Hospital variation and cesarean delivery: studies of contemporary practice patterns in Canada and the United States

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Abstract

In Canada, 27% of deliveries were performed by cesarean in 2013, making Cesarean delivery the most commonly performed surgery in Canadian women. Given that high rates of cesarean have not been shown to be associated with better maternal and perinatal outcomes, there have been recommendations to reduce the overall rate of cesarean delivery, with a focus on preventing the first ("primary") cesarean. To best determine how to reduce the rate of primary cesarean delivery, an understanding of indication-specific patterns of cesarean is needed. The goal of this thesis was to advance our understanding of indication-specific cesarean delivery rates through the use of inter-institutional practice variation.

To explore contemporary practice patterns in Canada, this thesis used data across three provincial birth registries, and focused on low-risk nulliparous women delivered following the onset of labour. Practice patterns in the timing of cesarean delivery by indication are illustrated, and an examination of adherence to clinical guidelines on the management of labour is presented. We find that many cesarean deliveries are performed early during labour and demonstrate substantial variation across hospitals in their compliance with clinical guidelines on the management of labour. Next, inter-hospital variation in the rates of cesarean delivery for labour dystocia is examined. After stabilization for hospital size and adjustment for maternal, fetal, and hospital characteristics, variability in rates across hospitals remained high. Together, these findings suggest that hospitals with the highest rates may benefit from conducting internal reviews and examining adherence to best practice guidelines on the management of labour dystocia.

This thesis then examines women who had a previous cesarean delivery using data from the United States' Nationwide Inpatient Sample. We find that the occurrence of a uterine rupture at a hospital is associated with a subsequent reduction to the hospital's trial of labour success rate (that is, the rate of women having a successful vaginal delivery, in those who underwent labour) and a short-term increase in the rate of repeat cesarean delivery. These findings suggest that obstetrical decision-making is impacted by the occurrence of rare, adverse events.

We recommend that provincial perinatal services monitor variation in rates of indication-specific cesarean delivery and guideline adherence across hospitals. Hospitals can then work towards improved adherence in support of safely lowering their rate of primary cesarean delivery. On the level of the health care practitioner, we recommend that providers are educated on the effects of cognitive biases associated with the occurrence of rare, adverse events in support of optimal decision-making. Maternal and child health stakeholders, hospitals, and care providers can thus work together to safely lower the cesarean delivery rate.

Résumé

Au Canada, 23% des bébés sont nés par césarienne en 2013, faisant de la césarienne la chirurgie la plus fréquemment réalisée chez les femmes Canadiennes. Considérant que l'augmentation des taux de césariennes n'a pas démontré une amélioration des issues maternelles et périnatales, des recommandations ont été émises afin de diminuer le taux de césarienne, en se penchant principalement sur les césariennes primaires. Afin d'optimiser la réduction du taux de césariennes primaires, il est nécessaire de comprendre les pratiques entourant cette intervention, selon les indications qui la justifient. L'objectif de cette thèse était de faire progresser notre compréhension des taux de naissance par césarienne, selon les indications pour lesquelles elles sont effectuées, en étudiant les variations de pratique interinstitutionnelle.

Afin d'étudier les pratiques contemporaines au Canada, les données des registres de naissance de trois provinces sont utilisées pour cette thèse, qui se concentre sur les femmes nullipares en travail présentant une grossesse à bas risque. Les pratiques entourant le moment où la césarienne est réalisée selon les indications sont illustrées, et une évaluation du respect des directives cliniques sur la gestion du travail est présentée. Nous avons observés que plusieurs césariennes sont réalisées en début de travail et qu'il y a une variation considérable entre les hôpitaux en ce qui concerne l'application des directives cliniques sur la gestion du travail. Ensuite, la variation inter-hôpital des taux de césariennes ayant comme indication la dystocie du travail a été examinée. Après l'équilibration selon le nombre d'accouchements par hôpital et avoir fait les ajustements pour les caractéristiques maternelles, fœtales et hospitalières, la variabilité dans les taux entre les hôpitaux demeurent élevée. Ensemble, ces résultats suggèrent que les hôpitaux ayant les plus haut taux de césariennes pourraient avoir avantage à réaliser des révisions de dossiers à l'interne et à évaluer le respect des meilleures directives cliniques sur la gestion de la dystocie du travail.

Cette thèse examine ensuite les femmes qui ont une césarienne antérieure en utilisant des données de l'*United States' Nationwide Inpatient Sample*. Nous trouvons que l'occurrence d'une

rupture utérine est associée à une réduction subséquente du taux de succès de l'essai de travail (le taux de femmes qui ont réussi un accouchement vaginal sur celles qui ont été en travail) à l'hôpital où la rupture a eu lieu et à une augmentation, à court terme, du taux de césariennes répétées. Ces résultats suggèrent que la prise de décision en obstétrique est influencée l'occurrence d'évènements indésirables rares.

Nous recommandons que les services périnataux provinciaux surveillent la variation des taux de césariennes selon les indications justifiant l'intervention ainsi que le respect des directives à travers les hôpitaux. Ces hôpitaux peuvent alors travailler à améliorer le respect des directives visant à diminuer de façon sécuritaire leur taux de césariennes primaires. Afin d'appuyer la prise de décision optimale, nous recommandons que les professionnels de la santé soient sensibilisés aux effets des biais cognitifs qui sont associés à l'occurrence d'évènements indésirables rares. Les parties prenantes en santé maternelle et infantile, les hôpitaux et les fournisseurs de soins peuvent alors travailler ensemble afin de diminuer de façon sécuritaire les taux de césariennes.

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My thesis committee was made complete by Dr. Erin Strumpf and Dr. Haim Abenhaim. Thank you both for your thoughtful consideration of my questions and providing helpful feedback during committee meetings. I cannot think of a better group to study cesarean delivery with than an economist, an obstetrician, and a couple of epidemiologists!

Looking further back, I tiptoed into the world of biostatistics after Dr. Stephen Walter agreed to take me on as an intern during my last year of my undergraduate degree. This foray into biostatistics provided my first real sense of the type of work I wanted to be involved with and you gave me countless opportunities during four months to learn, thrive, and grow! It was a pleasure to work with you.

Shortly thereafter, I began a Master's in Statistics under the mentorship of Dr. John Petkau and Dr. Yinshan Zhao. John is an excellent professor, and his belief in me was most encouraging in times of doubt to continue with my studies, while giving me the space and encouragement to carve my own path and make what felt like a scary leap into the strange new world of epidemiology.

Moving to Montreal was complemented by the introduction to a group of equally caring and intelligent epidemiologists-in-training. In particular, I owe several ounces of my sanity to Deshayne Fell and her family for providing me with a home away from home. Sandra Isidean, Serene Joseph, and Kathryn Morrison, were equally important companions, and I am thankful for their support. To my colleagues in the Purvis basement, especially Ryan, Erika, and Alissa, you have been wonderful friends and office mates who made each day spent underground a little brighter.

Lastly, my family at home has served as a continuing source of support. Thank you to my parents for constantly believing in me, and encouraging me along this path, and to my brother and sister for the phone calls, texts, and visits.

Contribution of authors

Manuscript 1

Riddell CA, Kaufman JS, Strumpf EC, Abenhaim HA, Hutcheon JA. Cervical dilation at time of cesarean delivery in nulliparous women: a population-based cohort study. To be summited to BJOG.

The objectives of this study were developed by Dr. Hutcheon and myself. I submitted the requests for the data extracts from the three provincial birth registries and obtained ethics approval from McGill, University of British Columbia, and University of Alberta. I was responsible for all aspects of preparing and pooling the data for analysis, and performed all of the analyses. Drs. Kaufman, Abenhaim, Strumpf, and Hutcheon reviewed the manuscript critically for intellectual content, and provided approval of the final version.

Manuscript 2

Riddell CA, Hutcheon JA, Strumpf EC, Abenhaim HA, Kaufman JS. Inter-institutional variation in use of cesarean delivery for labour dystocia: a population-based cohort study. To be submitted to BJOG.

The objectives of this study were developed by myself and Dr. Hutcheon and uses the same data obtained for the first manuscript. I was primarily responsible for the conception of the study design and analytical design, and was aided by all co-authors in these discussions. Drs. Kaufman and Hutcheon were particularly involved in discussions of methodology, and interpretation of the findings. I conducted all of the statistical analyses and drafted the article, and all authors reviewed and provided feedback on the draft, and approved the final version.

Manuscript 3

Riddell CA, Kaufman JS, Hutcheon JA, Strumpf EC, Teunissen PW, Abenhaim HA. Effect of uterine rupture on a hospital's future rate of vaginal birth after cesarean delivery. Obstet Gynecol. 2014; 124(6): 1175-1181.

A hypothesis posed by Dr. Abenhaim provided the motivation for this paper. I conceptualized the preliminary methodological design that was then refined after committee meetings with Drs. Kaufman, Hutcheon, Strumpf, and Abenhaim. The datasets used for this study was partially provided to me from Dr. Hutcheon (years 1998-2007) and I requested the additional years (2008-2010) from the data provider. I appended the datasets required to produce the study cohort, performed all analyses and wrote the first draft of the manuscript. All authors contributed to the interpretation of the findings, and Dr. Teunissen aided me in relating the findings to research in the medical decision-making literature.

Statement of originality

The work contained in this thesis represents an original contribution to the field of perinatal epidemiology. To my knowledge, we have presented the first examination of the timing of cesarean delivery according to both cervical dilation and indication for cesarean. The literature now contains several studies examining variation in cesarean delivery across institutions, but the study in this thesis was the first to look specifically at cesarean delivery for the indication of labour dystocia. Further, these two papers are the first to combine data across three provincial birth registries for pooled analysis, across provinces that account for more than 60% of deliveries occurring each year in Canada. Finally, our evaluation of the impact of uterine rupture on a hospital's future rate of vaginal birth after cesarean delivery was the first study that I know of to use epidemiologic data to quantify how one woman's adverse event impacts other women's care in the obstetrical setting.

While I have received guidance from my committee members and co-authors on statistical, clinical and methodological aspects of this thesis, I declare that the conception, execution, and drafting of the work in this thesis were my own.

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List of abbreviations

AB	Alberta
BC	British Columbia
BMI	Body mass index
BORN	Better Outcomes Registry & Network
CCI	Canadian Classification of Health Interventions
CI	Confidence interval
CIHR	Canadian Institutes of Health Research
GA	Gestational age
ICD-9-CM	International Classification of Diseases, 9th revision, clinical modification
ICD-10-CA	International Classification of Diseases, 10th revision, Canadian version
IQR	Inter-quartile range
ON	Ontario
RR	Risk ratio
TOL	Trial of labour
TOLAC	Trial of labour after cesarean delivery
UR	Uterine rupture
VBAC	Vaginal birth after cesarean delivery

1| Introduction

Cesarean delivery is the most common inpatient surgical operation performed in Canada and the United States, with 27% and 33% of deliveries being performed by cesarean in each country, respectively.[1,2] While cesarean delivery is often warranted and can be life-saving, the continuous increase in its usage over time coupled with the variability across institutions warrant careful investigation of factors that might lead to unnecessary use. Further, uncomplicated cesarean delivery costs 1.6 times as much as uncomplicated vaginal delivery and is associated with increased risks to the mother.[3,4]

Studies of inter-institutional variation in health service utilization have been valuable in illustrating the presence of excessive variation across institutions that may indicate suboptimal care or lack of consensus on best practice. As variation across institutions is often the result of differences in local policies or practice guidelines, such studies can reduce confounding by indication, a concern in studies of cesarean delivery where maternal characteristics are important risk factors.

Much research has focused on the overall rate of cesarean delivery or cesarean delivery in a specific obstetrical subpopulation, rather than indication-specific rates, even though the decision to perform a cesarean delivery is the end result of a number of distinct clinical events. An understanding of indication-specific patterns of cesarean delivery is needed in order to identify which policies or practice changes an institution should implement to help optimise its cesarean delivery rate. The indications of labour dystocia and non-reassuring fetal monitoring are of particular interest because they are commonly used and vulnerable to subjectivity. Further, there are few studies illustrating the timing during labour when these cesarean deliveries are performed, despite concerns that cesarean deliveries for labour dystocia are being performed before reaching the minimum dilation recommended for diagnosis of this condition.[5]

1.1 Research objectives

The overarching goal of this thesis was to advance our understanding of indication-specific cesarean delivery rates through the use of inter-institutional practice variation. The specific objectives were:

i. To examine the timing of cesarean delivery for labour dystocia and cesarean delivery for non-reassuring fetal monitoring according to cervical dilation.
ii. To quantify the extent of inter-institutional variation in rates of cesarean delivery for labour dystocia, before and after accounting for case-mix and hospital-level differences.
iii. To determine how the occurrence of severe uterine rupture in one woman affects the likelihood of repeat cesarean delivery in other women cared for at the same hospital.

1.2 Organization of the thesis

This thesis begins with a discussion of background information in Chapter 2, followed by an overview of the two data sources that were analyzed in this thesis in Chapter 3. Chapter 4 used data from three Canadian provincial birth registries to examine when during labour cesarean deliveries are performed in nulliparous women according to their indication for cesarean. Using the same dataset, Chapter 5 further examines hospital-level rates of cesarean delivery for the indication of labour dystocia and investigates whether differences between hospitals can be explained by differences in the characteristics of their obstetric populations or by hospital-level factors. Chapter 6 uses data from the United States' Nationwide Inpatient Sample and shifts the focus to women who have had a previous cesarean delivery. We examine the impact of one woman's severe uterine rupture on the trial of labour attempt rate and trial of labour success rate at the hospital where she delivered. Chapter 7 provides a summary of conclusions from the three research manuscripts, with a focus on implications for clinical practice and areas for future research.

2| Background

2.1 Epidemiology of cesarean delivery

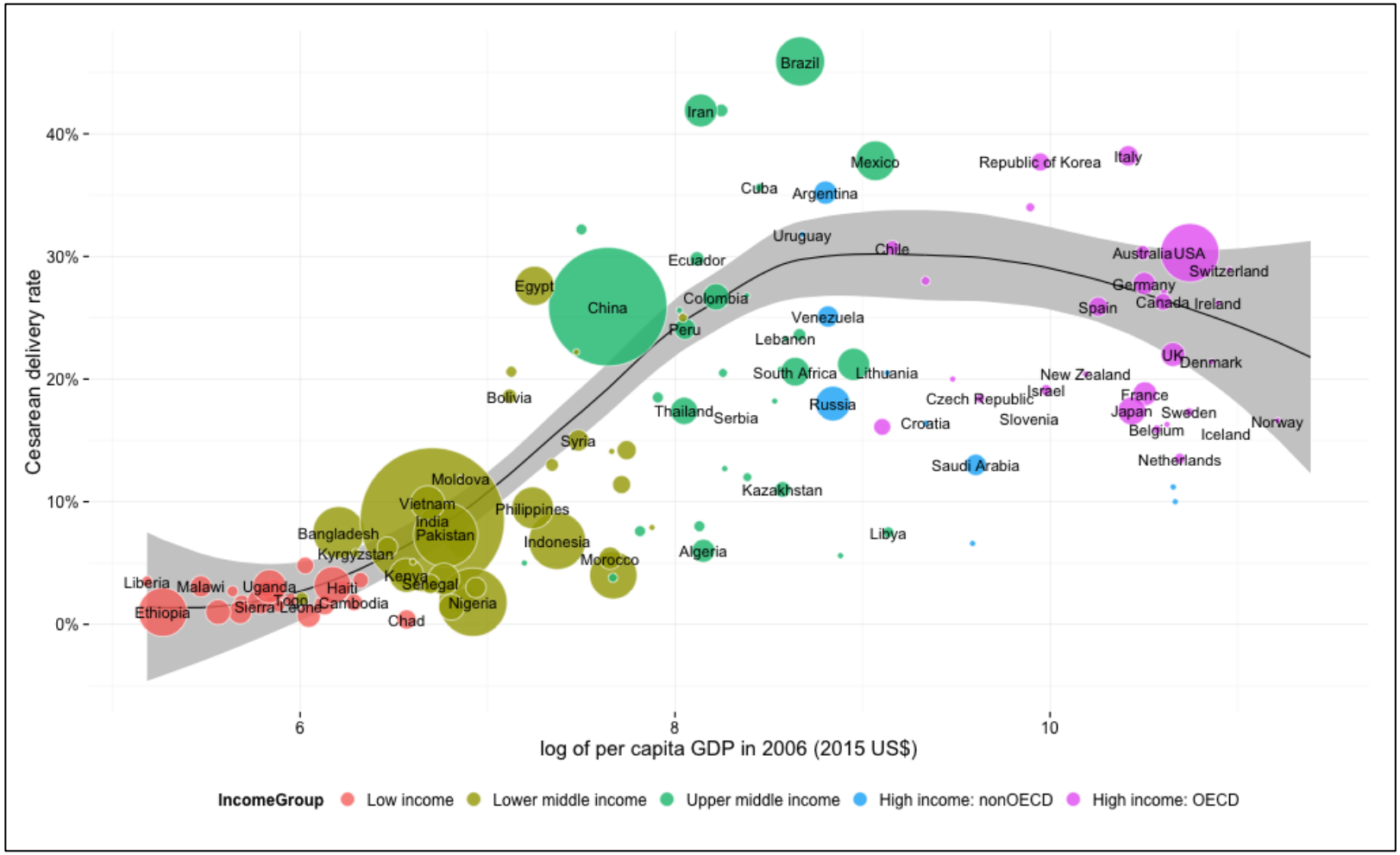
Cesarean delivery is defined as birth of a fetus through incisions made in the abdominal and uterine walls.[6] The Society of Obstetricians and Gynaecologists of Canada's policy on normal childbirth states that cesarean delivery should be used only when there is a threat to the health of the mother or baby, and that it should not be offered without obstetrical indication.[7] Here, we overview the use of cesarean delivery across the globe, present trends within Canada, examine risk factors, and discuss harms associated with overuse.

2.1.1 Global incidence of cesarean delivery

Cesarean delivery rates vary dramatically across the globe, with higher rates in developed nations and lower rates in developing nations (Figure 2-1).[8] In 1985, the World Health Organization stated that no region should have rates of cesarean delivery higher than 10-15%, and since then, many countries have regarded 15% as the optimal or target rate of cesarean delivery and have benchmarked against this goal.[9,10] Across the globe, 40% of countries had rates lower than 10%, with the vast majority located in Africa and Asia. Roughly 10% of countries have rates between 10-15%, and the remaining 50% of countries have rates higher than 15% (Figure 2-1).[8]

The prescriptive application of an optimal cesarean delivery rate is debatable. The basis of such an idea is that increasing the rate of cesarean delivery in countries with low levels has been shown to be associated with decreased maternal and neonatal mortality and morbidity,[11,12] while increases within countries with rates higher than 10-15% have not been associated with decreases,[12] and in some cases have been linked with increases in morbidity.[11,13] A recent study using 2012 data for all member states of the World Health Organization found that a rate up to 19% was associated with lower maternal and neonatal mortality, suggesting that the previously prescribed optimal rate may be too low.[14] Overall, rates of cesarean delivery vary considerably by country and there is a consensus that the relatively high rates of cesarean delivery found in many developed countries do not further improve maternal and fetal outcomes.

Figure 2-1: Cesarean delivery rates by country, as a function of gross domestic product

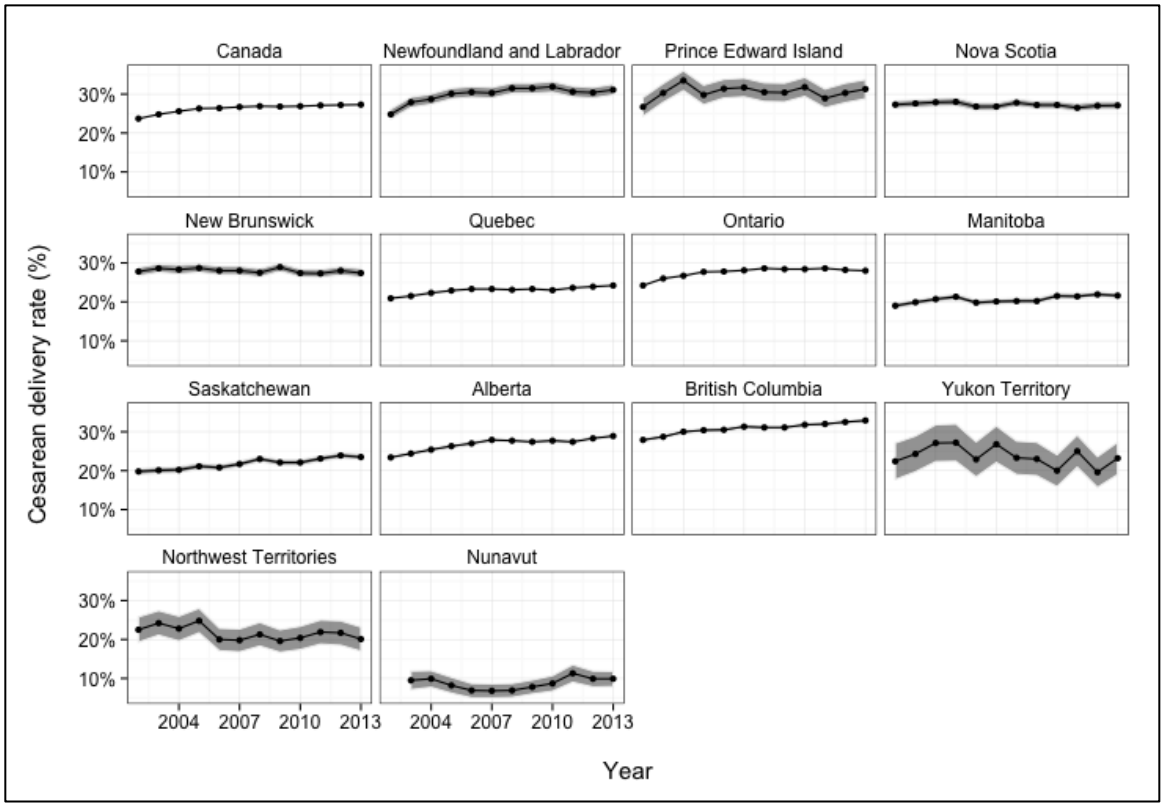


Only a selection of countries is labelled to limit cluttering. Income groupings are based on gross national income per capita from 2014. Grey ribbon illustrates the 95% confidence band around the smoothed fitted curve. This graph was created using cesarean delivery data from Gibbons et al. (2010) and GDP data from the World Bank.[8,15]

2.1.2 Contemporary trends in the overall rate of cesarean delivery in Canada

In Canada, the proportion of women who underwent a cesarean delivery increased from 23.7% in 2003 to 27.3% in 2013, with most provinces witnessing a gradual rise in cesarean delivery over this time period (Figure 2-2). The rate of cesarean delivery also varies by province. For example, in 2013 the rate of cesarean delivery was more than ten percentage points higher in British Columbia than in Manitoba.

Figure 2-2: Cesarean delivery rates over time in Canada, by province



Grey bands illustrate 95% confidence bands around the yearly estimates of the cesarean delivery rate. This graph was created using data from the Canadian Institute for Health Information.[2]

The wide variation in the use of cesarean delivery across Canadian provinces requires closer examination and elicits questions regarding what might lead to women in some provinces to undergo cesarean delivery at a much higher rate than women in other provinces. The overall rate of cesarean delivery obscures important information about the subpopulations that are most at risk for this procedure and the reasons why the cesarean deliveries were performed.

2.1.3 Risk factors for cesarean delivery

Maternal characteristics

Two of the most well-known features associated with a higher risk of cesarean delivery are advanced maternal age and high body mass index (BMI). These risk factors act through various pathways, of which some are causal while others are associational. In this section, we discuss the mechanisms that lead older or overweight women to have a higher rate of cesarean delivery.

In Canada, 25% of women aged 20 to 34 years had a cesarean delivery, compared with 35% in women 35 to 39 years of age and 41% in women 40 or older.[16] Older women are more likely to have pre-existing diabetes (Type 2) and hypertension, and are at increased risk of developing gestational diabetes, hypertensive disorders of pregnancy, pre-eclampsia, placenta previa and placental abruption.[16–21] These complications themselves are predictors of cesarean delivery, with the placental conditions being contraindications to vaginal delivery. Further, increased rates of abnormal fetal presentation and prior myomectomy among older women are determinants of pre-labour cesarean delivery in these women.[18,22]

Gareen et al. attempted to isolate the direct effect of maternal age on the risk of cesarean delivery and found an appreciable positive association between maternal age and cesarean delivery after adjustment for several measured obstetrical predictors among nulliparous women.[23] Whereas the unadjusted risk ratio was 2.16 [95% CI: 1.79, 2.68] comparing 35 year olds to 20 year olds, the adjusted risk ratio was 1.74 [95% CI: 1.25, 2.43]. Further adjustment for the indication of labour dystocia attenuated the relationship, suggesting that older women are more at-risk for having a cesarean delivery for this indication than their younger counterparts.[23]

The risk of cesarean delivery is estimated to be 1.4 times as high [95% CI: 1.0, 1.8] for overweight women (BMI between 26.1 to 29.0 kg/m^2) compared to women of normal BMI (19.8 to 26.0 kg/m^2), 1.5 times as high [95% CI: 1.1, 2.1] for obese women (BMI 30 to 34.9 kg/m^2), and 3.1 times as high [95% CI: 2.3, 4.8] for morbidly obese women (BMI $\geq$ 35 kg/m^2).[24] Obese women are of increased risk of undergoing cesarean delivery for labour

dystocia during the first stage of labour.[25–28] One study estimated that nulliparous obese women required one hour and forty-five minutes longer to progress from 4 cm to 10 cm compared to nulliparous women of normal BMIs.[25] Physiologic studies have also shown *in vitro* that secretions from adipose tissues are associated with reduced uterine contractability.[29] High BMI is also associated with increased fetal weight and fetal macrosomia (discussed below). Lastly, as with advanced maternal age, high BMI is associated with comorbidities that are predictors of cesarean delivery, including pre-existing and gestational hypertension, and pre-existing (Type 2) diabetes and gestational diabetes.

Overall, older and heavier women are at higher risk for having a cesarean delivery. While the "effect" of age most likely acts through its associations with conditions and complications that predict cesarean delivery, BMI likely has both direct effects on labour progression and labour dystocia and associational effects through associated conditions.

Obstetrical Characteristics

Characteristics of the pregnancy itself, such as obstetrical history (or lack thereof), fetal characteristics, or placental complications are also associated with cesarean delivery. In Canada, nulliparous women delivering term singletons in cephalic position have a 28% chance of having a cesarean delivery.[30] The risk of having a cesarean delivery among multiparous women differs markedly according to her previous pregnancy experience. For multiparous women with no previous cesarean delivery, 9% will have a cesarean delivery, compared to 81% in the subgroup with previous cesarean delivery.[30]

Breech position of the fetus and multiple births are obstetrical conditions that often lead to planned cesarean delivery. In Canada, 94% of nulliparous women with breech singletons and 63% of multiple births were delivered by cesarean delivery between 2007 and 2011.[30] Estimated fetal size is also associated with cesarean delivery. Fetuses with the most severe growth restrictions may be delivered by planned cesarean delivery if it is deemed that undergoing labour or labour induction would be deleterious to their health.[31] Growth-restricted fetuses undergoing labour are at an increased risk of cesarean delivery for fetal distress.[31] Suspected fetal macrosomia also impacts the rate of cesarean delivery. When a

fetus is truly macrosomic, this condition may inhibit labour progress and lead to labour dystocia. Clinical suspicion of macrosomia (even if the suspicion is later proven incorrect) has been associated with a higher rate of cesarean delivery.[32]

Placenta previa and placental abruption are two conditions requiring cesarean delivery. Women with placenta previa will schedule a pre-labour cesarean delivery, but those experiencing bleeding or antepartum haemorrhage before their scheduled cesarean may require an emergent cesarean delivery. Mild placental abruptions do not necessarily require cesarean delivery (especially when the fetus is immature or when vaginal delivery appears imminent), while severe abruptions require immediate cesarean delivery.[33]

2.1.4 Harms associated with over-use of cesarean delivery

Overuse of cesarean delivery has the potential to create more harm than benefit. A Canadian study estimated that the surgery is associated with an approximate 3-fold risk of complications compared with planned vaginal delivery.[34] While the absolute risks of all complications were low in this study, the largest contributing factors were the risk of wound hematoma (1.30% vs. 0.27%), puerperal infection (0.60% vs. 0.21%) and anesthetic complications (0.53% vs. 0.21%).[34] Risks of severe morbidity were also higher in women with planned cesarean delivery, including the risks of severe postpartum complications such as hemorrhage requiring hysterectomy, cardiac arrest, and thromboembolism.[34]

A woman's first cesarean delivery can lead to increased downstream risks in future pregnancies. The majority of these women will continue to have cesarean deliveries in subsequent births.[30,35] While the second cesarean delivery is associated with a decrease in maternal morbidity, additional cesarean deliveries are associated with increases to risk, with the largest increases seen in the risk of placenta accreta and hysterectomy.[36] Additionally, planned repeat cesarean deliveries tend to be conducted during early-term gestation (often late in the 38th week), and, as such, have been associated with increases in respiratory distress syndrome in the neonate.[37–39]

In terms of burdens on the healthcare system, women with planned cesarean delivery had hospital stays that were 1.5 days longer compared with women who had planned vaginal deliveries.[34] The risk of re-hospitalization is estimated to be twice as high and the overall costs twice as expensive compared to vaginal delivery.[40,41]

2.2 Methods to classify cesarean delivery

There are several methods to classify cesarean deliveries.[42] Here, we discuss two methods that classify cesarean delivery according to who is having the procedure, and a third method that classifies cesarean delivery according to why it was performed. These methods provide approaches to compare cesarean delivery rates across units (e.g., countries or hospitals) or over time and better understand differences between these units or trends over time.

