

Association of Short Interpregnancy Interval With Pregnancy Outcomes According to Maternal Age

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IMPORTANCE Interpregnancy intervals shorter than 18 months are associated with higher risks of adverse pregnancy outcomes. It is currently unknown whether short intervals are associated with increased risks among older women to the same extent as among younger women.

OBJECTIVE To evaluate whether the association between short interpregnancy (delivery to conception) interval and adverse pregnancy outcomes is modified by maternal age.

DESIGN, SETTING, AND PARTICIPANTS A population-based cohort study conducted in British Columbia, Canada, evaluated women with 2 or more singleton pregnancies from 2004 to 2014 with the first (index) pregnancy resulting in a live birth. Data analysis was performed from January 1 to July 20, 2018.

MAIN OUTCOMES AND MEASURES Risks of maternal mortality or severe morbidity (eg, mechanical ventilation, blood transfusion >3 U, intensive care unit admission, organ failure, death), small-for-gestational age (<10th birthweight percentile for gestational age and sex), fetal and infant composite outcome (stillbirth, infant death, <third birthweight percentile for gestational age and sex, delivery <28 weeks), and spontaneous and indicated preterm delivery. Risks of each outcome for 3- to 24-month interpregnancy intervals were estimated, according to maternal age at index birth (20-34 and ≥ 35 years). Adjusted risk ratios (aRRs) comparing predicted risks at 3-, 6-, 9-, and 12-month intervals with risks at 18-month intervals for each age group were calculated. The potential role of other factors explaining any differences (unmeasured confounding) was examined in several sensitivity analyses.

RESULTS Among 148 544 pregnancies, maternal mortality or severe morbidity risks were increased at 6-month compared with 18-month interpregnancy intervals for women aged 35 years or older (0.62% at 6 months vs 0.26% at 18 months; aRR, 2.39; 95% CI, 2.03-2.80), but not for women aged 20 to 34 years (0.23% at 6 months vs 0.25% at 18 months; aRR, 0.92; 95% CI, 0.83-1.02). Increased adverse fetal and infant outcome risks were more pronounced for women aged 20 to 34 years (2.0% at 6 months vs 1.4% at 18 months; aRR, 1.42; 95% CI, 1.36-1.47) than women 35 years or older (2.1% at 6 months vs 1.8% at 18 months; aRR, 1.15; 95% CI, 1.01-1.31). Risks of spontaneous preterm delivery at 6-month interpregnancy intervals were increased for women 20 to 34 years old (5.3% at 6 months vs 3.2% at 18 months; aRR, 1.65; 95% CI, 1.62-1.68) and to a lesser extent for women 35 years or older (5.0% at 6 months vs 3.6% at 18 months; aRR, 1.40; 95% CI, 1.31-1.49). Modest increases in risks of small-for-gestational age and indicated preterm delivery at short intervals did not vary meaningfully by maternal age. Sensitivity analyses suggested that observed associations were not fully explained by unmeasured confounding.

CONCLUSIONS AND RELEVANCE The findings of this study suggest that short interpregnancy intervals are associated with increased risks for adverse pregnancy outcomes for women of all ages.

JAMA Intern Med. doi:10.1001/jamainternmed.2018.4696
Published online October 29, 2018.

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Interpregnancy intervals (intervals between delivery and conception of the subsequent pregnancy) shorter than 18 months appear to be associated with increased risks of adverse outcomes, including preterm delivery, small-for-gestational-age (SGA) birth, and infant mortality.¹⁻⁶ Based on these associations, clinical postpartum practice^{7,8} and public health^{9,10} guidelines recommend interpregnancy intervals of at least 18 to 24 months.

However, it is currently unknown whether short intervals are associated with increased risks among older women to the same extent as among younger women. In the United States, women with a first birth at age 30 years or older have shorter interpregnancy intervals compared with women who began childbearing at younger ages.^{11,12} Older maternal age is associated with increased reproductive birth risks, including infertility, chromosomal anomalies, and adverse birth outcomes.¹³ Women who have delayed childbearing must balance the risks associated with a shorter interpregnancy interval against the risks of older maternal age at conception if they delay subsequent pregnancies to achieve the recommended interpregnancy interval.

Pregnancy and maternal characteristics associated with short interpregnancy interval may vary by maternal age (eg, unintended pregnancy, lower socioeconomic position, perinatal loss in the first pregnancy).^{14,15} Therefore, the association between short interpregnancy interval and adverse outcomes may vary by maternal age such that short intervals might not be associated with increased risks in older women. With limited previous work on this question,¹⁶ the extent to which the associations between short interpregnancy interval and adverse pregnancy outcomes vary by maternal age is poorly understood. The objective of this study was to evaluate whether the associations between short interpregnancy interval and pregnancy outcomes vary by maternal age.

Methods

Study Population

This population-based cohort was drawn from all women with at least 2 consecutive singleton pregnancies in British Columbia, Canada, from April 1, 2004, to March 31, 2014, using population-based health databases. Data analysis was performed from January 1 to July 20, 2018. Our primary database was the British Columbia Perinatal Data Registry,¹⁷ maintained by Perinatal Services British Columbia, which contains demographic and clinical data abstracted from obstetrical and newborn medical records for nearly 100% of live or stillbirth births in British Columbia of 20 or more completed weeks' gestation or birthweight of 500 g or more, including maternal postpartum readmissions up to 42 days after delivery and baby transfers and readmissions up to 28 days post birth. Population Data BC, a multi-university data platform that provides researchers with deidentified linkages of British Columbia's administrative data, linked the British Columbia Perinatal Data Registry with additional population-level databases, including physician billing,¹⁸ outpatient prescription,¹⁹ and hospital discharge records,²⁰ census and community size data,^{21,22}

Key Points

Question Is the association of short interpregnancy interval with pregnancy outcomes modified by maternal age?

Findings In this cohort study of 148 544 pregnancies, maternal mortality or severe morbidity risks were increased at short interpregnancy intervals among women 35 years or older but not for women aged 20 to 34 years; in contrast, increased risks of adverse fetal and infant outcomes and spontaneous preterm delivery were more pronounced for women aged 20 to 34 years than for those 35 years and older. Modest increases in risks of small-for-gestational-age birth and indicated preterm delivery at short intervals were not meaningfully different across maternal age groups.

Meaning Short interpregnancy intervals appear to be associated with increased risks for adverse pregnancy outcomes for women of all ages; maternal risks at short intervals may be greater for older women, whereas fetal and infant risks may be greater for younger women.

and vital statistics records.²³ The University of British Columbia/Children's and Women's Health Centre of British Columbia Research Ethics Board approved this study with waiver of informed consent.

Live births and stillbirths of 20 or more completed weeks' gestation were identified using the British Columbia Perinatal Data Registry. Pregnancies ending before 20 weeks' gestation were identified using physician billing, hospital discharge, or outpatient prescription codes for spontaneous or induced abortion (codes in eTable 1 in the Supplement). We excluded post-interval (subsequent) pregnancies if the preinterval pregnancy ended in a spontaneous or induced abortion at less than 20 weeks' gestation, stillbirth, or neonatal death, because the association between interpregnancy interval and outcomes in the subsequent pregnancy may be different following a live birth than following a perinatal or neonatal loss,²⁴ and guidelines differ for pregnancy spacing following a loss.¹⁰ Women with more than 2 eligible interpregnancy intervals in the study period could contribute more than 1 observation for the analyses.

