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First birth Caesarean section and subsequent fertility: a population-based study in the USA, 2000–2008

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STUDY QUESTION: Is first birth Caesarean delivery associated with a lower likelihood of subsequent childbearing when compared with first birth vaginal delivery?

SUMMARY ANSWER: In this study of US women whose first delivery was in 2000, those who had a Caesarean delivery were less likely to have a subsequent live birth than those who delivered vaginally.

WHAT IS ALREADY KNOWN: Some studies have reported lower birth rates subsequent to Caesarean delivery in comparison with vaginal delivery, while other studies have reported no difference.

STUDY DESIGN, SIZE, DURATION: We conducted a retrospective cohort study of 52 498 women who had a first singleton live birth in the State of Pennsylvania, USA in 2000 and were followed to the end of 2008 via Pennsylvania birth certificate records to identify subsequent live births during the 8- to 9-year follow-up period.

PARTICIPANTS/MATERIALS, SETTING, METHODS: Birth certificate records of first singleton births were linked to the hospital discharge data for each mother and newborn, and linked to all birth certificate records for each mother's subsequent deliveries which occurred in 2000 to the end of 2008. Poisson regression models were used to evaluate the association between first birth factors and whether or not there was a subsequent live birth during the follow-up period.

MAIN RESULTS AND THE ROLE OF CHANCE: Over an average of 8.5 years of follow-up, 40.2% of women with a Caesarean first birth did not have a subsequent live birth, compared with 33.1% of women with a vaginal first birth (risk ratio (RR): 1.21, 95% confidence interval (CI): 1.18–1.25). Adjustment for the demographic confounders of maternal age, race, education, marital status and health insurance coverage attenuated the RR to 1.16 (95% CI: 1.13–1.19). Specific pregnancy and childbirth-related complications associated with not having a subsequent live birth included diabetes-related disorders, abnormalities of organs and soft tissues of the pelvis, fetal abnormalities, premature or prolonged rupture of membranes, hypertensive disorders, amnionitis, fetal distress and other maternal health problems. However, adjustment for the pregnancy and childbirth complications had little effect on the RR of not having a subsequent live birth (RR = 1.15, 95% CI: 1.11–1.19).

LIMITATIONS, REASONS FOR CAUTION: We were unable to distinguish between women who did not have a subsequent live birth and those who moved out of the state, which may have introduced a selection bias if those who had Caesarean births were more likely to emigrate than those who delivered vaginally. In addition we were unable to measure pre-pregnancy body mass index, weight gain during pregnancy and prior infertility, which would have been helpful in our efforts to reduce selection bias.

WIDER IMPLICATIONS OF THE FINDINGS: The results of this study provide further corroboration of previous studies that have reported reduced fertility subsequent to Caesarean section in comparison with vaginal delivery.

STUDY FUNDING/POTENTIAL COMPETING INTERESTS: This study was funded by the US National Institute of Child Health and Human Development (NICHD, R01-HD052990). No competing interests are declared.

Key words: Caesarean section / fertility / parturition / reproduction / pregnancy complications

Introduction

The Caesarean delivery rate has increased markedly over the past two decades in countries throughout the world (Niino, 2011). Studies conducted in Africa, England, Finland, Norway, Scotland, Sweden and the USA have reported that women who deliver by Caesarean are less likely to have one or more subsequent live births than women who deliver vaginally (Zdeb et al., 1984; Hemminki, 1986; LaSala and Berkeley 1987; Hall et al., 1989; Hemminki and Merilainen 1996; Jolly et al., 1999; Hemminki et al., 2005; Mollison et al., 2005; Collin et al., 2006; Smith et al., 2006; Tollanes et al., 2007). However, the authors of a study of women undergoing planned Caesarean section for breech presentation in comparison with those with a spontaneous vertex vaginal delivery reported that the increased risk of not having a subsequent birth among those who had delivered by Caesarean section was no longer a strong association after adjustment for maternal and obstetric characteristics and concluded that 'It is unlikely that delivering by Caesarean section in a first pregnancy decreases a woman's likelihood of having a second viable pregnancy' (Smith et al., 2006). Another study of women who underwent Caesarean section for breech presentation in comparison with those who had a spontaneous vertex vaginal delivery reported similar results and also concluded that first birth Caesarean delivery does not have a deleterious effect on subsequent fertility (Eijsink et al., 2008).