2.2.1 Primary versus repeat cesarean delivery

Many studies classify cesarean delivery according to whether it was the primary cesarean delivery or a repeat cesarean delivery. These studies have found that the primary cesarean delivery rate has increased in a fashion parallel to the overall rate of cesarean delivery in the United States.[43,44] In Nova Scotia, changing maternal characteristics and related changes to obstetrical practice have been shown to account for increases in primary cesarean delivery,[45] whereas studies from the United States have found that increases in their primary rate of cesarean delivery were not related to changes in maternal risk profiles.[46,47]

While studies of the relationship between primary cesarean delivery and risk factors are important, they do not provide complete information on why each cesarean delivery was ultimately performed. Some cesareans are pre-planned for indications such as breech, while others occur during labour in women attempting vaginal delivery. Thus, this classification system cannot fully elucidate the underlying causes of cesarean delivery.

2.2.2 The Robson Classification System

The Robson classification system was proposed in 2001 as a way of prospectively classifying women into ten mutually exclusive subpopulations that are clinically relevant (Box 1).[48] It has been characterized as, "Conceptually easy, clearly defined categories, that are totally inclusive, mutually exclusive; little room for misunderstanding or misclassification."[42] By monitoring rates of cesarean delivery in each group, comparisons can be made within hospitals or health regions over time, or between hospitals/health regions. Thus, if a hospital or health region has a high cesarean delivery rate, this system can be used to pinpoint which group of women are experiencing a higher rate than expected (compared with other hospitals or earlier time points).

Box 1: Robson Classification System

1. Nulliparous, singleton, cephalic, at or after term (≥37 weeks), with spontaneous labour
2. Nulliparous, singleton, cephalic, at or after term (≥37 weeks), with induced labour or pre-labour cesarean delivery
3. Multiparous (excluding previous cesarean delivery), singleton, cephalic, at or after term (≥37 weeks), with spontaneous labour
4. Multiparous (excluding previous cesarean delivery), singleton, cephalic, at or after term (≥37 weeks), with induced labour or pre-labour cesarean delivery
5. Previous cesarean delivery, singleton, cephalic, at or after term (≥37 weeks)
6. All nulliparous breeches
7. All multiparous breeches (including previous cesarean delivery)
8. All multiple pregnancies (twins or higher order multiples)
9. All abnormal lies (include previous cesarean delivery)
10. All singleton, cephalic, pre-term births (<37^0 weeks, including previous cesarean delivery)

Using data from five Canadian provinces, Kelly et al. estimated that women comprising Group 5 (previous cesarean delivery) contributed most to the overall rate of cesarean delivery, in line with what is found in other countries.[49–51] This group comprised 11% of the obstetrical population, and had a cesarean delivery rate of 81%. Groups 1 and 2, representing most nulliparous women, were the next largest contributing groups. The rates of cesarean delivery in these groups were lower than in Group 5 (16% and 38%, respectively) but overall they accounted for 37% of the total obstetrical population.[30] Reducing the rate of cesarean delivery in Group 5 has proven difficult in contemporary practice and is challenged by concerns for heightened maternal and perinatal risks associated

with vaginal birth after previous cesarean delivery.[52] To determine how best to lower cesarean delivery in Groups 1 and 2, knowledge of indication for cesarean delivery is necessary.

2.2.3 Indication for cesarean delivery

Partitioning cesarean delivery according to primary vs. repeat cesarean delivery or using the Robson Classification System is a useful starting point for understanding cesarean delivery. However, these classification systems do not provide information on why the cesarean delivery was performed for many subgroups. This information is contained in the indication for cesarean delivery, which denotes the most proximal cause of operative birth.

Indications for primary cesarean delivery

The three most common indications for primary cesarean delivery are labour dystocia, non-reassuring fetal monitoring, and breech position,[45] in descending order. For each indication, different heightened maternal and fetal risks are being assessed in deciding whether to operate. Studies that have examined indication-specific cesarean delivery rates over time have found that cesarean delivery rates increased for several indications.[45,53] A study from Nova Scotia found that cesarean deliveries increased by 14% for labour dystocia (Relative risk (RR): 1.14, 95% confidence interval (CI): [1.07, 1.20]), 21% for non-reassuring fetal monitoring (RR: 1.21, CI: [1.10, 1.33]), and 24% for breech presentation (RR 1.24, CI: [1.14, 1.35]) between 1988 and 2000.[45] The estimated increase in cesarean delivery for breech is likely related to the increasing evidence published at that time supporting planned cesarean delivery as the optimal mode of delivery for breech fetuses.[54] The other indications involve diagnoses that are more clinically subjective. For example, the diagnosis of labour dystocia involves an assessment of the rate of cervical dilation, the amount of cervical effacement, and fetal descent to determine if labour is following the "normal" progression. Risk factors for dystocia, such as advanced maternal age and pre-pregnancy BMI are also considered, increasing the complexity of the diagnosis. Evidence is needed to understand how heightened use of these indications at some institutions may relate to lower clinical thresholds for diagnosis of these conditions or to true differences in maternal and fetal characteristics associated with diagnosing these conditions.

Repeat cesarean delivery

Previous cesarean delivery is the indication that contributes the most to the overall cesarean delivery rate in Canada, with nearly one-third of all cesarean deliveries performed for this indication.[30] Of women with a previous cesarean delivery, 81% will deliver by this method in subsequent births in Canada, and 89% in the United States, despite the support of trial of labour after cesarean as a reasonable approach by the American College of Obstetricians and Gynecologists and the Society of Obstetricians and Gynaecologists of Canada.[30,35,55,56]

Researchers examining the high rate of planned repeat cesarean delivery in many countries have investigated the impact of non-medical factors, including the medico-legal environment, on the decision to have a repeat cesarean delivery.[57–59] Using data from the United States, Zwecker et al. estimated that the likelihood of vaginal birth after previous cesarean delivery was reduced in states with malpractice premiums greater than $100,000 USD compared to states with premiums less than $50,000 USD (Odds ratio = 0.60, 95% CI= [0.37, 0.98]).[57] Corroborating this finding, Yang et al. also found reductions in the vaginal birth rate after previous cesarean delivery in states with lower premiums (Risk difference= 3.5 fewer VBACs per 1,000 women with a previous cesarean delivery for every $10,000 decrease in malpractice premiums, p-value = 0.01), and that states with caps on non-economic damages and pre-trial screenings experienced higher rates of vaginal birth after previous cesarean.[59] These findings illustrate that the decision to offer trial of labour after previous cesarean delivery is impacted by the medico-legal environment and the perception of risk associated with conducting the procedure.

2.3 Timing of cesarean delivery over the course of labour in nulliparous women

In addition to the indication for cesarean delivery, when during labour a cesarean is performed is important. The Friedman curve, introduced in 1954 by Emanual Friedman, was introduced as a graphical tool to describe the average rate of cervical dilation that could be expected to occur over the "normal" course of labour.[60,61] The curve divides labour into two phases: the latent phase and the active phase. The latent phase begins at the onset of regular

uterine contractions and contains the period of time characterized by a relatively slow rate of cervical dilation over time. Friedman found that, on average, women exited the latent phase at cervical dilations between 3 and 4 cm. At this time, they entered the active phase, initiated by acceleration in the rate of dilation, and followed by a constant slope of acceleration and a short period of deceleration when a woman nears full dilation.

Based on Friedman's analyses, definitions of abnormal labour and labour arrest were created and reflected in national guidelines that suggested the minimal dilation labour dystocia should be diagnosed and what actions should be taken in the presence of labour dystocia to support vaginal delivery. In Canada, women should not be diagnosed as having labour dystocia until they have reached 3 to 4 cm dilation and are 80-90% effaced.[62] Thus, cesarean deliveries that have been identified as being due to labour dystocia should not be performed at dilations lower than 3 to 4 cm.

In 2010, the Consortium on Safe Labor published contemporary labour curves for a large, population-based cohort of women. Their results suggested that the time required for a women to progress through labour was longer than what had been suggested by Friedman.[5] For example, they found that while the median time to progress from 3 to 4 cm was 1.8 hours in nulliparous women, the 95th percentile was 8.1 hours.[5] They also found that the active phase of labour may not commence until a woman reaches 6 cm dilation, and using this dilation as a threshold they found that many women underwent cesarean delivery early, especially nulliparous women with induced labour.[63] Based on these findings, the authors suggested that guidelines based on Friedman's curves may not apply to the progress of labour in contemporary populations, and that women may be undergoing cesarean delivery before the active phase of labour has been reached as a result of an out-dated definition of what constitutes normal labour. Other than these data from the Consortium on Safe Labor, no population-based studies have investigated the timing of cesarean delivery, and no studies have stratified timing of cesarean delivery according to indication for cesarean delivery.

2.4 Inter-hospital variation in cesarean delivery in nulliparous women

As illustrated in Figure 2-1, cesarean delivery rates vary markedly by country. Even within Canada, variation between provinces appears high (Figure 2-2). On the global scale, variation across countries is thought to be driven primarily by lack of basic obstetric services for many mothers in developing nations, and what is thought to be over-use among many developed nations.[8,64–67] Even within countries, variations across hospitals in the rate of cesarean delivery overall or for a subgroup of the obstetrical population have been found,[68–71] raising the question about whether some hospitals are over-using the procedure.

Crude differences across hospitals varied ten-fold from 7.1 percent to 69.9 percent across 593 hospitals in the United States in 2009.[70] As cesarean delivery is more expensive that vaginal delivery, and its usage has increased in developed countries without a concomitant decrease in maternal and fetal adverse outcomes,[11–13] an examination of variability may aid surveillance efforts by identifying hospitals that may be over-utilizing the procedure. Interventions within these hospitals may prove effective at safely reducing the rate of cesarean delivery.

There have been numerous studies in recent years on variability in cesarean delivery across hospitals,[68–71] all of which consider the overall rate of cesarean delivery at the hospital or cesarean delivery for specific obstetrical subpopulations. However, none of these studies has incorporated information on the indication for the cesarean delivery into the analysis.
As labour dystocia in nulliparous women is the most common indication for cesarean delivery[53] and since evidence suggests that labour dystocia is over-diagnosed,[5] it is important to determine how cesarean delivery for this specific indication varies across hospitals, and to develop methods to identify hospitals that may be performing too many cesarean deliveries for this indication.

In a broader setting, there has been a long history of performing comparisons across hospitals or across units of geography in attempts to highlight those units with the highest or lowest rates of some adverse or positive outcome. Regardless of the substantive question, two major challenges in performing such comparisons are:

1. Differences in the size of the units (here the hospitals) will lead to systematic differences in the precision of the crude rates, as an example. Perhaps hospital A is much smaller than hospital B, and so its rate is calculated with a higher level of imprecision. This information is sometimes overlooked when considering only the average for each hospital/unit and making recommendations based on the rank alone.[72]
2. Differences in the underlying characteristics of the individuals who comprise the units may lead to a confounded comparison across units. Whereas the previous challenge can be precisely measured statistically, the magnitude of bias due to differences in underlying characteristics will likely differ according to the substantive question and is difficult to fully measure or control for statistically.

Appropriate statistical methods are critical to preventing national and provincial maternal and child health stakeholders from taking inappropriate action and identifying hospitals as over-using cesarean delivery when their rates may be appropriate, given their size or the characteristics of women who deliver there.

2.5 Summary

In summary, cesarean delivery is a heterogeneous outcome and indication-specific cesarean delivery should be considered to determine how best to reduce its rate. In primary cesarean deliveries, the most commonly used indications are labour dystocia and non-reassuring fetal monitoring. Labour dystocia may be over-diagnosed in contemporary practice, especially at early cervical dilations.

Very few papers have investigated timing of cesarean delivery in relation to cervical dilation, and even less is known about timing of indication-specific cesarean delivery. Information on when and why cesarean deliveries are performed during labour is needed to better assess the appropriateness of the procedure. This is especially true for the indication of labour dystocia, which should not be diagnosed at early cervical dilations.

A body of research has examined inter-institutional variation in cesarean delivery, overall or within subgroups of the obstetrical population. However, incorporation of the indication for cesarean delivery into the analysis is needed. An examination on inter-institutional variation in cesarean delivery for labour dystocia will provide important information on how much variation currently exists. Such information could be used by provincial perinatal data-holders to better monitor and more fairly compare indication-specific cesarean delivery rates across Canadian hospitals.

Previous cesarean delivery is the most common indication for cesarean delivery in Canada and the United States, and previous research has shown that the medico-legal environment and risk perception impact the rate of vaginal birth after previous cesarean delivery. An understanding of other events that impact this rate through changes in risk perception would provide important information on how medical decisions are made in scenarios deemed to be at high risk.

3| Overview of data sources

3.1 Provincial perinatal birth registries from Canada

To study contemporary practice patterns across Canada, we combined data across three provincial perinatal registries between 2008 and 2012, inclusive. We obtained data extracts from the Better Outcomes Registry & Network (BORN) Ontario's BORN Information System,[73] Alberta's PeriLinkAB,[74] and the British Columbia Perinatal Data Registry.[75] These provinces contain 37%, 15%, and 11%, of births within Canada, and overall, comprise 63% of Canada's obstetrical population.[76] We considered applying for data from the Nova Scotia Atlee Perinatal Database, but opted against it due to logistical constraints (individual-level data cannot leave the province). Alberta's and British Columbia's registries capture more than 99% of all births occurring in these provinces. During the study period, Ontario's birth registry (formerly known as the Niday Perinatal Database) was upgraded, and between 2006 and 2010 ascertainment of births within the province improved from 89% to 100%.[77] Thus, this pooled dataset contains a large proportion of contemporary, Canadian births with detailed medical chart record data including indication and timing of cesarean.

These databases have been highly used for conducting observational research studies (for examples, see the noted references).[78–83] The vast majority of analyses that used these databases were restricted to data from a single provincial perinatal data registry. We are aware of one study that used data from multiple provincial perinatal birth registries.[84] Those authors performed parallel analyses within each province, and pooled their results using forest plots. Thus, this thesis goes one step further, by pooling the data for analysis.

3.1.1 Data abstraction

These data registries contain maternal-level obstetrical and neonatal medical chart data. The process of abstracting data from a woman's medical records to the provincial perinatal registry varies from province to province. In Ontario, no provincially-standardized medical record forms are available, implying potential variation across hospitals in documentation procedures. Some hospitals use electronic medical records, and these forms contain data entry fields, values, and lists that link directly to variables within the BORN Information

System. In Alberta, all hospitals record information on the standardized provincial delivery record. In British Columbia, standardized forms are available, but hospitals can use their own versions to record information.

The process of transferring information from medical records to the birth registries also varies. In Ontario, nurses or data entry clerks are responsible for abstracting information from the medical records, except in the case where the hospital uses electronic medical records and the information is automatically captured in the birth registry. In Alberta, unit clerks and nurses perform the abstraction, with dedicated health information management coders in Calgary hospitals. In British Columbia, trained medical abstractors perform the abstraction.

3.1.2 Data de-identification

All of the provinces had procedures in place to limit the risk of re-identification of mothers and infants with data in their registries. Certain variables are considered "quasi-identifiers", meaning that, when known in combination, these variables pose a heightened risk of potential re-identification of a woman or her child. Using Ontario as an example, some quasi-identifiers include maternal age, infant date of birth, and birth weight. If data on these variables were given in their most granular form, the likelihood of identifying the mother or child is increased. To limit this risk to an acceptable threshold, Ontario uses the Privacy Analytics Risk Assessment Tool. This software generalizes continuous variables through categorization and masks values of variables when the risk of re-identification is above the threshold. We requested the size of the binning categories (i.e., 5 year age bans for maternal age), but if the bins were considered too narrow then we were asked to further generalize the variable in question. To ensure consistency in the data captured across the provinces, we used the categories agreed upon with Ontario in our data requests to the other provinces.

3.1.3 Data pooling

The data contained in the provincial perinatal registries were used to identify the study population and to perform the data analysis. While much of the information was similar

across cohorts, certain variables were coded differentially across datasets, or not at all. The biggest difference across provinces was that the British Columbia Perinatal Data Registry contains selected variables from the Discharge Abstract Database abstract. The Discharge Abstract Database uses International Statistical Classification of Diseases, 10th revision, Canadian version (ICD-10-CA) codes for diagnoses and the Canadian Classification of Health Interventions (CCI) codes for procedures, while the other databases code this information using the fields available in their datasets. Below, we provide more information about key variables used for cohort identification and data analysis, and point out main differences across the datasets.

Indication for cesarean delivery

Indication for cesarean delivery is one of the most important variables in these analyses. In Ontario and Alberta, multiple indications for cesarean delivery can be coded in the registries, while in British Columbia only the primary indication can be indicated. Table 3-1 illustrates the original coding for indication for cesarean delivery, and how these categories were collapsed in the first study of this thesis, which examines timing of cesarean delivery according to indication for cesarean delivery.

Table 3-1: Comparison of indication for cesarean delivery across provincial birth registries

Alberta	British Columbia	Ontario	Collapsed Indication
Arrest of progress in labour - first stage	Dystocia/CPD	Nonprogressive labour/descent/dystocia	Labour dystocia
Arrest of progress in labour- second stage	Dystocia/CPD	Nonprogressive labour/descent/dystocia	Labour dystocia
-	Malposition/Malpresentation	-	Labour dystocia
Fetal heart rate abnormalities	Non-reassuring fetal heart rate pattern	Non-reassuring fetal status	Non-reassuring fetal monitoring
-	-	Cord prolapse	Other
Maternal endocrine disease (diabetes)	-	Diabetes (Niday only)	Other
Failed trial of forceps	-	Failed forceps/vacuum	Other
Fetal malformation	-	Fetal anomaly	Other
-	-	Macrosomia	Other
-	Maternal request	Maternal request	Other
-	-	Prelabour ROM (Niday)	Other
Other	Other	Other - fetal health problem	Other
Other	Other	Other - maternal health problem	Other
Unknown	Unknown - Reason is unclear/unknown		Other
-	Active herpes	-	Other
Intrapartum hemorrhage	-	-	Other
-	-	IUGR/SGA	Other
-	-	Pre-eclampsia	Other
Pyrexia in labour	-	-	Other
Maternal Hypertension	-	-	Other
Maternal cardiac disease	-	-	Other
Rhesus isoimmunization	-	-	Other
Fetal illness	-	-	Other
Prior hysterectomy	-	-	Other
Advanced maternal age	-	-	Other
Maternal exhuastion	-	-	Other

table continued on next page

Alberta	British Columbia	Ontario	Collapsed Indication
The following Indications are not applicable since these deliveries were excluded from the dataset:			
Breech or transverse lie	Breech	Breech	Excluded
Placenta previa	Placental previa	Placenta previa	Excluded
-	Abruptio placenta	Placenta abruption	Excluded
-	-	Prematurity (Niday)	Excluded
Elective repeat CS	Repeat CS	Previous CS	Excluded
Multiple pregnancy	-	-	Excluded

List of Abbreviations: CPD, cephalopelvic disproportion; ROM, rupture of membranes; IUGR/SGA, intra-uterine growth restriction/small for gestational age; CS,cesarean section

Coding of labour dystocia differed by province. Ontario's coding for this variable is the simplest, as their variable "Non-progressive labour/descent/dystocia" clearly categorized all labour dystocia. Alberta has two variables that categorises labour dystocia according to the stage of labour, which were amalgamated in our analyses. British Columbia has a primary category for labour dystocia, but also has an alternate indication "Malposition/malpresentation" that tends to be used during the later cervical dilations and has been noted as being ambiguous and difficult to distinguish from labour dystocia/lack of descent during the second stage of labour.[85] Thus, we categorized this indication as labour dystocia in the study of timing of cesearean delivery (Chapter 4).

Maternal and fetal characteristics used for risk adjustment

In our study of inter-institutional variation in cesarean delivery for labour dystocia across hospitals, we adjust the hospital-level rates for factors that may differ by hospital catchment area and may predispose a woman to cesarean delivery. One of the challenges of pooling the data across provinces was that this information is recorded in different ways across the datasets.

Table 3-2 overviews main differences across the databases in how these factors were coded, and Table 3-3 lists the ICD-10-CA codes used to identify pre-existing and gestational comorbidities in British Columbia. Ideally, ICD codes would have been used across all the provinces for identification, but we were unable to gain access and link to the Discharge Abstract Database that contained these codes in Ontario and Alberta.

Table 3-2: Variables used for risk adjustment

Variable	Notes
Maternal age	Maternal age in years was categorized by the data providers into five-year age bands to decrease the risk of re-identification. Ages for some mothers were masked (and are effectively missing) in the Ontario dataset to further decrease risk of re-identification.
Gestational age at birth, completed weeks	**Ontario and Alberta:** Gestational age in completed weeks is based on the best estimate of gestational age at delivery. **British Columbia:** Two variables related to gestational age (in days) were included in the dataset. If gestational age based on ultrasound was measured, this was the variable used in the analysis. If this variable was missing, the estimate based on last menstrual period was used. If both of these were missing, the gestational age (in weeks) as recorded by the clinician on the clinical record was used. The variable was then categorized by completed weeks.
Suspected intrauterine growth restriction	**Ontario:** This information was listed as an obstetrical complication, but could also be found as an indication for labour induction or cesarean delivery. **Alberta:** "Small-for-dates" can be indicated on the antepartum risk assessment, but could also be found as an indication for labour induction. **British Columbia:** This information was listed as an obstetrical complication only.
Obstetrical or pre-existing comorbidities	Pre-existing medical conditions: pre-existing diabetes, pre-existing hypertension, heart disease, or renal disease. Obstetrical complications: gestational diabetes, hypertensive disorders of pregnancy. **Ontario:** Primarily this information was extracted from the variables storing information on maternal pre-existing and obstetrical conditions. Some conditions were also listed as indications for labor induction or cesarean delivery. Renal disease is not captured in the dataset so unadjusted for as a pre-existing comorbidity for Ontario women. **Alberta:** Primarily this information was extracted from variables collected as part of the antepartum risk assessment. Some conditions were also listed as indications for labour induction or operative delivery. There is no variable for Eclampsia in the Alberta dataset. **British Columbia:** All gestational and pre-existing co-morbidities were measured if the corresponding ICD-10-CA code was included on the maternal record. The codes used for identification are found in Table 3-3.

Table 3-3: ICD-10-CA codes used to identify gestational and pre-existing comorbidities in the British Columbia Perinatal Data Registry

Variable	ICD-10-CA Code(s)
Pre-existing diabetes	O245, O246, O247, E10, E11, E13, E14
Gestational diabetes	O248
Pre-existing hypertension	O100, O104, O109, O16
Gestational hypertensive disorders of pregnancy	O11, O12, O13, O14
Heart disease	O101, I11, O103, I13
Renal disease	O102, I12, O103, I13

3.2 United States Nationwide Inpatient Sample

To study the impact of a uterine rupture event on hospital-level rates of vaginal birth after previous cesarean delivery (Chapter 6), we required a very large dataset that captured the relevant obstetrical information, contained hospital identifiers, and birthdate information. The Nationwide Inpatient Sample is a database of hospital inpatient stays within the United States. Every year, a 20% stratified sample of community hospitals is selected and data on all inpatient visits to these hospitals is included. Below, we provide the algorithms used to identify the obstetrical population and to identify labour that we could not discuss in detail in the published manuscript. We also discuss our decisions regarding the use of survey weights in the descriptive and etiologic analyses.

3.2.1 Identification of the study population

The Nationwide Inpatient Sample has been used previously to study the obstetrical population. Kuklina et al developed an algorithm to identify delivery visits (Table 3-4). 96.6% of the deliveries identified in this paper had the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis code of V27 on their record. A remaining 3.4% were identified using a combination of other ICD-9-CM diagnosis and procedure codes as well as another set of codes, called the diagnosis-related group codes.[87] After applying Kuklina et al.'s algorithm to identify women's delivery visits, we restricted the study population to those women with a previous cesarean delivery using ICD-9-CM codes (65.420, 65.421, and 65.423).

3.2.2 Identification of women who entered labour

The Nationwide Inpatient Sample has been used previously to study trends in trial of labour after cesarean delivery over time. We used the algorithm developed by Simon and Uddin to identify deliveries with labour (Table 3-5).[88] This algorithm was based on a modified list of codes that were used in previous studies and uses ICD-9-CM diagnosis and procedure codes that should be included only on delivery records of women who had labour.[89,90]

Table 3-4: Algorithm used to identify the obstetrical population

Description	Code(s)	Percent of total deliveries identified in Kuklina et al, 2008[1]
Outcome of delivery	ICD-9-CM = V27	96.6%
Normal delivery	ICD-9-CM = 650	0.35%
Diagnosis-related group (DRG) delivery codes	370 (complicated cesarean delivery) 371 (uncomplicated cesarean delivery) 372 (complicated vaginal delivery) 373 (uncomplicated vaginal delivery) 374 (uncomplicated vaginal delivery with sterilization and/or dilatation and curettage) 375 (vaginal delivery with operation room procedure except sterilization and/or dilatation and curettage	3.03%
Selected delivery related procedures	ICD-9-CM = 720, 721, 7221, 7229, 7231, 7239, 724, 726 (forceps) ICD-9-CM = 7251, 7252, 7253, ICD-9-CM = 7254 (breech extraction) ICD-9-CM = 7271, 7279 (vacuum extraction) ICD-9-CM = 728, 729 (other specified and unspecified delivery) ICD-9-CM = 7322 (internal and combined version and extraction) ICD-9-CM = 7359 (other manually assisted deliveries ICD-9-CM = 736 (episiotomy)	0.02%
Exclusions	ICD-9-CM = 630 (hydatidiform mole) ICD-9-CM = 631 (other abnormal product of conception) ICD-9-CM = 633 (ectopic pregnancy) ICD-9-CM = 632, 634, 635, 636, 637, 638, 639, 69.01, 69.51, 74.91, 75.0 (abortion)	

[1] Elements were examined hierarchically in the order listed.

Algorithm from: EV Kuklina et al. An enhanced method for identifying obstetric deliveries: implications for estimating maternal morbidity. Matern Child Health J. 2008; 2:469-477

Table 3-5: Algorithm used to identify labour

Description	ICD-9-CM Code
Diagnosis codes	650 (normal delivery), 653.4, 653.5, 653.8, 653.9 (disproportion), 658.2 (delayed delivery after spontaneous or unspecified rupture of membranes), 658.3 (delayed delivery after artificial rupture of membranes), 659.0, 659.1 (failed induction), 659.2 (maternal pyrexia during labour, unspecified), 659.3 (generalized infection during labour), 660.xx (obstructed labour), 661.xx (abnormality of forces of labour), 662.xx (long labour), 664.xx (trauma to perineum and vulva during delivery), 665.1 (rupture of uterus during labour)
Procedure codes	72.0, 72.1, 72.2, 72.3, 72.4 (forceps operation), 73.01, 73.09 (artificial rupture of membranes), 73.1 (other surgical induction of labour), 73.3 (failed forceps), 73.4 (medical induction of labour), 73.5 (manually assisted delivery), 73.6 (episiotomy), 73.93-73.99 (other operations assisting delivery), 75.32 (fetal EKG [scalp]), 75.38 (fetal puse oximetry), 75.6 (repair of other current obstetric laceration)

Algorithm from: AE Simon and SG Uddin. National trends in primary cesarean delivery, labor attempts and labor success, 1990-2010. Am J Obstet Gynecol. 2013; 209:1.e1-1.e8

3.2.3 Use of survey weights

As the Nationwide Inpatient Sample is conducted using a stratified sample of hospitals, sampling weights are provided for each year to account for sample design. These weights were used in the descriptive presentation of trends in the outcome variables, but not in our main etiologic analysis. While weights are necessary to account for sampling design when reporting nationally-representative trends, they do not need to be used in studies of etiologic questions.[91] In particular, our analytic model is conditioned on the unit of the hospital-year, which is a finer stratum than what was used in the sampling scheme. By doing so, we have used a form of model-based adjustment for sampling that gives rise to unbiased estimates.[91]

4| Cervical dilation at time of cesarean delivery in nulliparous women

4.1 Preamble

There is little published research on when during labour cesarean deliveries are performed. Cervical dilation at time of cesarean delivery is important, because cesarean deliveries for labour dystocia should not be performed before 3 to 4 cm dilation according to clinical guidelines, while cesarean deliveries for non-reassuring fetal monitoring can occur at any dilation. Although labour dystocia and non-reassuring fetal monitoring are the most commonly used indications for cesarean delivery in nulliparous women, little is known about when these indications are used.