Exposure and Outcome Definitions

We defined interpregnancy interval as the time in months between the first eligible birth in the study period (the index birth) and the conception of the subsequent pregnancy. To calculate this interval, we subtracted the index birth date from the subsequent birth date minus the gestational age at birth of the subsequent pregnancy (using an algorithm-based estimate of gestational age based on last menstrual period, first ultrasonography [<20 weeks], clinical estimate from newborn examination, and documentation from maternal record). For subsequent pregnancies that ended in spontaneous or induced abortion at less than 20 weeks, we assumed the diagnosis, treatment, or hospital admission date to be the pregnancy loss date, and imputed gestational age at 12 weeks (97% were missing a gestational age estimate).

Outcomes included (1) maternal mortality or severe morbidity (mechanical ventilation, intensive care unit admission, organ failure, blood transfusion >3 U, unanticipated post-

partum surgical procedure, or death) through pregnancy up to 42 days postpartum,²⁵ (2) SGA birth (<10th percentile for sex and gestational age),²⁶ (3) fetal and infant composite (still-birth, infant death within 1 year after birth, extreme SGA birth [<3rd percentile], delivery <28 weeks), (4) spontaneous preterm delivery at less than 37 weeks, and (5) indicated preterm delivery at less than 37 weeks. Outcomes were defined using *International Classification of Disease, Ninth Edition* or *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision*, Canadian Classification of Interventions, Version 9, and British Columbia Medical Service Plan billing codes. Detailed variable definitions are provided in eTable 1 in the [Supplement](#).

Statistical Analysis

We examined the association between interpregnancy interval and each outcome in the overall population and stratified by categories of maternal age at index birth: younger than 20 years, 20 to 34 years, and 35 years or older. First treating interpregnancy interval as a categorical variable, we tabulated the incidence of each outcome by interpregnancy interval in 6-month categories (<6, 6-11, 12-17, 18-23, and ≥24 months). Next, we used logistic regression and postestimation calculations²⁷ to estimate predicted odds of each outcome in 1-month increments of interpregnancy interval from 3 to 24 months, which we then transformed to predicted absolute risks. To allow for curvilinear shapes, we modeled interpregnancy interval as a continuous variable using restricted cubic splines, with 4 knots at the 5th, 35th, 65th, and 95th percentiles of interpregnancy interval in the study population (5.7, 15.3, 24.8, and 55.3 months).²⁸ For each outcome, we fit unadjusted models including only interpregnancy interval spline terms and adjusted models also including baseline (ie, measured at or before the index birth) covariates identified as potential confounders of the association between short interpregnancy interval and adverse maternal and infant outcomes: nulliparity, smoking before or during index pregnancy, low neighborhood income, inadequate prenatal care, and outcome of index pregnancy (eg, preterm delivery in index pregnancy in model for preterm delivery). In unstratified models using the overall population, we also adjusted for maternal age. Adjusted risks were standardized to population average covariate values based on interpregnancy intervals of 18 months. We examined variance inflation factors to assess multicollinearity between variables included in adjusted models and considered values of 3 or higher as potentially concerning.

We plotted absolute predicted risks with 95% CIs in the overall population and separately for each age category to display the associations visually. We then used predicted absolute risks to calculate risk ratios (RRs) with 95% CIs comparing predicted risks at 3-, 6-, 9-, and 12-month interpregnancy intervals with predicted risks at the 18-month interval reference length, at population mean covariate values based on interpregnancy intervals of 18 months. In age-stratified analyses, we estimated RRs separately for each category of maternal age and performed a test for interaction for each outcome at each interval length.²⁹ Findings were considered significant at $P < .05$ (2-sided).

We used robust variance estimation to account for non-independence of 2 or more interpregnancy intervals in the same woman. Analyses for all outcomes other than maternal mortality or severe morbidity were restricted to births at 20 weeks' or more gestation, as pregnancies ending earlier than 20 weeks were not at risk of birth outcomes. Analyses for SGA birth were restricted to those 22 to 43 weeks, owing to availability of reference charts. We excluded 616 records of pregnancies of 20 weeks or more owing to missing gestational age. We imputed missing values for number of antenatal visits (10 382 [7.0%]), using multiple imputation with 30 imputations based on all covariates and outcomes combined according to the Rubin formula.³⁰ For individuals with missing neighborhood income values for the index birth year (7857 [5.3%]), we assigned values from proximal years if available (7654 [5.2%]) and imputed missing values for the remaining 203 (0.1%). All analyses were conducted using Stata, version 14.2 (StataCorp).³¹

Sensitivity Analyses

To assess whether our results were sensitive to age categorization thresholds, we repeated analyses for women younger than 30 years and 30 years or older and for women younger than 40 years and 40 years or older. We conducted several analyses to examine the potential role of unmeasured and residual confounding. We (1) adjusted for additional measured baseline clinical and sociodemographic covariates that could be potential confounding variables (eg, rural residence, obesity, infertility treatment); (2) assessed potential confounding by pregnancy intention by restricting to pregnancies following an infertility diagnosis on the assumption that these pregnancies were more likely to be intended, (3) calculated E values, which represent the minimum strength of association that unmeasured confounding variables (eg, pregnancy intention,³² intimate partner violence^{33,34}) would need to have with both interpregnancy interval and each outcome to fully explain the observed association³⁵; and (4) used the outcome of the index pregnancy as a negative control, on the assumption that no association between the outcome of the index pregnancy and interpregnancy interval could provide evidence against unmeasured confounding.³⁶ These approaches are detailed further in eAppendix 1 in the [Supplement](#). To ensure that our findings were not sensitive to our methodologic approach of imputing missing data, we compared estimates using multiple imputation with those applying simple imputation (mean or missing indicator) and a complete case approach.

Results

Our study population included 123 122 women and 148 544 pregnancies subsequent to a live index birth (some women contributed more than 1 interpregnancy interval). Of these, 121 242 pregnancies (81.6%) continued to 20 weeks' or more gestation and the remaining 27 302 (18.4%) ended in spontaneous or induced abortion at less than 20 weeks. The majority of pregnancies (123 821 [83.4%]) were in women between ages 20 and 34 years at the index (preinterval) birth, while 7184 (4.8%) were

Table 1. Sociodemographic and Clinical Characteristics of the Study Population According to Interpregnancy Interval Category in 148 544 Pregnancies

