

OBSTETRICS

The relationship between cesarean delivery and fecundability: a population-based cohort study

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BACKGROUND: Previous studies have found that women who undergo cesarean delivery have fewer pregnancies. Cesarean delivery is also more common among women with lower fecundability. The potential role of cesarean delivery in reduced fecundability is not known.

OBJECTIVE: This study aimed to assess the bidirectional relationship between cesarean delivery and fecundability.

STUDY DESIGN: This was a prospective cohort study based on data from the Norwegian Mother, Father, and Child Cohort study linked with the Medical Birth Registry of Norway. We estimated the fecundability ratio (per cycle probability of pregnancy) and relative risk of infertility (time to pregnancy ≥ 12 months) by mode of delivery in the previous delivery among 42,379 women. For the reverse association, we estimated the relative risk of having a cesarean delivery by fecundability (the number of cycles women needed to conceive) among 74,024 women.

RESULTS: The proportion of women with infertility was 7.3% (2707/37,226) among women with a previous vaginal delivery and 9.9% (508/5153) among women with a previous cesarean delivery, yielding an adjusted relative risk of 1.21 (95% confidence interval, 1.10–1.33). Women with a previous cesarean delivery also had a lower fecundability

ratio (0.90; 95% confidence interval, 0.88–0.93) than women with a previous vaginal delivery. When assessing the reverse association between fecundability and cesarean delivery, we found that women who did not conceive within 12 or more cycles had a higher risk for cesarean delivery (adjusted relative risk, 1.57; 95% confidence interval, 1.48–1.66) than women who conceived within the first 2 cycles. The associations remained after controlling for sociodemographic and clinical risk factors and were observed across parity groups.

CONCLUSION: Among women with more than 1 child, those who had a previous cesarean delivery subsequently had a lower fecundability ratio and an increased infertility risk than those who had a vaginal delivery. However, women who needed a longer time to conceive were also more prone to be delivered by cesarean delivery, indicating a bidirectional relationship between cesarean delivery and fecundability. This could suggest a common underlying explanatory mechanism and that the surgical procedure itself may not or only partly directly influence fecundability.

Key words: cesarean delivery, fecundability, fecundability ratio, infertility, mode of delivery, prospective, time to pregnancy

Introduction

Time to pregnancy (TTP), which refers to the duration of attempts a couple makes to conceive before succeeding,¹ is an important measure of fecundability, which is defined as the capacity to establish a clinical pregnancy in a cycle.^{1,2} Infertility, defined as having tried to conceive for more than 12 months without success, is indicative of decreased fecundability.² It can persist without resolution, or it may be resolved either through spontaneous means, treatment, or by changing partners.^{1,3} A

couples' biology, social, behavioral, and environmental factors may also contribute and influence the likelihood of pregnancy.^{1,3}

Findings of a relationship between cesarean delivery (CD) and later fertility is inconclusive. Reviews have reported fewer pregnancies and longer interpregnancy intervals following a CD,^{4–6} although others found no difference.^{7,8} Medical indications for CD, uterine scarring, and placental abnormalities have been proposed as explanations for the reduction in fecundability following a CD.^{5,9} Alternatively, this reduction may be attributed to a voluntary decision made by couples.^{10–12} However, most of these studies used interpregnancy interval to measure fecundability,^{4–8,10} which is largely determined by the couple's desire for pregnancy spacing and therefore cannot differentiate between voluntary and involuntary delays in pregnancy.⁹ They also failed to account for potential risk factors, such as smoking, contraceptive use,^{8,10} or access to

infertility treatment,^{7–9} whereas other studies have short follow-up periods.¹³ CD is also more prevalent among women with reduced fecundability.^{9,14–16} Murphy and colleagues⁹ found a correlation between CD and infertility in both directions in the Avon Longitudinal study. However, they were unable to account for indications of CD and intrapartum and postpartum complications, hence, they were unable to distinguish between the indications and the procedure itself. No other studies, to our knowledge, have assessed the potential bidirectional relationship between CD and fecundability in a nationwide cohort.

Over the years, changes in reproductive behavior (use of contraception, delayed childbearing),² along with changes in obstetrical practices, may have contributed to a lower threshold for CD in numerous countries,^{5,6} including Norway.¹⁷ As a consequence, more first-time mothers are exposed to CD,¹⁸ making it important to examine the

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AJOG at a Glance

Why was this study conducted?

This study aimed to assess the bidirectional relationship between cesarean delivery and fecundability.

Key findings

Women with a history of cesarean delivery had an increased risk for reduced fecundability and infertility and women with lower fecundability were more likely to have a cesarean delivery.

What does this add to what is known?

Previous studies have linked cesarean deliveries with subsequent reduced fecundability, but this could be because of a common underlying mechanisms, rather than the surgical procedure itself.

link between CD and fecundability. This study used a large, prospective cohort to investigate the bidirectional relationship between CD and fecundability.

Materials and methods

We studied women who participated in the Norwegian Mother, Father, and Child Cohort Study (MoBa). MoBa was a population-based, pregnancy cohort study that was conducted by the Norwegian Institute of Public Health.¹⁹ Pregnant women were recruited throughout Norway at the time of routine second-trimester ultrasound screening between 1999 and 2008, and the participation rate was 41%. Version 12 of the quality-assured data files, released in January 2019, served as the basis for this study. We used information from a self-reported questionnaire completed at 15 to 18 weeks' gestation. Women could participate with more than 1 pregnancy, and the MoBa cohort consisted of 95,200 women and 114,500 children. Additional information on the mother's health and pregnancy outcomes was collected by linking to the Medical Birth Registry of Norway (MBRN) using the mother's personal identification number. The MBRN comprises all live and stillbirths in Norway from 16 weeks of gestation onwards since 1967, based on mandatory notification.²⁰ The attending health professionals are responsible for providing information to the MBRN.

This study was approved by the Regional Committees for Medical and

Health Research Ethics (2014/404) and informed consent was obtained from all MoBa participants.

Study population

We included women with at least 1 recorded pregnancy in MoBa and excluded women who did not complete the recruitment questionnaire and women with incomplete TTP data (Figure). The MoBa pregnancy is referred to as the index pregnancy.

When exploring the association between CD in the previous pregnancy and fecundability, we excluded women without a registered birth before the index pregnancy and those with in vitro fertilization (IVF) in their previous pregnancy because of the possibility of preexisting fertility problems.²¹

To examine the reverse association between fecundability and the risk for CD, women with a history of CD were excluded because the likelihood of recurrence is high.¹⁷

Fecundability

At recruitment, participants were asked if their pregnancy was planned or not. If the pregnancy was planned, women were asked to indicate how long they had been trying to conceive by choosing 1 of the following options: "<1 month," "1–2 months," or "≥3 months." If the latter option was selected, they were asked to specify the exact number of months.

A pregnancy was considered planned if the participant answered affirmatively to the question about whether the

pregnancy was intended and if they provided information on the duration of trying to conceive while not using contraceptives. Women were also asked about their average menstrual cycle length. We corrected the TTP for the woman's reported average cycle length. For cases in which participants did not provide information about the cycle length (4943, 6.2%), a cycle length of 28 days was assumed.