Using data from all hospitals performing deliveries in Ontario, Alberta, and British Columbia, this chapter first describes contemporary practice patterns in the timing of cesarean delivery in nulliparous women according to indication for cesarean delivery. We then consider two aspects of clinical guidelines on the management of labour dystocia and investigate how commonly cesarean deliveries for this labour dystocia are performed before 4 cm and without the use of oxytocin. We explore variation across hospitals in their rates of non-adherence to these guidelines, and provide suggestions for how this information might be used to support the goal of preventing the first cesarean delivery.

This manuscript is being submitted to the *British Journal of Obstetrics and Gynecology*.

4.2 Title page and footnotes

Title: Cervical dilation at time of cesarean delivery in nulliparous women: a population-based cohort study

Short title: Cervical dilation at time of cesarean in nulliparous women

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4.3 Abstract

Objectives: Our objective was to describe contemporary practice patterns in the timing of cesarean delivery in relation to cervical dilation, overall and by indication for cesarean. Our secondary objective was to examine how commonly cesarean delivery was performed for labour dystocia at dilations below 4 cm or without the use of oxytocin, overall and between hospitals.

Design: Retrospective population-based cohort study.

Setting: Ontario, Alberta, and British Columbia, Canada, 2008-2012.

Population: Nulliparous women in labour who delivered term singletons in cephalic position.

Methods: Histograms were used to examine the distribution of cervical dilation at time of cesarean delivery, overall and by indication for cesarean. Funnel plots were used to illustrate variation in hospital-level rates of cesarean deliveries for labour dystocia that were performed early (<4 cm dilation) or without the use of oxytocin.

Main Outcome Measures: Cervical dilation (in centimetres) at time of cesarean delivery.

Results: 392,025 women comprised the population-based cohort, of whom 18.8% had a cesarean delivery. 23.0% (95% CI: 22.4-23.5) of first stage cesareans for labour dystocia had dilations <4 cm (hospital-level inter-quartile range (IQR): 16.1% to 31.9%). 23.9% (95% CI: 23.4-24.4) of women having cesarean delivery for labour dystocia did not receive oxytocin to treat their dystocia (hospital-level IQR: 17.2% to 47.3%).

Conclusions: The substantial variability across hospitals in the proportion of cesareans done before 4 cm dilation or without oxytocin suggests the need for institutions to review their practices and ensure that practice guidelines are followed in management of labour.

Tweetable abstract: Many cesareans for labour dystocia are performed early during labour (<4 cm dilation) or without oxytocin.

Keywords: Cesarean delivery, cervical dilation, labour dystocia, clinical guidelines

4.4 Introduction

Numerous studies have examined trends in primary cesarean delivery over time, and risk factors for primary cesarean delivery.[43–47] However, primary cesarean delivery is a heterogeneous event. For example, a woman may have a primary cesarean delivery because her fetus is in breech position, or for an intrapartum indication such as labour dystocia or non-reassuring fetal monitoring. In each case, different heightened maternal and fetal risks are being weighed in the decision to perform a cesarean. Thus, in order to identify and monitor specific strategies to reduce the primary cesarean delivery rate, an understanding of the different paths to primary cesarean delivery is crucial.

Population-based data describing details of both *when* and *why* primary cesarean deliveries occur are scarce. While data are published on the characteristics of women who undergo cesarean delivery, such as the breakdown of the overall cesarean delivery rate according to Robson categories,[30,50,92] fewer studies examine *why* (indication)[45,53] and *when* cesarean deliveries occur.[5, 93] In Canada, labour dystocia should not be diagnosed before a woman reaches 3 to 4 cm dilation, implying that cesarean for this indication should not occur prior to 3 to 4 cm (Fraser et al. 1995),[62] while cesarean deliveries for non-reassuring fetal monitoring can occur at any dilation.

In this study, our objective was to describe contemporary practice patterns in the timing of cesarean delivery in relation to cervical dilation, overall and by indication for cesarean, in a large Canadian population-based cohort. We were specifically interested in examining cesarean deliveries performed during the first stage of labour: how often cesarean deliveries for the indication of labour dystocia were performed prior to 4 cm dilation, how often they were performed without use of oxytocin, and to what extent these practices vary across hospitals.

4.5 Methods

Data Sources

Records from deliveries occurring between 2008 and 2012 were extracted from three Canadian provincial perinatal birth registries: the Better Outcomes Registry & Network (BORN) Ontario (BORN Information System),[73] the Alberta Perinatal Health Program (PeriLinkAB),[74] and Perinatal Services British Columbia (British Columbia Perinatal Data Registry).[75] Combined, these provinces account for 63% of births in Canada.[76] The registries contain medical record data abstracted from obstetrical charts, and include information on mode of delivery, cervical dilation prior to cesarean, hospital of birth, and maternal demographic and clinical characteristics related to labour and delivery. Ongoing quality checks of all the registries are conducted, with published data on quality for Ontario's and British Columbia's registries.[86,94] Institutional review boards at McGill University, University of Alberta, and University of British Columbia approved this study.

Study Cohort

We restricted our study cohort to nulliparous women with term (37^{+0} – 41^{+6} weeks inclusive), singleton, and cephalic pregnancies delivered following onset of labour, as we were interested in the timing of cesarean delivery during labour. We excluded women with placental previa or abruption, or deliveries out of hospital or at hospitals with less than 100 deliveries per year or hospitals that did not perform cesarean deliveries in a given calendar year.

Cervical Dilation

Cervical dilation at time of cesarean is recorded in centimetres on a woman's delivery record and/or her labour partogram, and abstracted into the perinatal databases. Women without this information were excluded from the analysis. Canadian guidelines recommend that women should not be diagnosed as having labour dystocia until they have reached 3 to 4 cm dilation and are 80 to 90% effaced.[62] We calculated overall and hospital-level non-adherence to this guideline by calculating the proportion of first stage cesarean deliveries for labour dystocia that occurred prior to reaching 4 cm. We chose 4 cm in our primary analysis due to anecdotal evidence that 4 cm was used more often in practice.[95] Since women in Alberta and

Ontario can have multiple indications for cesarean, we defined non-adherence to this guideline as occurring if a woman's *only* indication for cesarean delivery was labour dystocia and the cesarean delivery occurred before she reached 4 centimetres dilation.

Indications for cesarean delivery

The indication is recorded on a woman's delivery record by one of the healthcare providers responsible for her care during labour and delivery. The process of recording this information differs by province, and may differ across hospitals within British Columbia and Ontario as these provinces do not mandate the use of standardized forms.

In Alberta, the provider will check the reason(s) for operative delivery on a standardized form that includes twenty options and an additional free-form response to specify other indications not captured by the checklist.[96] In British Columbia, for hospitals using the standardized labour and birth summary form, the primary indication is recorded in a free-form field and categorized into 10 categories when the information is entered into the birth registry.[97] If this information is missing from this form, it may instead be abstracted from other documents, including the operative report or progress notes.[85] In Ontario, most hospitals use forms with checklists in which the provider can choose multiple indications for cesarean delivery. For Ontario hospitals using electronic medical records, these check lists contain 16 indications, in line with those indications recorded in the birth registry (D. Bedard, personal communication, August 4, 2015).

We categorized each woman's indication for cesarean delivery into four categories: i) those with labour dystocia as one of the indications (without non-reassuring fetal monitoring also recorded), ii) those with non-reassuring fetal monitoring as one of the indications (without labour dystocia also recored), iii) those having both labour dystocia and non-reassuring fetal monitoring as indications, possibly among others, and iv) all other women. In British Columbia, the third category contains no women, since only one indication can be recorded in this province.

Statistical analyses

We first describe demographic and obstetrical characteristics of our cohort. We then describe obstetrical interventions used in the cohort, and report the number and proportion of women who were induced with oxytocin, or had any exposure to oxytocin during labour, by province and overall. The number and proportion of women delivering by cesarean are also reported, and broken down by indication for cesarean delivery.

To describe *when* and *why* cesarean deliveries are performed, histograms were used to illustrate the proportion of cesarean deliveries performed at each centimetre of cervical dilation. Each bar of the histogram was partitioned according to indication for cesarean delivery to illustrate trends in indication-specific practices.

We calculated the proportion of first-stage cesarean deliveries for labour dystocia performed at or before 4 cm dilation as the number of cesarean deliveries for labour dystocia performed between 0 to 3 cm dilation (inclusive) divided by all cesarean deliveries performed for labour dystocia in the first stage of labour (i.e., with dilations of 9 cm or less). This calculation was performed using all the data to give an overall rate of non-adherence to the Canadian guideline, and for each hospital individually. We plotted the hospital-level rates against the number of women in each hospital who had a first-stage cesarean delivery for labour dystocia using a funnel plot.[98] We included 95% control bands around the overall average on the plot to identify hospitals with averages that are not statistically different from the overall average, and hospitals with averages outside of the region. To describe variability in adherence across hospitals, we calculated the intra-quartile range (IQR) of these rates, the proportion of hospitals that were outside of the 95% control bands on the funnel plot, and the proportion with rates significantly higher than the overall average. A high proportion of out-of-bounds hospitals is indicative of high inter-institutional variation in the adherence to the guideline on when to perform these cesareans, and can be used to highlight those hospitals with rates much higher or lower than the average.

In many studies of inter-hospital variation, such as the study of hospital readmission rates, it is appropriate to adjust for characteristics of patients who attended the hospitals in order to make fair comparisons across hospitals. We opted against making any such adjustments

because there are no maternal risk factors that are appropriate reasons for diagnosis of dystocia before 4 cm or the performance of cesarean delivery for this indication at early dilations.

Once labour dystocia is diagnosed, Canadian expectant management protocol first supports a regimen of oxytocin augmentation before performing a cesarean delivery for this indication alone.[62] Thus, we calculated the overall and hospital-level proportion of first-stage cesarean deliveries for labour dystocia that were performed in women who had not been exposed to oxytocin (for augmentation and/or induction, as distinguishing between augmentation and induction is challenging in many cases) and illustrated these rates using a funnel plot, using the same methods described above.

We also explored the relationship between these two aspects of nonadherence to the clinical guideline on labour dystocia. We plotted each hospital's rate of cesarean delivery for labour dystocia performed without oxytocin as a function of its rate of cesarean delivery for labour dystocia performed before 4 cm. We used local polynomial regression to fit a smooth curve to the data and describe the relationship between nonadherence to these two aspects of the clinical guideline.

Sensitivity Analysis

Our main analyses used "less than 4 cm" to define cesarean deliveries for labour dystocia that are non-adherent with clinical guidelines. However, the Canadian guideline specifies that labour dystocia should not be diagnosed until the cervix has reached 3 to 4 cm, implying that 3 cm could have alternatively been used. Thus, we used 3 cm in a sensitivity analysis to examine the overall rate of non-adherence as well as variation in non-adherence across hospitals.

4.6 Results

403,205 nulliparous women had singleton deliveries between 2008 and 2012 that met our study criteria. Of the 84,757 women who had a cesarean delivery, 11,180 (13.2%) were excluded because their records did not contain information on cervical dilation at time of cesarean delivery (8.2% in Alberta, 15.6% in British Columbia, and 14.3% in Ontario). Thus, 392,025 women comprised the cohort included in this analysis.

Women who had their first cesarean deliveries were older and more likely to be overweight or obese than women who had vaginal deliveries (Table 4-1). They were also more likely to have gestational diabetes or a hypertensive disorder of pregnancy. Their babies were born at later gestational ages and those having an indication of labour dystocia or other (i.e., an indication other than labour dystocia or non-reassuring fetal monitoring) had higher birth weights. The distribution of maternal age, pre-pregnancy BMI, pre-existing morbidities, gestational morbidities, gestational age, and birthweight of pregnancies with available cervical dilation were not meaningfully different than those with missing data (results available on request).

The breakdown of women by province of birth is shown in Table 4-2. Across provinces, 20.7% of births were induced with oxytocin, and 51.9% of the women were exposed to oxytocin at some point during their labours. 18.8% of women in the study had a cesarean delivery, with 10.4% of records including the indication of labour dystocia (but no non-reassuring fetal monitoring), 5.2% including the indication of non-reassuring fetal monitoring (but no labour dystocia), and 2.0% of records including both of these indications. Only 1.1% of women had a cesarean delivery for other indications.

Pattern of cesarean delivery across cervical dilation

The pattern of cesarean deliveries by cervical dilation is illustrated in Figure 4-1. 14,881 of 73,577 (20.2% [95% CI: 19.9%, 20.5%]) of cesareans were performed before a woman reached 4 cm, 39,847 (54.2% [95% CI: 53.8%, 54.5%]) were performed at dilations between 4 cm and 9 cm inclusive, and 18,849 (25.6% [95% CI: 25.3%, 25.9%]) were performed at 10 cm, during the second stage of labour. The most common cervical dilation reached before

cesarean delivery was 4 cm during the first stage of labour, for both labour dystocia and non-reassuring fetal monitoring. These patterns were strikingly similar across provinces.

Cesarean delivery for labour dystocia performed before reaching 4 cm dilation

Overall, 24,202 of women had a cesarean delivery for labour dystocia as the only indication during the first stage of labour. Of these women, 5,558 (23.0% [95% CI: 22.4%, 23.5%]) had their cesarean deliveries before they reached 4 cm dilation. Across hospitals, this proportion varied from 0% to 73.2%, with the middle 50% of hospitals exhibiting rates between 16.1% and 31.9% (Figure 4-2). Of the 170 hospitals, 70 (41%) had rates outside the 95% control limits around the average non-adherence rate. By way of comparison, if all hospitals had the same underlying rate of non-adherence, we would expect 8.5 hospitals (5%) to have rates outside of the 95% control limits. Thus, the observed number of hospitals is much higher than that expected if we assume that only random variability is impacting variation across hospitals. 36 of these hospitals (21.2%) had rates significantly higher than the overall average. Such a high proportion of hospital with rates outside of these bounds implies considerable variability across hospitals in their policies and practices related to the timing of diagnosis of labour dystocia and cesarean delivery for this indication.

Sensitivity analysis: Cesarean delivery for labour dystocia performed before reaching 3 cm dilation

Lowering the threshold from 4 cm to 3 cm reduced the overall rate of non-adherence from 23.0% to 12.0% (95% CI: 11.6%, 12.4%). Variation across hospitals remained high, with hospitals exhibiting non-adherence rates between 0% and 63.5% and the middle 50% of hospitals having rates between 5.5% and 20.7% (Figure 4-3). Further, 44% of hospitals had non-adherence rates that were outside of the control limits. Thus, using a lower threshold leads to an overall lower rate of non-adherence to this aspect of the guideline, although hospitals still exhibited a wide range of variability.

Cesarean delivery for labour dystocia without the use of oxytocin

Among women delivered by cesarean for labour dystocia in the first stage of labour 5,783 of 24,202 (23.9% [95% CI: 23.4%, 24.4%]) did not receive oxytocin. Across hospitals, the proportion of cesarean deliveries for labour dystocia performed without oxytocin varied

from 0% to 100%, with the middle 50% of hospitals having rates between 17.2% and 47.3% (Figure 4-4). 113 of the 170 (66%) had rates that lie outside the 95% control limits, including 76 hospitals (44.7%) with rates significantly higher than the average. Thus, there was considerable practice variation across hospitals in use of oxytocin prior to cesarean delivery for labour dystocia.

Hospitals with higher rates of cesarean delivery performed for labour dystocia before 4 cm appear more likely to have higher rates of cesarean delivery for labour dystocia without the use of oxytocin, although residual variation was high (Figure 4-5).

Pattern of non-reassuring fetal monitoring according to oxytocin usage

As the peak at 4 cm in cesarean delivery for non-reassuring fetal monitoring was unanticipated, we conducted a post-hoc analysis to explore the relationship between oxytocin usage and timing of cesarean delivery for this indication. It was hypothesized that the peak might be observed only in women exposed to oxytocin, if initiation of oxytocin augmentation led to fetal distress. Thus, we hypothesized that women not exposed to oxytocin would not exhibit a pattern showing a peak at 4 cm.

We used histograms to contrast the timing of cesarean deliveries for non-reassuring fetal monitoring in women exposed to oxytocin compared to women not exposed to oxytocin. Of the 203,447 women who received oxytocin, 9,287 (4.6% [95% CI: 4.5%, 4.7%]) had a cesarean for non-reassuring fetal monitoring as the only indication. Of the 188,578 women who did not receive oxytocin, 8,118 (4.3% [95% CI: 4.2%, 4.4%]) had a cesarean for this indication.

Cesarean deliveries were more likely to be conducted at earlier dilations in women who did not receive oxytocin than in women who received oxytocin (the proportion within 0-3 cm: 33.2% [95% CI: 32.2%, 34.2%] with no oxytocin exposure vs. 24.1% [95% CI: 23.3%, 25%] in those exposed to oxytocin) (Figure 4-6). Further, for dilations between 4 cm and 10 cm, more cesarean deliveries were conducted in women who received oxytocin compared to women who did not receive oxytocin. Interestingly, regardless of oxytocin exposure, first-

stage cesarean deliveries for non-reassuring fetal monitoring peak at 4 cm, suggesting that the use of oxytocin is not responsible for the peak at 4 cm in women having a cesarean delivery for this indication.

Table 4-1: Characteristics of nulliparous women delivering term singletons in cephalic position following labour in hospitals in Ontario, Alberta, and British Columbia, Canada, 2008-2012.

	Vaginal Delivery n (%)	CS for labour dystocia (LD) n (%)	CS for non-reassuring fetal monitoring (NRFM) n (%)	CS for LD and NRFM n (%)	CS for other indications n (%)
Number of women	318,448	40,842	20,480	7,893	4,362
Maternal age, years					
<25	91,602 (29)	7,603 (18.8)	4,051 (20)	1,377 (17.7)	970 (22.5)
25-29	107,915 (34.1)	13,118(32.5)	6,333(31.2)	2,534(32.6)	1,356(31.4)
30-34	84,768 (26.8)	12,992 (32.2)	6,202 (30.6)	2,500 (32.2)	1,269 (29.4)
≥ 35	31,951 (10.1)	6,646 (16.5)	3,709 (18.3)	1,359 (17.5)	720 (16.7)
Body mass index[1] (kg/m²)					
Underweight (BMI < 18.5)	5,187 (8)	435 (4.3)	266 (5.6)	40 (4.4)	41 (4.7)
Normal (18.5 ≥ BMI < 25)	42,826 (65.7)	5,885 (58.7)	2,833 (59.2)	485 (53.4)	512 (58.7)
Overweight (25 ≥ BMI < 30)	12,707 (19.5)	2,521 (25.2)	1,164 (24.3)	253 (27.8)	229 (26.3)
Obese (BMI ≥ 30)	4,494 (6.9)	1,179(11.8)	521(10.9)	131(14.4)	90(10.3)
Pre-existing comorbidities	4,699 (1.5)	1,105(2.7)	500(2.5)	224(2.9)	165(3.8)
Gestational diabetes	13,215 (4.3)	3,023(7.6)	1,258(6.3)	419(5.5)	389(9)
Hypertensive disorders of pregnancy[2]	17,340 (5.7)	4,015(10.1)	1,973(9.9)	674(8.9)	672(15.7)
Gestational age, weeks					
37-38	71,662 (22.5)	6,306 (15.4)	3,529 (17.2)	1,122 (14.2)	1,004 (23)
39	90,162 (28.3)	8,929(21.9)	4,594(22.4)	1,691(21.4)	1,009(23.1)
40-41	156,624 (49.2)	25,607 (62.7)	12,357 (60.3)	5,080 (64.4)	2,349 (53.9)

Table continued on the next page

Table 4-1 continued

	Vaginal Delivery n (%)	CS for labour dystocia (LD) n (%)	CS for non-reassuring fetal monitoring (NRFM) n (%)	CS for LD and NRFM n (%)	CS for other indications n (%)
Birth weight, grams					
<3000	61,379 (19.4)	2,962 (7.3)	4,706 (23.1)	1,069 (13.7)	578 (13.4)
3,000-3,499	137,498 (43.4)	12,274(30.3)	8,013(39.4)	2,931(37.6)	1,361(31.5)
3,500-3,999	94,026 (29.7)	15,912 (39.3)	5,737 (28.2)	2,691 (34.5)	1,510 (34.9)
≥ 4000	24,134 (7.6)	9,338 (23.1)	1,888 (9.3)	1,113 (14.3)	875 (20.2)

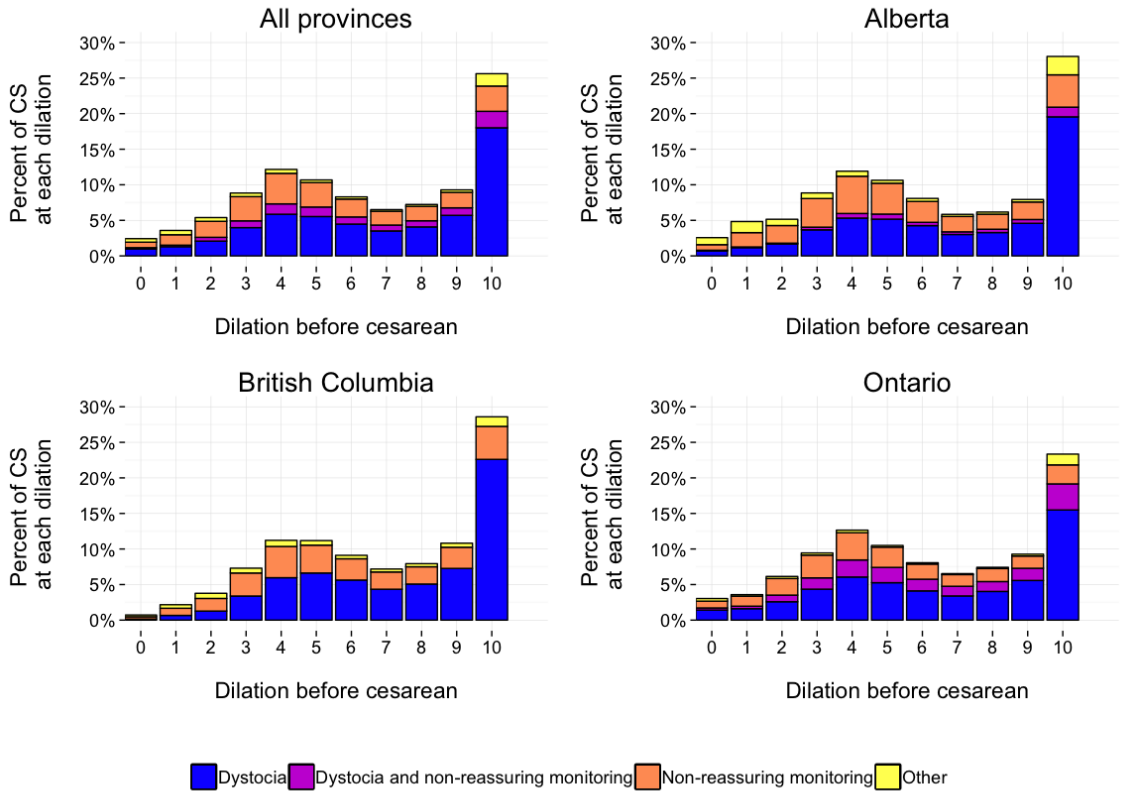
Notes:

1. BMI was only recorded in British Columbia (all years) and in Ontario after April 2012. In British Columbia, BMI was missing for 28.15% of women, and in Ontario it was missing for 32.31% of women after April 2012.
2. Hypertensive disorders of pregnancy include gestational hypertension, pre-eclampsia, and eclampsia.

Table 4-2: Oxytocin usage and mode of delivery of nulliparous women delivering term singletons in cephalic position following labour in hospitals in Ontario, Alberta, and British Columbia, Canada, 2008-2012

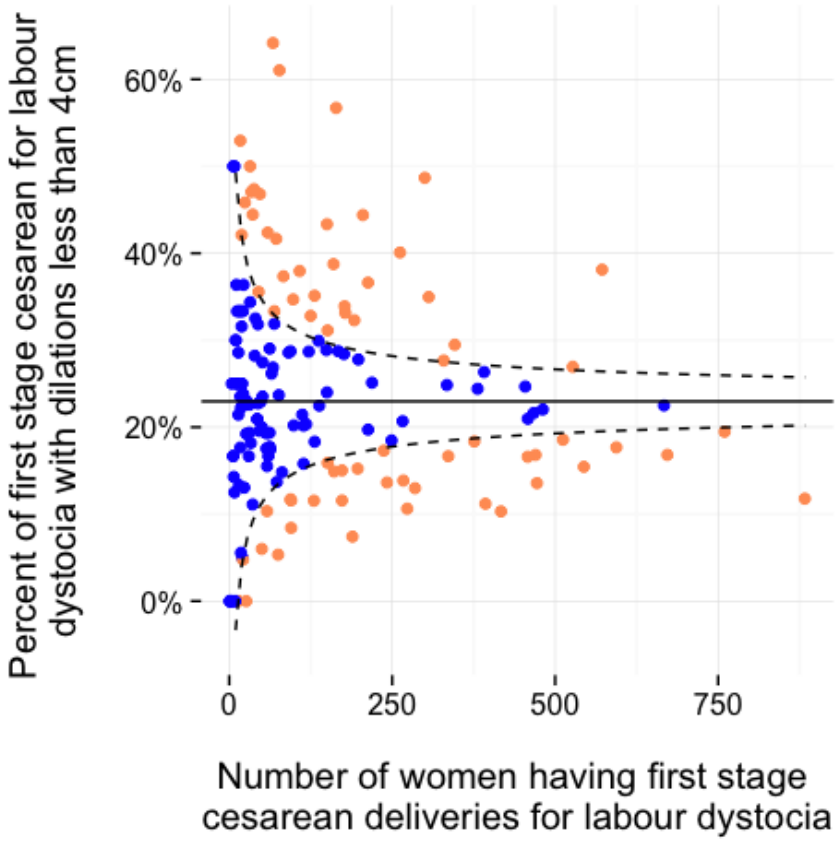
	Alberta n (%)	British Columbia n (%)	Ontario n (%)	Overall n (%)
Number of women	86,027	74,296	231,702	392,025
Induction with oxytocin	16,998 (19.8)	10,812 (14.6)	53,533 (23.1)	81,343 (20.7)
Any oxytocin usage	47,981 (55.8)	32,691 (44.0)	122,775 (53.0)	203,447 (51.9)
Cesarean delivery	17,843 (20.7)	15,927 (21.4)	39,807 (17.2)	73,577 (18.8)
Cesarean for labour dystocia	9,348 (10.9)	10,034 (13.5)	21,460 (9.3)	40,842 (10.4)
Cesarean for non-reassuring fetal monitoring	5,905 (6.9)	4,796 (6.5)	9,779 (4.2)	20,480 (5.2)
Cesarean for both dystocia and non-reassuring fetal monitoring	934 (1.1)	0 (0.0)	6,959 (3.0)	7,893 (2.0)
Cesarean for other indications	1,656 (1.9)	1,097 (1.5)	1,609 (0.7)	4,362 (1.1)

Figure 4-1: Proportion of cesarean deliveries performed at each cervical dilation in Ontario, Alberta, and British Columbia, Canada, 2008-2012



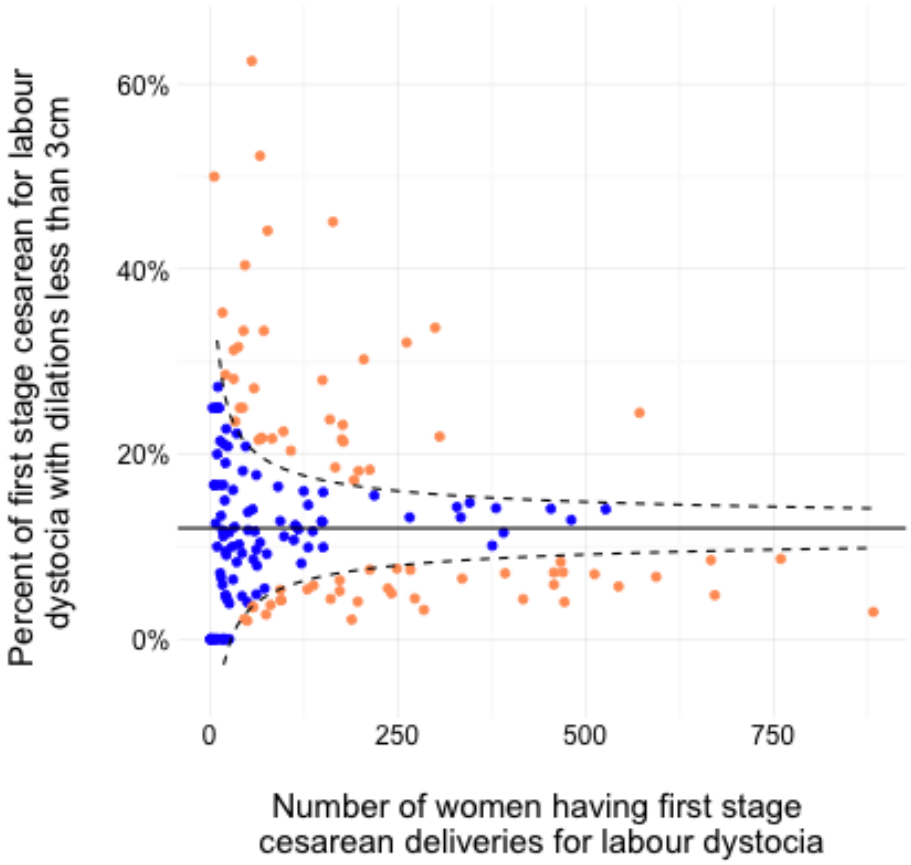
Cesareans are colour-coded according to indication:
Dystocia: cesareans with labour dystocia as one of the indications (without non-reassuring fetal monitoring).
Dystocia and non-reassuring monitoring: cesareans with both labour dystocia and non-reassuring fetal monitoring as indications, possibly among others.
Non-reassuring monitoring: cesareans with non-reassuring fetal monitoring as one of the indications (but no labour dystocia).
Other: all other indications for cesarean delivery.