Previous studies have demonstrated that maternal age is an important confounding factor because older women are more likely to deliver by Caesarean and less likely to have a subsequent child, even if they deliver vaginally (Hall et al., 1989; Murphy et al., 2002; Collin et al., 2006; Smith et al., 2006). Maternal age is both associated with the exposure (Caesarean delivery) and independently associated with the outcome (not having a subsequent live birth). However, other factors that are associated with Caesarean delivery, including maternal pregnancy and childbirth complications, may also be related to the post-Caesarean fertility deficit. Prior studies have not systematically investigated these possibilities. In addition, many of the prior studies have been conducted in countries with much lower Caesarean rates than in the USA and with the index pregnancies occurring in the 1960s to the 1980s, prior to the recent rise in the rate of Caesarean delivery.

In the USA, where Caesarean delivery is performed more commonly than in most other countries, it could be less strongly associated with reduced subsequent fertility for a variety of reasons. For example, US women might find Caesarean delivery less traumatic than women in other countries because more of their friends and family would have had Caesarean deliveries. It is also possible that the post-Caesarean fertility deficit found in prior studies no longer exists, or can be accounted for by confounding factors that prior studies did not measure.

In this study, we investigated the association between mode of delivery in two categories, Caesarean versus vaginal, as well as in three categories, Caesarean, instrumental vaginal and spontaneous vaginal. The objectives of this study were: (i) to investigate the association between mode of delivery at first childbirth, including instrumental delivery, and subsequent childbearing to see whether the decrement in childbearing subsequent to Caesarean delivery reported in several previous studies occurs among a sample of women in the USA who gave birth in the 21st century; (ii) to identify the maternal demographic factors and the fetal and maternal complications that precede first childbirth and are risk factors for Caesarean delivery and (iii) to investigate the extent to which these maternal demographic factors and fetal and maternal complications account for the post-Caesarean fertility deficit. The conceptual framework of this study can be seen in Fig. 1.

Materials and Methods

Cohort composition

The Pennsylvania Department of Health identified all singleton live births occurring in 2000 and provided birth certificates for those births. The Pennsylvania Health Care Cost Containment Council linked maternal and newborn hospital discharge data to the birth certificate data for 92.3% of the cohort, using maternal social security numbers. This linking allowed for inclusion of medical information pertaining to labour and delivery and post-delivery care, and information about health insurance coverage, that is available in

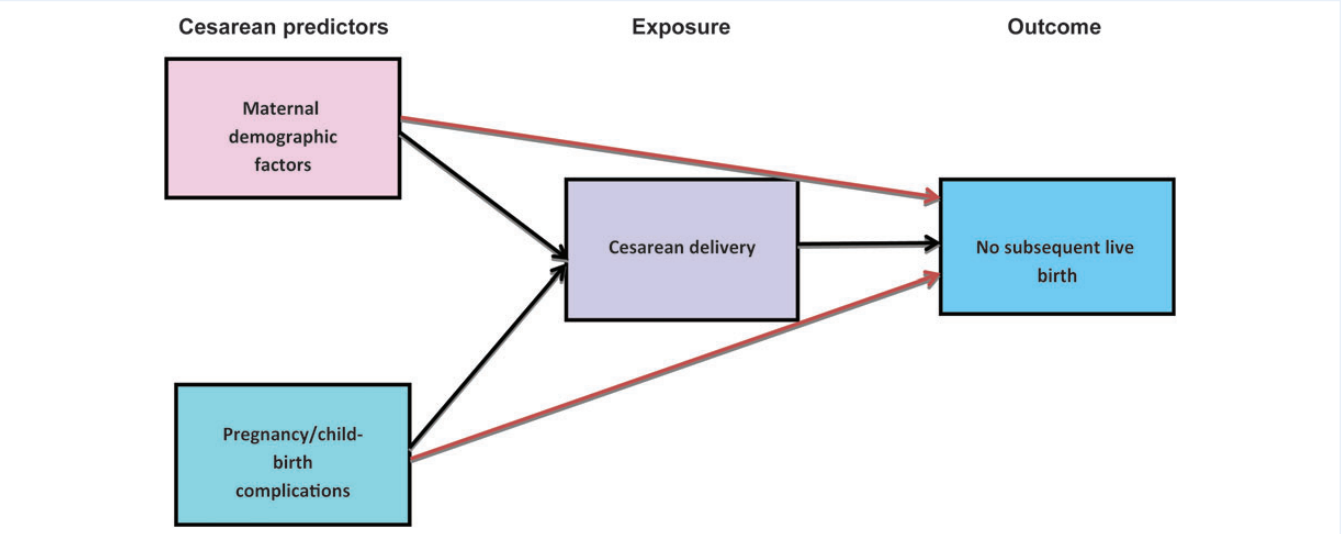

Figure 1 Conceptual framework of this study. The red lines indicate the direct effects of the Caesarean predictors on subsequent childbearing.