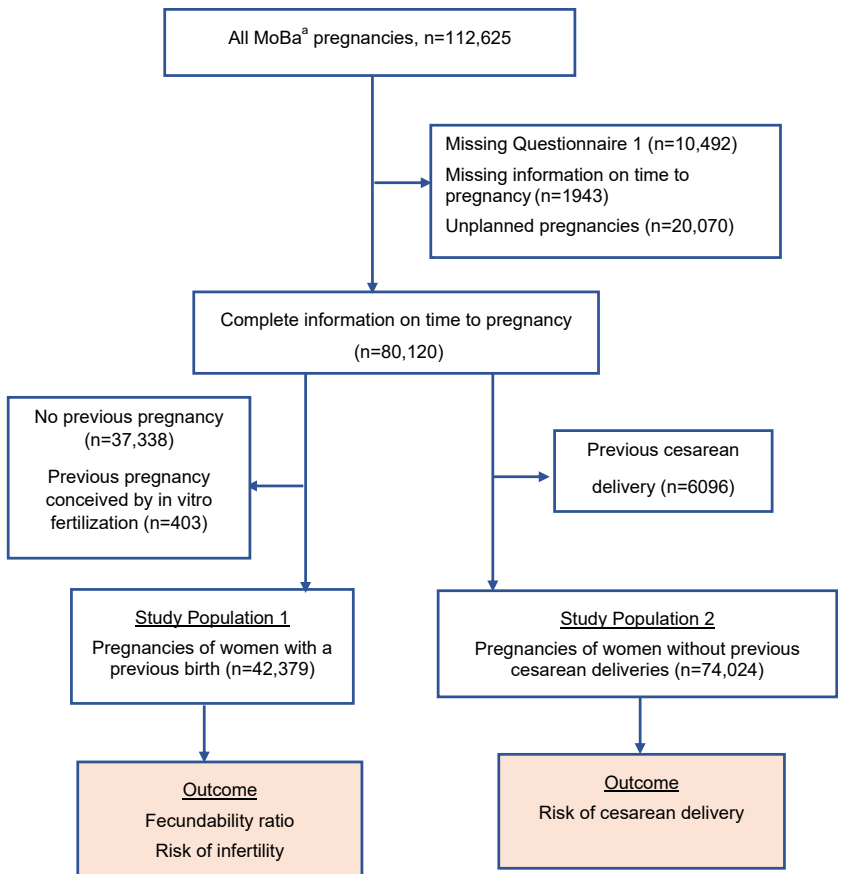
A total of 8061 (10.1%) women reported that the duration to conceive was ≥3 months without specifying the exact duration. For these cases, we assumed a 3-month duration. In addition, 1782 (2.2%) women reported pregnancies during their TTP period (mostly miscarriages), thus, we corrected the reported TTP by subtracting the pregnancy length and an additional month to allow time between the loss and the new start of trying. In cases where no pregnancy length was provided, we subtracted 8 weeks. For index pregnancies conceived by IVF with missing TTP information, we assumed a waiting time of ≥12 months.

Data on the mode of delivery in the previous and index pregnancy was obtained from the MBRN.

Covariates

In our analysis, we included maternal age (years) (<24, 25–34, ≥35), education (years) (low: ≤13 and high: >13), smoking status (nonsmoker, quit smoking in the current pregnancy, smoker), and prepregnancy body mass index (BMI) (<18.5, 18.5–24.9, 25–29.9, ≥30 kg/m²). We identified mothers with chronic conditions such as asthma, arthritis, hyper- and hypothyroidism, endometriosis, ovarian cysts, and myoma from the data. Data on all these covariates were collected at the time of recruitment at the index pregnancy (MoBa). Data on diabetes mellitus, chronic hypertension, and pregnancy complications (gestational hypertension, preeclampsia, preterm birth, placental abruption, and placenta previa) were retrieved from the MBRN and represented risk factors for CD and reduced fecundability.²² Women were grouped on the absence or presence

FIGURE
Flowchart of study population



Superscript letter a denotes Norwegian Mother, Father, and Child Cohort Study.

Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.

of 1 or more of the abovementioned chronic conditions and pregnancy complications.

Statistical analysis

Stata, version 17, (StataCorp, College Station, TX) was used for all statistical analyses. Robust clustered variance was used to account for women who participated with more than 1 pregnancy. Missing values for maternal education, smoking, BMI, and pregnancy complications were handled using multiple imputation by chained equation (MICE) (20 data sets) with logistic regression for maternal education and pregnancy complications and multinomial logistic regression for BMI and smoking.²³

Previous cesarean delivery and fecundability

We estimated the monthly probability of pregnancy (fecundability ratio [FR]) with 95% confidence intervals (CIs) according to CD in the previous birth using proportional probability regression with cycles as the unit of analysis. A FR >1 indicates a greater likelihood of conceiving in each cycle, whereas a FR <1 indicates a lower likelihood of conceiving in each cycle. We also estimated the relative risk (RR) of infertility (TTP ≥12 months) with 95% CIs using proportional probability regression with pregnancies as the unit of analysis. Women with a previous vaginal delivery were the reference in both models. Models were adjusted for maternal age

and complications in the previous birth, maternal education, smoking status, and chronic conditions (Supplemental Figure S1). To account for a lack of BMI data in the MBRN, we adjusted for prepregnancy BMI at the index pregnancy as a proxy.

In the main analyses, we excluded women with unplanned pregnancies. This group comprised women who either answered no to the question of planning their pregnancy or who answered yes but reported using contraceptives, because they lacked reliable data on TTP.^{1,3,24} To evaluate the potential impact of selection, we performed a sensitivity analysis that included women with unplanned pregnancies and a separate sensitivity analysis that excluded pregnancies of women who reported trying to conceive for ≥3 months without specifying the exact duration. To account for a change in the CD over the years, we conducted an analysis that was restricted to women <35 years of age at the time of exposure.¹⁸ Furthermore, we stratified our analysis by the number of years between the previous delivery and the index pregnancy (up to 3 years and 3 to 7 years). About 95% of Norwegian women give birth to their second child within 7 years.²⁵

Given that the indications may differ between emergency and planned CD,²⁶ we conducted stratified analyses by the type of previous delivery (vaginal delivery, planned CD, or emergency CD). In addition, to investigate if the association between a previous CD and fecundability differed by the number of previous CDs and the sequence of CDs, we performed additional analyses. Finally, we stratified by parity to account for the possible variation in social and behavioral risk factors.⁹

Fecundability and risk for cesarean delivery

We also investigated the reverse association, namely, the risk for CD by number of cycles women needed to conceive (<3 [reference], 3–6, 7–11, and ≥12). To obtain the RR with 95% CI, we used a generalized linear model with a log-link

and binomial distribution. Because of the convergence difficulties with the log-binomial model, Poisson regression models were used. The model was adjusted for maternal age at time of conception, maternal education, pre-pregnancy BMI, smoking status, and chronic conditions (Supplemental Figure S2). We conducted a sensitivity analysis that included women with a previous CD and similar sensitivity analyses as previously described. In addition, we adjusted for complications in the index pregnancy to account for the possibility that these might increase the risk for CD.

In both analytic designs, to account for uncertainty in TTP, we conducted sensitivity analyses stratifying on cycle regularity (yes/no), excluding women who reported pregnancy within the TTP period. Finally, we stratified analyses by spontaneous- and induced onset of labor.

Results

Previous cesarean delivery and fecundability

This analysis included 42,379 pregnancies of women with a previous birth among whom two-thirds only had 1 previous birth (Table 1). Women with a previous CD were older, had lower education, and a higher proportion of chronic conditions and complications than women with a previous vaginal delivery (Supplemental Table S1).

The FR was lower (0.90; 95% CI, 0.88–0.93) among women with a previous CD than among those with a previous vaginal delivery (Table 2). The absolute risk of infertility was 7.3% (2707/37226) and 9.9% (508/5153) among women with a previous vaginal delivery and a CD, respectively, with a corresponding RR among women with a previous CD of 1.21 (95% CI, 1.10–1.33) (Table 3). Restricting this analysis to only complete cases did not change the estimates.

Excluding women ≥ 35 years of age or pregnancies for which women reported a period of ≥ 3 months of trying to conceive without specifying the duration of TTP showed almost similar results (Supplemental Tables S2 and S3). In

addition, the fecundability patterns were similar among women with planned and those with emergency CDs and across different parity groups.

Restricting the time interval to between the year of the previous birth and the start of trying to conceive the index pregnancy to either <3 years or 3 to 7 years did not change the pattern. Among women with ≥ 2 births, there was no difference in the fecundability or infertility patterns irrespective of whether the CD happened earlier or in the previous birth and whether a woman had 1 or multiple CDs (Supplemental Tables S4 and S5).

The proportion of women younger than 25 years was higher among women with unplanned pregnancies (Supplemental Table S6). However, including them in the analysis did not alter the results.

Fecundability and risk for cesarean delivery

This analysis included 74,024 index pregnancies. A total of 10.9% of pregnancies (8038/74024) were to women with infertility (Supplemental Table S7). Women with infertility had lower education, smoked more, were more overweight or obese, and more often had chronic conditions and pregnancy complications than women who conceived within 12 months. Nearly two-thirds of these pregnancies were to nulliparous women.