Figure 4-2: Inter-hospital variability in the proportion of first stage cesarean deliveries performed for labour dystocia that are before 4 cm dilation in Ontario, Alberta, and British Columbia, Canada, 2008-2012



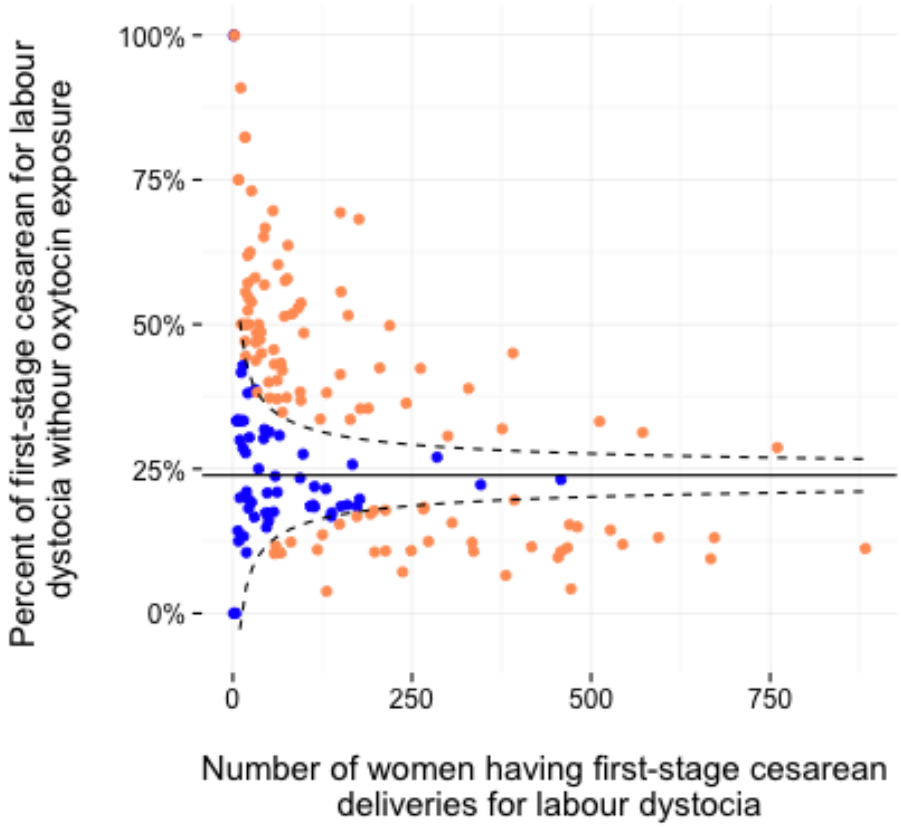
The solid line denotes the overall proportion of cesarean deliveries for labour dystocia that are performed before 4 cm dilation. The dashed lines denote the upper and lower 95% control bands around the overall average. Each circle represents a hospital, where the orange circles represent hospitals with rates outside of the 95% control band around the overall average.

Figure 4-3: : Inter-hospital variability in the proportion of first stage cesarean deliveries performed for labour dystocia that are before 3 cm dilation in Ontario, Alberta, and British Columbia, Canada, 2008-2012



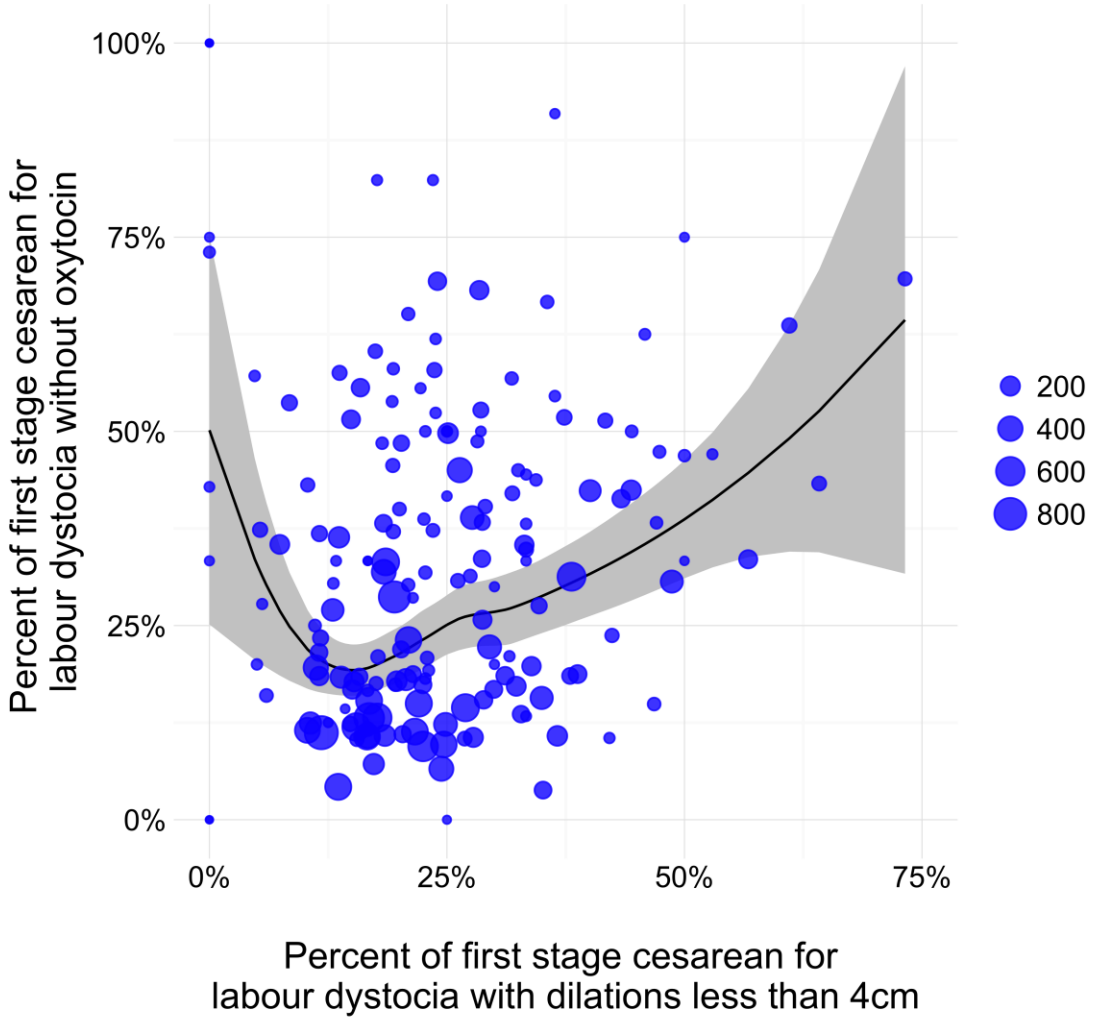
The solid line denotes the overall proportion of cesarean deliveries for labour dystocia that are performed before 3 cm dilation. The dashed lines denote the upper and lower 95% control bands around the overall average. Each circle represents a hospital, where the orange circles represent hospitals with rates outside of the 95% control band around the overall average.

Figure 4-4: Inter-hospital variability in the proportion of first-stage cesarean deliveries performed for labour dystocia without oxytocin exposure in Ontario, Alberta, and British Columbia, Canada, 2008-2012



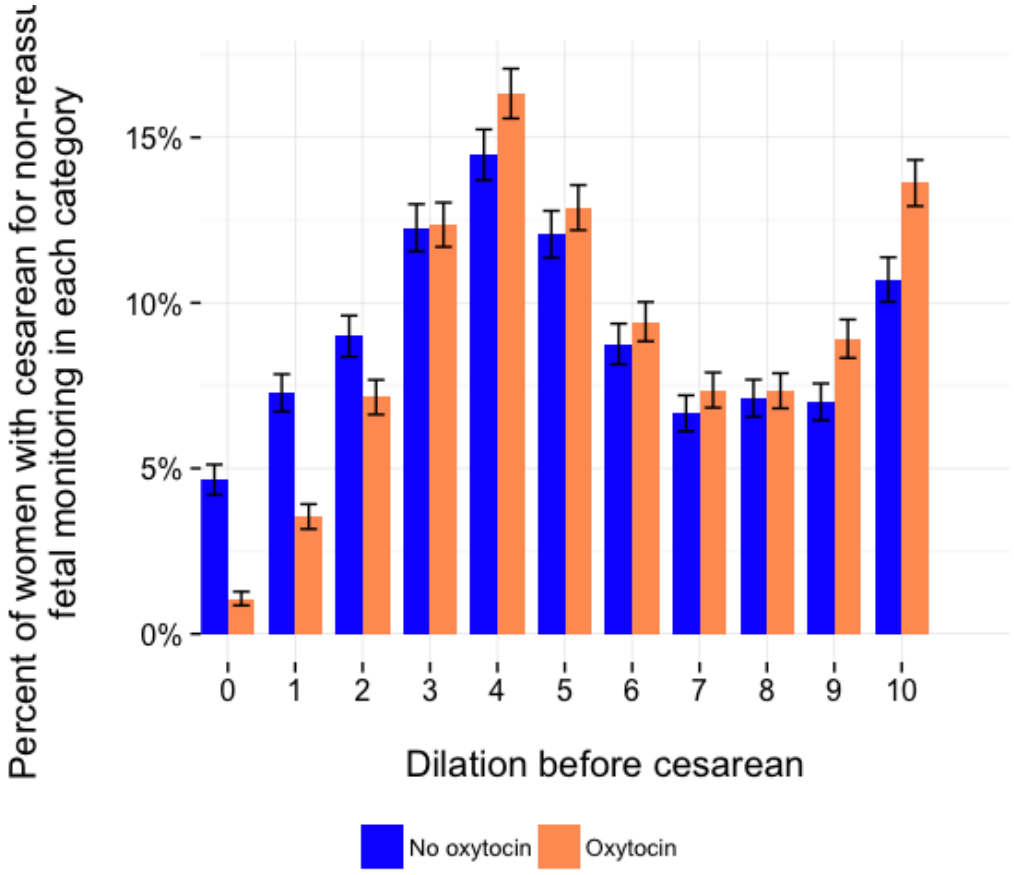
The solid line denotes the overall proportion of cesarean deliveries for labour dystocia in women who had not received oxytocin. The dashed lines denote the upper and lower 95% control bands around the overall average. Each circle represents a hospital, where the orange circles represent hospitals with rates outside of the 95% control band around the overall average.

Figure 4-5: Relationship between non-adherence to two aspects of the labour dystocia guidelines, in Ontario, Alberta, and British Columbia, Canada, 2008-2012



This graph depicts each hospital's rate of first-stage cesarean deliveries for labour dystocia without oxytocin as a function of its rate of first-stage cesarean deliveries for labour dystocia performed before reaching 4 cm. The points are sized according to the number of women who had a first-stage cesarean delivery or labour dystocia. There was a positive relationship between these rates, implying that hospitals with higher rates of non-adherence to one aspect of the guideline are likely to be non-adherent to the other aspect of the guideline.

Figure 4-6: Timing of cesarean delivery for non-reassuring fetal monitoring in women who have been exposed to oxytocin compared to women who have not been exposed to oxytocin in Ontario, Alberta, and British Columbia, Canada, 2008-2012



The bars represent the proportion of cesarean deliveries for non-reassuring fetal monitoring performed at each cervical dilation, within oxytocin exposure category. The black bars indicate the 95% confidence interval for the estimate of the proportion within each centimetre of cervical dilation.

4.7 Discussion

Main Findings

In this large, population-based cohort study, we described the practice patterns on timing of cesarean delivery in relation to cesarean delivery during labour in nulliparous women, both overall and by indication for cesarean. We found that 20.2% of cesareans were performed before a woman reached 4 cm, 54.2% were performed at dilations between 4 cm and 9 cm inclusive, and 25.6% were performed during the second stage of labour. For the indication of labour dystocia, non-adherence to clinical guidelines was evident, with 23.0% of first stage cesareans for labour dystocia occurring before reaching 4 cm dilation and 23.9% of first-stage cesarean deliveries for labour dystocia performed in women without exposure to oxytocin. Non-adherence to these guidelines varied substantially across institutions, with 21.2% and 44.7% of hospitals having average rates significantly higher than the overall average, for each guideline, respectively. Lastly, the peak of cesarean delivery for non-reassuring fetal monitoring at 4 cm was unanticipated, and did not appear to be associated with receipt of oxytocin.

Strengths and Limitations

Our dataset included detailed clinical records on indication for cesarean delivery and its timing, representing a richness of information that is rarely found in population-based studies of cesarean delivery. Indication for cesarean delivery is especially important, because the reasons leading to the decision to perform a cesarean delivery varies from woman to woman, implying that studies of trends or variability in the overall rate of cesarean can reflect changes or differences in many underlying maternal characteristics and/or hospital-level processes or policies. Further, research examining the timing of cesarean delivery during the course of labour is scarce. Combining these important variables into our analysis, we were able to study the timing of cesarean delivery by indication and found a peak at four centimetres for both labour dystocia and non-reassuring fetal monitoring, with nearly identical trends observed across the three provinces under study. Such trends have not been previously explored, and invoke further questions about why such a peak should be observed for both indications.

A limitation to our data is that cervical dilation at time of cesarean delivery was missing for 13.2% of cesareans performed. If missingness was not at random, it could be that the true pattern in timing of cesarean delivery is different than that observed in our dataset. Reassuringly, measured characteristics were not meaningfully different between mothers with and without cervical timing measures. While the proportion of missing data varied by hospital, the distribution of missing data was similar between hospitals that had in-bounds vs. out-of-bounds rates of non-adherence to the clinical guideline. Cervical dilation is prone to measurement error. A recent study that used a position-tracking system to accurately estimate cervical dilation found that the mean absolute error between the gold standard measurement of cervical dilation and that performed by the healthcare professional was 1.06 cm (95% CI: 0.88 to 1.25) for dilations between 4.1 cm and 6 cm.[99] However, since only clinical measurements are available during routine intra-partum decision-making, this bias in measurement does not affect our finding that cesarean deliveries for labour dystocia are being performed at estimated dilations lower than the clinical threshold.

Our analyses of the variability in how often hospitals perform early cesarean deliveries for labour dystocia were not adjusted for any maternal characteristics, because guidelines on labour dystocia apply to the entire obstetrical cohort and therefore should not be related to a woman's risk factors during labour and delivery. As we did not adjust, this analysis revealed a substantial degree of variation across hospitals, and many hospitals had rates *statistically* different from the overall average. This does not imply that all of these hospitals are "abnormal", but instead should be used as a signal to administrators at sites with high or low rates to investigate the reasons for their discordance from the overall average.[72]

The variation of inter-institutional rates of cesarean delivery for labour dystocia in women who did not receive oxytocin should be interpreted with some caution. Contra-indications to the use of oxytocin or maternal preferences regarding oxytocin may differ across hospitals and be correlated with adherence to this guideline across hospitals. Thus, one limitation of our study was our inability to adjust for such contraindications/maternal preferences in the study of adherence to this guideline.

While our data are relatively rich compared with other commonly used sources, they do not contain information about the timing (i.e., initiation and duration) and dose of oxytocin, nor the timing of electronic fetal monitoring. In particular, the increase in later-timed cesarean deliveries for non-reassuring fetal monitoring in women receiving oxytocin could reflect the fact that labour augmentation was more likely to occur after a woman progressed through the early dilations (e.g., following a diagnosis of dystocia at 4 cm). Due to lack of data, we were unable to incorporate timing of augmentation into our analyses to determine the extent to which timing of cesarean by oxytocin status is influenced by the timing of oxytocin receipt. However, women who did not receive any oxytocin still exhibited a peak in cesarean deliveries at 4 cm, which supports the notion that oxytocin is not responsible for this pattern. Another explanation for the peak is that it may reflect when electronic fetal monitoring was initiated (since electronic fetal monitoring is causally associated with cesarean delivery compared with intermittent auscultation[100]). Alternatively, tolerance for non-reassuring fetal monitoring may be lower at earlier dilations (compared to later dilations when delivery is more imminent). Again, due to lack of data, we cannot investigate these hypotheses using our dataset.

Interpretation

One other study has looked specifically at the adherence to guidelines on the management of labour dystocia in a Canadian population.[101] Using data from one hospital in Ottawa, Ontario, the authors found that 39.7% of first-stage cesarean deliveries for labour dystocia did not adhere to at least one aspect of the guideline. Specifically, 10.9% were performed in women with dilations less than 4 cm,[101] suggesting that the study hospital had a higher adherence rate than the overall average across the hospitals in our study.

In terms of cervical dilation at the time of cesarean delivery, a study conducted on a sample of deliveries to hospitals in Los Angeles and Iowa showed similar patterns of cesarean delivery for labour dystocia according to cervical dilation.[93] This study used data from 1993-1994, and this pattern was only examined in 231 women who had cesarean deliveries for lack of progress. With regards to population-based studies, the Consortium on Safe Labor has published research on the timing of cesarean delivery, stratified by parity, type of labour, and

previous uterine scar. A high proportion of nulliparous women underwent cesarean delivery prior to 6 cm.[63] In contrast with our paper, the study's authors considered a threshold of 6 cm in their analysis, because they had found in previous work that the active phase of labour may not begin until 6 cm and had recommended this a new threshold, which was later adopted by the American College of Obstetricians and Gynecologists in 2014.[5,102]

4.8 Conclusion

We found that cesarean deliveries during the first stage of labour peaked at 4 cm dilation, with similar patterns seen for labour dystocia and non-reassuring fetal monitoring. We found evidence of non-adherence to clinical guidelines on the timing of cesarean deliveries for labour dystocia and the performance of cesarean deliveries for labour dystocia in women who did not receive oxytocin, and observed high rates of variation across hospitals in non-adherence to these guidelines. This suggests that monitoring rates may be useful to identify hospitals above the upper bound. Those hospitals may want to perform internal audits to determine why their non-adherence rates are relatively high and review practice guidelines on the management of labour dystocia. In contrast, hospitals with lower rates of non-adherence may provide insight on processes that are aligned with decreasing non-adherence that can serve as a model for other hospitals.

4.9 Acknowledgements

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opinions or policies of the provincial data providers, including the Better Outcomes Registry & Network (BORN) Ontario, the Alberta Perinatal Health Program, or British Columbia's Perinatal Services BC.

4.10 Supplementary Analyses

As a supplementary analysis, we explored which maternal-level and hospital-level variables were associated with the performance of a cesarean delivery for labour dystocia before 4 cm dilation. We restricted the cohort to women who had a first-stage cesarean delivery for labour dystocia, and thus our model identified determinants of *early* cesarean delivery for labour dystocia, rather than the *occurrence* of cesarean delivery for labour dystocia. The variables we examined included: maternal age (categorized into 5-year age bands), pre-existing comorbidities (using an indicator variable equal to unity if a women had any of: pre-existing diabetes, hypertension, heart disease, or renal disease), gestational diabetes (using an indicator variable), hypertensive disorders of pregnancy (any of gestational hypertension, pre-eclampsia, or eclampsia), antenatally-suspected intra-uterine growth restriction, and estimated gestational age of the fetus (categorized into completed weeks). We further included an indicator variable for teaching status of the hospital and overall obstetrical volume (categorized into five groups) to explore whether hospital characteristics were predictive of non-adherence.

To estimate the relative risk of non-adherence associated with each risk factor, we used hierarchical Poisson regression using a log-link function and assumed a constant offset term across mothers.[103] This model overestimates the magnitude of the coefficient standard errors,[104] which we accommodated using the Huber-White robust variance.[105] Our model also included a random intercept term for each hospital to account for correlated measures among women who delivered at the same hospital. This model was fit using the *gllamm* procedure in Stata 12.1 (LP).[106,107]

Sensitivity Analysis

Body mass index (BMI) is an important risk factor for cesarean delivery but was not recorded for the Alberta cohort, and was known to be missing a large portion of women in the Ontario and British Columbia cohorts, suggesting that imputation of missing data would be inadvisable. To explore BMI's association with guideline non-adherence, the model was expanded to include BMI in the cohort of women with measured BMI. These findings were contrasted to another model that did not contain BMI, but was restricted to women with

measured BMI (to isolate the effect of BMI inclusion on the model while removing the effect of performing the model on a restricted subgroup).

Results

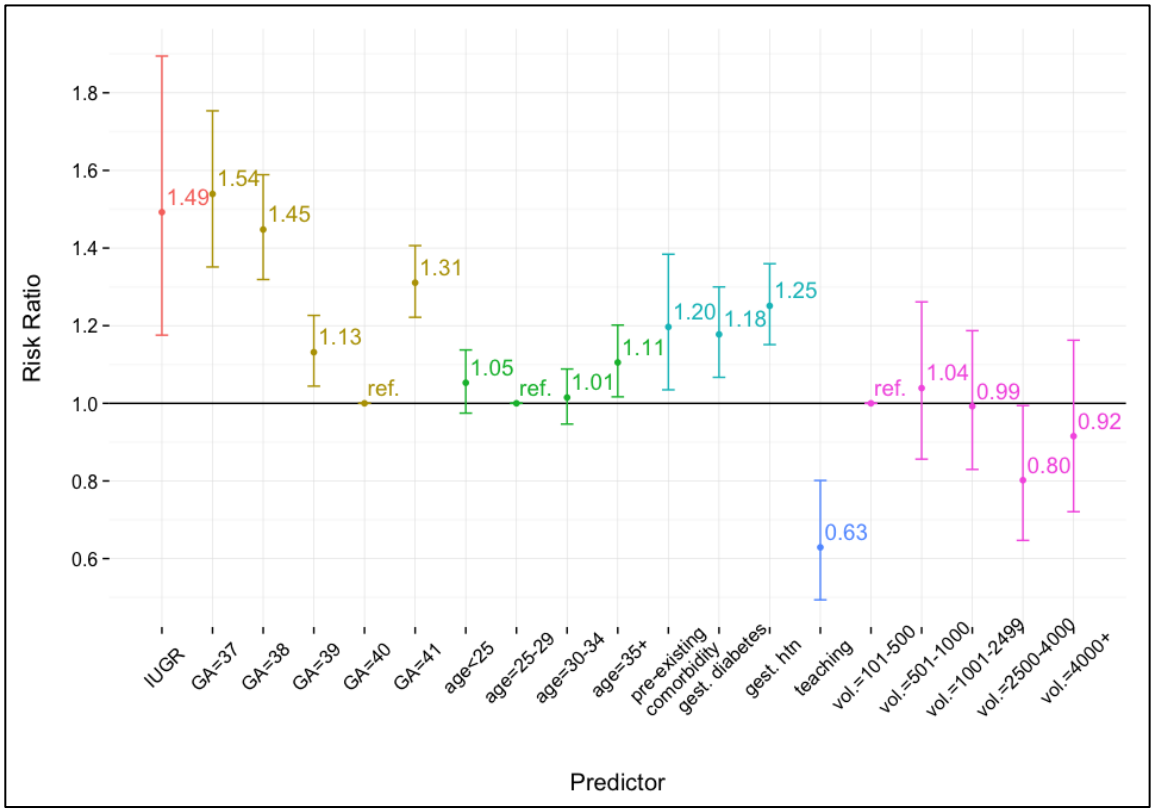
We found several maternal and fetal characteristics to be associated with cesarean deliveries for labour dystocia performed before four centimetres dilation (Figure 4-7). Deliveries of fetuses with antenatally-suspected intrauterine growth restriction had a 49% higher risk of their cesarean delivery for labour dystocia occurring before 4 cm (risk ratio (RR): 1.49, 95% Confidence interval (CI):[1.18, 1.89]). Estimated gestational age (GA) was also predictive of earlier timing. Early-term deliveries during the 37th and 38th weeks were associated with more than a 40% increase in risk of earlier timing compared to deliveries occurring in the 40th week (GA=37 RR: 1.54, CI:[1.35, 1.75]; GA=38 RR: 1.45, CI:[1.32, 1.59]). Post-dates deliveries were associated with a 31% increases in risk (GA=41 RR: 1.31, CI:[1.22, 1.41]). The youngest and oldest mothers had very small increases in their risk of earlier timing, although the magnitude of the increases was small. Mothers with pre-existing and gestational comorbidities were more likely to have an earlier-timed cesarean delivery for labour dystocia compared to women without these conditions.

Women who delivered at teaching hospitals had a 37% lower risk of having an earlier-timed cesarean delivery for labour dystocia (RR: 0.63, CI:[0.49, 0.8]). On the other hand, obstetrical volume did not seem to significantly impact the likelihood of earlier timing, although women who delivered at a hospital with an annual obstetrical volume between 2,500 and 4,000 deliveries per year were 20% less likely to have an earlier timed cesarean delivery (RR: 0.80, CI:[0.65, 0.99]).

To investigate the impact of pre-pregnancy BMI on non-adherence to guidelines, we refit the model using only women with non-missing BMI measures. Of the 24,202 women who had a cesarean delivery for labour dystocia as the only indication during the first stage of labour, only 7,048 had BMI measures on their delivery records. An analysis of these women found that non-normal BMI was also associated with earlier-timed cesarean deliveries for this indication compared to having a BMI in the normal range (RR underweight: 1.16,

CI:[0.87, 1.55]; RR overweight: 1.19, CI:[1.04, 1.36]; RR obese: 1.40, CI:[1.22, 1.61]). We further investigated how sensitive the fit of our model was to this restriction to women with non-missing BMI. We find no evidence that restricting the cohort to women with BMI measurements materially impacted the magnitude/direction of the coefficient estimates for the other variables in the model, although precision was decreased, likely because sample size decreased by roughly two-thirds.

Figure 4-7: Risks of first stage cesarean deliveries performed for labour dystocia before 4 cm dilation associated with maternal and hospital-level predictors



List of abbreviations
IUGR: suspected intra-uterine growth restriction; GA: gestational age; age: maternal age; pre-existing comorbidity includes pre-existing diabetes, hypertension, heart disease, or renal disease; gest. diabetes: gestational diabetes; gest. htn: gestational hypertension; teaching: indicator variable for teaching hospitals; vol.: yearly total obstetrical volume.

Effect estimates are colour-coded to group categorical variables (e.g., all gestational age categories are shown in yellow), or similar variables (e.g., all maternal comorbidities are shown in teal).

Discussion

Our predictive model of early-timed cesarean delivery for labour dystocia suggests that non-adherence is associated with the presence of maternal/fetal characteristics that are considered risk factors for overall cesarean delivery. These findings imply that such characteristics affect care providers' decisions about when during labour cesarean deliveries for dystocia should be performed, or that the true underlying reason for such cesarean deliveries was not labour dystocia, but rather concern about factors that heighten maternal or fetal risks during pregnancy, labour or delivery. Further, we found that delivering at a teaching hospital was associated with a reduced risk of earlier timing. This finding suggests that care providers at these hospitals are more cognizant of/adherent to such guidelines, although the association may be related to other differences between teaching and non-teaching hospitals that were not captured in our data sources.