Characteristic ^a	Interpregnancy Interval, No. (%) of Women					
	All (N = 148 544)	<6 mo (n = 8375)	6-11 mo (n = 25 085)	12-17 mo (n = 33 500)	18-23 mo (n = 26 534)	≥24 mo (n = 55 050)
Maternal age, y						
<20	7184 (4.8)	825 (9.9)	1390 (5.5)	1246 (3.7)	980 (3.7)	2743 (5.0)
20-34	123 821 (83.4)	6767 (80.8)	20 595 (82.1)	27 829 (83.1)	22 078 (83.2)	46 552 (84.6)
≥35	17 539 (11.8)	783 (9.4)	3100 (12.4)	4425 (13.2)	3476 (13.1)	5755 (10.5)
Nulliparity	96 139 (64.7)	4241 (50.6)	15 245 (60.8)	22 608 (67.5)	18 302 (69.0)	35 743 (64.9)
Low neighborhood income ^b	33 513 (22.6)	2552 (30.5)	5832 (23.2)	6868 (20.5)	5525 (20.9)	12 736 (23.2)
Rural residence ^c	18 970 (12.8)	1335 (16.0)	3533 (14.1)	4279 (12.8)	3208 (12.1)	6615 (12.0)
Inadequate prenatal care (<5 visits) ^d	9190 (6.7)	989 (12.9)	1789 (7.1)	1807 (5.8)	1383 (5.6)	3222 (6.3)
Smoking	15 882 (10.7)	1860 (22.2)	3095 (12.3)	2789 (8.3)	2153 (8.1)	5985 (10.9)
Infertility diagnosis or non-IVF infertility medication use	14 388 (9.7)	695 (8.3)	2781 (11.1)	3705 (11.1)	2654 (10.0)	4553 (8.3)
BMI ^e						
<18.5	6906 (6.7)	399 (7.5)	1128 (6.6)	1409 (6.0)	1120 (6.0)	2850 (7.5)
18.5 to <25	64 052 (62.3)	2887 (54.3)	10 396 (60.6)	15 118 (64.2)	11 965 (63.8)	23 686 (62.2)
25 to <30	20 345 (19.8)	1175 (22.1)	3607 (21.0)	4542 (19.3)	3645 (19.4)	7376 (19.4)
≥30	11 544 (11.2)	857 (16.1)	2029 (11.8)	2470 (10.5)	2017 (10.8)	4171 (11.0)
History of stillbirth or neonatal death	1469 (1.0)	116 (1.4)	280 (1.1)	345 (1.0)	240 (0.9)	488 (0.9)
History of preterm delivery	4322 (2.9)	431 (5.2)	885 (3.5)	864 (2.6)	662 (2.5)	1480 (2.7)
History of spontaneous abortion	30 890 (20.8)	2164 (25.8)	5943 (23.7)	7211 (21.5)	5370 (20.2)	10 202 (18.5)
Postinterval (subsequent) pregnancy ending in spontaneous or induced abortion <20 wk	27 302 (18.4)	2907 (34.7)	5010 (20.0)	4892 (14.6)	3872 (14.6)	10 621 (19.3)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); IVF, in vitro fertilization.

^a Characteristics were assessed at or before the index birth.

^b Census tract neighborhood income missing in 7857 (5.3%) observations.

^c Community size information missing in 5931 (4.0%) observations.

^d Number of antenatal visits missing in 10 382 (7.0%) observations.

^e Body mass index missing in 45 743 (30.8%) observations.

in women younger than 20 years and 17 539 (11.8%) were in women 35 years or older at the index birth.

The distribution of interpregnancy interval differed somewhat by maternal age at index birth (eFigure 1 in the [Supplement](#)). Interpregnancy intervals shorter than 6 months were less common among women 35 years or older at the index birth than women aged 20 to 34 years (4.4% vs 5.5%). Women 35 years or older more often had interpregnancy intervals 6 to 11 and 12 to 17 months long than women aged 20 to 34 years (6-11 months, 17.7% vs 16.6% and 12-17 months, 25.2% vs 22.5%) but had fewer intervals 24 months or longer (32.8% vs 37.6%).

Sociodemographic and clinical characteristics of the study population at the time of index birth according to interpregnancy interval categories are reported in [Table 1](#). Low neighborhood income, inadequate prenatal care, and smoking in pregnancy were most common among women with interpregnancy intervals shorter than 6 months. Women with interpregnancy intervals shorter than 6 months were also more likely to have a history of stillbirth, neonatal death, preterm delivery, or spontaneous abortion. In addition, pregnancies following intervals shorter than 6 months were much more likely to end in spontaneous or indicated abortion at less than 20 weeks. As reported in eTable 2 in the [Supplement](#), maternal age younger than 20 years, smoking, inadequate prenatal care, and low neighborhood income also were associated with spontaneous or indicated abortion at less than 20 weeks.

The incidence of each outcome according to 6-month categories of interpregnancy interval for all women, and separately for those younger than 20 years, 20 to 34 years, and 35 years or older at index birth, is reported in [Table 2](#). [Figure 1](#) displays the unadjusted and adjusted predicted risk curves for each outcome according to 1-month increments of interpregnancy interval from 3 to 24 months. Risk curves were U- or L-shaped for all outcomes, with nadirs near 18 months, and similarly low risks for most outcomes from 12- to 24-month intervals. Adjusted RRs (aRRs) comparing predicted risks at 3-, 6-, 9-, and 12-month intervals with predicted risks at the referent 18-month interval length are tabulated in [Table 3](#).

In the overall population, interpregnancy intervals of less than 12 months were associated with modest increases in risk of maternal mortality or severe morbidity (predicted risk, 0.30% at 6 months and 0.25% at 18 months; aRR comparing 6-month with 18-month intervals: 1.18; 95% CI, 1.09-1.27) and larger increases in risk of adverse fetal and infant outcomes (predicted risk, 2.0% at 6 months compared with 1.5% at 18 months: aRR, 1.36; 95% CI, 1.31-1.40), and spontaneous preterm delivery (predicted risk, 5.3% at 6 months compared with 3.3% at 18 months: aRR, 1.59; 95% CI, 1.56-1.62). Risk of SGA birth and indicated preterm delivery were only slightly higher at 6-month intervals (aRRs, 1.11; 95% CI, 1.08-1.14 and 1.08; 95% CI, 1.04-1.13, respectively).

Table 2. Incidence of Outcomes According to Categories of Interpregnancy Interval, Stratified by Maternal Age at Index Birth in 148 544 Pregnancies