the hospital discharge data but not on the birth certificate. Reasons for unsuccessful linkages ($n = 4490$) included the delivery not taking place in a hospital ($n = 600$), the mother's birth certificate social security number being either missing ($n = 1149$) or not matching any social security numbers found in the hospital discharge data, or other discrepancies ($n = 2741$). Those who were not linked differed from those who were linked in that they were more likely to be Black, Hispanic and other non-white races, younger, less educated and foreign born. Women who could not be matched to maternal hospital discharge data were not included in the study because they were only half as likely to be found to have a subsequent delivery as the rest of the population, indicating an impaired ability to match to subsequent deliveries. Women whose infant died within the first 12 months ($n = 151$) were excluded due to the tendency of couples to replace the loss (Skjaerven *et al.*, 1988). Women who underwent any procedure during the first childbirth hospitalization that would definitely or potentially impair future fertility were excluded; these included sterilization ($n = 297$), oophorectomy ($n = 74$), hysterectomy ($n = 22$) and endometrial ablation ($n = 1$). Additional exclusions included 1 maternal death, 11 women for whom the date of the second live birth was too soon after the first birth to be plausible (<20 weeks) and 3 women who were found to have codes for both Caesarean and vaginal delivery at first childbirth. The final sample of 52 498 women who had first singleton live births in Pennsylvania in 2000 was linked to all subsequent live births found in the Pennsylvania birth certificate data in 2000–2008 via the mother's social security number. The flow chart of sample selection can be seen in Fig. 2.

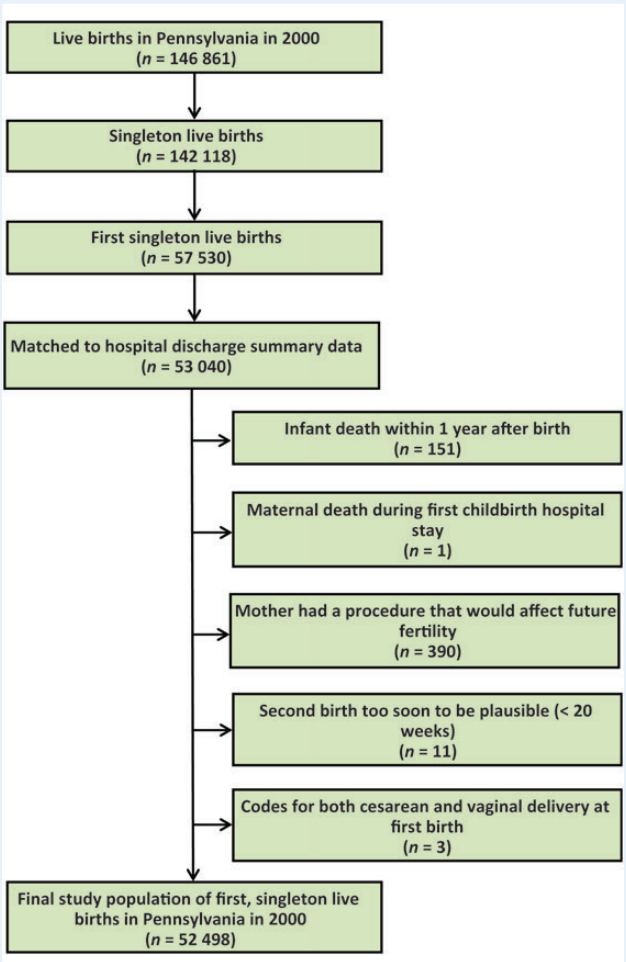

Figure 2 Flow chart of sample selection.

Ethical approval

This study was approved by the Penn State College of Medicine's Institutional Review Board.

Study variables

The International Classification of Diseases 9th Clinical Modification (ICD-9) Diagnosis Related Group (DRG) codes were used to identify vaginal (372–375) and Caesarean deliveries (370–371) from hospital discharge records (Russo *et al.*, 2009). To identify which of the vaginal deliveries were instrumental, we used the birth certificate data (which has variables for forceps and vacuum deliveries), the ICD-9 diagnostic code 669.5 (forceps or vacuum extractor delivery without mention of indication), and the ICD-9 procedure codes of 72.0–72.4 (forceps delivery) and 72.7–72.9 (vacuum extraction). If any of these sources indicated that the delivery was instrumental, it was categorized as instrumental.