5| Inter-institutional variation in cesarean delivery for labour dystocia in nulliparous women

5.1 Preamble

In the previous chapter, we considered cesarean delivery for any indication during labour in nulliparous women, and explored when during labour these cesareans occurred. Chapter 4 also explored inter-hospital variability in adherence to two aspects of clinical guidelines on the management of labour dystocia in the first stage of labour.

In this chapter, we focus exclusively on cesareans performed for the indication of labour dystocia. Similar to the previous chapter, we examine inter-hospital variation in cesarean delivery for labour dystocia using funnel plots, but we standardise these hospital-level rates for maternal, fetal, and hospital-level factors. These factors are aspects of "case-mix" that are risk factors for cesarean delivery and plausibly differ by hospital catchment area.

Continuing our exploration of clinical guidelines, we explore how a woman's risk of cesarean delivery for labour dystocia is affected by a hospital's rate of instrumental vaginal delivery. As instrumental vaginal delivery is recommended as an alternative for some second-stage cesareans, this analysis provides an estimate of the extent of this relationship. This analysis is different methodologically from what we've presented thus far because it uses only within-hospital variation, rather than between-hospital variation. We use variation in the yearly rates of instrumental vaginal delivery for each hospital across calendar time to examine the relationship between changes to a hospital's own rate of instrumental vaginal delivery and an individual's risk of cesarean delivery. The benefit of this approach is that it removes the risk of confounding by factors that vary across hospitals but are constant on the hospital-level.

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5.2 Title page and footnotes

Title: Inter-institutional variation in use of cesarean delivery for labour dystocia: a population-based cohort study

Short Title: Variation in cesarean section for dystocia

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5.3 Abstract

Objectives: 1) To establish the amount of inter-hospital variation in use of cesarean delivery for labour dystocia, after accounting for maternal, fetal, and hospital characteristics. 2) To investigate the extent to which risk of cesarean delivery for labour dystocia is influenced by changes in hospitals' instrumental vaginal delivery rates.

Design: Retrospective population-based cohort study.

Setting: Ontario, Alberta, and British Columbia, Canada, 2008-2012.

Population: Nulliparous women delivering term singletons in cephalic position following labour.

Methods: Hospital-specific rates of cesarean delivery for labour dystocia were computed using hierarchical logistic regression, with adjustment for maternal, fetal and hospital characteristics. The relationship between a hospital's yearly rate of instrumental vaginal delivery and risk of cesarean delivery for second-stage labour dystocia was examined using fixed effects logistic regression.

Main Outcome Measures: Cesarean delivery for labour dystocia.

Results: Among 403,205 women delivering at 170 hospitals, the middle 95% of hospitals had cesarean delivery rates for labour dystocia that ranged from 4.5% to 24.7%. Differences in maternal case-mix and hospital characteristics explained only a small amount of this variation (95% central interval of adjusted cesarean delivery rates: 6.3% to 21.7%). Shifting hospitals' instrumental vaginal delivery use from the rate of the institution at the 25th percentile (16.6% among women reaching second stage) to that of the 75th percentile (29.6%) was estimated to lead to a clinically insignificant reduction in the risk of cesarean delivery for labour dystocia (0.8 percentage points [95% CI: -1.4, -0.3]).

Conclusions: Considerable inter-hospital variation in rates of cesarean section for labour dystocia remains after accounting for measured differences in maternal and hospital factors. Guidelines advocating increases to the rate of instrumental vaginal delivery in an attempt to decrease the rate of cesarean delivery for labour dystocia may be less effective than anticipated.

Keywords: Cesarean delivery; labour dystocia; instrumental vaginal delivery; hierarchical logistic regression; fixed effects

Tweetable abstract: Inter-institutional rates of cesarean delivery for labour dystocia vary considerably even after adjustment.

5.4 Introduction

The overall rate of cesarean delivery was 26% in England and 27% in Canada in 2012.[2,64] Such high rates of cesarean delivery have created concerns that the surgery may be overutilised in developed countries.[65–67] Considerable variation between hospitals in use of cesarean delivery has been noted,[68–71] which may also be indicative of over-use or lack of consensus on best practice.

However, the decision to perform a cesarean delivery is the end result of a number of distinct clinical situations: the decision-making leading to a cesarean for breech presentation is different from that for elective repeat cesarean or cesarean for labour dystocia. In order to identify which policies or practice changes an institution should implement to help optimise their cesarean delivery rate, an understanding of indication-specific patterns of cesarean delivery is needed.

In this study, our first objective was to investigate the degree of variation between hospitals in use of cesarean delivery for labour dystocia across three Canadian provinces, and to determine how much of this variation could be explained by differences in maternal, fetal, and hospital characteristics. We focused on labour dystocia because it is the most common indication for primary cesarean delivery,[53] it may be diagnosed too readily in contemporary obstetrical populations,[63,101] and recent guidelines address cesarean for this indication.[102] One of these guidelines advocates increased use of instrumental vaginal delivery as a strategy to reduce the number of cesarean deliveries due to dystocia.[102] Thus, in our second objective we sought to estimate the magnitude of reduction in risk of cesarean delivery for dystocia that could be achieved with realistic institutional-level increases in the use of instrumental delivery.

5.5 Materials and methods

Data sources

Provincial perinatal databases containing abstracted obstetrical chart records from mothers delivering between 2008 and 2012 in the Canadian provinces of Ontario (BORN Information System)[73], Alberta (PeriLinkAB)[74], and British Columbia (British Columbia

Perinatal Data Registry)[75] were obtained and pooled for analysis. Births in these provinces account for more than 60% of the Canadian obstetrical population (242,768 of 385,937 births in 2013).[76] Each dataset included information on maternal demographic characteristics and clinical information related to labour and delivery abstracted from the medical record. All of the registries undergo ongoing data verification and quality checks with published information on quality available for Ontario and British Columbia.[86,94] Table 3-2 describes any notable differences in variables across the registries. The institutional review boards at the McGill University Faculty of Medicine, the University of Alberta, and the University of British Columbia approved this study.

Study cohorts

We restricted our cohort to nulliparous women who delivered in-hospital, live-born singletons in cephalic position at term gestation (37-41 completed weeks). Women with a pre-labour cesarean delivery were excluded, as were deliveries to women with placenta previa or placenta abruption, as these events often require emergent cesarean delivery. We also excluded all births at hospitals with total annual obstetrical volumes of fewer than 100 deliveries per year or deliveries to hospitals with no cesarean in a given calendar year, as these hospitals likely had limited ability to perform cesarean deliveries.

For our second study objective (examining the extent to which risk of cesarean delivery for labour dystocia is influenced by changes in hospitals' instrumental vaginal delivery rates), the cohort was further restricted to women who reached the second stage of labour. Second stage of labour was identified based on the cervical dilation at time of cesarean (10 cm) and duration of the second stage of labour (documented as >0 minutes). In Alberta, a third variable that indicated the stage of labour at the time of operative delivery for the indication of labour arrest was also used.

Cesarean delivery for labour dystocia

Indication for cesarean delivery is recorded on the maternal delivery record by a healthcare provider involved with the woman's labour and delivery. Alberta, uses check boxes for arrest during the first stage of labour and arrest during the second stage of labour to indicate the

presence of labour dystocia when an operative delivery is performed. The standardized form for British Columbia contains a field for primary indication of cesarean, but indication for cesarean delivery may also be obtained from the surgical report. Most hospitals in Ontario use charts or electronic medical records that contain a specific section or checklist for choosing the indication(s) for cesarean delivery, although the province does not have standardized forms.

The Society of Obstetricians and Gynaecologists of Canada recommend that labour dystocia not be diagnosed until a woman is at least 3 to 4 cm dilated and 80 to 90% effaced. Primary labour dystocia is diagnosed when the rate of cervical dilation is less than 0.5 cm over four hours. Secondary dystocia is defined as the arrest of progress during the active stage of labour for more than two hours.[62]

Calculation of crude rates

We calculated the observed cesarean delivery rates for the indication of labour dystocia for each hospital. We plotted the hospital-level rates against the number of deliveries at the hospital that were included in the analysis. This plot takes on a funnel shape, with lower-volume hospitals having higher variation in their cesarean deliveries rates.[72,98] We reported the range for the middle 95% of the hospitals, known as the 95% central interval, as well as the inter-quartile range alongside the widths of these intervals.

We then stabilised and adjusted the cesarean delivery rates to account for imprecise estimates from small hospitals and for differences in patient case-mix and hospital characteristics. After each stabilisation and adjustment step, we plotted the updated rates and reported the 95% central interval and inter-quartile range to exhibit the effects of stabilisation or adjustment on the range of the hospital-level rates.

Stabilisation of crude rates

A common concern when making inter-hospital comparisons is that the rates for smaller institutions are calculated based on only a small number of deliveries, which can produce unstable estimates. To produce rates for smaller hospitals that more accurately reflect their

"true" underlying rate, we generated "stabilised" rates using hierarchical logistic regression with a random intercept for each hospital.[108]

Adjustment for patient and hospital factors

After the rates were stabilised, we examined the extent to which inter-hospital differences in use of cesarean delivery for labour dystocia were explained by differences in maternal, fetal, and hospital characteristics. We used the method recommended by the Centers for Medicare & Medicaid Services Hospital Compare[109] that has also previously been used to report health care organization-specific rates of perinatal mortality in the United Kingdom[110] (See Appendix B for information about the computation of stabilised and adjusted rates). Briefly, this method compared the predicted number of cesarean deliveries for labour dystocia at each hospital to that expected given the unique case-mix distribution at the hospital. When this ratio is larger than one, the hospital performs more cesareans than expected given measured maternal and fetal characteristics, and when it is less than one, the hospital performs fewer than expected. Each hospital's ratio is then multiplied by the overall rate of cesarean delivery for labour dystocia in the population to generate their adjusted rate.

Our list of maternal and fetal case-mix factors, which were decided upon a priori, included: maternal age, gestational diabetes, hypertensive disorders of pregnancy (including gestational hypertension, pre-eclampsia, and eclampsia), pre-existing maternal conditions (including pre-existing diabetes, hypertension, heart disease, or renal disease), as well as antenatally-suspected intra-uterine growth restriction and gestational age (a proxy for estimated fetal size, which is a risk factor for labour dystocia[6]). Maternal body mass index (BMI) is a known risk factor for cesarean delivery but is not collected by the Alberta registry and is missing at a high rate in the British Columbia and Ontario datasets. To evaluate the effect of including BMI in the model, we conducted a sensitivity analysis. In this analysis, we restricted the dataset to using women with maternal pre-pregnancy BMI measures from British Columbia and the most recent year of Ontario data (in which the rate of missing data is reduced due to an upgrade in the registry). We conducted the analysis before and after adjustment for BMI to examine how much variability is reduced when BMI is incorporated into the model.

We then added hospital-level factors, including teaching status (indicating those hospitals involved in the education of medical practitioners) and annual obstetrical volume to account for measured differences across hospitals that may be associated with labour management. If accounting for hospital factors explains a large proportion of the variability, this would suggest that interventions related to these adjusted-for institutional-level characteristics might help to reduce the variability in the risk of cesarean delivery for labour dystocia across hospitals. Lastly, indicator variables for province were also included in the model to account for any variation due to time-fixed differences across provinces, such as differences in coding practices or variable definitions.

Link between instrumental delivery and cesarean delivery due to labour dystocia

We used a hospital fixed effects logistic model[111,112] to investigate the extent to which changes in a hospital's yearly rate of instrumental vaginal delivery (delivery following use of forceps and/or vacuum) were linked with changes in a woman's risk of cesarean delivery due to dystocia. We repeated our analyses using data from each province separately to confirm that our overall findings were consistent within each province. With these models, only variation within hospitals in their yearly rates of instrumental delivery was used to estimate the effect of a hospital's rate of instrumental vaginal delivery on an individual's likelihood of cesarean delivery for labour dystocia. Using within-hospital changes completely controlled for confounding due to hospital-level factors (like size, policies, or the hospital's unique case-mix) but were fixed within hospitals, analogous to a case-crossover design in which individual patients are observed repeatedly and compared to themselves.[113] We used the model to predict the average risk of cesarean delivery for labour dystocia at varying rates of instrumental vaginal delivery. To illustrate how changing hospital-level practice could potentially impact a woman's risk of cesarean delivery for labour dystocia, we calculated the difference in the average likelihood of cesarean delivery for labour dystocia if all hospitals had the instrumental vaginal delivery rate at the 25th percentile (i.e., a relatively low rate of instrumental vaginal delivery) vs. at the 75th percentile (i.e., a relatively high rate). This risk difference exemplifies the reduction in risk that could be anticipated if an overall increase in the instrumental delivery rate was realized within the realm of what is realistic given contemporary practice.

We used the glmer function available from the lme4 library[114] in the R language and environment (version 3.1.3)[115] to run the logistic models with random hospital intercepts for the analysis of the first objective. In these models, the outcome of interest was having a cesarean delivery for labour dystocia. These models included sequential adjustment for the noted case-mix and hospital-level factors. We then used the logit function available in Stata/SE version 12.1[107] to run the hospital fixed effects models utilized in the study of the second objective. For this objective, we restricted the study population to women who reached the second stage of labour. The effect of interest was the average change in the risk of cesarean delivery for labour dystocia (in the second stage) associated with moving a hospital's yearly rate of instrumental vaginal delivery. These models included indicator variables for each hospital and adjustment for all noted case-mix factors. The cluster option was used to adjust the standard errors for the clustering of women within hospitals and hospitals within provinces. The margins command was used to estimate the average marginal effects and 95% confidence intervals were computed using the delta method. Sample code for the models and further description is provided in Appendix B.

5.6 Results

Between 2008 and 2012, 403,205 births across 170 hospitals meet our study inclusion criteria (Table 5-1). The median number of eligible women per hospital over the five-year period was 1,240, with the smallest hospital contributing 31 deliveries and the largest hospital contributing 12,890 deliveries. The overall primary cesarean delivery rate was 21.0%, and the cesarean delivery rate for the indication of labour dystocia was 12.7%. These nulliparous women were most likely to have delivered between the ages of 25 and 29 years and during the 40th week of gestation.

Considerable inter-institutional variation was observed in use of cesarean delivery for labour dystocia, with rates for the middle 95% of hospitals ranging from 4.5% to 24.7%, and the middle 50% of hospitals ranging from 9.5% and 16.4%. As shown in Figure 5-1a, smaller hospitals had greater variability in rates. Figure 5-1b compares each hospital's rate after stabilisation to its crude rate. Stabilising the rates impacted only the smallest hospitals with less than 1,000 deliveries. For these hospitals, stabilisation changed the rates to be closer to

the overall average rate in the population. After stabilization, the 95% central interval narrowed slightly, and ranged from 5.6% to 23.9%, with the middle 50% of stabilised rates ranging from 9.8% to 16.3% (Table 5-2).

We examined the change in rates after adjusting for maternal and fetal characteristics. Figure 5-1c compares each hospital's adjusted and stabilised rate to their rate under stabilisation only. If a hospital's adjusted rate is lower (higher) than its unadjusted rate, this means that it performed fewer (more) cesarean deliveries than expected given the unique case mix of women who delivered at the hospital. The reduction in variability following adjustment reflects how much of the variation in crude rates can be explained by a hospital's case mix. The 95% central interval ranged from 6.4% to 24.6% and the middle 50% of stabilized rates ranged from 10.1 to 16.1, which represents a modest narrowing of variability in rates across hospitals (Table 5-2).

In a sensitivity analysis, we additionally adjusted for maternal BMI in women with non-missing measures who delivered in British Columbia (at any time) or in Ontario (after April 2012, when the birth registry was upgraded). Adjusting for BMI reduced the width of the 95% central interval by 2.3 percentage points, illustrating that differences in maternal BMI are related to differences in cesarean delivery for labour dystocia across hospitals (Table 5-3).

The final step included adjustment for hospital factors (Figure 5-1d). The 95% central interval of the stabilised and adjusted rates was 6.3% to 21.7% and the middle 50% of hospitals had adjusted rates between 9.7% and 15.6%. Overall, while stabilisation and adjustment reduced variability in rates of cesarean delivery across hospitals, the 95% central interval and interquartile range narrowed only slightly, leaving considerable variability among hospitals unexplained (Table 5-2). Appendix B contains summary model output for the stabilization-only model, and the model adjusting for all individual- and hospital-level factors.

For our second objective, we estimated how a woman's risk of cesarean for the indication of labour dystocia would change if the hospital she attended increased its rate of instrumental

vaginal delivery. Twenty-four percent of women entering the second stage of labour had an instrumental vaginal delivery, and 7% had a cesarean delivery, of which 63% were for the indication of labour dystocia. Figure 5-2 illustrates the estimated average risk of cesarean for labour dystocia across the range of rates of instrumental vaginal delivery exhibited by hospitals in the population.

As expected, the rate of instrumental vaginal delivery was negatively associated with the risk of cesarean for labour dystocia. However, the magnitude of this relationship was of low clinical impact in all the provincial models, as well as in the pooled model. Using the pooled model, shifting all hospitals from performing instrumental vaginal deliveries in 16.6% of women reaching the second stage to 29.6% (which would correspond to shifting the instrumental delivery rate from the 25th to 75th centile of hospitals rates) was associated with a reduction in the cesarean delivery for labour dystocia of 0.8 percentage points [95% CI: -1.4, -0.3]. This finding suggests that changes in the rate of instrumental vaginal delivery may be more likely to lead to fewer spontaneous (non-instrumental) vaginal deliveries, rather than fewer cesareans.

Table 5-1: Characteristics of nulliparous women delivering term singletons in cephalic position following labour in hospitals in Ontario, Alberta, and British Columbia, Canada, 2008-2012.

		AB n(%)	BC n(%)	ON n(%)	Overall n(%)
Number of women		87,630	77,235	238,340	403,205
Number of hospitals		44	39	87	170
Spontaneous vaginal delivery		47,914 (54.7)	43,100 (55.8)	146,576 (61.9)	237,590 (59.2)
Instrumental vaginal delivery		20,270 (23.1)	15,269 (19.8)	43,700 (18.5)	79,239 (19.7)
Cesarean delivery		19,446 (22.2)	18,866 (24.4)	46,445 (19.5)	84,757 (21.0)
Cesarean delivery for labour dystocia		10,885 (12.4)	7,809 (10.1)	32,537 (13.7)	51,231 (12.7)
Proportion of cesareans with an indication of labour dystocia*		56.0%	41.4%	70.1%	60.4%
Case mix adjustment factors					
Maternal age, years	<25	28,372 (32.4)	18,687 (24.2)	60,619 (25.8)	107,678 (26.9)
	25-29	30,938 (35.3)	24,777 (32.1)	78,996 (33.6)	134,711 (33.7)
	30-34	20,702 (23.6)	22,842 (29.6)	67,671 (28.8)	111,215 (27.8)
	>=35	7,596 (8.7)	10,929 (14.2)	27,888 (11.9)	46,413 (11.6)
Gestational diabetes		3,896 (4.5)	5,803 (7.5)	9,433 (4.2)	19,132 (4.9)
Hypertensive disorders of pregnancy^		6,967 (7.9)	4,975 (6.4)	13,906 (6.3)	25,848 (6.7)
Pre-existing comorbidity^^		1,595 (1.8)	599 (0.78)	4,855 (2.1)	7049 (1.8)
Suspected intrauterine growth restriction		2,178 (2.5)	1,324 (1.7)	5,419 (2.3)	8932 (2.3)
Gestational age at birth, weeks	37	5,789 (6.6)	4748 (6.1)	14,932 (6.3)	25,469 (6.3)
	38	12,651 (14.4)	11,343 (14.7)	36,192 (15.2)	60,186 (14.9)
	39	23,707 (27.1)	21,000 (27.2)	64,131 (26.9)	108,838 (27.0)
	40	28,095 (32.1)	24,575 (31.8)	78,376 (32.9)	131,046 (32.5)
	41	17,388 (19.8)	15,569 (20.2)	44,709 (18.8)	77,666 (19.3)
Hospital adjustment factors					
Teaching status		2 (4.5)	2 (5.1)	10 (11.5)	14 (8.2)
Annual obstetrical volume	101-500	30 (68.2)	17 (43.6)	27 (31.0)	74 (43.5)
	501-1000	2 (4.5)	8 (20.5)	17 (19.5)	27 (15.9)
	1001-2499	4 (9.1)	10 (25.6)	21 (24.1)	35 (20.6)
	2500-4000	3 (6.8)	2 (5.1)	16 (18.4)	21 (12.4)
	>=4001	5 (11.4)	2 (5.1)	6 (6.7)	13 (7.6)

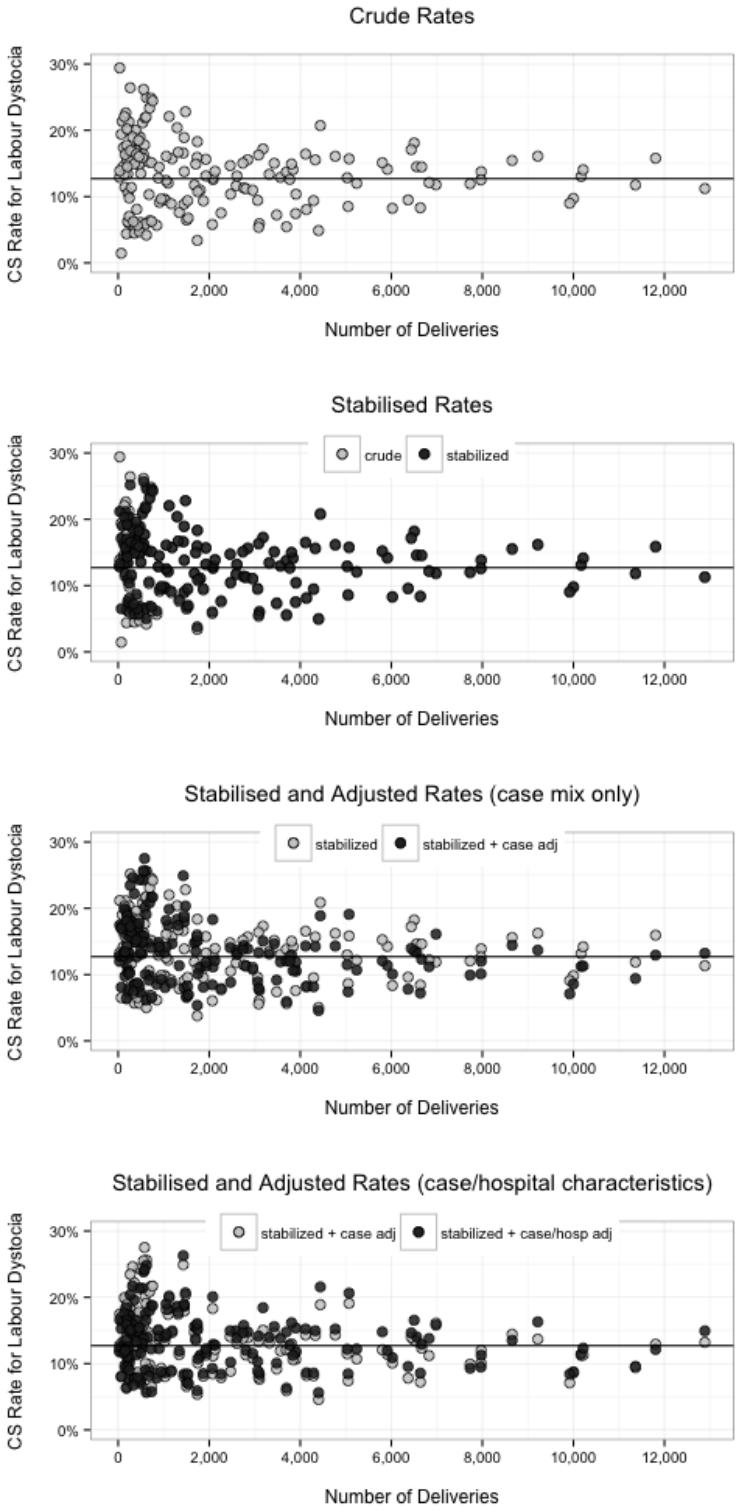
List of abbreviations: AB, Alberta; BC, British Columbia; ON, Ontario

* In Ontario and Alberta, multiple indications for cesarean could be listed, while in British Columbia only the primary indication is given

^ Hypertensive disorders of pregnancy include gestational hypertension, pre-eclampsia, and eclampsia.

^^ Includes insulin dependent or non-insulin dependent diabetes, pre-existing hypertension, heart or renal disease.

Figure 5-1: Variation in institutional rates of cesarean delivery for labour dystocia across hospitals in Ontario, Alberta, and British Columbia, Canada, 2008-2012.



These rates are based on:

a) crude rates
b) crude rates stabilised to account for random variation
c) stabilised rates adjusted for patient case-mix, and
d) stabilised rates adjusted for patient case-mix and hospital characteristics.

Solid line indicates the population average rate of 12.7%.

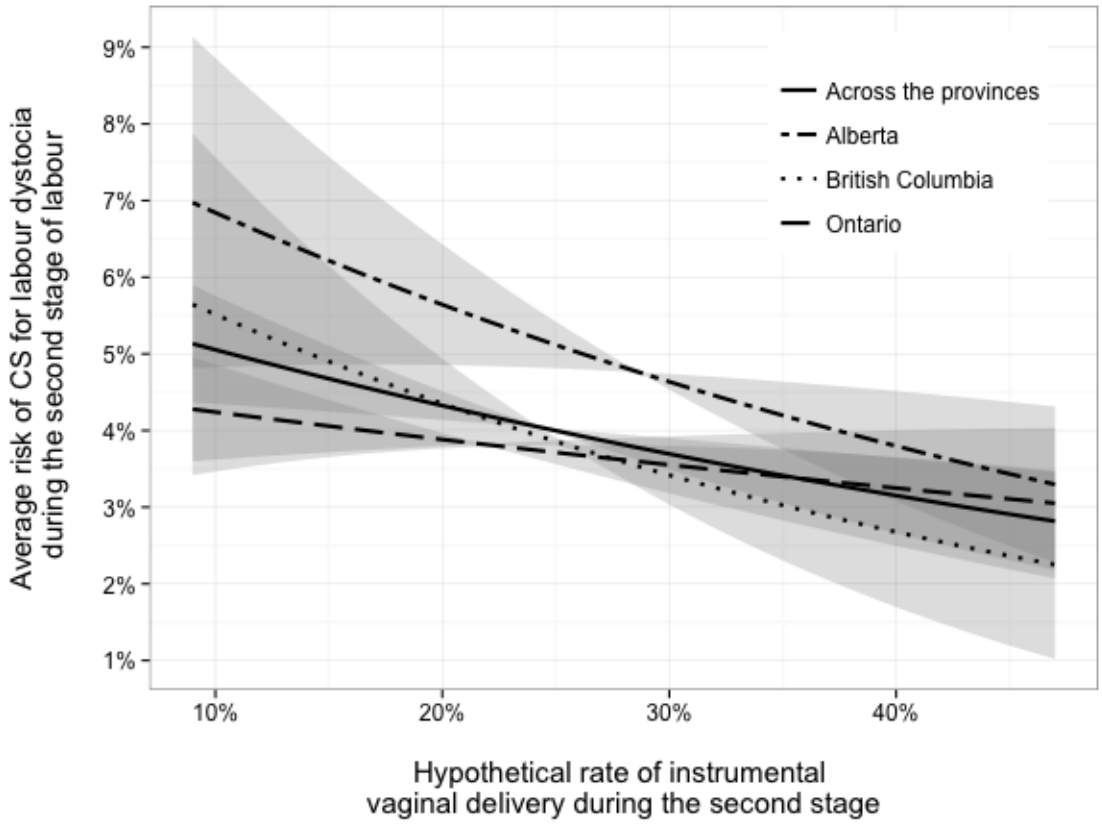
Table 5-2: Comparison of 95% central intervals and inter-quartile ranges of hospital-level rates of cesarean delivery for labour dystocia across hospitals in Ontario, Alberta, and British Columbia, Canada, 2008-2012.