Characteristic ^a	Pregnancy Interval, No. (%) of Women					
	All	<6 mo	6-11 mo	12-17 mo	18-23 mo	≥24 mo
Maternal Mortality or Severe Morbidity^b						
All women	476 (0.4)	28 (0.3)	72 (0.3)	89 (0.3)	78 (0.3)	209 (0.4)
Maternal age, y						
<20	30 (0.4)	Suppressed ^c	6 (0.4)	6 (0.5)	Suppressed ^c	10 (0.4)
20-34	379 (0.3)	15 (0.2)	57 (0.3)	71 (0.3)	59 (0.3)	177 (0.4)
≥35	67 (0.4)	9 (1.2)	9 (0.3)	12 (0.3)	15 (0.5)	22 (0.4)
Adverse Fetal and Infant Composite^d						
All women	2358 (2.0)	164 (3.0)	387 (1.9)	452 (1.6)	389 (1.7)	966 (2.2)
Maternal age, y						
<20	134 (2.7)	13 (2.8)	17 (1.9)	24 (2.8)	23 (3.2)	57 (2.8)
20-34	1939 (1.9)	136 (3.0)	318 (1.9)	362 (1.5)	313 (1.6)	810 (2.1)
≥35	286 (2.2)	15 (3.0)	51 (2.2)	66 (1.9)	55 (2.1)	99 (2.5)
Small-for-Gestational Age						
All women	4986 (4.1)	272 (5.0)	739 (3.7)	1069 (3.8)	878 (3.9)	2028 (4.6)
Maternal age, y						
<20	222 (4.5)	21 (4.5)	39 (4.5)	34 (4.0)	31 (4.3)	97 (4.8)
20-34	4281 (4.2)	218 (4.8)	643 (3.8)	916 (3.8)	747 (3.9)	1757 (4.6)
≥35	482 (3.7)	33 (6.6)	57 (2.4)	119 (3.4)	100 (3.8)	173 (4.4)
Spontaneous Preterm Delivery						
All women	5363 (4.4)	454 (8.3)	1030 (5.2)	1133 (4.0)	859 (3.8)	1887 (4.3)
Maternal age, y						
<20	374 (7.5)	45 (9.6)	81 (6.4)	51 (7.0)	51 (7.0)	133 (6.5)
20-34	4413 (4.3)	381 (8.5)	820 (4.9)	912 (3.8)	719 (3.7)	1581 (4.1)
≥35	576 (4.4)	28 (5.6)	129 (5.6)	157 (4.5)	89 (3.4)	173 (4.4)
Indicated Preterm Delivery						
All women	3376 (2.8)	162 (3.0)	538 (2.7)	671 (2.4)	593 (2.6)	1412 (3.2)
Maternal age, y						
<20	141 (2.8)	11 (2.4)	23 (2.6)	22 (2.6)	21 (2.9)	64 (3.1)
20-34	2796 (2.7)	132 (2.9)	439 (2.6)	555 (2.3)	478 (2.5)	1192 (3.1)
≥35	439 (3.4)	19 (3.8)	77 (3.3)	94 (2.7)	93 (3.5)	156 (4.0)

^a Analyses for adverse fetal and infant composite, small-for-gestational age, spontaneous preterm delivery, and indicated preterm delivery were restricted to the 121 242 pregnancies that continued to 20 or more weeks of gestational age.

^b Maternal mortality or severe morbidity included death according to vital statistics records, organ failure, unanticipated surgical procedure, blood transfusion of more than 3 U, ventilation, or admission to the intensive care

unit during pregnancy, delivery admission, up to 42 days postpartum.

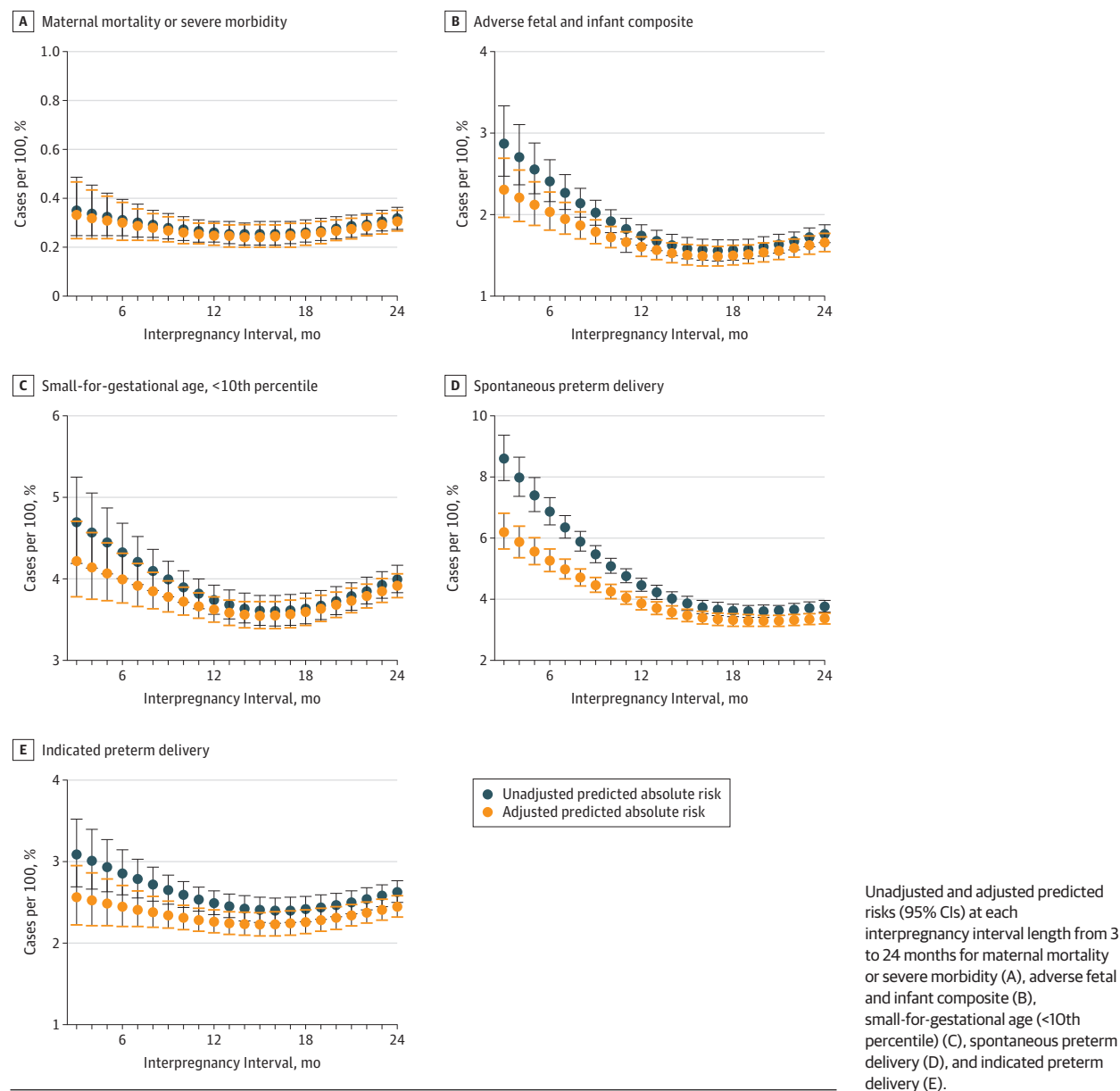
^c The No. (%) was suppressed if cell counts were less than 5, in accordance with data privacy regulations for British Columbia population health data.

^d Adverse fetal and infant composite included stillbirth, infant mortality, delivery earlier than 28 weeks, and birth weight less than the third percentile for gestational age and sex.