The risk for CD increased by increasing number of cycles to achieve pregnancy (Table 4). The absolute risk for CD among women who conceived within the first 2 cycles was 10.3% (3979/38,764), whereas it was 17.6% (1414/8038) among women who conceived after ≥ 12 cycles. In comparison with women who conceived within the first 2 cycles, those who did not conceive within 12 or more cycles had a 57% higher risk for CD (RR, 1.57; 95% CI, 1.48–1.66). These patterns were similar across parity groups (Supplemental Table S8). Adjusting for complications in the index pregnancy attenuated the risk but did not change the pattern, whereas including women with a previous CD did not change our result.

In both analytical designs, our results remained consistent when stratifying by cycle regularity, labor onset and when excluding women who reported pregnancy during TTP (Supplemental Table S9).

Comment

Principal findings

Among women with more than 1 child, we identified decreased fecundability following a previous CD. However, we also confirmed the reverse association in that women with reduced fecundability were more likely to have a CD. Associations remained after controlling for sociodemographic and clinical risk factors and were observed among different parity groups. Our results suggest that there is a bidirectional association that may be explained by shared underlying mechanisms for CD and reduced fecundability.

Results in the context of what is known

We found a decrease in fecundability following both planned and emergency CD, in contrast with a smaller Danish study that only observed a decline among women with a planned CD.²⁷ We observed a consistent association between CD and fecundability among women who had previously given birth to only 1 child and those who had 2 or more previous births. The impact of CD did not differ whether it occurred in the previous delivery or in earlier deliveries or whether CD occurred only once or multiple times.

We also found an increased risk for CD among women with reduced fecundability, in line with previous studies.^{14–16,21} The increased CD risk remained after accounting for parity and other potential risk factors, albeit to a lesser extent. It is plausible that the increased risk for CD among women with infertility could, in part, be attributed to maternal preference.^{14,28} A previous Norwegian study, based on the MoBa questionnaire around 30 weeks of pregnancy, found that 10% of women preferred CD, and this was even higher among women who became pregnant through IVF.²⁸

The occurrence of uterine scarring owing to a previous CD has been linked

TABLE 1

Characteristics of the study participants of the Norwegian Mother, Father and Child Cohort (1999–2008) with linked data from the Medical Birth Registry of Norway

Characteristics	Pregnancies among women with a previous birth n (%)	Pregnancies of women without previous cesarean deliveries n (%)
Total	42,379	74,024
Mode of delivery ^a		
Vaginal delivery	37,226 (87.8)	65,433 (88.4)
Cesarean delivery	5153 (12.2)	8591 (11.6)
Time to previous pregnancy (mo)		
<12	39,164 (92.4)	65,986 (89.1)
≥12	3215 (7.6)	8038 (10.9)
Maternal age (y) ^a		
<25	9128 (21.7)	8560 (11.6)
25–34	31,416 (74.1)	56,373 (76.2)
≥35	1835 (4.3)	9091 (12.2)
Maternal education (y)		
≤13	14,023 (33.1)	21,855 (29.5)
>13	28,193 (66.5)	51,878 (70.1)
Missing	163 (0.4)	291 (0.4)
Smoking		
Nonsmoker	31,154 (73.5)	53,267 (72.0)
Quit smoking in the current pregnancy	7275 (17.2)	14,473 (19.6)
Current smoker	3198 (7.6)	5056 (6.8)
Missing	752 (1.8)	1228 (1.6)
Prepregnancy body mass index (kg/m ²)		
<18.5	1052 (2.5)	2076 (2.8)
18.5–24.9	26,265 (62.0)	48,289 (65.2)
25–29.9	9882 (23.3)	15,813 (21.4)
≥30	4226 (10.0)	6411 (8.7)
Missing	954 (2.3)	1435 (1.9)
Chronic conditions ^b		
None	34,947 (82.5)	60,547 (81.8)
One or more	7432 (17.5)	13,477 (18.2)
Pregnancy complications ^{a,c}		
None	36,737 (86.7)	65,579 (88.6)
One or more	4784 (11.3)	7802 (10.5)
Missing	858 (2.0)	643 (0.9)
Parity (previous births)		
Nulliparous	0	35,369 (47.8)
1	28,607 (67.5)	26,222 (35.4)
≥2	13,772 (32.5)	12,080 (16.3)
Missing	0	353 (0.5)

^a Measured at the time of previous pregnancy in the first column and at the time of index pregnancy in the second column; ^b Self-reported chronic conditions, including asthma, arthritis, chronic hypertension, diabetes mellitus, endometriosis, epilepsy, hypo- or hyperthyroids, ovarian cyst, and myoma; ^c Includes gestational hypertension, preeclampsia, placental abruption, placental previa, and preterm birth. *Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.*

TABLE 2

Cesarean delivery in the previous birth and fecundability ratio in the pregnancy registered in the Norwegian Mother, Father, and Child Cohort Study

Previous mode of delivery	No. (total)	No. cycles	Fecundability ratio		
			Unadjusted (95% CI)	Adjusted ^a (95% CI)	Adjusted ^b (95% CI)
All women	42,379				
Vaginal delivery	37,226	145,512	1.00 (ref)	1.00 (ref)	1.00 (ref)
Cesarean delivery	5153	22,909	0.87 (0.85–0.89)	0.90 (0.88–0.93)	0.86 (0.80–0.93)

The results for N=42,379 pregnancies are presented.

CI, confidence interval.

^a Complete case analysis. Model adjusted for maternal age and pregnancy complications in the previous birth, maternal education, smoking, prepregnancy body mass index and chronic conditions, and accounting for women who participated with several pregnancies; ^b Multiple imputation carried out to include 10,697 cycles. Model adjusted for same factors as in ^a.

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to adverse pregnancy outcomes, such as ectopic pregnancy and abnormal placentation.^{4–6} Similar mechanisms have been proposed to explain the difficulty in conceiving after a CD.¹³ However, our findings of a bidirectional relationship between CD and fecundability support the idea of common underlying explanatory mechanisms for both conditions rather than that the procedure of a CD itself influences fecundability. Both pregnancy complications and chronic conditions were more prevalent among women with CD and reduced fecundability. However, adjusting for these confounders had little influence on either sides of the association, suggesting other potential common underlying mechanisms. Maternal anxiety could be a plausible explanation. Studies have linked anxiety to difficulties in conceiving²⁹ and the requirement for

more obstetrical interventions, including CD.^{14,21,30} Future studies that assess the role of maternal anxiety on fecundability and interventions during childbirth are needed.

Clinical implications

With some exceptions,^{7,8} previous studies have found that women without known fecundability problems may experience decreased fecundability and infertility following a CD.^{4–6} In addition, a systematic review and meta-analysis of 7 observational studies among women who underwent assisted reproductive technology treatment also showed a decrease in pregnancy rates among those with a history of CD.³¹ In light of these findings, it is suggested that the global rise in CD, together with delayed childbearing,² may have substantial implications for subsequent reproduction.^{5,6,13}

Our study found an association between CD and a subsequent reduction in fecundability and an even stronger association between reduced fecundability and the risk for CD, indicating potential shared mechanisms between decreased fecundability and CD.

Strength and limitations

This study has several strengths, including a large sample size from a prospective, population-based pregnancy cohort with comprehensive information on both exposure and outcome, thereby minimizing recall bias. The use of linked data allowed for the investigation of a bidirectional relationship between CD and fecundability. In addition, unlike most previous studies,^{4–6,8,10} we had access to data on pregnancy intention and, for women who planned their pregnancy, the TTP.

TABLE 3

Cesarean delivery in the previous birth and relative risk of infertility in the pregnancy registered in the Norwegian Mother, Father, and Child Cohort Study

Previous mode of delivery	No. (total)	No. (%) cases infertility	Relative risk of infertility		
			Unadjusted RR (95% CI)	Adjusted ^a RR (95% CI)	Adjusted ^b RR (95% CI)
All women	42,379				
Vaginal delivery	37,226	2707 (7.3)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Cesarean delivery	5153	508 (9.9)	1.36 (1.24–1.48)	1.21 (1.10–1.33)	1.20 (0.97–1.47)

The results for N=42,379 pregnancies are presented.