	95% central interval (width)	Inter-quartile range (width)
a) Crude rates	4.5% - 24.7% (20.2)	9.5% - 16.4% (6.9)
b) Stabilisation only	5.6% - 23.9% (18.3)	9.8% - 16.3% (6.5)
c) Stabilisation and adjustment for case-mix	6.4% - 24.6% (18.2)	10.1% - 16.1% (6.0)
d) Stabilisation and adjustment for case-mix and hospital factors	6.3% - 21.7% (15.4)	9.7% - 15.6% (5.9)

Table 5-3: Comparison of 95% central intervals and inter-quartile ranges of hospital-level rates of cesarean delivery for labour dystocia across hospitals in Ontario and British Columbia in women with non-missing pre-pregnancy body mass index (BMI)

	95% central interval (width)	Inter-quartile range (width)
a) Crude rates	4.2% - 24.1% (19.8)	9.3% - 16.2% (6.8)
b) Stabilisation only	5.4% - 19.5% (14.1)	9.3% - 14.6% (5.4)
c) Stabilisation and adjustment for case-mix	6.8% - 21.5% (14.6)	9.3% - 13.9% (4.6)
d) Stabilisation and adjustment for case-mix and adjustment for BMI	7.1% - 19.4% (12.3)	9.6% - 13.7% (4.0)

Figure 5-2: Estimated average risk of cesarean for labour dystocia as a function of the instrumental rate of vaginal delivery during the second stage of labour. 95% confidence intervals are indicated using grey shading.



5.7 Discussion

Main findings

The rate of cesarean delivery for the indication of labour dystocia varied considerably across hospitals in three Canadian provinces, even after accounting for differences in maternal, fetal, and hospital characteristics. This remaining inter-hospital variation suggests that clinical decision-making is impacted by factors other than the ones we measured and adjusted for and may indicate over-use among hospitals with significantly higher rates.

Our findings further suggest that a woman's risk of cesarean for labour dystocia during the second stage of labour may not be substantially impacted if hospitals increase their rates of instrumental vaginal delivery. While a successful instrumental vaginal delivery precludes a cesarean delivery on the maternal-level, adopting a higher rate of instrumental vaginal delivery on the hospital-level does not necessarily imply a lower rate of cesarean delivery, since instrumental deliveries may be performed on the subset of women who would have otherwise had a spontaneous (non-instrumental) vaginal delivery.

Strengths and limitations

A major strength of our analysis was the use of birth registries for three Canadian provinces encapsulating 60% of the Canadian obstetrical population. The provincial birth registries provided detailed medical chart information (such as indication for cesarean, hospital identifier, and maternal comorbidities) that is often challenging to obtain from large administrative perinatal databases. The large sample size also increased the statistical precision of our findings and supports generalizability within these provinces and to other populations with similar obstetric practice patterns.

In order to interpret the high inter-hospital variation as indicative of over-use or lack of consensus on best practice, our adjustment model should include all maternal and fetal risk factors for cesarean delivery for labour dystocia that may vary in distribution across hospitals. While we used both restriction (to singletons, cephalic, nulliparous, term gestations with labour) and statistical adjustment for a multitude of potential confounders, residual confounding may exist. We did not adjust for maternal pre-pregnancy body mass index

(BMI) as this variable is not collected by the Alberta registry and is missing for 26% of the women in the British Columbia dataset and 72% of women in the Ontario dataset. We adjusted for BMI in a sensitivity analysis using the records with non-missing BMI measures and found that adjustment did lead to a reduction in the variability of the stabilised and adjusted hospital-level rates of cesarean delivery for labour dystocia. Thus, BMI is an important unadjusted for confounder in this analysis, because high BMI is a strong risk factor for cesarean delivery and BMI is known to vary by hospital catchment area. Concerns of residual confounding by factors that vary across hospitals are substantially reduced in our study of the relationship between hospital-level rate of instrumental vaginal delivery and the risk of cesarean delivery for labour dystocia, because we employed a statistical approach that only utilized within-hospital variation in the rate of instrumental vaginal delivery, implying that time-invariant differences between hospitals cannot be confounders in this analysis.

Published studies have shown that mode of delivery is measured with high validity in the birth registries in Ontario and British Columbia.[86,94] It is possible that comorbid conditions, especially those that are less severe, were under-reported, or that some hospitals are better at recording comorbidities than others. Only if the patterning of poor measurement is correlated with the patterning of cesarean delivery for labour dystocia, could mismeasurement in these characteristics lead to residual confounding in the study of inter-hospital variation.

Fixed effects regression relies on having "enough" intra-hospital variation in the yearly instrumental vaginal delivery rates to estimate the effect of changing these rates on risk of cesarean delivery for labour dystocia. Thus, one concern with using this method is that variation over the years 2008 to 2012 in instrumental vaginal delivery may be too low and lead to imprecise estimates. We found our effect to be estimated quite precisely, perhaps due to a combination of the large number of hospitals, high number of deliveries at many hospitals, coupled with adequate intra-hospital variation.

Interpretation

Other studies have examined the variation in overall rates of cesarean delivery in specific target populations, such as low- or high-risk women,[69,70] women without a previous cesarean delivery[69] or according to Robson categories.[68,71] A study conducted using nationwide data from the United States did not find that adjustment for measured maternal factors explained variation across hospitals,[69] while two studies conducted using data from New South Wales, Australia found that accounting for case-mix factors did lead to a reduction in variance among hospitals.[68,71] None of these studies examined variation for a specific indication for cesarean delivery, however.

Both Ontario and British Columbia have reporting mechanisms in place to communicate rates of cesarean delivery according to the Robson classification system.[30] The Robson classification system stratifies the obstetrical population according to important maternal and fetal characteristics (parity, multiplicity, gestational age, fetal position, presence of previous cesarean, presence of labour, presence of induction).[48] Within Robson categories, women are more homogeneous, thereby controlling for some case-mix differences across hospitals that will impact their cesarean rates. We recommend that these provinces also consider reporting stabilised and adjusted rates, as was done in this paper. We further advocate monitoring the rates by indication for cesarean delivery. These systems can then be used to identify hospitals with significantly higher rates of cesarean delivery, which could then perform audits to try and identify factors that explain their higher rates or implement evidence-based programs meant to reduce their rates of cesarean delivery.

Historically, rises in the overall cesarean delivery rate occurred over the same time period as decreases in the rate of instrumental vaginal delivery.[116] Ecologically, this may have suggested that increasing the rate of instrumental vaginal delivery would lead to fewer cesarean deliveries. However, this hypothesis was not supported in our findings when we compared hospitals to themselves over time, which is a more controlled comparison than looking at country-level trends over time.

5.8 Conclusion

The considerable degree of inter-hospital variation in adjusted cesarean delivery rates for the indication of labour dystocia may indicate over-use or lack of consensus on best practice and suggests that interventions to reduce the rate of cesarean delivery for labour dystocia in hospitals found to have significantly higher rates may be effective. To identify these hospitals, provincial reporting systems that monitor variation in inter-institutional rates should incorporate stabilisation and adjustment for case-mix differences and consider indication-specific rates. Further, we did not find that increases to a hospital's rate of instrumental vaginal delivery were associated with decreases in the rate of cesarean delivery for labour dystocia, suggesting that this specific mechanism at reducing the rate may be less effective than anticipated.

5.9 Acknowledgements

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6| The impact of a severe uterine rupture event on a hospital's subsequent rate of vaginal birth after cesarean delivery

6.1 Preamble

The previous two chapters focused on cesarean deliveries in nulliparous women with labour, and suggested ways to monitor hospital-level practice in support of safe prevention of the first cesarean delivery.

In this chapter, we change our focus to women with a previous cesarean delivery, the Robson subgroup of the obstetrical population that makes the largest contribution to the overall rate of cesarean delivery. While the proportion of women with a previous cesarean undergoing repeat cesarean delivery has fluctuated over time, currently 81% in Canada and 89% in the United States will have a repeat cesarean delivery, with the majority of these women having a planned cesarean delivery before labour has commenced. In these countries, only a small subgroup attempts vaginal delivery. Their labours are monitored extremely closely due to concerns for uterine rupture.

Uterine rupture involves a completed separation of all layers of the uterine wall.[117] Complete rupture of an unscarred uterus is a catastrophic event, often resulting in fetal death, extensive maternal blood loss, and maternal mortality.[118] In developed countries the risk of uterine rupture of an unscarred uterus is estimated to be 0.006% compared with a risk of 0.303% in women who had a previous cesarean delivery.[118,119] Because of this large difference in the risk of the event, the focal point of research on uterine rupture in developed countries is conducted in women who have had a previous cesarean delivery.

In a systematic review of the literature, it was estimated that women who undergo labour have a 0.47% risk of uterine rupture compared to 0.026% in women who had a repeat cesarean delivery.[119] In terms of maternal morbidity associated with rupture, between 14% and 33% of women who had a uterine rupture required a hysterectomy. No maternal deaths were reported because of uterine rupture across five studies included in the review. The risk

of perinatal death after uterine rupture varied between 0% and 20%, for a pooled estimate of 6.2% among eight studies, and a risk between 0% and 2.8% among term births only, as reported from two studies.[119]

Uterine rupture is repeatedly mentioned as a catastrophic event directly associated with attempting labour after a previous cesarean delivery. Moreover, medico-legal factors have been shown to be associated with the likelihood of having a vaginal birth after previous cesarean. Therefore, we hypothesized that the occurrence of a uterine rupture might influence the trial of labour attempt rate and the rate of vaginal birth after previous cesarean at the hospital where the uterine rupture occurred. In the decision-making literature, events that are considered rare but catastrophic have been found to have profound effects on subsequent decision-making.[120] Thus, we were interested in investigating whether the occurrence of a uterine rupture at a hospital impacted the proportions of women having a trial of labour or a vaginal delivery after previous cesarean.

To investigate this relationship, we used a difference-in-differences design that essentially performs pre-post comparisons in hospitals that had at least one severe uterine rupture, and controls for underlying secular trends using data from hospitals that did not have ruptures during the same periods of calendar time. As severe uterine ruptures are very rare events, we use thirteen years of data from the Nationwide Inpatient Sample, a publicly available dataset from the United States that provides data from a 20% stratified sample of community hospitals. The resulting manuscript, entitled "Effect of Uterine Rupture on a Hospital's Future Rate of Vaginal Birth After Cesarean Delivery", was published in *Obstetrics & Gynecology* (2014; 6: 1175-1181).

6.2 Title page and footnotes

Title: The Effect of Uterine Rupture on a Hospital's Future Rate of Vaginal Birth After Cesarean Delivery

Short Title: Uterine Rupture and Obstetric Management

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6.3 Abstract

Objective

To identify whether a hospital's vaginal birth after cesarean delivery rate, trial of labor after cesarean delivery rate, or trial of labor success rate decrease after the occurrence of a uterine rupture.

Methods

The study population was drawn from the Nationwide Inpatient Sample, a sample of U.S. hospitals, between 1998 and 2010. We extracted deliveries to women with a previous cesarean delivery. International Classification of Diseases, 9th Revision, Clinical Modification codes were used to identify severe uterine ruptures and rates of vaginal birth, trial of labor, and trial of labor success. We used the difference-in-differences design and compared the rates of the outcomes before and after a rupture across hospitals, using hospitals without ruptures to control for secular trends. Included in the analysis were 1,202,284 delivery records from 7,975 hospitals-years without ruptures and 211,850 records from 510 hospital-years with uterine ruptures.

Results

Before the occurrence of a severe uterine rupture, there were an estimated 60 successful vaginal deliveries for every 100 women with a previous cesarean delivery who entered labor. In the month following the rupture, the trial of labor success rate decreased by an estimated 25 cases per 1000 labors (95% confidence interval [CI]: 6-44 per 1000, *P*=.01) before returning to baseline. The percent of women with a previous cesarean delivery who attempted vaginal delivery did not significantly change after the rupture. Overall, there were 17 more cesareans per 1000 women with a previous cesarean (95% CI: 4-31 per 1000, *P*=.01) in the month after the uterine rupture.

Conclusion

The decrease in the trial of labor success rate after a recent uterine rupture is likely the result of short-term changes in risk evaluation.

6.4 Introduction

Uterine rupture is often cited as the most catastrophic event associated with attempting labor after a previous cesarean delivery and past research has focused on predicting uterine rupture and the risks associated with rupture for mother and baby.[121–124] In this article, we explore whether the occurrence of rupture in one woman affects the obstetric management of labor and delivery in other women cared for at the same hospital. Such an effect may be present, because psychology researchers have found that recent events can affect decision-making.[120]

In this article, our objective was to identify the extent to which a hospital's vaginal birth after cesarean delivery (VBAC) rate, trial of labor after cesarean delivery (TOLAC) rate, or trial of labor success rate decreased in the months following a uterine rupture. We hypothesized that the occurrence of a uterine rupture might alter health care providers' perception of risk or decrease their risk tolerance, leading to decreases in TOLAC, and trial of labor success. A reduction in either of these rates would lead to an increase in the hospital-level rate of repeat cesarean delivery.

6.5 Materials and methods

The study population was drawn from hospital deliveries in the Nationwide Inpatient Sample, Healthcare Cost and Utilization Project, Agency for Healthcare Research and Quality[125] between 1998 and 2010, inclusive. The Nationwide Inpatient Sample is the largest all-payer inpatient care database that is publicly available in the Unites States and is part of the Healthcare Cost and Utilization Project. The data are reviewed for completeness, undergo logic checks, and are compared with other national data sources of hospital care, such as the National Hospital Discharge Survey to maintain database quality. The data have been used extensively for research and quality assurance projects.[126,127] Each year contains data from approximately 8 million hospital stays in 1,000 hospitals sampled to approximate a 20-percent stratified sample of U.S. hospitals.[125] Due to the nature of the random sampling of hospitals in the sample, hospitals can contribute data across multiple calendar years, but these years may be scattered across the study period. As the number of years each hospital was sampled for inclusion into the dataset differs, we discuss hospital-years throughout this paper, where one hospital-year encapsulates all deliveries to a particular hospital within a

given calendar year. The Institutional Review Board at the McGill University Faculty of Medicine approved this study.

International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis and procedure codes were used to identify the study population, cases of severe uterine rupture, and the delivery outcomes. The specific codes are noted in Appendix C. Delivery admissions were identified using the algorithm described by Kuklina et al,[87] and from these we extracted women with a previous cesarean as our study population. The ICD-9-CM definition for uterine rupture was established before increased concern about rupture, and includes milder complications such as lacerations of the uterus and obstetrical trauma not elsewhere classifiable.[128] We created a composite outcome for severe uterine rupture by restricting to ruptures accompanied by hysterectomy, post-partum haemorrhage, blood transfusion, embolization, or stillbirth, or a combination of these outcomes. We were unable to identify severe ruptures that resulted in neonatal morbidity or mortality because the dataset does not link maternal and neonatal records. We decided *a priori* to only include ruptures associated with severe maternal morbidity or stillbirth, because these ruptures were most likely to impact practice and decision-making. Restricting to severe events may have also increased the validity of our variable, because a validation study of another administrative database found that severe events tend to be more accurately coded than less severe events.[129] Multiple ruptures at a hospital were used if they occurred in different years. Outcomes were the hospital-level VBAC rate (number of vaginal births to women with a previous cesarean divided by number of women with previous cesarean), TOLAC rate (number of women entering labor with a previous cesarean divided by number of women with previous cesarean) and trial of labor success rate (number of vaginal births to women with a previous cesarean divided by number of women entering labor after a previous cesarean). As there is no ICD code for labor, it was identified using the algorithm described by Uddin and Simon.[130]

The difference-in-differences methodology was employed to estimate changes in rates of the outcomes after uterine rupture that are above and beyond changes experienced by hospitals that do not have ruptures.[112] This methodology is a type of controlled pre-post design, and is

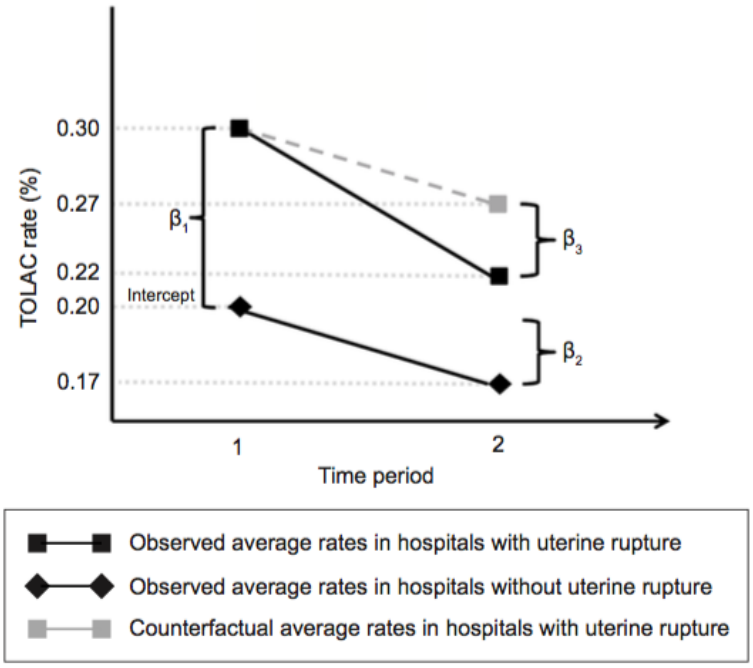
often superior to the more commonly used pre-post design that can suffer from confounding as a result of underlying time trends in the outcomes. The design uses all hospitals to estimate a common time trend in the outcome that is subtracted from the change in the outcome experienced by hospitals with uterine rupture (Figure 6-1). The design controls directly for pre-uterine rupture differences in TOLAC rates and delivery volume between hospitals with and without ruptures, and any other time-fixed characteristics of hospitals that differ between hospitals with and without ruptures.

We used a conditional linear probability model to estimate changes in each of our outcomes (VBAC, TOLAC, and trial of labor success rates) at the time of uterine rupture within hospitals that are over and above changes experienced by hospitals without uterine rupture. Twelve indicator variables denoted the number of months after each rupture's occurrence, where the first indicated deliveries in the same calendar month as the rupture, the second indicated deliveries in the calendar month after the rupture, and the last indicated deliveries in the 11th calendar month after the rupture. Estimating an effect for each month separately allowed us to investigate the presence of the lag of the effect, the duration (in months) that any effect appears to last, and allowed the magnitude of the effect to vary. In addition, the intercept term from each model can be interpreted as the average pre-uterine rupture rate of the outcome at a hospital.[131] A construction of the model starting from a simpler framework is given in Appendix C. All statistical analyses were conducted using Stata 12.1 [107] and both Stata and R 3.0.2 [115] were used to create the figures. Statistical code is provided in Appendix C. We used the sampling weights provided with the data to calculate nationally representative trends in the outcomes.[132]

The design assumes that hospitals with and without uterine ruptures do not differentially experience other changes to the outcome rate at the time of the rupture, such as a change in hospital protocol only at hospitals with uterine rupture in the month of the rupture. To test this, we conducted a negative control test,[133] where a failure to "pass" the test would provide an indication that this model assumption is invalid. To conduct the test we fit the same model but used an outcome that could not plausibly be impacted by the occurrence of rupture. We chose diabetes (both pre-existing and gestational diabetes; see Appendix C for

ICD-9-CM codes) as the placebo outcome. As the proportion of women with a previous cesarean delivery who also have diabetes should not change with the occurrence of a rupture, any non-null effect estimate of rupture on the portion of women with diabetes would reveal a violation of the assumption, and imply the existence of other hospital-level changes at the time of the rupture, and a potential bias in the estimated effects from the primary analyses. The model also assumes that the underlying time trends in the VBAC, TOLAC, and the trial of labor success rates are parallel in hospitals with and without uterine rupture. To assess the validity of this assumption, we repeated the primary analyses estimating the common secular trend using only hospitals that had a uterine rupture occurrence.

Figure 6-1: Hypothetical illustration of differences-in-differences design.



In this illustration, hospitals without uterine ruptures have an average trial of labor after cesarean delivery (TOLAC) rate of 20% in the first time period compared with hospitals with ruptures that have an average TOLAC rate of 30% at that time. The absolute difference between these, 10% points, can be estimated by a difference-in-differences regression model and is symbolized here as β_1. In the second time period, the hospitals without ruptures have an average TOLAC rate of 17%. Because these hospitals do not have ruptures, this decrease is the result of other forces that led to a reduction in the TOLAC rate. If hospitals with ruptures experienced a reduction of the same absolute magnitude as hospitals without, their rate would have changed from 30% to 27%. However, the observed rate is 22%, showing an additional 5% point reduction in the TOLAC rate. We would conclude that the occurrence of uterine rupture led to five fewer women entering labor per 100 women with a previous cesarean delivery at a hospital than if the rupture had not occurred.

6.6 Results

We identified 10,888,501 deliveries (between 741,787 and 930,086 each year) in 3,128 hospitals, of which 1,534,755 (14%) had a previous cesarean delivery in 2,986 hospitals. In 1998, 88,171 women (12% of the obstetric population) had a previous cesarean delivery, and by 2010, 128,664 (17% of the obstetric population) had a previous cesarean delivery. Two coding errors were detected and resulted in the exclusion of one hospital-year of deliveries and the recoding of the ICD-9-CM code for cesarean delivery in a subset of hospitals in 2000 (details in Appendix C). Eight percent of deliveries were missing information on delivery month and were excluded from the analysis. The vast majority of these exclusions were deliveries in Florida, which did not provide admission month in the data set. California, New York, and West Virginia each had some records with missing admission month: 0.01, 0.13, and 11.34% of deliveries in each state were missing admission month, respectively.

After exclusions, there were 1,414,134 deliveries to women with a previous cesarean delivery across 2,859 hospitals and 600 severe uterine rupture events. These hospitals were observed for a total of 8,485 hospital-years, implying that the average hospital contributed data in the sample across 3 years. Of the 600 severe uterine ruptures, 510 were the first uterine rupture to occur at a hospital in a given calendar year and it is these ruptures that are used in the analysis. There were 211,850 deliveries in 510 hospital-years containing uterine ruptures and 1,202,284 deliveries in 7,975 hospital-years that did not have ruptures.

The VBAC rate decreased from 35% in 1998 to 10% in 2006 and plateaued thereafter (Figure 6-2). In 1998, the TOLAC rate was 50%. By 2006, it decreased to 19%. The trial of labor success rate decreased from 70% in 1998 to 51% in 2010 in these women.
In 1998, the risk of severe uterine rupture was 6.1 ruptures per 10,000 women with a previous cesarean delivery, and this decreased to approximately 4.2 severe ruptures per 10,000 in 2010.

Figure 6-3 depicts the risk difference estimates (also referred to as "excess risk") for changes in the VBAC, TOLAC, and trial of labor success rates, where each estimate can be interpreted as the change in the absolute risk of the outcome (at the specified time point

compared with pre-rupture months) experienced by hospitals that had a uterine rupture, above any secular change in the outcomes experienced by hospitals with no rupture. Although the overall VBAC rate decreased in time (Figure 6-2), the VBAC rate in hospitals with uterine rupture was estimated to experience an additional decrease, especially in the month immediately after the rupture (Figure 6-3a). In this first post-rupture month, for every 1,000 women with a previous cesarean delivery, 17 fewer women had a vaginal delivery (estimate: -17/1,000; 95% confidence interval [CI] -4/1,000 to -31/1,000, P=.01). In subsequent months, the direction of the effect continued to be negative, but the estimates were not statistically significant.

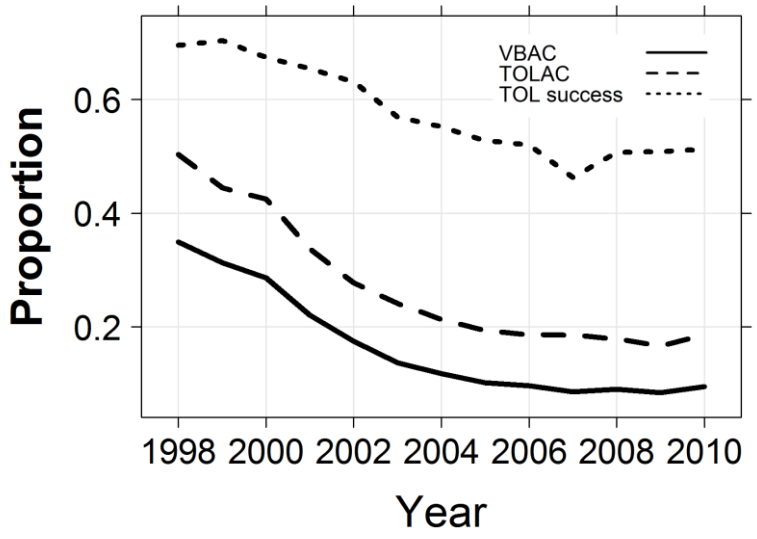
Figure 6-3b illustrates the estimated risk differences for the TOLAC rate. For deliveries in the same month, the estimate is consistent with no difference in TOLAC rate, because the estimated excess risk in TOLAC was 14 per 1,000 (95% CI -1/1,000 to 29/ 1,000, P=.06). In the 11 months after the rupture, all of the point estimates are negative and every CI includes the null value except for the fifth month.

Before a uterine rupture occurrence, the average rate of trial of labor success was estimated to be 60 successful vaginal deliveries per 100 labors in women with a previous cesarean delivery, as estimated by the intercept term of the model. In the month of the uterine rupture, the trial of labor success rate was significantly lower compared with previous months (estimate -55/ 1,000; 95% CI -70/1,000 to -40/1,000, P<.001) after accounting for the secular time trend (Figure 6-3c). The trial of labor success rate was still significantly lower in the month directly after the uterine rupture (estimate -25/1,000; 95% CI -44/1,000 to -6/1,000, P=.01). By the third month, however, there appeared to be no difference between the exposed and unexposed hospitals, suggesting that the effect of a uterine rupture on the trial of labor success was transient.

To investigate the model assumptions, we examined the effect of uterine rupture on a negative control outcome: the portion of women in the study population who had diabetes. Our results support the notion that there was no effect of uterine rupture occurrence on the portion of women with diabetes; all of the effect estimates include the null value and there

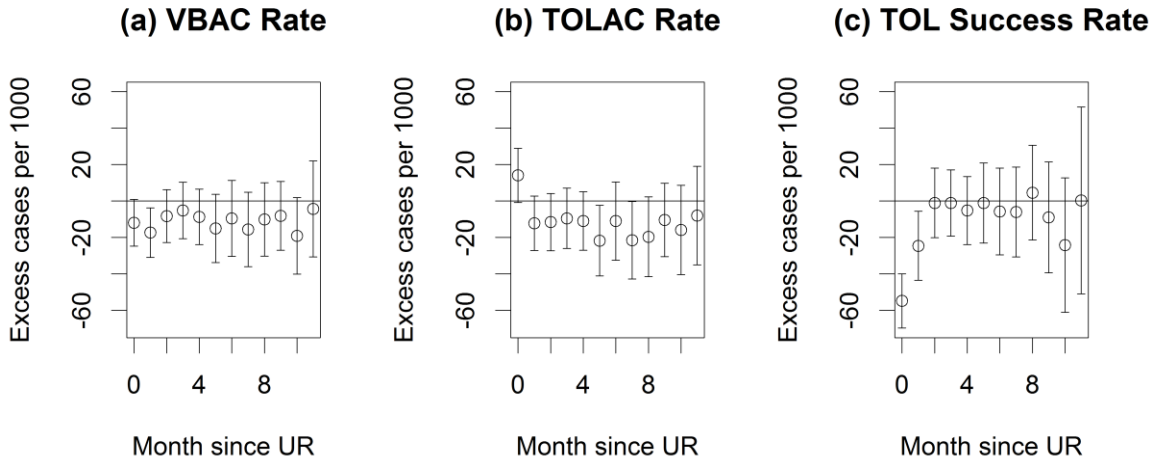
was no discernible trend in the effect estimates across time (Figure 6-4). Second, we repeated the main analyses using only hospital-years that contained a uterine rupture occurrence. Results supported the model assumption that the underlying trends in the outcomes would not differ between those hospitals that experienced a uterine rupture and those that did not in the absence of a uterine rupture (Figure 6-5).

Figure 6-2: Time trends in vaginal birth after cesarean delivery (VBAC), trial of labor after cesarean delivery (TOLAC), and trial of labor (TOL) success rates among women with a previous cesarean delivery in the Nationwide Inpatient Sample, 1998–2010.



Both the TOLAC rate and the TOL success rate (weighted to be representative of the U.S. population) decreased during the time period studied. The rates are multiplied to yield the overall VBAC rate, which decreased as a result.

Figure 6-3: Estimated effect of uterine rupture on the vaginal birth after cesarean delivery (A), trial of labor after cesarean delivery (B), and trial of labor success rates (C) using data from women with a previous cesarean delivery in the Nationwide Inpatient Sample, 1998–2010 (excess cases per 1,000 women).



This figure shows the additional cases of the outcome in hospitals with uterine ruptures in each of the 12 months after the rupture as compared with prerupture months. These estimates control for underlying time trends.

Figure 6-4: Estimated effect of uterine rupture on the placebo outcome of the rate of diabetes (excess cases per 1,000 women).