Previous studies of the association between mode of delivery and subsequent childbearing have considered maternal age and measures of socioeconomic status (SES) as confounders (Zdeb *et al.*, 1984; Hemminki *et al.*, 1985; Hemminki, 1986; LaSala and Berkeley 1987; Hall *et al.*, 1989; Mollison *et al.*, 2005; Collin *et al.*, 2006; Smith *et al.*, 2006), primarily because older women and those of higher SES tend to be more likely to have Caesarean delivery. The factors that we included as confounders in this study were maternal age, race/ethnicity, education, marital status and health insurance coverage.

Maternal age, race/ethnicity, education and marital status were obtained from the birth certificate record and health insurance coverage was obtained from the mother's hospital discharge data. The fetal/newborn factors included gestational age, birthweight, gender and intrauterine growth retardation (IUGR). These variables were obtained from the birth certificate record, except for IUGR. If there was an ICD-9 code of 764.0–764.9 ('slow fetal growth and malnutrition') in the hospital discharge data or the variable of 'growth retardation' was checked in the birth certificate data, the newborn was categorized as having IUGR.

We also measured the pregnancy and childbirth complications that have been identified in previous studies as indications for Caesarean delivery, which occur prior to delivery and tend to lead to the decision to perform Caesarean section (Henry *et al.*, 1995; Gregory *et al.*, 2002; Korst *et al.*, 2004; Kabir *et al.*, 2005; Kuklina *et al.*, 2008; Kahn *et al.*, 2009). These pregnancy and childbirth complications were measured among women regardless of mode of delivery. The categories of ICD-9 diagnostic codes used in this study are shown in the Supplementary data, Table SI. We used 18 categories of complications. The hospital discharge summary data allowed for one primary diagnostic code and up to eight secondary diagnostic codes. The complications were noted in the secondary diagnostic codes; therefore a woman could have up to eight complications noted in her discharge summary data. We created a variable that was a count of the number of pregnancy and childbirth complications (indications) per woman. This variable was further categorized into 0, 1 and 2 or more complications.

Statistical analysis

Analyses were conducted using SAS, Version 9.2 (SAS Institute, Cary, NC, USA). The associations between the predictors shown in Tables I and II and both mode of delivery and subsequent childbearing were assessed via the Chi-square test.

We measured the association of mode of delivery at first childbirth and not having a subsequent live birth, comparing Caesarean versus vaginal delivery (combining both vaginal modes), as well as spontaneous vaginal versus instrumental vaginal delivery and spontaneous vaginal versus Caesarean, while controlling for confounding maternal demographic factors (age, race/ethnicity, health insurance coverage, marital status and education) and the

Table I Maternal and neonatal factors at first birth in 2000 by first birth mode of delivery and subsequent live birth, 2000–2008.

		Mode of first live birth					
		Spontaneous vaginal (%)	Instrumental vaginal (%)	Caesarean (%)		No subsequent live birth (%)	
	Overall (%)	59.7	17.0	23.4	*P*-value	34.8	*P*-value
Age at first birth (years)							
<20	19.5	71.5	13.5	15.0	<0.001	29.1	<0.001
20–24	25.6	65.2	15.0	19.8		33.5	
25–29	27.3	57.0	18.4	24.6		30.4	
30–34	19.6	51.0	20.0	29.0		36.0	
35+	7.9	43.2	19.6	37.2		65.0	
Race/ethnicity							
White, non-Hispanic	79.6	58.4	17.8	23.8	<0.001	33.5	<0.001
Black, non-Hispanic	13.0	66.5	11.5	22.1		39.9	
Hispanic	4.1	64.6	12.8	22.6		34.6	
Other/missing	3.3	56.3	23.9	19.8		45.8	
Education (years)							
<12	13.9	69.4	13.8	16.7	<0.001	28.2	<0.001
12	31.9	60.2	16.1	23.7		38.3	
>12	54.2	56.6	18.4	24.9		34.4	
Marital status							
Married	59.2	55.1	18.9	26.0	<0.001	32.5	<0.001
Single	40.8	66.3	14.2	19.6		38.1	
Insurance							
Private	70.4	56.8	18.2	24.9	<0.001	34.7	0.035
Public	27.5	66.7	13.8	19.6		35.2	
Self-pay	2.1	62.6	16.9	20.5		31.5	
Gestational age (weeks)							
<34	2.4	52.9	4.0	43.1	<0.001	44.4	<0.001
34–36	6.2	64.1	11.7	24.2		39.5	
37+	91.4	59.5	17.7	22.8		34.2	
Birthweight (grams)							
<2500	7.0	58.4	8.2	33.4	<0.001	42.8	<0.001
2500–3499	55.9	64.6	16.7	18.7		34.7	
3500–3999	28.2	55.8	19.3	24.9		33.6	
>4000	8.9	41.6	18.1	40.3		32.8	
Gender							
Male	51.1	57.3	18.2	24.5	<0.001	34.8	0.188
Female	48.9	62.1	15.7	22.2		35.1	
Intrauterine growth retardation							
Yes	2.3	44.4	8.3	47.3	<0.001	43.0	<0.001
No	97.7	60.0	17.2	22.8		34.6	