Figure 2 presents adjusted risk curves after stratification by maternal age category (20-34 years and 35 years or older at index birth). Due to the small number of index pregnancies in women younger than 20 years, predicted risks for this group were unstable and are not presented. Risks for maternal mortality or severe morbidity differed meaningfully by age group. We found increased risks of maternal mortality or severe morbidity at 6-month compared with 18-month interpregnancy intervals for women 35 years or older (predicted risk of 0.62% at 6 months compared with 0.26% at 18 months: aRR, 2.39; 95% CI, 2.03-2.80), but not for women aged 20 to 34 years (predicted risk of 0.23% at 6 months compared with 0.25% at 18 months: aRR, 0.92; 95% CI, 0.83-1.02). Conversely, the increased risk of spontaneous preterm delivery at short interpregnancy intervals was more

pronounced for younger women (predicted risk of 5.3% at 6 months compared with 3.2% at 18 months: aRR, 1.65; 95% CI, 1.62-1.68 for women 20-34 years at index birth) than older women (predicted risk of 5.0% at 6 months compared with 3.6% at 18 months: aRR, 1.40; 95% CI, 1.31-1.49 for women 35 years or older at index birth). Similarly, increased risk of adverse fetal and infant outcomes was more pronounced for women 20 to 34 years of age (predicted risk of 2.0% at 6 months vs 1.4% at 18 months: aRR, 1.42; 95% CI, 1.36-1.47) than women 35 years or older (predicted risk of 2.1% at 6 months vs 1.8% at 18 months: aRR, 1.15; 95% CI, 1.01-1.31, respectively). The shapes of the curves were similar across age groups for the other outcomes, generally with the lowest risk at 18-month intervals, although not substantially higher at 12- or 24-month intervals. Women younger

Figure 1. Absolute Risk of Pregnancy and Birth Outcomes According to Interpregnancy Interval, British Columbia, 2004-2014 in 148 544 Pregnancies



than 20 years at index birth had the highest risks of spontaneous preterm delivery across the interpregnancy interval spectrum and similar risks of other outcomes. Incidences and curves for component outcomes of the fetal and infant composite were similar to those of the composite and are presented in eTable 3, eFigures 2 and 3 in the [Supplement](#).

Adjustment did not meaningfully change estimates for maternal mortality or severe morbidity. Increases in adverse fetal and infant composite, SGA birth, and spontaneous preterm delivery risks at short intervals were attenuated after adjustment. Aside from expected multicollinearity between cubic spline terms,²⁸ no variance inflation factors exceeded 2, indicating no problematic multicollinearity.

Sensitivity Analyses

Curves were similar when older maternal age was defined as 30 years or older (eFigure 4 in the [Supplement](#)). Because of the small number of women 40 years or older at index birth ($n = 896$), findings using this threshold were challenging to interpret owing to wide 95% CIs and are not presented. Sensitivity analyses examining the role of unmeasured or residual confounding indicated that confounding was unlikely to entirely explain our observed results (eAppendix 2 in the [Supplement](#)). Curves were similar after restricting to pregnancies following an infertility diagnosis (eFigures 5 and 6 in the [Supplement](#)), substantial confounding would be required to fully explain the observed association (eTable 4

Table 3. Adjusted Risk Ratios (aRRs) Comparing Estimated Risks of Each Outcome at 3-, 6-, 9-, and 12-Month Interpregnancy Intervals With Estimated Risks Following 18-Month Intervals in 148 544 Pregnancies^a

Outcome	Pregnancy Interval, aRR (95% CI)				
	3 mo	6 mo	9 mo	12 mo	18 mo
Maternal Mortality or Severe Morbidity					
All women	1.31 (1.10-1.56)	1.18 (1.09-1.27)	1.07 (1.06-1.07)	0.99 (0.98-1.00)	1 [Reference]
Age at preinterval birth, y					
20-34	0.93 (0.75-1.15)	0.92 (0.83-1.02)	0.91 (0.89-0.93)	0.91 (0.91-0.91)	1 [Reference]
≥35	3.50 (2.30-5.28)	2.39 (2.03-2.80)	1.65 (1.63-1.67)	1.21 (1.18-1.26)	1 [Reference]
P value for interaction	<.001	<.001	<.001	<.001	
Adverse Fetal and Infant Composite					
All women	1.54 (1.42-1.67)	1.36 (1.31-1.40)	1.19 (1.19-1.20)	1.07 (1.07-1.08)	1 [Reference]
Age at preinterval birth, y					
20-34	1.64 (1.50-1.78)	1.42 (1.36-1.47)	1.23 (1.23-1.23)	1.09 (1.08-1.10)	1 [Reference]
≥35	1.25 (0.96-1.62)	1.15 (1.01-1.31)	1.07 (1.05-1.09)	1.01 (0.99-1.02)	1 [Reference]
P value for interaction	.05	.001	<.001	<.001	
Small-for-Gestational Age					
All women	1.17 (1.10-1.25)	1.11 (1.08-1.14)	1.05 (1.05-1.06)	1.01 (1.00-1.01)	1 [Reference]
Age at preinterval birth, y					
20-34	1.17 (1.07-1.24)	1.11 (1.07-1.14)	1.05 (1.05-1.06)	1.01 (1.01-1.01)	1 [Reference]
≥35	1.23 (0.93-1.61)	1.13 (0.98-1.31)	1.05 (1.02-1.08)	0.99 (0.97-1.01)	1 [Reference]
P value for interaction	.73	.81	>.99	.05	
Spontaneous Preterm Delivery					
All women	1.87 (1.79-1.96)	1.59 (1.56-1.62)	1.35 (1.35-1.35)	1.17 (1.16-1.17)	1 [Reference]
Age at preinterval birth					
20-34	1.98 (1.89-2.08)	1.65 (1.62-1.68)	1.38 (1.38-1.38)	1.17 (1.17-1.18)	1 [Reference]
≥35	1.54 (1.33-1.79)	1.40 (1.31-1.49)	1.26 (1.25-1.27)	1.15 (1.14-1.16)	1 [Reference]
P value for interaction	.002	<.001	<.001	<.001	
Indicated Preterm Delivery					
All women	1.13 (1.05-1.23)	1.08 (1.04-1.13)	1.04 (1.03-1.04)	1.00 (1.00-1.01)	1 [Reference]
Age at preinterval birth					
20-34	1.11 (1.03-1.22)	1.07 (1.03-1.11)	1.03 (1.02-1.04)	1.00 (1.00-1.00)	1 [Reference]
≥35	1.12 (0.88-1.42)	1.08 (0.96-1.22)	1.04 (1.01-1.07)	1.01 (1.00-1.02)	1 [Reference]
P value for interaction	>.99	.89	.46	>.99	

Abbreviation: aRR, adjusted risk ratio.

^a Analyses for adverse fetal and infant composite, small-for-gestational age, spontaneous preterm delivery, and indicated preterm delivery were restricted to the 121 242 pregnancies that continued to 20 or more weeks of gestational age. Interpregnancy interval was modeled using restricted cubic splines with 4 knots placed at the 5th, 35th, 65th, and 95th percentiles of interpregnancy interval in the study population (5.7, 15.3, 24.8, and 55.3 months). After restricting to pregnancies continuing to 20 weeks of gestation or longer for all fetal outcomes (adverse fetal and infant composite, small-for-gestational age, spontaneous preterm delivery, indicated preterm delivery), the 5th, 35th, 65th, and 95th percentiles of interpregnancy interval shifted to 6.3, 15.5, 24.6, and 55.4 months. Models were adjusted for smoking in or prior to index pregnancy, low neighborhood income at index birth, inadequate prenatal care (<5 visits) in index pregnancy, relevant outcome of index pregnancy (eg, prior spontaneous preterm delivery adjusted for in model for spontaneous preterm delivery), with risks estimated at population average values for 18-month interpregnancy intervals.

in the [Supplement](#)), and negative control analyses produced different curve shapes, with no relationship or attenuated relationships with short interpregnancy interval (eFigure 7 in the [Supplement](#)).

