3] Consequently, affected women require more frequent and intensive peripartum management.

HDPs are a well-established risk factor for long-term cardiovascular disease, including MI, stroke, HF, AF, and cardiovascular mortality.[4-29] However, most evidence to date has been derived from Western populations. A prior Korean nationwide study of approximately 420 000 women who delivered between 2007 and 2010 demonstrated an increased risk of ischemic heart disease and stroke after preeclampsia.[40] Our study extends this evidence by including all HDP subtypes in a contemporary, population-based cohort of Asian women from South Korea. Even after comprehensive adjustment for metabolic, socioeconomic, and pregnancy-related factors, HDPs remained independently associated with adverse cardiovascular outcomes, suggesting residual vascular susceptibility beyond conventional risk factors.

In subgroup analyses, HDPs were associated with an increased risk of cardiovascular events regardless of delivery mode, indicating that their long-term cardiovascular burden persists beyond obstetric or procedural factors despite the high rate of cesarean delivery in South Korea.[41] We observed a higher cardiovascular risk associated with HDPs in nonnulliparous than in nulliparous women, possibly reflecting residual effects of prior pregnancies.[42] Previous studies suggest that HDPs in multifetal pregnancy may not be associated with cardiovascular risk,[43] and a similar pattern was observed in our study.

Existing studies have consistently shown that preeclampsia is associated with an elevated risk of future cardiovascular disease,[14,16,20,21,24,25] but evidence for other HDP subtypes has been limited. Although several studies have reported associations between gestational hypertension and increased risks of coronary artery disease or mortality,[7,13,27] direct comparisons with other HDP subtypes beyond preeclampsia and comprehensive evaluations across diverse cardiovascular outcomes remain limited. In our analysis, women with superimposed preeclampsia exhibited both the highest incidence and the highest adjusted risk of cardiovascular events among all subtypes. Superimposed preeclampsia, defined as new-onset preeclamptic features in women with preexisting chronic hypertension, is associated with earlier and more severe maternal and fetal complications, yet it often remains underrecognized due to diagnostic challenges stemming from overlapping clinical features with chronic hypertension.[44] Although this subtype accounts for fewer than 5% to 10% of all HDP cases,[8,9,28,29] our findings indicate that their long-term cardiovascular risk is disproportionately high. We also found that un-

specified hypertension was consistently associated with increased risks for cardiovascular outcomes. Retaining this category reflects clinical coding and minimizes misclassification bias, and sensitivity analyses after excluding this category produced results consistent with the primary findings.

Beyond the composite outcome, we observed heterogeneity in the associations between HDP subtypes and specific cardiovascular end points. All subtypes were associated with higher risks of HF and stroke, and most were also associated with cardiovascular death, whereas associations for MI and AF were confined to certain subgroups. Specifically, MI risk was elevated in women with unspecified hypertension, whereas AF risk was elevated primarily in those with chronic hypertension and unspecified hypertension. Consistent with our findings, a mendelian randomization analysis demonstrated that genetically predicted gestational hypertension was associated with higher coronary artery disease risk.[7] In contrast, chronic hypertension may promote long-term atrial remodeling and electrical instability, increasing susceptibility to AF.[45] These mechanistic differences provide a plausible biological basis for the divergent patterns observed in our study.

Taken together, our findings emphasize the need for long-term cardiovascular surveillance in women who have experienced HDPs. Given the subtype-specific risks observed—particularly the markedly elevated risk with superimposed preeclampsia—earlier and more frequent blood pressure, lipid, and glucose screening, along with lifestyle counseling, may be warranted in these high-risk women. Integrating HDP subtype information into postpartum care pathways, and potentially linking it to primary care records to support ongoing cardiovascular risk assessment, may facilitate more effective risk stratification and long-term management.

### Limitations

This study has several limitations. First, although it represents a large nationwide cohort of deliveries, not all pregnancies were included because eligibility was restricted to women who underwent a general health examination within 2 years before pregnancy (Figure 1). This criterion was necessary to ensure standardized baseline information and valid covariate adjustment. Second, HDPs and their subtypes were identified using claims data. Although this approach is practical for large-scale analyses, it is prone to misclassification; however, we minimized this through a strict hierarchical classification algorithm, the validity of which was confirmed in a small subset of patients from our institution. Third, the overall incidence of cardiovascular events was low, partly reflecting the young age of participants, which may have limited power to detect associations for less common HDP subtypes. Fourth, we lacked information on HDP history from previous pregnancies. However, our parity-restricted sensitivity analysis supports the robustness of the primary findings. Fifth, despite adjustment for extensive baseline characteristics, unmeasured factors such as family history, dietary patterns, or laboratory markers during pregnancy could still confound the results. Sixth, the database lacked information on HDP severity and timing of onset (eg, early- vs late-onset preeclampsia). Seventh, postpartum trajectories, including persistence of hypertension, initiation of preventive therapies, or lifestyle changes, were unavailable, which may mediate long-term risk. Finally, as an observational study, our results cannot establish causality.

## Conclusions

In this cohort study, all HDP subtypes were independently associated with increased long-term cardiovascular risk, with the highest risk observed in superimposed preeclampsia. Although HF and stroke risks were elevated across all subtypes, associations with MI and AF varied by subtype. These findings suggest potential heterogeneity in cardiovascular outcomes following HDPs and underscore the need to incorporate HDP subtype into postpartum risk assessment.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