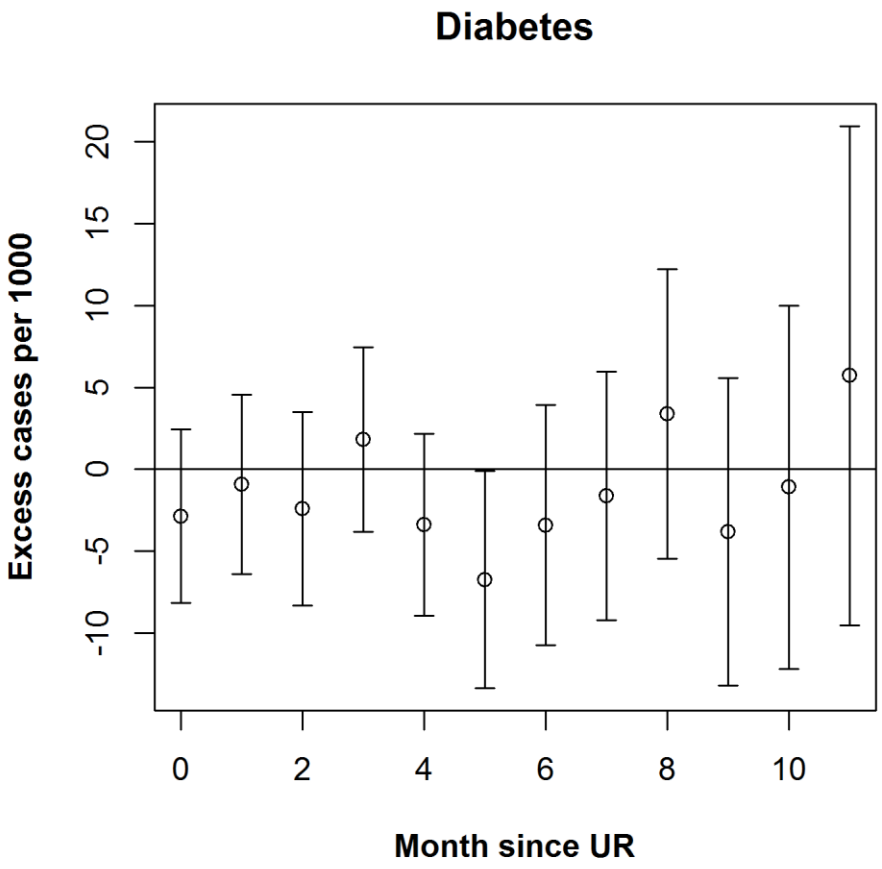
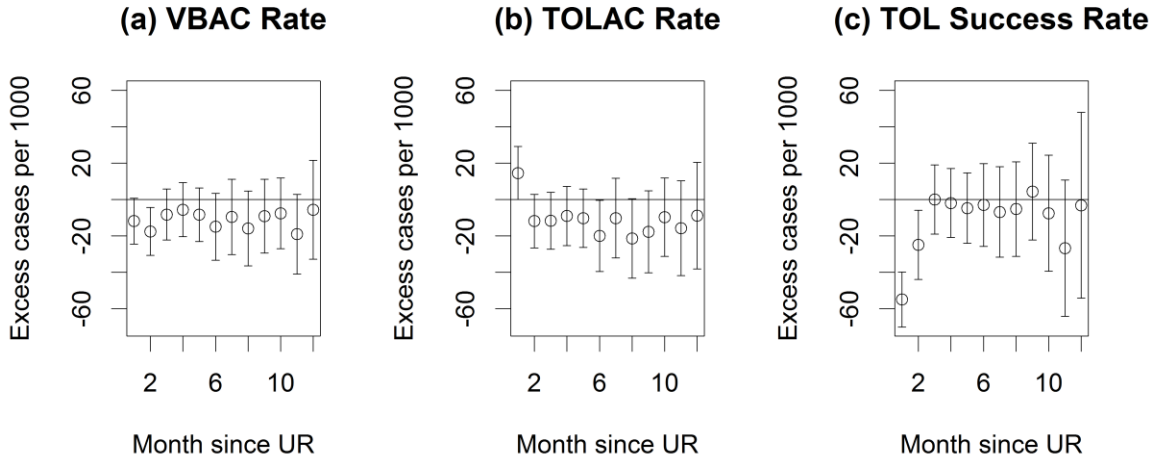


Figure 6-5: Estimated effect of uterine rupture on the vaginal birth after cesarean delivery (A), trial of labor after cesarean delivery (B), and trial of labor success rates (C) when using only hospital-years containing a uterine rupture (excess cases per 1,000 women).



6.7 Discussion

Our results show that there was a decrease in the rate of successful trials of labor in women with a previous cesarean delivery and a lower VBAC rate in the month after a severe uterine rupture despite a stable TOLAC rate. This suggests that health care providers may alter conceptualization of the intrapartum risks of trials of labor after cesarean delivery and subsequently alter their labor management of patients in the month after severe rupture.

Rupture may lead health care providers to increase their estimate of the underlying risk of rupture and lead them to favour intra-partum cesarean delivery more readily. However, as ruptures will occur even under appropriate care, the rupture itself does not provide additional information to the clinician regarding other women's risk. This cognitive bias is termed the "availability heuristic".[134] Alternatively, health care providers may become more risk averse after a severe rupture, known as "regret aversion".[135] Finally, providers may focus on the similarities between the woman who had the rupture and other women entering labor thereafter. If they may neglect the fact that the baseline risk of uterine rupture is extremely low, they may mistakenly conclude that subsequent women's chances of rupture are high since they are clinically similar. This bias is termed the "representativeness heuristic".[136]

As clinical decision-making directly influences patient outcomes, it is important to optimize this process and reduce the effects of any cognitive bias.[137] Here, the occurrence of uterine rupture may have led to more repeat cesarean deliveries, likely unnecessarily. By adhering closely to clinical guidelines, including guidelines on the management of labor in women with previous cesarean, such an effect should not persist. However, cognitive biases are pervasive and difficult to avoid and may warrant additional attention to minimize their effects.[120] Educating decision-makers about such biases may be effective at reducing their impacts on decision-making.[137]

Our study had several limitations. Firstly, our definition of severe uterine rupture could not identify ruptures resulting in neonatal morbidity or mortality as this information was not included on the maternal record. Arguably, ruptures resulting in neonatal injury or death

would have an even larger effect on practice and decision-making. If so, the effect we estimated in our study may be an underestimate of the true effect.

We identified labor using a previously published algorithm of ICD-9-CM codes. It is possible that some labors were missed, which would lead to an underestimate of the TOLAC rate and an overestimate of the trial of labor success rate. Any bias in the measurement of labor should have no impact on the effect estimate as such bias would have impacted deliveries occurring both pre- and post-rupture in all hospitals. Furthermore, by measuring labor occurrence rather than labor intention the labor rate will also include a small proportion of women who entered labor but had intended a repeat cesarean delivery. However, this subgroup's size should not vary at a hospital pre- and post-rupture and therefore should not impact our findings.

We chose to conduct our analysis on the hospital- rather than the clinician-level, as it is impossible to know whether the clinician coded on a delivery record had managed all of a woman's care, solely performed an emergent cesarean, or been involved in some other role.
Only admission month is coded, implying that deliveries in the month of the rupture cannot be temporally ordered around the event. Thus, changes occurring only in the very short-term may be undetected in our analysis. For the TOLAC rate, the additional concern is of reverse causality in the first month, as a higher TOLAC rate may have led to a uterine rupture. Thus, we focus our interpretation on the months after the uterine rupture.

Our study allowed us to study medical decision-making *in-situ*. We applied a rigorous design that allowed better confounding control than statistical adjustment methods. Here, confounding can persist only if there are forces that impact the hospitals that have uterine rupture at the same time as the rupture and do not also impact the hospitals without the rupture, which is improbable. The other threat of confounding is if hospitals with and without uterine rupture had different pre-uterine rupture rates of the outcomes. We investigated this assumption and found no evidence suggesting a violation.
Our results suggest that recent adverse events may affect medical decision-making and increase health care providers' hesitancy to prolong labor in women with a previous

cesarean. By recognizing how adverse events can affect risk evaluation, providers can increase their awareness of these cognitive biases and move towards optimal decision-making in situations with high uncertainty.

7| Conclusions

7.1 Summary of findings

The first study in this thesis described the timing of intra-partum cesarean delivery according to indication for cesarean. Using data from three provincial birth registries in Canada, we found that 20% of cesareans are performed in women before they reached 4 cm dilation, 54% are performed at dilations between 4 and 9 cm, and 26% are performed during the second stage of labour. In terms of guideline non-adherence, 23.0% [95% CI: 22.4%, 23.5%] of first-stage cesarean deliveries for the indication of labour dystocia occurred early (<4 cm), and 23.9% [95% CI: 23.4%, 24.4%] of first-stage procedures occurred in women without oxytocin exposure. Across hospitals, non-adherence varied widely for both guidelines investigated. We had not anticipated the peak in first-stage cesarean for non-reassuring fetal monitoring at 4 cm, and a post-hoc analysis indicated that this peak was not associated with receipt of oxytocin.

The second study focused more closely on the indication of labour dystocia, the most common indication for cesarean delivery among nulliparous women. We found high variability in hospital-level rates of cesarean delivery for labour dystocia, even after accounting for differences in maternal, fetal, and hospital characteristics (95% central interval 6.3% to 21.7%). This remaining variability suggested that additional factors not adjusted for impacted clinical decision-making and that over-use of cesarean delivery may have occurred in those hospitals with the highest adjusted rates. Additionally, our analyses suggested that a woman's risk of labour dystocia during the second-stage was not substantially altered by changes to hospitals' rates of instrumental vaginal delivery; shifting hospitals' instrumental delivery rates from the 25th percentile (16.6%) to the 75th percentile (29.6%) was associated with only a 0.8 percentage point reduction (95% CI: -1.4, -0.3) in a woman's risk of cesarean delivery for labour dystocia during the second stage.

Overall, findings from these first two studies suggest high rates of hospital-level variability in adherence to clinical guidelines on the management of labour dystocia, and in the adjusted rates of cesarean delivery for labour dystocia.

In the third study, our focus shifted towards hospital levels rates of cesarean delivery and trial of labour in women who had a previous cesarean. We investigated how the occurrence of a severe uterine rupture impacted hospital-level trends in these outcomes. We estimated that the trial of labour success rate decreased by an estimated 25 cases per 1,000 labours (95% CI: 6-44/1,000) in the month following the uterine rupture, and that there were 17 more cesarean deliveries per 1,000 women with a previous cesarean (95% CI: 4-31/1,000). These effects were short-lived however, and rates returned to baseline levels in subsequent months, suggesting that severe uterine rupture has an immediate, but temporary effect on these outcomes.

7.2 Limitations and research challenges

7.2.1 Measurement of labour dystocia

While mode of delivery is well-measured, the diagnosis of labour dystocia has been described as equivocal or without a clear, uniform definition.[42] Indeed, in the first study we found evidence of variation among hospitals in the percent of women diagnosed early (<4 cm), which may be indicative of differential rates of adherence to the national definition.[62] In the second study, we then found high variation in cesarean delivery for labour dystocia. This may be suggestive of differential management of labour dystocia across hospitals or of differential definitions of labour dystocia (with some hospitals diagnosing labour dystocia at lower clinical thresholds than others). Likely, it is some combination of these explanations.

In epidemiology, we typically strive to minimize bias due to measurement error in studies of causal relationships. In our studies of variation across hospitals, differences in diagnosis and therefore measurement of labour dystocia is part of the variation we are trying to capture, as differences in diagnosis will impact the timing of interventions used to manage labour dystocia. In hospitals with high stabilised and adjusted rates of labour dystocia, it is difficult to determine whether they are due to differential diagnosis or other aspects of management (e.g., different oxytocin treatment regimes), making it challenging how best to advise hospitals to reduce their rates of cesarean delivery.

7.2.2 Confounding in studies utilizing variation between or within hospitals

In our first and second studies we performed comparisons across hospitals. Such comparisons are at risk of confounding by unmeasured factors that differ among hospitals and are causes of the outcome. Ideally, we would like to measure and adjust for all individual-level factors that impact a woman's risk of cesarean delivery. Assuming no other bias, variability in adjusted rates implies that the hospital where a woman gives birth significantly alters her individual-level risk of cesarean delivery, which is an important observation. More likely, some confounders (known or unknown) are unadjusted for in such studies, often due to unavailability of data, and residual confounding due to differences among hospitals likely remains.

Two of our analyses used intra-hospital variation to estimate causal effects. In the second objective of the second study, we used variation over time *within* hospitals to estimate how changes in a hospital's rate of instrumental vaginal delivery impact the likelihood of cesarean delivery for labour dystocia at the hospital. In the third study, we examined the trial of labour attempt and success rates *within* hospitals after a uterine rupture occurrence, but also used *between*-hospital variations to account for secular trends in these outcomes. Thus, research questions that can be studied using only variation within hospital are robust to confounding by all measured and unmeasured factors that differ across hospitals.

7.2.3 Generalizability of study findings

Our first two studies used Canadian data from provinces that comprise 63% of Canada's obstetrical population. Across these three provinces, we demonstrated considerable variability in cesarean delivery rates for labour dystocia and adherence to clinical guidelines. Thus, we are limited in our ability to generalize our findings to the rest of Canada. Findings from our third study are most directly generalizable to the obstetrical setting in the United States. The relevance of these findings to other countries is difficult to speculate, because the impact of an adverse clinical event on practice may vary according to environmental factors (such as the medico-legal environment and practice culture) that vary across countries.

7.3 Implications for obstetrical care

Currently, information is limited on timing of cesarean delivery during labour, and no previous studies have been published on indication-specific timing. Our study adds to understanding about when cesarean deliveries are performed during labour and corroborates population-based findings from the Consortium on Safe Labor indicating that a high proportion of women are undergoing early-timed cesarean deliveries,[63] and the findings from Oppenheimer et al. of a high rate of non-adherence to Canadian guidelines on the management of labour dystocia.[101]

We advocate that rates of cesarean delivery be monitored and reported according to the most common indications and adjusted for risk factors for cesarean delivery that are anticipated to vary by hospital catchment area. As well, unadjusted guideline non-adherence could be reported for:

i) The proportion of first-stage cesarean deliveries for labour dystocia performed before 4 cm.

ii) The proportion of first-stage cesarean deliveries for labour dystocia performed without receipt of oxytocin.

All of this information could be displayed in a real-time dashboard that is accessible to all obstetric hospitals in each province, and be accompanied by a graphical display that facilitates comparison of performance to other hospitals. For example, using a funnel plot to display the data accounts for the imprecision in the rates estimated from smaller hospitals, and could be used to highlight hospitals with rates significantly higher or lower than the provincial average. Further, a histogram showing timing of cesarean delivery stratified by indication using each hospital's individual data would provide more detailed information on the distribution of cervical dilation at time of cesarean delivery for labour dystocia and could be used to monitor progress in shifting this distribution towards later-timed cesarean delivery over calendar time.

A dashboard containing this information would provide real-time (continuous) audit information to hospitals, while also providing comparison information from other hospitals within each province. Randomized trials of audits and feedback have been found to be

generally effective at increasing guideline adherence, especially in units with low baseline compliance.[138] A recent cluster-randomized trial implemented in a majority of Quebec hospitals found that a multi-faceted approach to reduce cesarean delivery led to a 1.8 percentage point reduction in the overall cesarean delivery rate.[139] The approach included onsite training of nurses and physicians in evidence-based clinical best practices, clinical audits, and implementation of best practices and was facilitated by an opinion leader at each hospital. In another clinical trial, mandatory second opinions led to a 1.9 percentage point reduction in the overall cesarean delivery rate, and a 2.2 percentage point reduction in intra-partum cesarean deliveries.[140]

Overall, we recommend that a dashboard reporting the studied rates be used to highlight those hospitals with the highest rates of non-adherence and highest adjusted rates of indication-specific cesarean delivery. This information can serve as part of a multi-faceted approach to reduce cesarean delivery. Highlighted hospitals can implement strategies to reduce non-adherence and cesarean delivery, including review of evidence-based clinical guidelines, mandatory second opinions, and other evidence-based approaches.[141]

Our findings on the impact of severe uterine rupture on hospital-level rates of vaginal delivery after previous cesarean are in-line with several cognitive biases on decision-making, especially the availability heuristic: the perceived inflation of the risk of a rare event after its recent occurrence.[134–136] As these biases are pervasive and can operate subconsciously, healthcare professionals should be educated regarding them. Such awareness may reduce their effects on decision-making.[120,137]

7.4 Avenues for future research

Continuing studies of clinical guidelines on the management and diagnosis of labour dystocia

The Consortium on Safe Labor's recommendation that labour dystocia should not be diagnosed until 6 cm rather than 4 cm was adopted in 2014 by the American College of Obstetricians and Gynecologists and may have led to a change in practice in countries outside the United States, including Canada. It will be important to investigate the magnitude of the effect of this guideline change on practice and evaluate if avoiding early-timed

cesarean deliveries for labour dystocia leads to an overall lower rate of cesarean delivery, or if it merely shifts these cesarean deliveries to later dilations. Another possibility is that the indication of labour dystocia may be used less frequently at early dilations, and that this reduction in use may be offset by an increase in the use of the other indications. Thus, the intended and unintended effects if this change in the guideline should be investigated to best understand its total effect on practice.

Our investigations of variation in guideline adherence and in rates of cesarean delivery largely showed the presence of substantial variation across hospitals in Canada. Another guideline that we could not assess (due to lack of data) recommends that arrest of labour during the second stage should not be diagnosed until after three hours of pushing in nulliparous women.[102] If hospitals vary substantially in the average length of time, in minutes, until the performance of second stage cesarean delivery, then it is important to investigate whether women giving birth at hospitals that conduct second stage cesareans at later times have lower likelihoods of cesarean delivery. While the provinces included in our dataset collect these data, they are under-reported for women undergoing cesarean delivery. Thus, better reporting of timing of second-stage cesarean deliveries will be necessary in order to study this relationship.

Harnessing clinically adverse events to improve our understanding of the consequences of obstetrical interventions

The impact of uterine rupture on trial of labour attempt and success rates in women with a previous cesarean illustrated the potential for one clinical event to impact practice at a hospital. While the impact of uterine rupture was small, other such events may be associated with larger, and longer-lasting impacts on a clinician's or hospital's decision making. It is worthwhile to further investigate such events, because they may serve as "shocks" to clinical practice. Such shocks may lead to natural experiments by pseudo-randomising exposure status, because they are not associated with underlying trends or characteristics of the population. In such cases, methodologic techniques such as instrumental variable analyses, difference-in-differences, or regression discontinuity designs can be utilized to harness the exogenous variation in exposure status and overcome confounding bias that is inherent

when using observational data to study many of the consequences of obstetrical interventions (such as cesarean delivery) on maternal and infant health.

As an example, a recent editorial in *Obstetrics & Gynecology* stated that, "Obstetricians live in fear of term stillbirth. We have all been haunted by the delivery of a baby who never took a first breath and the pain of parents and the family undergoing a devastating loss. We second guess ourselves and want to deliver the next patient who walks in the door, for any indication…".[142] Here, the occurrence of term stillbirth may lead to an increase in earlier-timed labour inductions for the indication of "post-dates". By using term stillbirth as an instrumental variable, one could overcome bias from unmeasured confounders in the observational studies of the relationship between timing of labour induction and fetal health outcomes.

7.5 Conclusion

This thesis identified high inter-institutional variability in risk-adjusted cesarean delivery for labour dystocia in a large Canadian population-based cohort, as well as high variability in adherence to labour management guidelines. By monitoring these rates, and making the information available to hospitals, hospitals can work towards improved adherence in support of safely lowering their rate of primary cesarean delivery. Severe uterine ruptures were found to impact practice through a short-term change in the likelihood of having successful vaginal delivery in women who attempted labour after a previous cesarean delivery. On the level of the health care practitioner, efforts to reduce the impact of cognitive biases associated with the occurrence of rare, but high-risk events in support of optimal decision-making may also prevent unnecessary cesarean delivery. Through these mechanisms, provincial perinatal stakeholders, hospitals, and health care providers can work towards the common goal of preventing unnecessary cesarean deliveries.

Appendix A: Certificates of ethical approval

Manuscript 1: Cervical dilation at time of cesarean delivery in nulliparous women: a population-based cohort study

- McGill University Institutional Review Board (Study No. A03-E29-13B)
- University of Alberta Health Research Ethics Board – Health Panel (Study No. Pro00041695)
- University of British Columbia Children's & Women's Research Ethics Board (Study No. H13-02984)

Manuscript 2: Inter-institutional variation in use of cesarean delivery for labour dystocia: a population-based cohort study

- McGill University Institutional Review Board (Study No. A03-E29-13B)
- University of Alberta Health Research Ethics Board – Health Panel (Study No. Pro00041695)
- University of British Columbia Children's & Women's Research Ethics Board (Study No. H13-02984)

Manuscript 3: Effect of uterine rupture on a hospital's future rate of vaginal birth after cesarean delivery

- McGill University Institutional Review Board (Study No. A03-E29-13B)

Appendix B: Supplemental material to study 2 (Chapter 5)

Method used to calculate stabilised and risk-adjusted rates of cesarean delivery for labour dystocia

Risk adjusted rates are calculated by comparing the predicted number of cesareans for labour dystocia at a particular hospital to the predicted number of cesareans expected given the unique case-mix distribution at the hospital. If only stabilisation is performed (no risk adjustment), then the random intercept model will contain only the overall intercept (denoted by *Int*, below) and the hospital-level random intercepts (denoted by $hosp_h$). If both stabilisation and adjustment are occurring, then the model will additionally include covariates (denoted by $\mathbf{x_i}$), such as maternal age and gestational age.

1. Compute the predicted number of cesareans at each specific hospital

a) Using the model, the predicted probability of woman *i* having a cesarean delivery at hospital *h* is equal to:

$$\frac{1}{1+\mathrm{e}^{-(\hat{Int}+\hat{\beta}^{\mathsf{T}}\mathbf{x_i}+\hat{hosp}_h)}}$$

b) Thus, the predicted number of cesareans is equal to the summation of these predictions across all the women who delivered at the hospital:

$$\text{Smoothed Prediction} = \sum_{i=1}^{n_h} \frac{1}{1+\mathrm{e}^{-(\hat{Int}+\hat{\beta}^{\mathsf{T}}\mathbf{x_i}+\hat{hosp}_h)}}$$

2. Compute the predicted number of cesarean deliveries at the "average hospital"

a) In the preceding formulae, the hospital intercept was included in the model to incorporate the hospital-level effect on a woman's risk of cesarean delivery. Thus, women with the same measured maternal and fetal characteristics but who delivered at different hospitals will have different risks of cesarean delivery insofar as the hospital intercept terms differ. In the following formulae, we remove the hospital-level random intercept from the model. This conceptually corresponds to the hospital with the average contribution to an individual's risk of cesarean delivery.

We use this model to predict the probability of a woman having a cesarean delivery at the "average" hospital:

$$\frac{1}{1+\mathrm{e}^{-(\hat{Int}+\hat{\beta}^{\mathsf{T}}\mathbf{x_i}+0)}}$$

b) Thus, the predicted number of cesareans is equal to the predicted probability multiplied by the number of women who delivered at the hospital.

$$\text{Expected} = \sum_{i=1}^{n_h} \frac{1}{1+\mathrm{e}^{-(\hat{Int}+\hat{\beta}^{\mathsf{T}}\mathbf{x_i}+0)}}$$

3. We then take the ratio of the smoothed prediction and the expected prediction. A ratio larger than 1 implies that the hospital had more cesarean deliveries for labour dystocia than expected at the average hospital, given the unique mix of patients delivering at the hospital. Finally, this ratio is multiplied by the overall rate of cesarean delivery for labour dystocia in the entire population:

$$\frac{\sum_{h=1}^{H}\sum_{i=1}^{n_h} y_{hi}}{\sum_{h=1}^{H} n_h} \times \frac{\text{Smoothed Prediction}}{\text{Expected}}$$

This quantity is the stabilized and adjusted rate of cesarean delivery for labour dystocia for each hospital.

Modeling Appendix

Model 1 – which included only a random intercept for hospital and no adjustment for case-mix factors

```
library(lme4)

model1 <- glmer(cs_dystocia ~ 1 + (1|hospid), data=dat,
family=binomial(link="logit"), nAGQ=1))

#comment 1: this code specifies the use of the glmer function, from the
lme4 package in R. This function specifies a logistic regression model
(based on the specified family and link function) and includes a random
intercept term for each hospital ("hospid").

#comment 2: the above code also specifies the option nAGQ=1, implying
that only one point is used to evaluate the Gauss Hermite approximation
to the log-likelihood (see ??glmer in R for more information). In many
applications, one would want to set nAGQ to be larger, say equal to 4
or 8, to increase the precision of the model. We set nAGQ to equal all
numbers from 1 to 20 and found that using nAGQ=1 did not impact the
estimates of the intercept or standard deviation of the random effect.

summary(model1)

Generalized linear mixed model fit by maximum likelihood (Laplace
Approximation) ['glmerMod']
 Family: binomial  ( logit )
Formula: cs_dystocia ~ 1 + (1 | hospid)
   Data: dat

      AIC       BIC    logLik  deviance  df.resid
 302457.7  302479.5 -151226.9  302453.7    403203

Scaled residuals:
    Min      1Q  Median      3Q     Max
-0.5841 -0.4183 -0.3683 -0.3018  5.0674

Random effects:
 Groups     Name        Variance Std.Dev.
 hospid_num (Intercept) 0.2126   0.4611
```

```
Number of obs: 403205, groups:  hospid_num, 170

Fixed effects:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.93899    0.03589  -54.03   <2e-16 ***
```

After running Model 1 we calculate the stabilised rates for each hospital using the method described in the previous section of this appendix. Using the lme4 package in R this is done used the code:

```
p_withRE <- predict(model1, dat, re.form = NULL, type = "response")

#comment:  re.form=NULL includes the random effects in the prediction model, implying that this prediction incorporates the hospital random intercept in the prediction model.

p_noRE <- predict(model1, dat, re.form = NA, type = "response")

#comment: re.form=NA performs the prediction setting the hospital random intercept to 0 for all hospitals.

#comment: we then use the dplyr package to sum the predictions across all women in each hospital and then take the ratio of the two predicted counts:

library(dplyr)

counts <- dplyr::select(dat, hospid_num, p_withRE, p_noRE, cs_dystocia) %>%
          dplyr::group_by(hospid_num) %>%
          dplyr::summarise(count_obs = sum(p_withRE, na.rm=T),
                           count_exp = sum(p_noRE, na.rm=T),
                           number_women = n()) %>%
           dplyr::mutate(ratio_M0=count_obs_M0/count_exp_M0) %>%
          dplyr::mutate(SMR_M0=ratio_M0*overall.mean.csd)
```

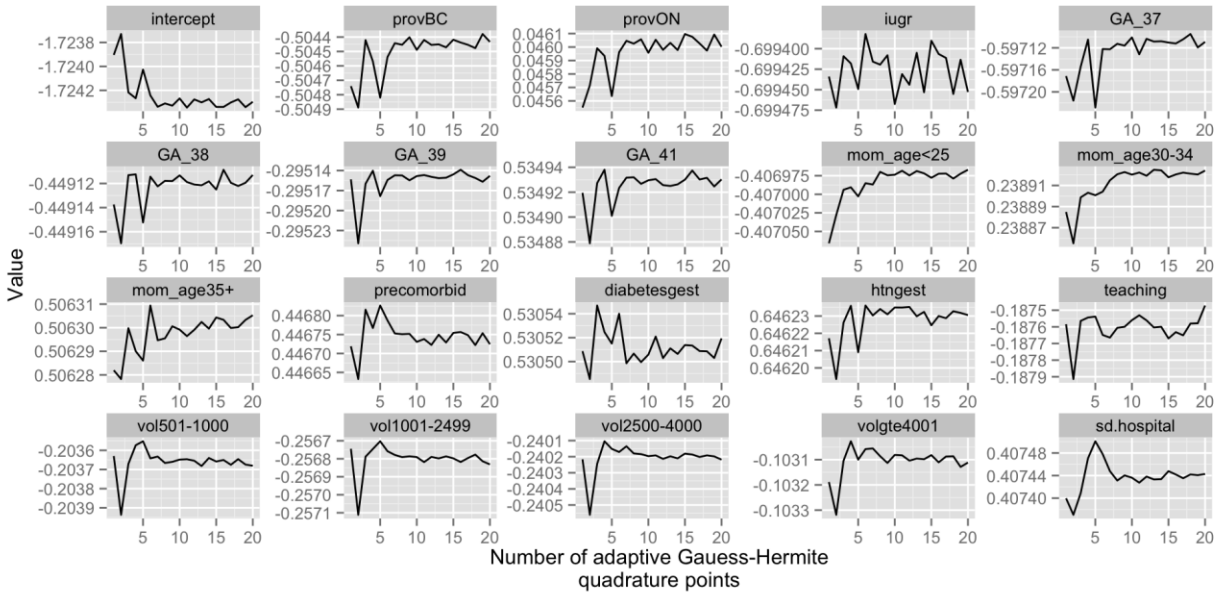
Model 3 – this model includes adjustment for measured maternal, fetal and hospital characteristics

```
library(lme4)

model3 <- glmer(cs_dystocia ~ 1 + prov + iugr_sga + gest_completed_weeks2 + mat_age_cat2 + pre_comorbid + diabetes_gest + htn_gest + factor(hosp_teaching) + hosp_volume + (1|hospid_num), data=dat, family=binomial(link="logit"), nAGQ=4, verbose=T)

#comment 1: this code specifies the use of the glmer function, from the lme4 package in R. This function specifies a logistic regression model (based on the specified family and link function) and includes a random intercept term for each hospital ("hospid"). "prov" specifies indicator variables for each province, while the remaining variables are the case-mix and hospital-level variables specified in the paper.

#comment 2: the above code also specifies the option nAGQ=4, implying that four points were used to evaluate the Gauss Hermite approximation to the log-likelihood (see ??glmer in R for more information). After the modeling output below, we include graphs depicting that four points is adequate for estimation of the covariates and the standard deviation of the random effect.

summary(model3) # is included on the following page:
```