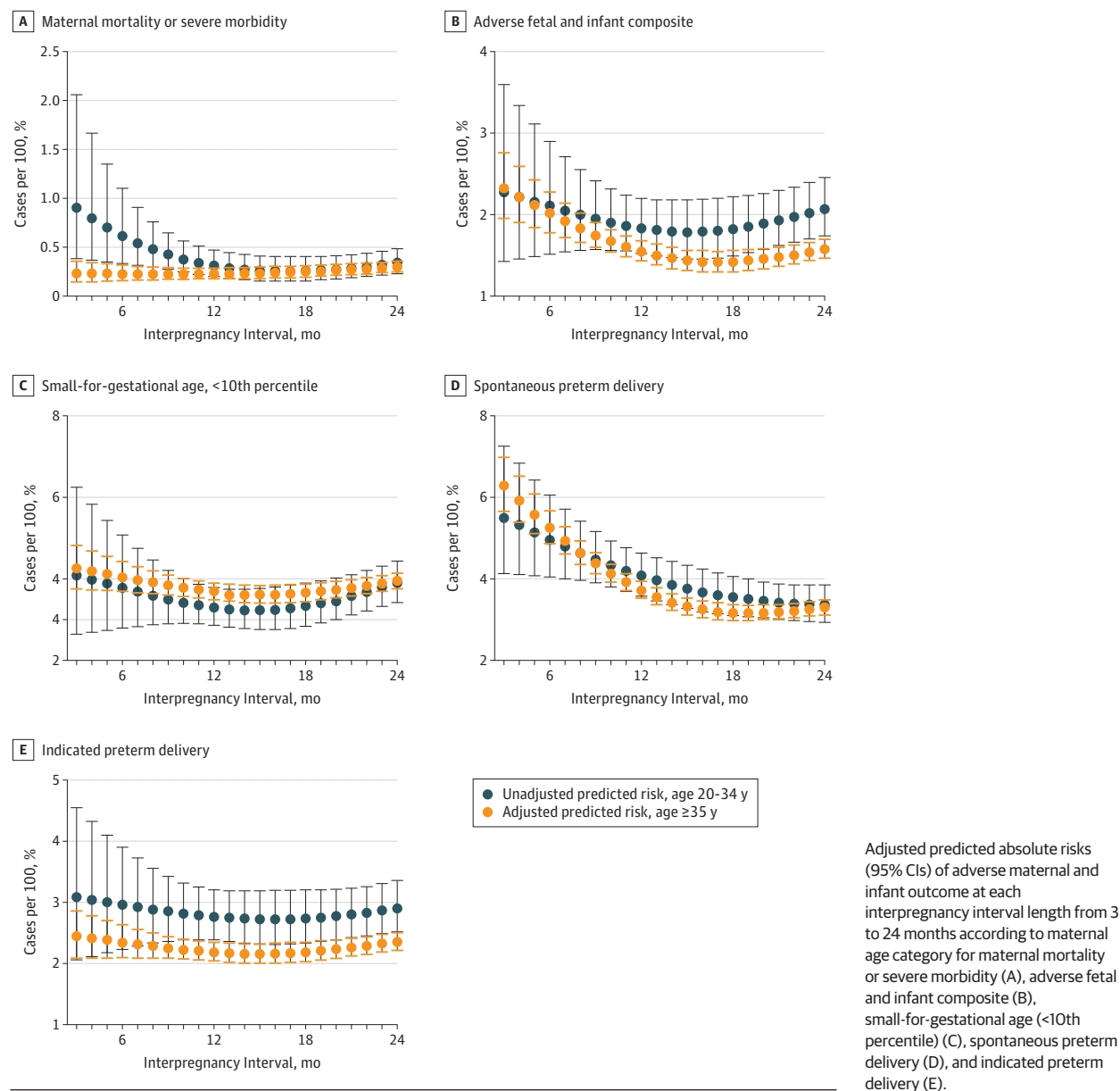
Discussion

Our study found that increased risks of maternal mortality or severe morbidity, adverse fetal and infant outcomes, and spontaneous preterm delivery following short (<12-month) interpregnancy intervals persisted after stratifying by maternal age. Women 35 years or older at index birth had increased risks of maternal mortality or severe morbidity at short interpregnancy intervals, while women aged 20 to 34 years did not.

Although short intervals were associated with elevated risks of spontaneous preterm delivery and adverse fetal and infant outcomes for women of all ages, these risks were highest among younger women. For other outcomes, elevation in risks at short interpregnancy intervals did not vary by maternal age categories. Overall, contrary to our hypothesis, risks following short interpregnancy intervals were not attenuated for older women.

Our results support a large body of literature examining increased risks of some fetal and infant outcomes, including preterm delivery, following short interpregnancy intervals.¹⁻⁶ While increased preterm delivery risk following short interpregnancy intervals has been studied extensively,^{1,5,11} to our knowledge, few previous studies⁴ have examined both spontaneous and indicated preterm delivery separately. We dem-

Figure 2. Absolute Risk of Pregnancy and Birth Outcomes According to Interpregnancy Interval Stratified by Maternal Age at Index Birth, British Columbia, 2004-2014 in 141 360 Pregnancies



onstrated that spontaneous preterm delivery was more strongly associated with short interpregnancy interval than was indicated preterm delivery. Furthermore, although the association between short interpregnancy interval and specific maternal outcomes have been studied in high-resource settings (eg, uterine rupture or blood transfusion,³⁷ abnormal placentation³⁸), previous studies of maternal mortality or severe morbidity were restricted to low-resource settings.³⁹ Because previous findings may not be generalizable to high-resource settings owing to differences in maternal age, parity, pregnancy intention, or nutritional status, our findings regarding maternal mortality or severe morbidity add new insight to the literature. The small number of maternal mortality events in our study population ($n = 5$; 3.4 per 100 000) precluded ex-

amination of maternal mortality as a separate outcome, although this may be of interest for future research.

Current clinical and public health recommendations suggest a minimum interpregnancy interval of 18 months,^{7,9} and some suggest a range from 18 to 60 months.¹⁰ However, our findings suggest that the optimal interpregnancy interval is closer to 18 months, with a range of 12 to 24 months having risks that generally are comparable to the nadir at 18 months. In fact, for some outcomes (adverse fetal and infant outcomes for women ≥ 35 years old, SGA birth for all women), risks are similar to the nadir even at 9-month intervals.

More than 20% of interpregnancy intervals among women 35 years or older were shorter than 12 months, when risks of some outcomes remain elevated for older women, and nearly

half were shorter than 18 months. Because pregnancies following short interpregnancy intervals among women 35 years or older at index birth are usually planned,^{11,12} clinical counseling toward intervals closer to 12 or 18 months may be effective in reducing the risks that we have shown are still associated with short intervals among older women. While we believe these findings will be useful to women and clinicians, women's decisions regarding the optimal timing and spacing of pregnancy are multifactorial, and modest increases in risk associated with short intervals may not outweigh other factors, including those unrelated to health outcomes, that women and families consider in spacing their pregnancies.