pregnancy/childbirth complications that often lead to Caesarean delivery. We investigated several different ways of controlling for the categories of pregnancy/childbirth complications that often lead to Caesarean delivery including controlling for (i) a count of the number of these complications that each woman had, (ii) a count of the number of complications that each woman had, only among those complications that were significantly associated with reduced subsequent fertility, (iii) the presence or absence of each of the categories of complications, only among those that were significantly associated with reduced subsequent fertility and (iv) the presence or absence of each of the 18 categories of complications. All four of these approaches produced nearly identical results. Therefore we used the last method, controlling for the presence or absence of each of the 18 categories

Table II Pregnancy and childbirth complications (indications for Caesarean section) at first birth in 2000 by first birth mode of delivery and subsequent live birth, 2000–2008.

		Mode of first live birth					
	Overall (%)	Spontaneous vaginal (%)	Instrumental vaginal (%)	Caesarean (%)	*P*-value	No subsequent live birth (%)	*P*-value
Umbilical cord complications	20.1	21.4	22.5	14.9	<0.001	34.5	0.532
Dystocia	18.2	7.0	18.2	46.7	<0.001	36.0	0.006
Fetal distress, abnormalities in fetal heart rate or rhythm	17.4	9.9	28.3	28.8	<0.001	37.6	<0.001
Premature or prolonged rupture of membranes	11.3	10.3	10.3	14.5	<0.001	37.8	<0.001
Gestational hypertension, pre-eclampsia, chronic hypertension	10.1	8.0	8.3	16.5	<0.001	38.3	<0.001
Malpresentation	8.8	1.4	3.8	31.2	<0.001	38.3	<0.001
Antepartum bleeding or placental conditions	5.5	3.9	5.6	9.6	<0.001	36.7	0.027
Cephalopelvic disproportion	4.7	0.2	0.5	19.3	<0.001	38.7	<0.001
Fetal abnormalities and other fetal conditions	4.6	4.4	3.8	5.9	<0.001	38.9	<0.001
Post-term pregnancy	4.5	3.7	4.4	6.5	<0.001	35.9	0.271
Hydramnios, oligohydramnios	3.6	2.8	2.4	6.4	<0.001	38.6	<0.001
Chronic diabetes, gestational diabetes, abnormal glucose tolerance	3.5	2.6	2.9	6.2	<0.001	45.2	<0.001
Amnionitis	3.0	2.0	2.7	5.8	<0.001	40.4	<0.001
Macrosomia	2.5	1.2	1.9	6.0	<0.001	36.5	0.201
Abnormalities of organs and soft tissues of pelvis	2.3	1.3	1.3	5.9	<0.001	45.9	<0.001
Failed induction	1.4	0.0	0.1	6.0	<0.001	40.4	0.001
Failed forceps or vacuum	0.8	0.1	1.4	2.5	<0.001	32.5	0.308
Other maternal health problems	29.6	28.8	27.3	33.0	<0.001	36.7	<0.001
Number of complications per woman							
0	24.6	34.2	24.4	0.0	<0.001	31.1	<0.001
1	32.0	36.3	33.0	20.3		33.9	
2+	43.4	29.5	42.6	79.7		37.5	

of complications. We dichotomized maternal age into two categories (aged 34 or younger versus 35 and older) because this variable was more strongly associated with the dependent variable dichotomized as opposed to continuous or in other categorizations. All of the RRs and 95% CIs were derived from modified Poisson regression models (Zou, 2004).

Results

The distributions of maternal demographic and fetal/newborn factors in relation to mode of first delivery and subsequent fertility are shown in Table I. Women 35 years old or older were at higher risk of having a Caesarean delivery and were less likely to have a subsequent birth. Among women aged 35 and older at first birth, only 35% had a subsequent live birth in comparison with 68% of those who were younger than 35 years old at first birth ($P < 0.001$). Women delivering at <34 weeks gestation were more likely to have a Caesarean and less likely to have a subsequent live birth than women delivering at later gestational ages. Similar results were seen when the newborn had IUGR.

Most of the pregnancy and childbirth complications occurred more commonly among women who had Caesarean delivery (Table II). Overall, >75% of the women had at least one of the 18 complications and nearly 80% of the women who had Caesarean delivery had two or more of these complications. In addition, the more complications a woman had, the less likely she was to have a subsequent live birth. As seen in Table II, 14 of the 18 complications were significantly associated with not having a subsequent live birth.