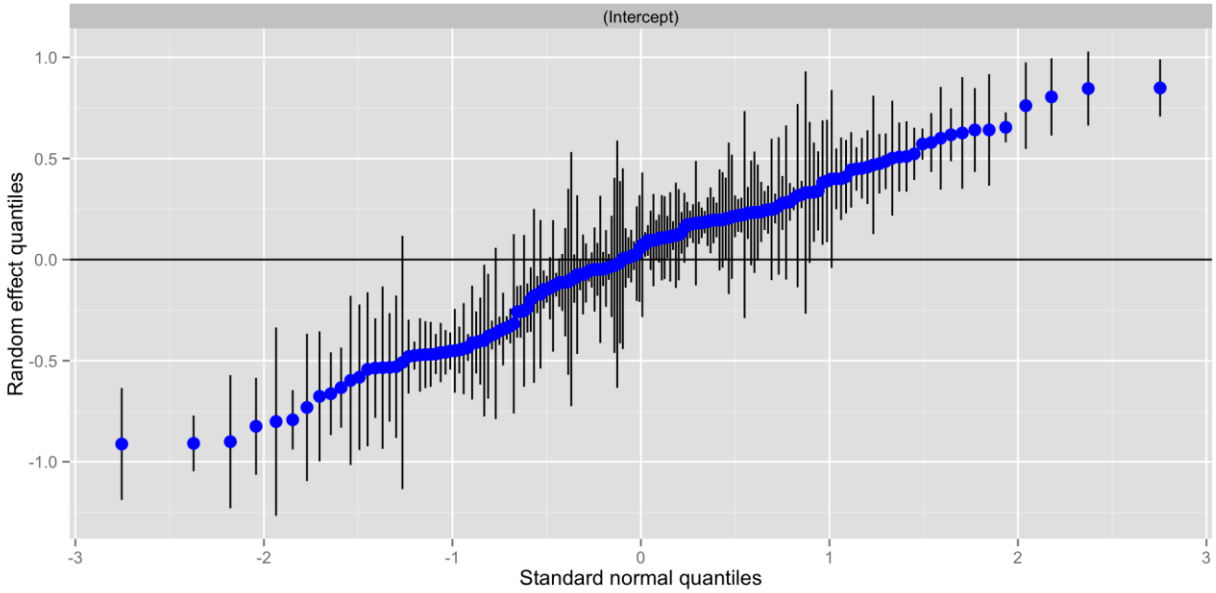
```
## Generalized linear mixed model fit by maximum likelihood (Adaptive
##   Gauss-Hermite Quadrature, nAGQ = 4) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## cs_dystocia ~ 1 + prov + iugr_sga + gest_completed_weeks2 + mat_age_cat2 +
##     pre_comorbid + diabetes_gest + htn_gest + factor(hosp_teaching) +
##     hosp_volume + (1 | hospid_num)
##    Data: dat
##
##       AIC       BIC    logLik  deviance  df.resid
##  275237.5  275454.6 -137598.8  275197.5    381684
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.5098 -0.4135 -0.3294 -0.2497  8.1566
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  hospid_num (Intercept) 0.166    0.4075
## Number of obs: 381704, groups:  hospid_num, 170
##
## Fixed effects:
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)              -1.72427    0.07215  -23.90  < 2e-16 ***
## provBC                   -0.50457    0.09789   -5.15 2.54e-07 ***
## provON                    0.04593    0.08405    0.55 0.584733
## iugr_sga1                -0.69942    0.04794  -14.59  < 2e-16 ***
## gest_completed_weeks237 -0.59710    0.02538  -23.53  < 2e-16 ***
## gest_completed_weeks238 -0.44911    0.01717  -26.16  < 2e-16 ***
## gest_completed_weeks239 -0.29514    0.01357  -21.75  < 2e-16 ***
## gest_completed_weeks241  0.53494    0.01285   41.64  < 2e-16 ***
## mat_age_cat2<25          -0.40699    0.01439  -28.28  < 2e-16 ***
## mat_age_cat230-34         0.23890    0.01256   19.02  < 2e-16 ***
## mat_age_cat235+           0.50629    0.01571   32.22  < 2e-16 ***
## pre_comorbid1             0.44677    0.03251   13.74  < 2e-16 ***
## diabetes_gest1            0.53052    0.02090   25.39  < 2e-16 ***
## htn_gest1                 0.64624    0.01775   36.40  < 2e-16 ***
## factor(hosp_teaching)1  -0.18754    0.12484   -1.50 0.133039
## hosp_volume501-1000      -0.20357    0.07185   -2.83 0.004607 **
## hosp_volume1001-2499     -0.25675    0.07275   -3.53 0.000417 ***
## hosp_volume2500-4000     -0.24010    0.08286   -2.90 0.003757 **
## hosp_volume>=4001        -0.10303    0.09519   -1.08 0.279108
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

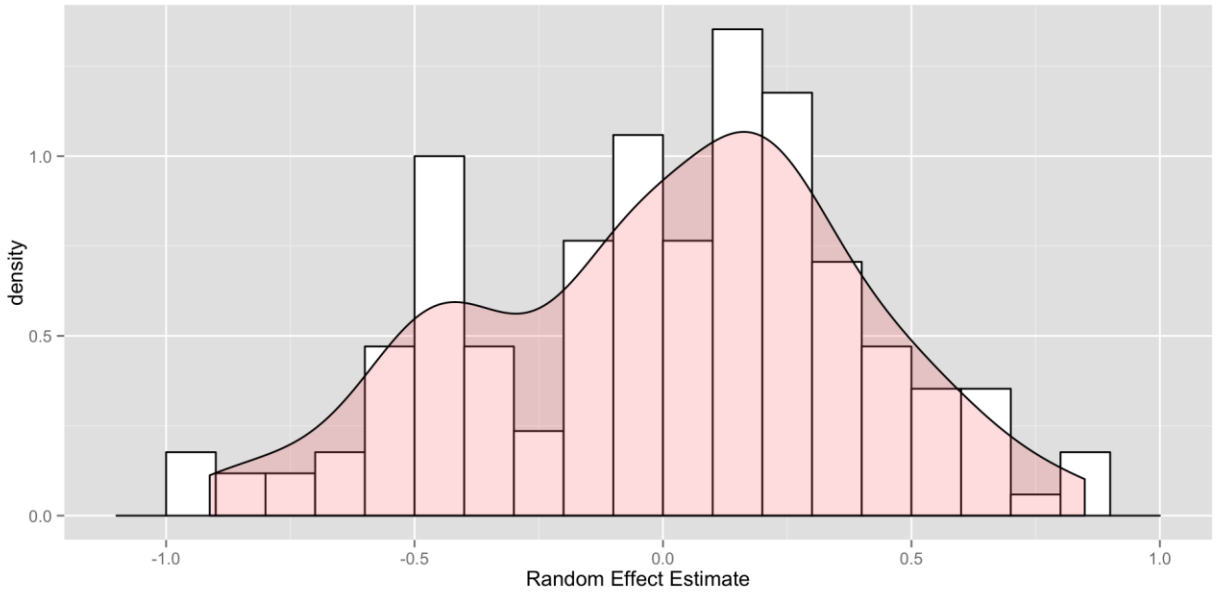
Modeling checks:

1. We varied the number of integration points (nAGQ option in the glmer function) used to estimate the model coefficients from 1 to 20. Increasing the number of integration points did not materially influence the parameter estimates as shown in the figure below:



2. We checked the distribution assumptions of the random effect using a QQ plot and a histogram:





The assumption that the random effect is normally distributed appears reasonable.

Objective 2 analysis

Model 4 (Across all provinces): Fixed effects model regressing cesarean delivery for labour dystocia as a function of individual case-mix factors, indicators for calendar year, indicators for hospital, and a hospital's yearly rate of instrumental vaginal delivery.

```
#comment: this analysis was run using Stata, whereas the previous analyses used
R.

logit cs_dystocia i.iugr_sga2 i.bweight_cat2_2 i.mat_age_cat2_2 i.pre_comorbid2
i.diabetes_gest2 i.htn_gest2 hosp_ivd_yr3 i.year2 i.hospid_num2, cluster(clust)

note: 45.hospid_num2 != 0 predicts failure perfectly
      45.hospid_num2 dropped and 51 obs not used

Logistic regression                                   Number of obs   =     317097
                                                      Wald chi2(17)   =          .
                                                      Prob > chi2     =          .
Log pseudolikelihood = -49768.744                     Pseudo R2       =     0.0767

                                (Std. Err. adjusted for 169 clusters in clust)
------------------------------------------------------------------------------
             |               Robust
 cs_dystocia | Odds Ratio   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 2.iugr_sga2 |   .5544414   .0776525    -4.21   0.000     .4213474    .7295768
             |
bweight_c~_2 |
     <2500g  |    .233015   .0381811    -8.89   0.000     .1690085    .3212618
 2500-2999g  |   .5308442   .0181831   -18.49   0.000     .4963761    .5677059
 3500-3999g  |   1.805206   .0371517    28.70   0.000     1.733839     1.87951
 4000-4499g  |   3.390453   .1056742    39.17   0.000     3.189535    3.604028
     >=4500  |   6.254638   .3363888    34.09   0.000     5.628888    6.949951
             |
mat_age_c~_2 |
      <25yo  |   .5450264   .0165859   -19.94   0.000      .513469    .5785232
    30-34yo  |   1.369774   .0339639    12.69   0.000     1.304798    1.437986
        35+  |   1.774554    .064418    15.80   0.000     1.652684    1.905411
             |
2.pre_como~2 |   1.297655   .0842155     4.01   0.000     1.142662    1.473672
2.diabetes~2 |   1.462949   .0731988     7.60   0.000     1.326292    1.613686
 2.htn_gest2 |    1.45058   .0573523     9.41   0.000     1.342416    1.567458
hosp_ivd_yr3 |   .1836595    .099662    -3.12   0.002     .0634034     .532003
             |
       year2 |
       2009  |   .9667012   .0406064    -0.81   0.420     .8903023    1.049656
       2010  |   .9739858   .0524237    -0.49   0.624     .8764712     1.08235
       2011  |   1.037568   .0569938     0.67   0.502     .9316652    1.155509
       2012  |    1.04584   .0624101     0.75   0.453     .9304007    1.175602
```

[Suppressed the rest of the output containing the estimates of the hospital level terms and the overall model intercept]

After this model was run, we then used the -margins- command to predict how changing the rate of instrumental vaginal delivery at the population-level would impact the average risk of cesarean delivery for labour dystocia during the second stage of labour. Briefly, margins predicts the risk of the outcome for each women based on her covariate pattern. Using margins however, one can specify the levels for a particular covariate and build the prediction after setting the covariate to the specified level. For example, using the following lines of code, one can compute the predicted risk of the outcome for each woman according to her covariate pattern but changing the rate of instrumental vaginal delivery to equal 0.09 (9%) for each hospital:

```
#first run the original model:
logit cs i.iugr_sga2 i.bweight_cat2_2 i.mat_age_cat2_2 i.pre_comorbid2
i.diabetes_gest2  i.htn_gest2  hosp_ivd_yr3  i.year2  i.hospid_num2,
cluster(clust)

#then have Stata compute the average risk of the outcome after setting
the rate of instrumental vaginal delivery to equal 0.09 (i.e., a low
rate):
margins, at(hosp_ivd_yr3=0.09) post

#to compute the average risk difference comparing a high and a low
level of instrumental vaginal delivery we instead use the following
lines of code:
margins, at(hosp_ivd_yr3=(0.09 0.47)) post
nlcom(RD: _b[2._at]-_b[1._at])

#Figure 2 was constructed by calculating margins at every value of
hosp_ivd_yr3 between 9% and 47%:
margins, at(hosp_ivd_yr3=(0.09(0.01)0.47))

#these calls to margins also calculate 95% confidence intervals for the
effect. Figure 2 was constructed using the ggplot function in R (from
the ggplot2 library).
```

Model 4a (Alberta Only): Fixed effects model regressing cesarean delivery for labour dystocia as a function of individual case-mix factors, indicators for calendar year, indicators for hospital, and a hospital's yearly rate of instrumental vaginal delivery.

```
logit cs_dystocia i.iugr_sga2 i.bweight_cat2_2 i.mat_age_cat2_2 i.pre_comorbid2
i.diabetes_gest2 i.htn_gest2 hosp_ivd_yr3 i.year2 i.hospid_num2 if prov=="AB",
cluster(clust)
Logistic regression                                 Number of obs   =      72375
                                                    Wald chi2(18)   =          .
                                                    Prob > chi2     =          .
Log pseudolikelihood = -12879.666                   Pseudo R2       =     0.0822

                                  (Std. Err. adjusted for 44 clusters in clust)
------------------------------------------------------------------------------
             |               Robust
 cs_dystocia | Odds Ratio   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 2.iugr_sga2 |   .4034486   .1044081    -3.51   0.000     .2429442    .6699923
             |
bweight_c~_2 |
     <2500g  |   .2134711   .0608328    -5.42   0.000      .122116     .373169
 2500-2999g  |   .5181364   .0270189   -12.61   0.000     .4677966    .5738932
 3500-3999g  |   1.735547   .0627904    15.24   0.000     1.616742    1.863083
 4000-4499g  |   3.443961   .2499635    17.04   0.000     2.987293     3.97044
    >=4500g  |   5.890649   .6245121    16.73   0.000     4.785429    7.251126
             |
mat_age_c~_2 |
      <25yo  |   .5649029   .0192715   -16.74   0.000     .5283665    .6039658
    30-34yo  |   1.481588   .0756086     7.70   0.000     1.340568    1.637443
      35+yo  |    1.82679   .1530184     7.19   0.000     1.550204    2.152723
             |
2.pre_como~2 |   1.154815   .1297649     1.28   0.200     .9265402    1.439331
2.diabetes~2 |   1.605805   .1028333     7.40   0.000     1.416391    1.820549
 2.htn_gest2 |   1.403727    .086813     5.48   0.000     1.243485    1.584619
hosp_ivd_yr3 |   .1157257   .1057848    -2.36   0.018     .0192906    .6942449
             |
       year2 |
          2  |   .8667941   .0361618    -3.43   0.001     .7987385    .9406483
          3  |   .9749565   .0615046    -0.40   0.688     .8615641    1.103273
          4  |   .9132824   .0611692    -1.35   0.176     .8009287    1.041397
          5  |   .8975161   .0807469    -1.20   0.229     .7524232    1.070588
```

[Suppressed the rest of the output containing the estimates of the hospital level terms and the overall model intercept]

Model 4b (British Columbia Only): Fixed effects model regressing cesarean delivery for labour dystocia as a function of individual case-mix factors, indicators for calendar year, indicators for hospital, and a hospital's yearly rate of instrumental vaginal delivery.

```
note: 45b.hospid_num2 != 0 predicts failure perfectly
      45b.hospid_num2 dropped and 51 obs not used
note: 83.hospid_num2 omitted because of collinearity

Logistic regression                                   Number of obs   =      63517
                                                      Wald chi2(18)   =          .
                                                      Prob > chi2     =          .
Log pseudolikelihood = -9595.5037                     Pseudo R2       =     0.0733

                                    (Std. Err. adjusted for 38 clusters in
clust)
------------------------------------------------------------------------------
               |               Robust
   cs_dystocia | Odds Ratio   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+--------------------------------------------------------------
   2.iugr_sga2 |   .7855465   .2567473    -0.74   0.460     .4139672    1.490658
               |
bweight_cat2_2 |
       <2500g  |   .1343039   .0580014    -4.65   0.000      .057608    .3131082
   2500-2999g  |   .5335476   .0369663    -9.07   0.000     .4657989      .61115
   3500-3999g  |   1.785091   .0604556    17.11   0.000     1.670447    1.907602
   4000-4499g  |   3.657745   .1976595    24.00   0.000      3.29015     4.06641
      >=4500g  |   6.990581   .5303045    25.63   0.000     6.024781    8.111204
               |
mat_age_cat2_2 |
        <25yo  |   .5542389   .0372731    -8.78   0.000     .4857948    .6323262
      30-34yo  |   1.327574   .0601617     6.25   0.000     1.214744    1.450884
        35+yo  |   1.766434   .1078188     9.32   0.000     1.567264    1.990915
               |
2.pre_comorb~2 |   1.586816   .2653649     2.76   0.006     1.143351    2.202287
2.diabetes_g~2 |   1.602782    .181421     4.17   0.000     1.283884    2.000889
   2.htn_gest2 |   1.316038   .1488523     2.43   0.015     1.054367    1.642648
  hosp_ivd_yr3 |    .074607   .1014245    -1.91   0.056     .0051953    1.071387
               |
         year2 |
            2  |    .908028   .0771807    -1.14   0.256     .7686855     1.07263
            3  |   .9666434   .0647847    -0.51   0.613     .8476539    1.102336
            4  |    1.00179   .1078841     0.02   0.987     .8111655     1.23721
            5  |   1.041449   .0928715     0.46   0.649     .8744436    1.240349
```

[Suppressed the rest of the output containing the estimates of the hospital level terms and the overall model intercept]

Model 4c (Ontario Only): Fixed effects model regressing cesarean delivery for labour dystocia as a function of individual case-mix factors, indicators for calendar year, indicators for hospital, and a hospital's yearly rate of instrumental vaginal delivery.

```
Logistic regression                                     Number of obs   =     181205
                                                        Wald chi2(17)   =          .
                                                        Prob > chi2     =          .
Log pseudolikelihood = -27265.266                       Pseudo R2       =     0.0740

                                    (Std. Err. adjusted for 87 clusters in
clust)
------------------------------------------------------------------------------
             |               Robust
  cs_dystocia | Odds Ratio   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+---------------------------------------------------------------
  2.iugr_sga2 |    .574651   .1082808    -2.94   0.003     .3972037    .8313715
              |
bweight_cat2_2 |
       <2500g |   .2797397   .0606903    -5.87   0.000     .1828452    .4279811
  2500-2999g  |   .5365884    .028502   -11.72   0.000      .483535    .5954629
  3500-3999g  |   1.846282    .057292    19.76   0.000     1.737339    1.962058
  4000-4499g  |   3.277915   .1367728    28.45   0.000     3.020514    3.557251
     >=4500g  |   6.112447   .5395024    20.51   0.000      5.14145    7.266824
              |
mat_age_cat2_2 |
        <25yo |   .5308798    .026531   -12.67   0.000     .4813456    .5855115
      30-34yo |   1.333631    .048064     7.99   0.000     1.242678    1.431242
        35+yo |   1.743482   .0884455    10.96   0.000     1.578471    1.925743
              |
2.pre_comorb~2 |     1.3727   .1204514     3.61   0.000     1.155805    1.630297
2.diabetes_g~2 |    1.29659   .0854728     3.94   0.000     1.139437    1.475418
  2.htn_gest2 |   1.521443   .0828587     7.71   0.000      1.36741    1.692827
 hosp_ivd_yr3 |   .3873004   .2654693    -1.38   0.166     .1010658    1.484197
              |
        year2 |
            2 |   1.051624   .0696099     0.76   0.447     .9236707    1.197303
            3 |   .9855059   .0960832    -0.15   0.881     .8140858    1.193021
            4 |   1.135987   .1003771     1.44   0.149     .9553447    1.350785
            5 |   1.147421    .113633     1.39   0.165     .9449862    1.393222
```

[Suppressed the rest of the output containing the estimates of the hospital level terms and the overall model intercept]

Appendix C: Supplemental material to study 3 (Chapter 6)

ICD-9-CM codes used to identify deliveries to women with a previous cesarean delivery

DX code	Description
65.420, 65.421, and 65.423	Previous cesarean delivery

ICD-9-CM codes used to define severe uterine ruptures

DX or PR code	Description
665.10 and 665.11	Uterine rupture during labor including rupture not elsewhere specified
68.3, 68.31, 68.39, 68.4, 68.41, 68.49, 68.5, 68.51, 68.59, 68.7, 68.71, 68.79, 68.9	Hysterectomy
99.03, 99.04, 99.05, 99.07, 99.08	Blood Transfusion
666.0, 666.1, 666.2, 666.3	Post-partum haemorrhage
38.86, 39.98	Embolization
V27.1, V27.3, V27.4, V27.6, V27.7	Stillbirth

ICD-9-CM Diagnosis and procedure codes used to identify labor

DX Code	Description	PR Code	Description
650	Normal delivery	72.0-72.4	Forceps, breech extraction, vacuum extraction, instrumental delivery
653.4	Fetopelvic disproportion	73.01	ROM
653.5	Fetopelvic disproportion NOS	73.09	Artificial ROM
653.8	Disproportion NEC	73.1	Surgical induction of labor NEC
653.9	Disproportion NOS	73.3-73.6	Failed forceps, medical induction, manual assisted delivery, episiotomy
658.2	Prolonged ROM NOS	73.93-.99	Other assisted delivery procedures
658.3	Delayed delivery after artificial ROM	75.32	Fetal EKG
659.0-659.1	Failed induction	75.38	Fetal pulse oximetry
659.2-659.3	Pyrexia (fever) during labor, septicemia (infection) during labor	75.6	Repair of OBGYN laceration to bladder, rectum/anus, NEC, other
660-662	Obstructed labor, dystocia, failed forceps, failed trial of labor, prolonged labor, abnormal labor, etc		
664	Perineal trauma/laceration or related		
665.1	Uterine rupture		

ICD-9-CM diagnoses to identify diabetes

DX Code	Description
250	Diabetes mellitus
648.0	Diabetes mellitus in pregnancy
648.8	Abnormal glucose tolerance in pregnancy (i.e., gestational diabetes)

Introduction to the difference-in-differences design

In the simplest DID scenario, two hospitals are observed over a calendar year, of which only one hospital has a uterine rupture (i.e., becomes exposed) during the year. In this scenario, the following linear probability model could be fit:

$$E(Y = 1|trt, time) = Int + \beta_1 I[trt = 1] + \beta_2 I[time = 2] + \beta_3 I[trt = 1 \,\&\, time = 2],$$

Where *trt*=1 denotes the hospital that becomes exposed and *time*=2 denotes the time period following the uterine rupture, and I[*] represents the indicator function that is equal to unity when the expression within the function is true and 0 otherwise. Thus, the third indicator variable equals unity only for deliveries in the hospital with the rupture following the occurrence of the rupture. In this model, the intercept estimates the average risk of the outcome in the first time period in the hospital that never had a uterine rupture. β_1 is the estimated difference in the risk of the outcome in the hospital with the uterine rupture compared with the hospital without the uterine rupture in the first time period. β_2 is the estimated change in the risk of the outcome between the time periods in the hospital that never have the uterine rupture. Finally, β_3 is the parameter of interest because it denotes the additional change in the mean of the outcome in the hospital that experiences a rupture above and beyond the change anticipated due to secular trends alone. In a linear model, β_3 corresponds to the estimated risk difference, which is the effect measure of interest in our study (Figure 6-1).

To generalize the above framework to a setting in which there are multiple hospitals observed over many time periods, one could include multiple indicator variables to denote the multiple hospitals and multiple time indicators to denote each time period. An alternative method, which we use in our paper, is to use conditional regression (specified in Stata using the -xtreg- command with the fe option), where the analysis is conditioned within the level of the hospital, or alternatively the hospital-year. This is equivalent to including indicator variables for hospital and year in the regression model, but has the added benefit of not requiring the estimation of these coefficients, as they are considered nuisance parameters in our model and do not need to be estimated.

Stata code for the conditional linear probability models

Model 1:

```
xtreg TOLsuccess i.timeCounter i.timeSinceUR_after, fe i(hospYrID) vce(robust)
```

Description of Model 1:

This is a model of the over-arching VBAC rate as it is a model of the successful trials of labor (`TOLsuccess`, i.e., successful vaginal deliveries) over all the women with a previous CS (i.e., unrestricted by whether there was a labor attempt). It models the VBAC rate as a function of 155 time indicator variables (`i.timeCounter`) and 12 exposure variables (`i.timeSinceUR_after`) conditional on hospital-year (`fe i(hospYrID)`), as specified in the main text.

Model 2:

```
xtreg TOLAC i.timeCounter i.timeSinceUR_after, fe i(hospYrID) vce(robust)
```

Description of Model 2:

This is a model of the trial of labor after cesarean (TOLAC) rate.

Model 3:

```
xtreg TOLsuccess i.timeCounter i.timeSinceUR_after if labor==1, fe i(hospYrID)
vce(robust)
```

Description of Model 3:

This is a model of the trial of labor success rate (`TOLsuccess`). It is constrained to the subset of women who attempted labor (`if labor==1`).

Further information

In all models, we specified the level of clustering as the hospital-year, and that the likelihood estimation should only use variation within the hospital-year to inform the estimation of the model coefficients. Specified in this way, the hospital-year indicator variables are treated as nuisance parameters and are not explicitly estimated by the model. While it would be most natural to specify the hospital rather than the hospital-year as the unit of clustering, we chose the hospital-year because this allows us to conduct the pre-post estimation using at most 11 months of data on either side of the uterine rupture which we deemed as sufficient to capture any hypothesized lag and effect on the outcomes of interest. Furthermore, clustering on the hospital-year allowed us to use multiple uterine ruptures within the same hospital to inform the analysis rather than discarding these events or making *a priori* assumptions about the effect duration that would impact how the exposure indicator variables were coded over time within the same hospital.

While the outcomes were binary, we used a linear probability model (LPM) rather than logistic regression. The LPM is additive in risk, implying that the model coefficients represented risk differences. This is the effect measure of interest because it can be interpreted directly as the excess number of cases attributed to the intervention.[143] We examined the predicted probabilities to ensure that they did not fall outside of the range of valid probabilities, which can sometimes be a concern with LPMs, but which should not be a concern in this setting where the outcomes have frequencies that are far from the boundaries of this range and the sample size is large.

The Huber White sandwich variance estimator was used to correct the model for the violation of the assumption of homoskedastic variance,[144] and to correct for any serial correlation of the deliveries occurring within each hospital over time.[145]

The NIS sampling weights are not used in our main etiologic analysis. Since our model was conditioned on hospital-year, this implies that we are conditioning on a finer strata than the one used to define the sampling scheme. This is therefore a form of "model-based

adjustment for sampling",[91] and gives rise to unbiased estimates of the parameters of interest.

Coding anomalies

1. Deliveries at one hospital in 2005 were excluded due to an implausibly high number of uterine ruptures. A cross-tabulation indicated that 157 uterine ruptures during labor occurred at this hospital in 2005. For comparison, the next highest number of uterine ruptures was 18 in 2005, suggesting a coding error during this period. As well, there were less than 400 uterine ruptures during labor in 2004 and 2006across all sampled hospitals. The 157 ruptures occurring at one institution were deemed to be due to misclassification. This hospital's data was removed for 2005 but other hospital-years were kept in the data as the problem did not persist to other years.

2. It appeared that during the years 2000 and 2001, several hospitals were mistakenly using the ICD-9-CM code for adrenal incision (ICD-9-CM code 0741) instead of the code for cesarean delivery (ICD-9-CM code 741). We noticed this error because the affected hospitals had unrealistically low cesarean deliveries rates (including rates of 0%), and upon examining the diagnosis codes, the common use of the 0741 adrenal code became apparent. This code is found in the data in the year 2000 for these hospitals and is never found elsewhere in the dataset of the entire obstetrical population. To address this, we re-coded the code as 741 and made note of the change in the dataset. The analysis was conducted using the re-coded information. This re-coding affected 2,872 deliveries (less than 0.03%) of the total obstetrical population.

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