Limitations

Our findings must be interpreted in the context of several limitations. Because our analyses examined differences in risks according to interpregnancy interval based on comparing outcomes of different women, they may be biased due to confounding by unmeasured factors that differ within and between women, including pregnancy intention^{11,12} and intimate partner violence.^{33,34} Previous studies found substantially attenuated associations between interpregnancy interval and adverse pregnancy outcomes using matched designs to examine successive interpregnancy intervals within the same women⁴⁰⁻⁴² compared with between-woman analyses. However, within-woman analyses cannot adequately account for the role of parity² and may not be generalizable to the overall population owing to restriction to women with at least 3 births and women with discordant health outcomes. While we cannot rule out unmeasured confounding, our sensitivity analyses examining the potential role of unmeasured or residual

confounding provide reassurance that our findings are unlikely to be entirely explained by confounding.

Conclusions

We present what we believe to be new, robust evidence to guide clinicians counseling women considering short interpregnancy intervals. Our study used a large, population-based cohort with clinical detail based on validated⁴³ medical record abstraction, supplemented through linkages to additional health care and demographic information. This database enabled us to overcome many methodologic limitations of previous studies in this area, including controlling for both stillbirth and neonatal loss in the index birth and accurately measuring intervals between pregnancies by including the 18.4% of subsequent pregnancies that ended in spontaneous or induced abortions at less than 20 weeks in our definition.^{44,45}

Short interpregnancy intervals (<12 months) are associated with increased maternal and fetal and infant risks for women aged 20 to 34 years and for women 35 years or older at index birth. Our findings indicate a shorter optimal interval than previously thought (12-24 months) for women of all ages. This finding may be reassuring particularly for older women who must weigh the competing risks of increasing maternal age with longer interpregnancy intervals (including infertility and chromosomal anomalies) against the risks of short interpregnancy intervals. We found evidence that confounding does not seem to fully explain the observed association between short interpregnancy interval and increased risks of several outcomes.

ARTICLE INFORMATION

Accepted for Publication: July 21, 2018.

Published Online: October 29, 2018.

doi:10.1001/jamainternmed.2018.4696

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Administrative, technical, or material support: Schummers.

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Conflict of Interest Disclosures: None reported.

Funding/Support: Dr Schummers was supported by National Research Service Award 1F31HD086970-01A1 from the Eunice Kennedy Shriver National Institute of Child Health and Human Development, National Institutes of Health, and received grant CPP-137903 from the Canadian Institutes for Health Research and the Public Health Agency of Canada (CIHR-PHAC) Family Planning Public Health Chair Seed Grant to support this project. Dr Hutcheon was supported by New Investigator Awards from the Michael Smith Foundation for Health Research and the Canadian Institutes for Health Research. Dr VanderWeele was supported by National Institutes of Health Award R01CA222147. Dr Norman was supported by a Research Scholar Award from the Michael Smith Foundation for Health Research and as applied Public Health Chair in Family Planning Research from the Canadian Institutes for Health Research and the Public Health Agency of Canada (CPP-137903).

Role of the Funder/Sponsor: The funding organizations had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Disclaimer: All inferences, opinions, and conclusions drawn in this publication are those of the authors, and do not reflect the opinions or policies of Population Data BC or the data stewards.

Meeting Presentations: This study was presented at the 2018 Meeting of the Society for Epidemiologic Research; June 19, 2018; Baltimore, Maryland; and 2018 Annual Meeting of the Society for Pediatric and Perinatal Epidemiologic Research; June 18, 2018; Baltimore, Maryland.

Additional Contributions: We thank Population Data BC for compiling the study data and facilitating data access.

REFERENCES

1. Conde-Agudelo A, Rosas-Bermúdez A, Kafury-Goeta AC. Birth spacing and risk of adverse perinatal outcomes: a meta-analysis. *JAMA*. 2006; 295(15):1809-1823. doi:10.1001/jama.295.15.1809
2. Merklinger-Gruchala A, Jasienska G, Kapiszewska M. Short interpregnancy interval and low birth weight: a role of parity. *Am J Hum Biol*. 2015;27(5):660-666. doi:10.1002/ajhb.22708