CI, confidence interval; RR, relative risk.

^a Complete case analysis. Model adjusted for maternal age and pregnancy complications in the previous birth, maternal education, smoking, prepregnancy body mass index and chronic conditions, and accounting for women who participated with several pregnancies; ^b Multiple imputation carried out to include 2613 cases. Model adjusted for same factors as for ^a.

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TABLE 4

Fecundability and relative risk of cesarean delivery in the pregnancy registered in the Norwegian Mother, Father, and Child Cohort Study

Categorization of fecundability (cycles to conception)	No. (total)	No. (%) cesarean deliveries	Relative risk of cesarean delivery		
			Unadjusted RR (95% CI)	Adjusted ^a RR (95% CI)	Adjusted ^b RR (95% CI)
All women	74,024				
<3 cycles	38,764	3979 (10.3)	1.00 (ref)	1.00 (ref)	1.00 (ref)
3–6 cycles	20,723	2411 (11.6)	1.13 (1.07–1.18)	1.11 (1.05–1.16)	1.12 (1.00–1.26)
7–11 cycles	6499	787 (12.1)	1.18 (1.07–1.24)	1.12 (1.04–1.21)	1.10 (0.92–1.31)
≥12 cycles	8038	1414 (17.6)	1.71 (1.60–1.79)	1.57 (1.48–1.66)	1.47 (1.29–1.67)

The results for N=74,024 pregnancies are presented.

CI, confidence interval; RR, relative risk.

^a Complete case analysis. Model adjusted for maternal age (at the time of trying to conceive), maternal education, smoking, prepregnancy body mass index, and chronic conditions (with 1 or more of the following conditions: asthma, arthritis, chronic hypertension, diabetes mellitus, endometriosis, epilepsy, hypo- or hyperthyroids, ovarian cyst, and myoma) and accounting for women who participated with several pregnancies; ^b Multiple imputation carried out to include 3139 cases. Model adjusted for the same factors as for ^a.

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Our analysis also went beyond the conventional 12-month cutoff and the estimated FR, providing a more comprehensive overview.^{1–3}

Our study has some limitations. We only included women who successfully conceived after their initial CD. This means that couples who were unable to conceive or who experienced pregnancy loss before 15 to 18 weeks following their first CD were not included, leading to the exclusion of women with poor fecundability, which could bias our estimates toward the null.^{1,3} Future research examining the relationship between CD and subsequent early pregnancy loss would be valuable.

Information on TTP was obtained through self-report by women. Although TTPs of <12 months tend to be recalled more accurately, longer durations are prone to recall bias.²⁷ However, by including only planned pregnancies in the main analyses, it could reduce any potential recall bias.³ Participants in MoBa were older, had higher education, were predominately Norwegian speaking and more often first-time mothers, when compared with the general population of pregnant women.³² Despite this selection, estimates of the association between exposures and outcomes were found to be comparable with the MBRN.³² Moreover, the overall CD rate was comparable with that of the

Norwegian population.¹⁸ Furthermore, using data from homogeneous populations, like the MoBa, could also be advantageous by controlling for confounders by restrictions.^{33,34} However, we lacked data on non-IVF treatments for infertility, particularly ovulation induction and intrauterine insemination, and the indications for CD. Therefore, the potential for unmeasured confounding factors could not be ruled out. Finally, in contrast with other high-income countries, Nordic countries generally have lower CD rates.¹⁷ Nevertheless, finding associations in a low-prevalence context could suggest that they may be even stronger in settings with higher CD rates.

Conclusion

We found evidence of a bidirectional relationship between CD and fecundability. This supports the idea that there may be common underlying explanatory mechanisms and that the surgical procedure itself may not or only partly directly influence fecundability. ■

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References

1. Baird DD, Wilcox AJ, Weinberg CR. Use of time to pregnancy to study environmental exposures. *Am J Epidemiol* 1986;124:470–80.
2. Smarr MM, Sapra KJ, Gemmill A, et al. Is human fecundity changing? A discussion of research and data gaps precluding us from having an answer. *Hum Reprod* 2017;32:499–504.
3. Weinberg CR, Baird DD, Wilcox AJ. Sources of bias in studies of time to pregnancy. *Stat Med* 1994;13:671–81.
4. Hemminki E. Impact of Caesarean section on future pregnancy – a review of cohort studies. *Paediatr Perinat Epidemiol* 1996;10:366–79.
5. Guroi-Urganci I, Bou-Antoun S, Lim CP, et al. Impact of Caesarean section on subsequent fertility: a systematic review and meta-analysis. *Hum Reprod* 2013;28:1943–52.
6. O'Neill SM, Kearney PM, Kenny LC, et al. Caesarean delivery and subsequent pregnancy interval: a systematic review and meta-analysis. *BMC Pregnancy Childbirth* 2013;13:165.
7. Evers EC, McDermott KC, Blomquist JL, Handa VL. Mode of delivery and subsequent fertility. *Hum Reprod* 2014;29:2569–74.
8. Smith GC, Wood AM, Pell JP, Dobbie R. First cesarean birth and subsequent fertility. *Fertil Steril* 2006;85:90–5.
9. Murphy DJ, Stirrat GM, Heron J; ALSPAC Study Team. The relationship between Caesarean section and subfertility in a population-based sample of 14 541 pregnancies. *Hum Reprod* 2002;17:1914–7.
10. Tollånes MC, Melve KK, Irgens LM, Skjærven R. Reduced fertility after cesarean

delivery: a maternal choice. *Obstet Gynecol* 2007;110:1256–63.

11. Porter M, Bhattacharya S, van Teijlingen E, Templeton A. Reproductive Outcome Following Caesarean Section (ROCS) Collaborative Group. Does caesarean section cause infertility? *Hum Reprod* 2003;18:1983–6.

12. Bhattacharya S, Porter M, Harrild K, et al. Absence of conception after caesarean section: voluntary or involuntary? *BJOG* 2006;113:268–75.

13. Kjerulff KH, Paul IM, Weisman CS, et al. Association between mode of first delivery and subsequent fecundity and fertility. *JAMA Netw Open* 2020;3:e203076.

14. DoPierala AL, Bhatta S, Raja EA, Bhattacharya S, Bhattacharya S. Obstetric consequences of subfertility: a retrospective cohort study. *BJOG* 2016;123:1320–8.

15. Luke B. Pregnancy and birth outcomes in couples with infertility with and without assisted reproductive technology: with an emphasis on US population-based studies. *Am J Obstet Gynecol* 2017;217:270–81.

16. Basso O, Baird DD. Infertility and preterm delivery, birthweight, and Caesarean section: a study within the Danish National Birth Cohort. *Hum Reprod* 2003;18:2478–84.

17. Pyykönen A, Gissler M, Lökkegaard E, et al. Caesarean section trends in the Nordic Countries - a comparative analysis with the Robson classification. *Acta Obstet Gynecol Scand* 2017;96:607–16.

18. Sima YT, Skjærven R, Kvalvik LG, Morken NH, Klungsoyr K, Sørbye LM. Caesarean delivery in Norwegian nulliparous women with singleton cephalic term births, 1967–2020: a population-based study. *BMC Pregnancy Childbirth* 2022;22:419.

19. Magnus P, Birke C, Vejrup K, et al. Cohort profile update: the Norwegian mother and child cohort study (MoBa). *Int J Epidemiol* 2016;45:382–8.

20. Irgens LM. The medical birth registry of Norway. *Epidemiological research and surveillance throughout 30 years. Acta Obstet Gynecol Scand* 2000;79:435–9.

21. Stern JE, Liu CL, Cabral HJ, et al. Factors associated with increased odds of cesarean delivery in ART pregnancies. *Fertil Steril* 2018;110:429–36.

22. Oppegaard KS, Dögl M, Sun C, Hill S, Ween-Velken M, Sørbye IK. Induction/induction of labor - Maturation of the cervix/cervix before birth [In Norwegian]. *Norwegian Society of Gynecology and Obstetrics*. Available at: <https://www.legeforeningen.no/foreningsledd/fagmed/norsk-gynekologisk-forening/veiledere/veileder-i-fodselshjelp/induksjonigangsettelse-av-fodsel-modning-av-cervixlivmorhalsen-for-fodsel/>. Accessed November 30, 2023.