Women who had an instrumental vaginal delivery at first birth were initially similar in subsequent childbearing to those who had a spontaneous vaginal delivery, although after 6 years the two vaginal modes of delivery diverged somewhat, as seen in the top curve shown in Fig. 3.

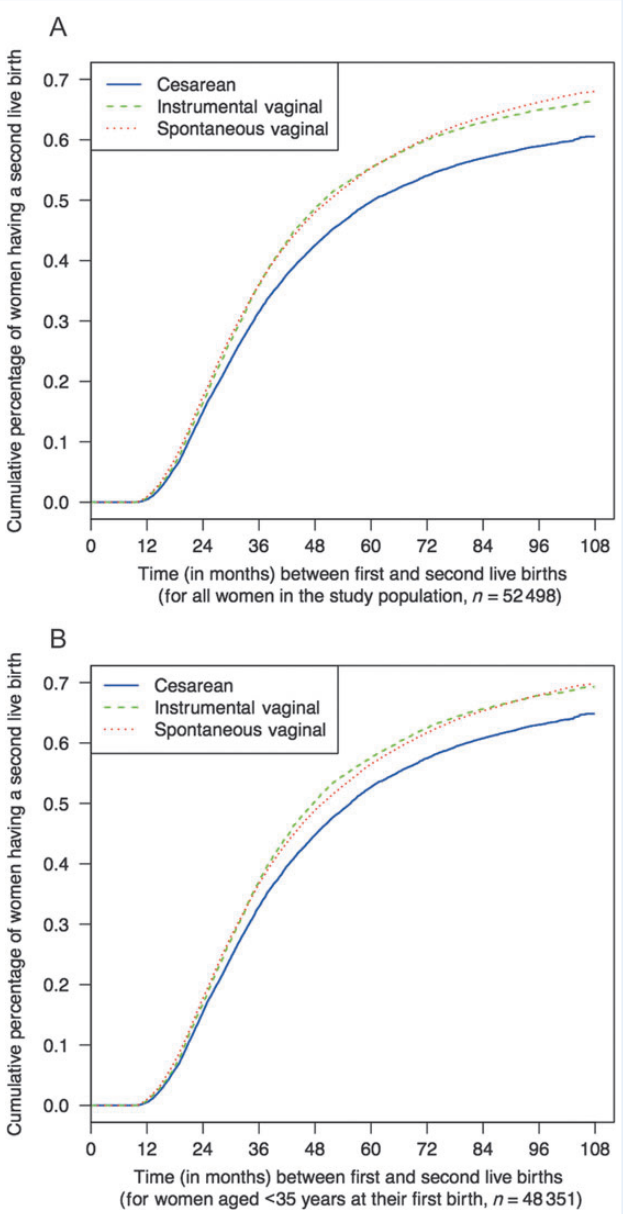

Figure 3 Cumulative percentage of women who had at least one further live birth in the 8- to 9-year follow-up period with the whole sample and with the women <35 years old at the time of first birth.- Women were followed for a time period ranging from 96 months (if their first birth was on 31 December 2000) to 108 months (if their first birth was on 1 January 2000).

The bottom curve excludes women who were aged 35 and older at the time of first birth in 2000. In that curve instrumental and spontaneous vaginal delivery are not different even after 8–9 years of follow-up, indicating that the difference between spontaneous and instrumental vaginal deliveries shown in the top curve is primarily a function of the older age of women who had delivered instrumental vaginal deliveries in comparison with those who had spontaneous vaginal deliveries.

Over the entire follow-up period, the observed percentages were that more than a third of the women overall (34.8%) had no subsequent live births, 43.4% had one subsequent live birth and 21.8% had two or more subsequent live births, as seen in Table III. However, women who had a spontaneous vaginal delivery at first childbirth were more likely to have two or more subsequent live births (24.3%) than those who had an instrumental vaginal delivery (21.3%, $P < 0.001$) or those who had a Caesarean delivery (15.7%, $P < 0.001$). Among women whose first birth was spontaneous vaginal, 67.2% had at least one subsequent live birth during the follow-up period, in comparison with 65.6% of those who had delivered by the instrumental vaginal route and 59.8% those whose first birth was by Caesarean ($P < 0.001$). We standardized these percentages to the population age distribution, as seen in Table III. Age standardization decreased the differences in subsequent childbearing by mode of delivery somewhat, in particular the differences between spontaneous vaginal and instrumental vaginal modes of delivery. However, even after age standardization, women who delivered by Caesarean were less likely to have a subsequent live birth. Among those who had a subsequent birth, the median interval between the first and second birth was nearly the same across the three modes of delivery.