3. McKinney D, House M, Chen A, Muglia L, DeFranco E. The influence of interpregnancy interval on infant mortality. *Am J Obstet Gynecol*. 2017;216(3):316.e1-316.e9. doi:10.1016/j.ajog.2016.12.018
4. Smith GCS, Pell JP, Dobbie R. Interpregnancy interval and risk of preterm birth and neonatal death: retrospective cohort study. *BMJ*. 2003;327(7410):313. doi:10.1136/bmj.327.7410.313
5. Wendt A, Gibbs CM, Peters S, Hogue CJ. Impact of increasing inter-pregnancy interval on maternal and infant health. *Paediatr Perinat Epidemiol*. 2012;26(1)(suppl 1):239-258. doi:10.1111/j.1365-3016.2012.01285.x
6. Zhang L, Shen S, He J, et al. Effect of interpregnancy interval on adverse perinatal outcomes in southern China: a retrospective cohort study, 2000-2015. *Paediatr Perinat Epidemiol*. 2018;32(2):131-140. doi:10.1111/ppe.12432
7. American College of Obstetricians and Gynecologists. ACOG Committee opinion 736: optimizing postpartum care. *Obstet Gynecol*. 2018;131(5):e140-e150. doi:10.1097/AOG.0000000000002633
8. Royal College of Obstetricians and Gynaecologists. Best practice in postpartum family planning. Vol. Best Practice Paper No 1. London, UK: Royal College of Obstetricians and Gynaecologists. <https://www.rcog.org.uk/globalassets/documents/guidelines/best-practice-papers/best-practice-paper-1---postpartum-family-planning.pdf>. Published June 2015. Accessed March 12, 2018.
9. Office of Disease Prevention and Health Promotion. Healthy People.gov. US Healthy people 2020 family planning objective 5. Healthy People 2020 Web site. <https://www.healthypeople.gov/2020/topics-objectives/topic/family-planning/objectives>. Updated September 7, 2018. Accessed March 3, 2018.
10. World Health Organization. Report of a WHO technical consultation on birth spacing. Geneva, Switzerland, 13-15, 2005. http://apps.who.int/iris/bitstream/10665/69855/1/WHO_RHR_07.1_eng.pdf. Published 2007. Accessed March 3, 2018.
11. Gemmill A, Lindberg LD. Short interpregnancy intervals in the United States. *Obstet Gynecol*. 2013;122(1):64-71. doi:10.1097/AOG.0b013e3182955e58
12. Cheslack Postava K, Winter AS. Short and long interpregnancy intervals: correlates and variations by pregnancy timing among US women. *Perspect Sex Reprod Health*. 2015;47(1):19-26. doi:10.1363/47e2615
13. Lean SC, Derricott H, Jones RL, Heazell AEP. Advanced maternal age and adverse pregnancy outcomes: a systematic review and meta-analysis. *PLoS One*. 2017;12(10):e0186287. doi:10.1371/journal.pone.0186287
14. Zhu BP, Rolfs RT, Nangle BE, Horan JM. Effect of the interval between pregnancies on perinatal outcomes. *N Engl J Med*. 1999;340(8):589-594. doi:10.1056/NEJM199902253400801
15. Finer LB, Zolna MR. Declines in unintended pregnancy in the United States, 2008-2011. *N Engl J Med*. 2016;374(9):843-852. doi:10.1056/NEJMsa1506575
16. de Weger FJ, Hukkelhoven CW, Serroyen J, te Velde ER, Smits LJ. Advanced maternal age, short interpregnancy interval, and perinatal outcome. *Am J Obstet Gynecol*. 2011;204(5):421.e1-421.e9. doi:10.1016/j.ajog.2010.12.008
17. Perinatal Services BC. Perinatal Data Registry; 2017. Available at: <http://www.perinatalservicesbc.ca/health-professionals/data-surveillance/perinatal-data-registry>. Updated 2018. Accessed March 12, 2018.
18. Population Data BC. Medical Services Plan (MSP) payment information file. V2; 2016. Data extract. Ministry of Health (2016). <https://www.popdata.bc.ca/data/health/msp>. Updated May 9, 2018. Accessed June 10, 2018.
19. Population Data BC. PharmaNet. V2. BC Ministry of Health. Data extract. Data Stewardship Committee (2017). <https://www.popdata.bc.ca/data/health/PharmaNet>. Updated May 9, 2018. Accessed June 10, 2018.
20. Population Data BC. Canadian Institute for Health Information. Discharge abstract database (hospital separations). V2. Data extract. 2015. Ministry of Health (2015). <https://www.popdata.bc.ca/data/health/dad>. Updated May 9, 2018. Accessed July 12, 2018.
21. Population Data BC. BC Ministry of Health (2015). Consolidation file. V2. Data Extract. Ministry of Health (2016). <https://www.popdata.bc.ca/data/population/consolidationfile>. Updated May 9, 2018. Accessed May 12, 2018.
22. Population Data BC. Statistics Canada. Small Area and Administrative Data Division (2009). Income band data; catalogue number 13C0016. Data extract (2017). <https://www.popdata.bc.ca/data/demographic/incomeband>. Updated May 9, 2018. Accessed June 12, 2018.
23. Population Data BC. BC Vital Statistics Agency (2015). Vital statistics deaths. V2. Data extract. BC Vital Statistics Agency (2016). <https://www.popdata.bc.ca/data/population/vsdeaths>. Updated May 9, 2018. Accessed June 17, 2018.
24. Love ER, Bhattacharya S, Smith NC, Bhattacharya S. Effect of interpregnancy interval on outcomes of pregnancy after miscarriage: retrospective analysis of hospital episode statistics in Scotland. *BMJ*. 2010;341:c3967. doi:10.1136/bmj.c3967
25. Geller SE, Rosenberg D, Cox S, Brown M, Simonson L, Kilpatrick S. A scoring system identified near-miss maternal morbidity during pregnancy. *J Clin Epidemiol*. 2004;57(7):716-720. doi:10.1016/j.jclinepi.2004.01.003
26. Kramer MS, Platt RW, Wen SW, et al; Fetal/Infant Health Study Group of the Canadian Perinatal Surveillance System. A new and improved population-based Canadian reference for birth weight for gestational age. *Pediatrics*. 2001;108(2):E35. doi:10.1542/peds.108.2.e35
27. Orsini N, Greenland S. A procedure to tabulate and plot results after flexible modeling of a quantitative covariate. *Stata J*. 2011;11(1):1-29.
28. Harrell FE. *Regression Modeling Strategies with Applications to Linear Models, Logistic Regression, and Survival Analysis*. New York, NY: Springer; 2001.
29. Altman DG, Bland JM. Interaction revisited: the difference between two estimates. *BMJ*. 2003;326(7382):219. doi:10.1136/bmj.326.7382.219
30. Carlini JB, Galati J, Royston P. A new framework for managing and analyzing multiply imputed data in Stata. *Stata J*. 2008;8(1):49-67.
31. Corp S. Stata statistical software: Release 14. College Station, TX: StataCorp, LP; 2015.
32. Hall JA, Benton L, Copas A, Stephenson J. Pregnancy intention and pregnancy outcome: systematic review and meta-analysis. *Matern Child Health J*. 2017;21(3):670-704. doi:10.1007/s10995-016-2237-0
33. Maxwell L, Nandi A, Benedetti A, Devries K, Wagman J, García-Moreno C. Intimate partner violence and pregnancy spacing: results from a meta-analysis of individual participant time-to-event data from 29 low-and-middle-income countries. *BMJ Glob Health*. 2018;3(1):e000304. doi:10.1136/bmjgh-2017-000304
34. Donovan BM, Spracklen CN, Schweizer ML, Ryckman KK, Saftlas AF. Intimate partner violence during pregnancy and the risk for adverse infant outcomes: a systematic review and meta-analysis. *BJOG*. 2016;123(8):1289-1299. doi:10.1111/1471-0528.13928
35. VanderWeele TJ, Ding P. Sensitivity analysis in observational research: introducing the E-value. *Ann Intern Med*. 2017;167(4):268-274. doi:10.7326/M16-2607
36. Lipsitch M, Tchetgen E, Cohen T. Negative controls: a tool for detecting confounding and bias in observational studies. *Epidemiology*. 2010;21(3):383-388. doi:10.1097/EDE.0b013e3181d61eeb
37. Stamilio DM, DeFranco E, Paré E, et al. Short interpregnancy interval: risk of uterine rupture and complications of vaginal birth after cesarean delivery. *Obstet Gynecol*. 2007;110(5):1075-1082. doi:10.1097/O1.AOG.0000286759.49895.46
38. Ananth CV, Skjaerven R, Klunnsøyr K. Change in paternity, risk of placental abruption and confounding by birth interval: a population-based prospective cohort study in Norway, 1967-2009. *BMJ Open*. 2015;5(2):e007023. doi:10.1136/bmjopen-2014-007023
39. Conde-Agudelo A, Belizán JM. Maternal morbidity and mortality associated with interpregnancy interval: cross sectional study. *BMJ*. 2000;321(7271):1255-1259. doi:10.1136/bmj.321.7271.1255
40. Class QA, Rickert ME, Oberg AS, et al. Within-family analysis of interpregnancy interval and adverse birth outcomes. *Obstet Gynecol*. 2017;130(6):1304-1311. doi:10.1097/AOG.0000000000002358
41. Ball SJ, Pereira G, Jacoby P, de Klerk N, Stanley FJ. Re-evaluation of link between interpregnancy interval and adverse birth outcomes: retrospective cohort study matching two intervals per mother. *BMJ*. 2014;349:g4333. doi:10.1136/bmj.g4333
42. Hanley GE, Hutcheon JA, Kinniburgh BA, Lee L. Interpregnancy interval and adverse pregnancy outcomes: an analysis of successive pregnancies. *Obstet Gynecol*. 2017;129(3):408-415. doi:10.1097/AOG.0000000000001891
43. Frosst G, Hutcheon J, Joseph KS, Kinniburgh B, Johnson C, Lee L. Validating the British Columbia Perinatal Data Registry: a chart re-abstraction study. *BMC Pregnancy Childbirth*. 2015;15:123. doi:10.1186/s12884-015-0563-7
44. Conzuelo-Rodriguez G, Naimi AI. The impact of computing interpregnancy intervals without accounting for intervening pregnancy events. *Paediatr Perinat Epidemiol*. 2018;32(2):141-148. doi:10.1111/ppe.12458
45. Naimi AI. Studying interpregnancy interval effects using observational data: some cautionary remarks. *BJOG*. 2016;123(8):1319. doi:10.1111/1471-0528.13743