23. White IR, Royston P, Wood AM. Multiple imputation using chained equations: issues and guidance for practice. *Stat Med* 2011;30:377–99.

24. Baird DD, Weinberg CR, Schwingl P, Wilcox AJ. Selection bias associated with contraceptive practice in time-to-pregnancy studies. *Ann N Y Acad Sci* 1994;709:156–64.

25. Skjærven R, Wilcox AJ, Klungsoyr K, et al. Cardiovascular mortality after pre-eclampsia in one child mothers: prospective, population based cohort study. *BMJ* 2012;345:e7677.

26. Kolås T, Hofoss D, Daltveit AK, et al. Indications for cesarean deliveries in Norway. *Am J Obstet Gynecol* 2003;188:864–70.

27. Radin RG, Mikkelsen EM, Rothman KJ, et al. Brief report: Cesarean delivery and subsequent fecundability. *Epidemiol (Camb Mass)* 2016;27:889–93.

28. Kringeland T, Daltveit AK, Møller A. What characterizes women in Norway who wish to have a caesarean section? *Scand J Public Health* 2009;37:364–71.

29. Nillni YI, Wesselink AK, Gradus JL, et al. Depression, anxiety, and psychotropic medication use and fecundability. *Am J Obstet Gynecol* 2016;215:453.e1–8.

30. Koelwijn JM, Sluijs AM, Vrijkotte TGM. Possible relationship between general and pregnancy-related anxiety during the first half of pregnancy and the birth process: a prospective cohort study. *BMJ Open* 2017;7:e013413.

31. Zhao J, Hao J, Xu B, Wang Y, Li Y. Impact of previous Caesarean section on

reproductive outcomes after assisted reproductive technology: systematic review and meta-analyses. *Reprod Biomed Online* 2021;43:197–204.

32. Nilsen RM, Vollset SE, Gjessing HK, et al. Self-selection and bias in a large prospective pregnancy cohort in Norway. *Paediatr Perinat Epidemiol* 2009;23:597–608.

33. Rothman K, Greenland S. Accuracy considerations in study design. In: Rothman K, Greenland S (eds.), 2nd ed. *Modern epidemiology*. Philadelphia: Lippincott-Raven; 1998:144–5.

34. Rothman KJ, Gallacher JE, Hatch EE. Why representativeness should be avoided. *Int J Epidemiol* 2013;42:1012–4.

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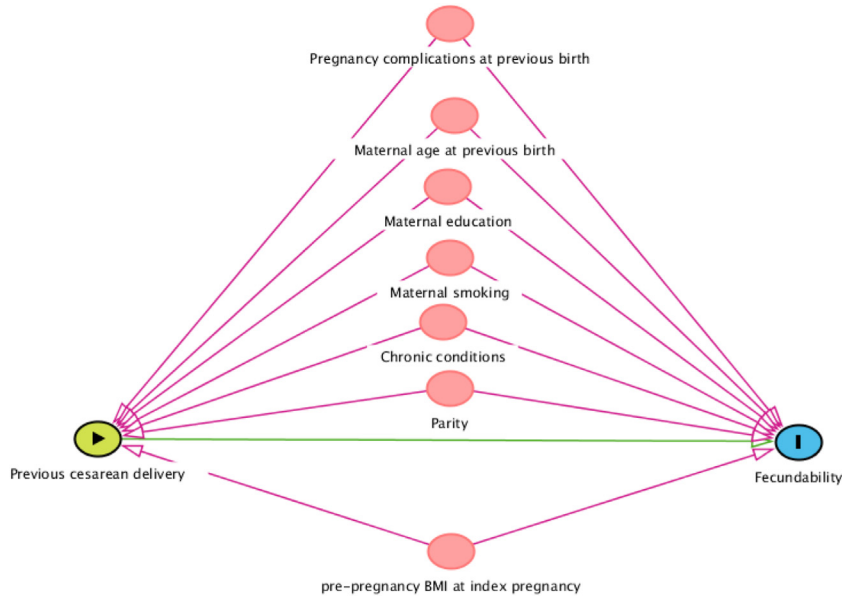
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FIGURE S1

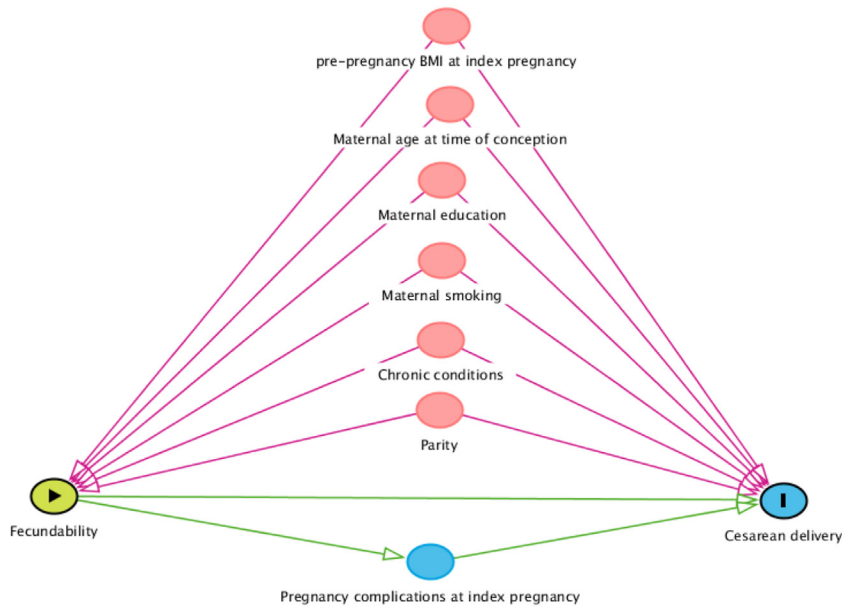
Directed acyclic graph illustrating the associations between our exposure (previous cesarean delivery), outcome (fecundability) and covariates. Self-reported chronic conditions include asthma, arthritis, chronic hypertension, diabetes mellitus, endometriosis, epilepsy, hypo/hyper thyroids, ovarian cyst and myoma, and pregnancy complications were gestational hypertension, preeclampsia, placental abruption, placental previa, preterm.



Sima. Cesarean delivery and fecundability. *Am J Obstet Gynecol* 2023.

FIGURE S2

Directed acyclic graph illustrating the associations between our exposure (fecundability), outcome (cesarean delivery) and covariates. Self-reported chronic conditions were asthma, arthritis, chronic hypertension, diabetes mellitus, endometriosis, epilepsy, hypo/hyper thyroids, ovarian cyst and myoma, and pregnancy complications were gestational hypertension, preeclampsia, placental abruption, placental previa, preterm.



Sima. Cesarean delivery and fecundability. *Am J Obstet Gynecol* 2023.