The unadjusted RR for not having a subsequent life birth when comparing Caesarean with spontaneous vaginal (1.23) was nearly the same as when comparing Caesarean with vaginal overall (spontaneous and instrumental combined) (1.21) (Table IV). Adjustment for the maternal demographic factors reduced the RR of not having a subsequent live birth for Caesarean delivery in comparison with vaginal delivery overall to 1.16, but further adjustment for the pregnancy and childbirth complications had little effect on the RR.

Discussion

In this large retrospective cohort study, we found that women who delivered their first child by Caesarean section were less likely to have a subsequent live birth over the course of an 8- to 9-year follow-up period. This association was due in part to confounding factors of maternal age, race, education, insurance coverage and marital status. However, even after we controlled for these factors, as well as pregnancy and childbirth complications, Caesarean delivery was still significantly associated with a deficit in subsequent childbearing.

This was the first study to systematically identify the pregnancy and childbirth complications that are considered to be indications for Caesarean delivery, in order to investigate the associations between these complications and subsequent fertility. There were two important findings of this effort. First, many of the pregnancy and childbirth complications that lead to Caesarean delivery were associated with reduced subsequent fertility. Second, many of the conditions considered to be indications for Caesarean occurred commonly among women who did not deliver by Caesarean. However, we were not able to quantify the severity of these conditions. It could be that these conditions lead to Caesarean delivery when they occur at higher levels of severity or urgency. We did find that women who had two or more of the 18 conditions were more likely to have Caesarean section, which suggests that the decision to operate may also be a function of the number of indicating conditions. This is the first study, to our knowledge, which assessed and compared rates of indications for Caesarean delivery across all three modes of delivery.

Few of the previous studies of mode of delivery in relation to subsequent childbearing investigated whether preterm delivery affects subsequent childbearing, even though preterm infants are more often

Table III First birth mode of delivery in relation to total number of subsequent live births, 2000–2008.

		Mode of first live birth			
	Overall (%)	Spontaneous vaginal (%)	Instrumental vaginal (%)	Caesarean %	*P*-value
Total number of subsequent live births					
0	34.8	32.8	34.4	40.2	<0.001
1	43.4	42.8	44.3	44.1	
2	17.0	18.6	16.5	13.2	
3	3.9	4.6	4.1	2.1	
4+	0.9	1.2	0.7	0.4	
Total number of subsequent live births, standardized to the population age distribution					
0	34.8	33.6	33.9	38.2	<0.001
1	43.4	43.1	43.9	44.5	
2	17.0	18.0	17.0	14.4	
3	3.9	4.3	4.4	2.5	
4+	0.9	1.1	0.8	0.5	
Time (months) to first subsequent birth (median)	34.2	34.3	33.8	34.7	0.090

Table IV Risk ratios of not having a subsequent live birth during the follow-up period, 2000–2008.

	Mode of first live birth		
	Spontaneous vaginal	Instrumental vaginal	Caesarean
Risk ratio of not having a subsequent live birth, unadjusted *Instrumental vaginal versus spontaneous vaginal and Caesarean versus spontaneous vaginal*	1.00 (reference)	1.05 (1.02–1.08)	1.23 (1.19–1.26)
Risk ratio of not having a subsequent live birth unadjusted *Caesarean versus vaginal (spontaneous and instrumental vaginal combined)*		1.00 (reference)	1.21 (1.18–1.25)
Risk ratio of not having a subsequent live birth, adjusted for confounders[a] *Instrumental vaginal versus spontaneous vaginal and Caesarean versus spontaneous vaginal*	1.00 (reference)	1.04 (1.00–1.07)	1.17 (1.14–1.20)
Risk ratio of not having a subsequent live birth adjusted for confounders[a] *Caesarean versus vaginal (spontaneous and instrumental vaginal combined)*		1.00 (reference)	1.16 (1.13–1.19)
Risk ratio of not having a subsequent live birth, adjusted for confounders[a] and complications[b] *Instrumental vaginal versus spontaneous vaginal and Caesarean versus spontaneous vaginal*	1.00 (reference)	1.04 (1.00–1.07)	1.17 (1.12–1.21)
Risk ratio of not having a subsequent live birth adjusted for confounders[a] and complications *Caesarean versus vaginal (spontaneous and instrumental vaginal combined)*		1.00 (reference)	1.15 (1.11–1.19)

[a]Maternal age (< 35 versus 35+), race, education, marital status and insurance.
[b]The presence or absence of each of the 18 complications seen in Table II

delivered by Caesarean than full term infants (MacDorman *et al.*, 2008). In this study infants born <34 weeks, as well as IUGR infants, were more likely to be delivered by Caesarean and less likely to have a sibling born over the course of the follow-up period. It could be that parents of preterm or IUGR children may be more likely to decide not to have more children, either because of the challenges of taking care of these children, or because they do not want to risk recurrence of such an event.