TABLE S1

Pregnancy characteristics by previous mode of delivery, The Norwegian Mother, Father and Child Cohort (1999–2008) linked with the Medical Birth Registry of Norway, N = 42,379

Characteristics	Total n (%)	Previous vaginal delivery n (%)	Previous cesarean delivery n (%)
All women	42379	37226	5153
Time to pregnancy (months)			
< 12	39164 (92.4)	34519 (92.7)	4645 (90.1)
≥ 12	3215 (7.6)	2707 (7.3)	508 (9.9)
Maternal age at previous delivery (years)			
< 25	9128 (21.5)	8208 (22.1)	920 (17.9)
25-34	31416 (74.1)	27516 (73.9)	3900 (75.7)
≥ 35	1835 (4.3)	1502 (4.0)	333 (6.5)
Maternal education (years)			
≤ 13	14023 (33.1)	12230 (32.9)	1793 (34.8)
> 13	28193 (66.5)	24859 (66.8)	3334 (64.7)
Missing	163 (0.4)	137 (0.4)	26 (0.5)
Smoking			
Non-smoker	31154 (73.5)	27404 (73.6)	3750 (72.8)
Quit smoking in the current pregnancy	7275 (17.1)	6368 (17.1)	907 (17.6)
Current smoker	3198 (7.6)	2789 (7.5)	409 (7.9)
Missing	752 (1.8)	665 (1.8)	87 (1.7)
Pre-pregnancy body mass index (kg/m ²)			
< 18.5	1052 (2.5)	945 (2.5)	107 (2.1)
18.5-24.9	26265 (62.0)	23504 (63.1)	2761 (53.6)
25-29.9	9882 (23.3)	8516 (22.9)	1366 (26.5)
≥ 30	4226 (10.0)	3425 (9.2)	801 (15.5)
Missing	954 (2.3)	836 (2.3)	118 (2.3)
Chronic conditions ^a			
None	34947 (82.5)	30961 (83.2)	3986 (77.4)
One or more	7432 (17.5)	6265 (16.8)	1167 (22.6)
Complications in the previous pregnancy ^b			
None	36427 (86.0)	32684 (87.8)	3743 (72.6)
One or more	5094 (12.0)	3787 (10.2)	1307 (25.4)
Missing	858 (2.0)	755 (2.0)	103 (2.0)
Parity (previous births)			
One	28607 (67.5)	24682 (66.3)	3925 (76.2)
Two or more	13772 (32.5)	12544 (33.7)	1228 (23.8)

^a Self-reported chronic conditions: asthma, arthritis, chronic hypertension, diabetes mellitus, endometriosis, epilepsy, hypo/hyper thyroids, ovarian cyst and myoma; ^b Gestational hypertension, preeclampsia, placental abruption, placental previa, preterm.

Sima. Cesarean delivery and fecundability. *Am J Obstet Gynecol* 2023.

TABLE S2

Cesarean delivery in the previous birth and fecundability ratio (FR) in the pregnancy registered in the Norwegian Mother, Father, and Child Cohort Study, N = 42,379

Group	Fecundability ratio			
	Adjusted FR ^a (95% CI)	Adjusted FR ^b (95% CI)	Adjusted FR ^c (95% CI)	Adjusted FR ^d (95% CI)
Previous mode of delivery				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	0.90 (0.88-0.93)	0.90 (0.87-0.92)	0.90 (0.88-0.92)	0.90 (0.88-0.92)
Previous mode of delivery				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Planned cesarean delivery	0.91 (0.86-0.95)	0.90 (0.86-0.94)	0.90 (0.86-0.95)	0.92 (0.88-0.96)
Emergency cesarean delivery	0.90 (0.87-0.93)	0.90 (0.87-0.92)	0.90 (0.87-0.93)	0.89 (0.86-0.91)
Time interval restricted to less than 3 years				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	0.90 (0.88-0.93)	0.90 (0.87-0.93)	0.90 (0.87-0.93)	0.89 (0.87-0.92)
Time interval restricted to 3 to 7 years				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	0.88 (0.83-0.93)	0.88 (0.83-0.93)	0.87 (0.82-0.93)	0.89 (0.84-0.93)
Parity (previous births)				
One				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	0.90 (0.87-0.93)	0.89 (0.87-0.92)	0.90 (0.87-0.93)	0.90 (0.88-0.93)
Two or more				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	0.93 (0.88-0.98)	0.92 (0.87-0.98)	0.93 (0.87-0.98)	0.94 (0.90-0.99)

^a Main model, adjusted for maternal age and pregnancy complications at previous birth, maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies; ^b Analysis restricted to women below the age of 35 only, model adjusted for same factors as ^a; ^c Excluding pregnancies where the women responded "3 months or more" of trying to conceive without specifying the exact duration, model adjusted for same factors as ^a; ^d Analysis including both planned and unplanned pregnancies, model adjusted for same factors as ^a.

Sima. Cesarean delivery and fecundability. *Am J Obstet Gynecol* 2023.

TABLE S3

Cesarean delivery in the previous birth and relative risk (RR) of infertility in the pregnancy registered in the Norwegian Mother, Father, and Child Cohort Study, N = 42,379

Group	Relative risk of infertility			
	Adjusted RR ^a (95% CI)	Adjusted RR ^b (95% CI)	Adjusted RR ^c (95% CI)	Adjusted RR ^d (95% CI)
Previous mode of delivery				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	1.21 (1.10-1.33)	1.21 (1.10-1.34)	1.22 (1.11-1.34)	1.23 (1.12-1.35)
Previous mode of delivery				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Planned cesarean delivery	1.20 (1.01-1.42)	1.19 (1.00-1.43)	1.23 (1.04-1.46)	1.18 (1.00-1.39)
Emergency cesarean delivery	1.21 (1.09-1.35)	1.22 (1.09-1.37)	1.21 (1.09-1.35)	1.24 (1.12-1.39)
Time interval restricted to less than 3 years				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	1.20 (1.06-1.34)	1.20 (1.06-1.36)	1.21 (1.07-1.36)	1.23 (1.09-1.38)
Time interval restricted to 3 to 7 years				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	1.36 (1.13-1.64)	1.36 (1.12-1.64)	1.38 (1.15-1.66)	1.36 (1.13-1.63)
Parity (previous births)				
One				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	1.20 (1.07-1.34)	1.21 (1.08-1.35)	1.20 (1.08-1.34)	1.20 (1.08-1.33)
Two or more				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	1.17 (0.96-1.43)	1.15 (0.93-1.42)	1.20 (0.98-1.45)	1.15 (0.95-1.39)

^a Main model, adjusted for maternal age and pregnancy complications at previous birth, maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies; ^b Analysis restricted to women below the age of 35 only, model adjusted for same factors as ^a; ^c Excluding pregnancies where the women responded "3 months or more" of trying to conceive without specifying the exact duration, model adjusted for same factors as ^a; ^d Analysis including both planned and unplanned pregnancies, model adjusted for same factors as ^a.

Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.

TABLE S4

Cesarean delivery in the previous birth and fecundability ratio in the pregnancy registered in the Norwegian Mother, Father, and Child Cohort Study, among women with two or more prior births

Group	Fecundability ratio (95% CI)	
	Unadjusted	Adjusted ^a
Sequence of mode of delivery		
Vaginal deliveries ^b	1.00 (Reference)	1.00 (Reference)
Cesarean delivery in the prior delivery	0.88 (0.82-0.94)	0.94 (0.88-1.00)
Cesarean delivery in earlier deliveries	0.88 (0.84-0.94)	0.92 (0.87-0.97)
Number of cesarean deliveries		
None (all vaginal deliveries)	1.00 (Reference)	1.00 (Reference)
One cesarean delivery	0.88 (0.86-0.90)	0.91 (0.88-0.93)
Two or more cesarean deliveries	0.87 (0.81-0.93)	0.93 (0.86-1.00)

^a Adjusted for maternal age and pregnancy complications at previous birth, maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies; ^b All previous deliveries.

Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.

TABLE S5

Cesarean delivery in the previous birth and relative risk of infertility in the pregnancy registered in the Norwegian Mother, Father, and Child Cohort Study, among women with two or more prior births

Group	Relative risk of infertility (95% CI)	
	Unadjusted	Adjusted ^a
Sequence of mode of delivery		
Vaginal deliveries ^b	1.00 (Reference)	1.00 (Reference)
Cesarean delivery in the prior delivery	1.46 (1.16-1.84)	1.22 (0.95-1.56)
Cesarean delivery in earlier deliveries	1.41 (1.18-1.68)	1.24 (1.02-1.50)
Number of cesarean deliveries		
None (all vaginal deliveries) ^b	1.00 (Reference)	1.00 (Reference)
One cesarean delivery	1.41 (1.19-1.67)	1.23 (1.03-1.48)
Two or more cesarean deliveries	1.49 (1.16-1.92)	1.25 (0.96-1.63)

^a Adjusted for maternal age and pregnancy complications at previous birth, maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies; ^b All previous deliveries.

Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.

TABLE S6

Characteristics of study population by pregnancy planning status registered in the Norwegian Mother, Father, and Child Cohort Study

Characteristics	Pregnancies in women with a previous birth		Pregnancies of women without previous cesarean deliveries	
	Planned	Unplanned	Planned	Unplanned
Total	42379	9953	74024	18480
Mode of delivery ^a				
Vaginal delivery	37226 (87.8)	8782 (88.2)	65433 (88.4)	16283 (88.1)
Cesarean delivery	5153 (12.2)	1171 (11.8)	8591 (11.6)	2197 (11.9)
Time to prior pregnancy (months)				
<12 months	39164 (92.4)	9762 (98.1)	65986 (89.1)	18100 (97.9)
≥12 months	3215 (7.6)	191 (1.9)	8038 (10.9)	380 (2.1)
Maternal age (years) ^a				
< 25	9128 (21.7)	2607 (26.2)	8560 (11.6)	4692 (25.4)
25-34	32225 (74.0)	6720 (67.5)	56373 (76.2)	11069 (59.9)
≥35	1917 (4.4)	626 (6.3)	9091 (12.2)	2719 (14.7)
Maternal education (years)				
≤13	14023 (33.1)	4459 (44.8)	21855 (29.5)	8394 (45.4)
>13	28193 (66.5)	5426 (54.5)	51878 (70.1)	9956 (53.9)
Missing	163 (0.4)	68 (0.7)	291 (0.4)	130 (0.7)
Smoking				
Non-smoker	31154 (73.5)	6645 (68.0)	53267 (72.0)	10976 (59.4)
Quit smoking in the current pregnancy	7275 (17.2)	1761 (18.0)	14473 (19.6)	4497 (24.3)
Current smoker	3198 (7.6)	1373 (14.0)	5056 (6.8)	2717 (14.7)
Missing	752 (1.8)	174 (1.8)	1228 (1.6)	290 (1.6)
Pre-pregnancy body mass index (kg/m ²)				
<18.5	1052 (2.5)	334 (3.4)	2076 (2.8)	817 (4.4)
18.5-24.9	26265 (62.0)	5929 (59.6)	48289 (65.2)	11682 (63.2)
25-29.9	9882 (23.3)	2199 (22.1)	15813 (21.4)	3617 (19.6)
≥30	4226 (10.0)	1160 (11.7)	6411 (8.7)	1765 (9.6)
Missing	954 (2.3)	331 (3.3)	1435 (1.9)	599 (3.2)
Chronic conditions ^b				
No	34947 (82.5)	7971 (80.1)	60547 (81.8)	14750 (79.8)
One or more	7432 (17.5)	1982 (19.9)	13477 (18.2)	3730 (20.1)
Pregnancy complications ^{a c}				
No	36427 (86.0)	8549 (85.9)	65579 (88.6)	16237 (87.9)
One or more	5094 (12.0)	1123 (11.3)	7802 (10.5)	2053 (11.1)
Missing	858 (2.0)	281 (2.8)	643 (0.9)	190 (1.0)
Parity (previous births)				
Nulliparous	0	0	35369 (47.8)	9392 (50.8)
One	28607 (67.5)	4196 (49.4)	26222 (35.4)	4577 (24.8)

Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.

(continued)

TABLE S6

Characteristics of study population by pregnancy planning status registered in the Norwegian Mother, Father, and Child Cohort Study (continued)

Characteristics	Pregnancies in women with a previous birth		Pregnancies of women without previous cesarean deliveries	
	Planned	Unplanned	Planned	Unplanned
Two or more	13772 (32.5)	5037 (50.6)	12080 (16.3)	4410 (23.9)
Missing	0	0	353 (0.5)	101 (0.6)

^a Measured at the time of previous pregnancy in the pregnancies in women with previous birth, and at the time of index pregnancy in pregnancies in women without previous cesarean delivery; ^b Self-reported chronic conditions: asthma, arthritis, chronic hypertension, diabetes mellitus, endometriosis, epilepsy, hypo/hyper thyroids, ovarian cyst and myoma; ^c Includes gestational hypertension, pre-eclampsia, placental abruption, placental previa, preterm.

Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.

TABLE S7

Pregnancy characteristics by time to pregnancy registered in the Norwegian Mother, Father, and Child Cohort Study, N = 74,024

Characteristics	Total n (%)	< 12 months n (%)	≥ 12 months n (%)
All women	74024	65986	8038
Mode of delivery			
Vaginal delivery	65433 (88.4)	58809 (89.1)	6624 (82.4)
Cesarean delivery	8591 (11.6)	7177 (10.9)	1414 (17.6)
Maternal age at the start of trying to conceive the index pregnancy (years)			
< 25	8560 (11.6)	7399 (11.2)	1161 (14.4)
25-34	56373 (76.1)	50435 (76.4)	5938 (73.9)
≥35	9091 (12.3)	8152 (12.4)	939 (11.7)
Maternal education (years)			
≤13	21855 (29.5)	18976 (28.8)	2879 (35.8)
>13	51878 (70.1)	46749 (70.9)	5129 (63.8)
Missing	291 (0.4)	261 (0.4)	30 (0.4)
Smoking			
Non-smoker	53267 (72.0)	47767 (72.4)	5500 (68.4)
Quit smoking in the current pregnancy	14473 (19.6)	12767 (19.4)	1706 (21.2)
Current smoker	5056 (6.8)	4348 (6.6)	708 (8.8)
Missing	1228 (1.7)	1104 (1.7)	124 (1.5)
Pre-pregnancy body mass index (kg/m²)			
<18.5	2076 (2.8)	1837 (2.8)	239 (3.0)
18.5-24.9	48299 (65.2)	43594 (66.1)	4695 (58.4)
25-29.9	15813 (21.4)	13950 (21.1)	1863 (23.2)
≥30	6411 (8.7)	5300 (8.0)	1111 (13.8)
Missing	1435 (1.9)	1305 (2.0)	130 (1.6)
Chronic conditions ^a			
None	60547 (81.8)	54822 (83.1)	5725 (71.2)
One or more	13477 (18.2)	11164 (16.9)	2313 (28.8)
Complications in the current pregnancy ^b			
None	65579 (88.6)	58903 (89.3)	6776 (84.1)
One or more	7802 (10.5)	6587 (10.0)	1215 (15.1)
Missing	643 (0.9)	496 (0.8)	147 (1.8)
Parity (previous births)			
Nulliparous	35369 (47.8)	30309 (45.9)	5104 (63.9)
One	26222 (35.4)	24126 (36.6)	2088 (26.2)
Two or more	12080 (16.3)	11248 (17.1)	791 (9.9)
Missing	353 (0.5)	303 (0.5)	50 (0.6)

^a Self-reported chronic condition: asthma, arthritis, chronic hypertension, diabetes mellitus, endometriosis, epilepsy, hypo/hyper thyroids, ovarian cyst and myoma; ^b Include gestational hypertension, preeclampsia, placental abruption, placental previa, preterm.

Sima. Cesarean delivery and fecundability. *Am J Obstet Gynecol* 2023.

TABLE S8

Fecundability and relative risk (RR) of cesarean delivery in the pregnancy registered in the Norwegian Mother, Father, and Child Cohort Study, N = 74,024