One of the main limitations of this study is that we were unable to distinguish women who moved out of the state of Pennsylvania from those who did not have a subsequent birth. This would be a potential source of bias if women who delivered their first child by Caesarean were more likely to move out of the state during the time period of our study than women who delivered vaginally. There is little data available on characteristics of people who move out of the state, so we do not know whether women who delivered their first child in 2000 by Caesarean were more likely to move out of state than those who delivered their first child vaginally. However, because some unknown per cent of the women who had their first child in 2000 would have moved out of the state of Pennsylvania and had one or more subsequent births in other states or countries, our estimates of subsequent fertility are likely underestimates.

Another limitation of this study is that we had no data on miscarriages and stillbirths previous to or subsequent to the first live birth. Most of the previous studies that have investigated this issue have reported lower rates of conception after Caesarean delivery, but no increased risk of subsequent miscarriage or stillbirth (Zdeb et al., 1984; Hemminki, 1986; LaSala and Berkeley 1987; Collin et al., 2006). However, two studies reported a higher miscarriage rate after Caesarean (Hall et al., 1989; Hemminki and Merilainen 1996), and a recently published abstract reported an increased risk of stillbirth and a longer between pregnancy interval after primary Caesarean delivery in comparison with vaginal delivery in a large population-based Danish cohort study (O'Neil, 2013).

The 2000 birth certificate data did not contain pre-pregnancy height and weight (which would have enabled us to determine pre-pregnancy body mass index), weight gain during pregnancy or previous infertility treatments. Studies have found that women who have difficulty conceiving are more likely to deliver by Caesarean and less likely to have more than one live birth than women who have no difficulty conceiving (LaSala and Berkeley 1987; Murphy et al., 2002).

Studies with sample sizes this large generally use ICD-9 codes noted in administrative data to identify indications for Caesarean delivery, because it would be a very laborious task to review the original medical records of such large samples. A study of administrative data in comparison with medical records as the gold standard for the identification of indications for elective primary Caesareans has reported that the accuracy of the administrative data ranged from 84 to 100% across the indications, although for most of the conditions, the accuracy was between 95 and 100% (Korst et al., 2004). Thus our use of administrative data to identify complications is not likely to have substantially affected the study results.

In this study we excluded women whose child died within the first year after birth ($n = 151$), because in such cases there is a tendency for families to replace the loss (Skjaerven et al., 1988). A recent study investigated the effect of mode of delivery following stillbirth or an infant loss (Tollanes et al., 2007), and reported that if the first child died, Caesarean delivery was not as strongly associated with reduced subsequent child bearing compared with those whose child survived.

We investigated the effects of newborn characteristics (such as gestational age) on subsequent fertility, but we did not control for these factors in the regression equations because these factors could be intermediate variables. Adjustment for such factors in the causal pathway may lead to biased estimates of association, particularly when there are also unmeasured potential causal intermediate variables (Greenland, 2003; Hafeman and VanderWeele 2011; VanderWeele et al., 2012). In the case of studies of childbearing subsequent to Caesarean delivery using administrative data, we have no information to explain why some women have one or more subsequent children while others do not.

In conclusion, this population-based US study of women who delivered their first child in 2000 and who were followed to the end of 2008 provides further support of the findings of previous studies showing that women who deliver their first child by Caesarean are less likely to have a subsequent birth. A recent systematic review and meta-analysis of the impact of Caesarean section on subsequent fertility reported that Caesarean was associated with an 11% lower subsequent birth rate, based on meta-analysis of 18 studies (Gurol-Urganci et al., 2013). In this study we found a 15% lower subsequent birth rate after Caesarean delivery, which was similar. In addition, the results of this study indicate that some, but not all, of the complications that tend to lead to Caesarean delivery are associated with deficits in subsequent childbearing.

Supplementary data

Supplementary data are available at http://humrep.oxfordjournals.org/.

Authors' roles

All authors have fulfilled all conditions required for authorship. K.H.K. conceived the study and prepared the final manuscript. J.Z. performed the analyses and drafted the tables and figures. C.S.W. contributed to conceptualization of analyses and preparing the manuscript, and C.V.A. made substantial contributions to the interpretation of data and intellectual content.

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Conflict of interest

None declared.

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