Group	Relative risk of cesarean delivery				
	Adjusted RR ^a (95% CI)	Adjusted RR ^b (95% CI)	Adjusted RR ^c (95% CI)	Adjusted RR ^d (95% CI)	Adjusted RR ^e (95% CI)
All women					
< 3 cycles	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
3-6 cycles	1.09 (1.04-1.15)	1.09 (1.03-1.15)	1.08 (1.02-1.14)	1.07 (1.02-1.12)	1.07 (1.02-1.13)
7-11 cycles	1.11 (1.03-1.19)	1.08 (1.00-1.17)	1.11 (1.03-1.19)	1.09 (1.01-1.17)	1.08 (1.00-1.16)
≥ 12 cycles	1.55 (1.46-1.64)	1.54 (1.44-1.63)	1.55 (1.46-1.64)	1.51 (1.43-1.59)	1.44 (1.36-1.52)
Parity (previous births)					
Nulliparous					
< 3 cycles	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
3-6 cycles	1.02 (0.97-1.09)	1.01 (0.95-1.08)	1.00 (0.94-1.08)	1.01 (0.96-1.07)	1.02 (0.96-1.08)
7-11 cycles	1.00 (0.92-1.09)	0.99 (0.90-1.08)	1.00 (0.92-1.09)	0.99 (0.91-1.07)	0.99 (0.91-1.08)
≥ 12 cycles	1.27 (1.19-1.36)	1.27 (1.18-1.36)	1.27 (1.19-1.36)	1.26 (1.19-1.33)	1.23 (1.15-1.31)
One					
< 3 cycles	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
3-6 cycles	1.02 (0.92-1.14)	1.05 (0.94-1.18)	1.02 (0.90-1.16)	1.03 (0.94-1.14)	1.02 (0.92-1.13)
7-11 cycles	1.01 (0.85-1.20)	0.95 (0.78-1.16)	1.01 (0.85-1.20)	1.07 (0.91-1.26)	1.01 (0.85-1.19)
≥ 12 cycles	1.45 (1.26-1.65)	1.47 (1.26-1.71)	1.44 (1.26-1.65)	1.45 (1.27-1.64)	1.36 (1.20-1.56)
Two or more					
< 3 cycles	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
3-6 cycles	1.10 (0.94-1.29)	1.22 (1.00-1.49)	1.09 (0.91-1.32)	1.06 (0.92-1.23)	1.06 (0.91-1.25)
7-11 cycles	0.93 (0.70-1.22)	1.01 (0.71-1.43)	0.93 (0.70-1.22)	0.91 (0.70-1.18)	0.91 (0.69-1.20)
≥ 12 cycles	1.50 (1.20-1.86)	1.57 (1.19-2.06)	1.49 (1.20-1.85)	1.43 (1.17-1.75)	1.41 (1.14-1.75)

^a Main model, adjusted for maternal age (at the time of trying to conceive), maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies; ^b Analysis restricted to women below the age of 35 only, model adjusted for same factors as ^a; ^c Excluding pregnancies where the women responded "3 months or more" of trying to conceive without specifying the exact duration, model adjusted for same factors as ^a; ^d Analysis including both planned and unplanned pregnancies, model adjusted for same factors as ^a; ^e Main model adjusted for complications in the index pregnancy and same factors as ^a.

Sima. Cesarean delivery and fecundability. *Am J Obstet Gynecol* 2023.

TABLE S9

The association between cesarean delivery and fecundability/infertility stratified by onset of labor, cycle regularity and uncertainty regarding time to pregnancy data

a. Onset of labor (spontaneous- and induced onset) in the previous birth

	Fecundability ratio (95% CI)					
	All women (n= 42,379)		Restricted to spontaneous births (n=34,887)		Restricted to Induced births (n=6243)	
	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a
All women						
Vaginal delivery	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Cesarean delivery	0.87 (0.85-0.89)	0.90 (0.88-0.93)	0.85 (0.82-0.88)	0.88 (0.84-0.92)	0.91(0.87-0.95)	0.92 (0.87-0.96)
	Relative risk of infertility (95% CI)					
	All women (n= 42,379)		Restricted to spontaneous births (n=34,887)		Restricted to Induced births (n=6243)	
	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a
All women						
Vaginal delivery	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Cesarean delivery	1.36 (1.24-1.48)	1.21 (1.10-1.33)	1.54 (1.36-1.75)	1.34 (1.22-1.59)	1.08 (0.90-1.29)	1.05 (0.87-1.26)

^a Adjusted for maternal age and pregnancy complications at the previous birth, maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies.

Sima. Cesarean delivery and fecundability. *Am J Obstet Gynecol* 2023.

Categorization of fecundability (N cycles to conception)	Relative risk (RR) of cesarean delivery (95% CI)					
	All women, n=74025		Restricted to spontaneous births only. n=59, 994		Restricted to Induced births only. n=9925	
	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a
All women						
< 3 cycles	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
3-6 cycles	1.13 (1.08-1.19)	1.11 (1.05-1.16)	1.16 (1.07-1.25)	1.13 (1.04-1.23)	1.20 (1.08-1.33)	1.18 (1.05-1.31)
7-11 cycles	1.18 (1.09-1.26)	1.12 (1.04-1.21)	1.19 (1.05-1.34)	1.13 (1.00-1.28)	1.20 (1.03-1.40)	1.15 (0.98-1.35)
≥ 12 cycles	1.71 (1.61-1.81)	1.57 (1.48-1.66)	1.77 (1.60-1.96)	1.63 (1.47-1.81)	1.55 (1.38-1.75)	1.46 (1.29-1.65)

^a Adjusted for maternal age (at the time of trying to conceive), maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies.

Sima. Cesarean delivery and fecundability. *Am J Obstet Gynecol* 2023.

b. Menstrual cycle regularity (All women and women with regular cycles)

Previous mode of delivery	Fecundability ratio (95% CI)			
	All women		Restricted to women with regular cycles	
	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a
All women				
Vaginal delivery	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Cesarean delivery	0.87 (0.85-0.89)	0.90 (0.88-0.93)	0.87 (0.84-0.89)	0.89 (0.87-0.92)
	Relative risk of infertility (95% CI)			
	All women		Restricted to women with regular cycles	
	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a
All women				
Vaginal delivery	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Cesarean delivery	1.36 (1.24-1.48)	1.21 (1.10-1.33)	1.35 (1.22-1.51)	1.23 (1.10-1.38)

^aAdjusted for maternal age and pregnancy complications at the previous birth, maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies. *Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.*

Categorization of fecundability (N cycles to conception)	Relative risk of cesarean delivery (95% CI)			
	All women		Restricted to women with regular cycles	
	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
All women				
< 3 cycles	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
3-6 cycles	1.13 (1.08-1.19)	1.11 (1.05-1.16)	1.12 (1.06-1.18)	1.09 (1.03-1.15)
7-11 cycles	1.18 (1.09-1.26)	1.12 (1.04-1.21)	1.14 (1.05-1.24)	1.08 (0.99-1.18)
≥ 12 cycles	1.71 (1.61-1.81)	1.57 (1.48-1.66)	1.65 (1.55-1.76)	1.53 (1.43-1.64)

^a Adjusted for maternal age (at the time of trying to conceive), maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies. *Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.*

c. Uncertainty regarding time to pregnancy data (All women and women with no reported pregnancy loss within time to pregnancy (TTP) period)

	Fecundability ratio (95% CI)			
	All women		No pregnancy loss within TTP period	
Previous mode of delivery	Unadjusted (95% CI)	Adjusted ^a (95% CI)	Unadjusted (95% CI)	Adjusted ^a (95% CI)
All women				
Vaginal delivery	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Cesarean delivery	0.87 (0.85-0.89)	0.90 (0.87-0.92)	0.88 (0.85-0.90)	0.90 (0.88-0.93)
	Relative risk of infertility (95% CI)			
	All women		No pregnancy loss within TTP period	
Previous mode of delivery	Unadjusted (95% CI)	Adjusted ^a (95% CI)	Unadjusted (95% CI)	Adjusted ^a (95% CI)
All women				
Vaginal delivery	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Cesarean delivery	1.36 (1.24-1.48)	1.21 (1.10-1.33)	1.36 (1.24-1.50)	1.22 (1.11-1.35)

^aAdjusted for maternal age and pregnancy complications at the previous birth, maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies. *Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.*

	Relative risk of cesarean delivery (95% CI)			
	All women		No pregnancy loss within TTP period	
Categorization of fecundability	Unadjusted	Adjusted ^a	Unadjusted	Adjusted ^a
(N cycles to conception)				
All women				
< 3 cycles	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
3-6 cycles	1.13 (1.08-1.19)	1.11 (1.05-1.16)	1.12 (1.07-1.18)	1.10 (1.04-1.15)
7-11 cycles	1.18 (1.09-1.26)	1.12 (1.04-1.21)	1.16 (1.08-1.25)	1.11 (1.03-1.20)
≥ 12 cycles	1.71 (1.61-1.81)	1.57 (1.48-1.66)	1.66 (1.57-1.76)	1.53 (1.44-1.63)

^a Adjusted for maternal age (at the time of trying to conceive), maternal education, smoking and chronic conditions, accounting for women participating with several pregnancies. *Sima. Cesarean delivery and fecundability. Am J Obstet Gynecol 2023.*