Gestational diabetes screening changes and impacts on diagnosis

by

Elizabeth M K Nethery

B.Ap.Sc., The University of British Columbia, 1998
M.Sc., The University of British Columbia, 2008
M.S.M, Bastyr University, 2014

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Population and Public Health)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

November 2022

The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the dissertation entitled:

Gestational diabetes screening changes and impacts on diagnosis

submitted by Elizabeth M.K. Nethery in partial fulfilment of the requirements for

the degree of Doctor of Philosophy

in Population and Public Health

Examining Committee:

Dr. Patricia Janssen, Professor, School of Population and Public Health, UBC

Supervisor

Dr. Jennifer Hutcheon, Associate Professor, Department of Obstetrics & Gynecology, UBC

Supervisory Committee Member

Dr. Michael Law, Professor, School of Population and Public Health, UBC

Supervisory Committee Member

Dr. Geoff Cundiff, Professor, Department of Obstetrics & Gynecology, UBC

University Examiner

Dr. KS Joseph, Professor, School of Population and Public Health, UBC

University Examiner

Dr. M Karen Campbell, Professor, Department of Epidemiology and Biostatistics, Western University

External Examiner

Additional Supervisory Committee Members:

Dr. Andrew Kotaska, Assistant Professor, Department of Obstetrics, University of Manitoba

Supervisory Committee Member

ABSTRACT

Background: Gestational diabetes mellitus (GDM) affects between 2-40% of pregnancies worldwide, depending on diagnostic and screening methods. Changes in screening practices are not well understood because administrative sources lack data on whether or how individuals were screened. The objectives of this thesis were to: 1) validate a method to identify prenatal screening for GDM and other conditions in administrative health data; 2) describe changes in GDM screening; 3) evaluate the relative contributions of screening and population characteristics to changes in GDM risk; 4) characterize the impact of the COVID-19 pandemic on pregnancy weight gain and infant birthweight.

Methods: Laboratory billing records from BC's universal health insurance system for prenatal screening tests were compared with medical records by calculating validation properties. All pregnancies (birth ≥20wks or ≥500g) in British Columbia, Canada, 2005-2019, with linked perinatal health and administrative data, were used to examine time trends in GDM screening methods, trends within subgroups, and the effect of screening changes on prevalence. A second cohort from Washington State, 2016-2020, was analyzed using an interrupted time series design, to assess COVID-19 impacts on pregnancy weight gain and infant birthweight using z-scores.

Results: GDM screening in laboratory billing records had a high sensitivity (97% [95% CI: 90, 99]) and specificity (>99% [95% CI: 86, <99]) compared with medical records. GDM diagnoses in BC more than doubled from 7.2% in 2005 to 14.7% in 2019 (n=550,783 pregnancies). Most of this increase was explained by changes in screening; adjustment for population factors had minimal impact. In Washington state, using an interrupted time series, pregnancy weight gain z-score increased by 0.08 (95% CI 0.03, 0.13) after the COVID-19 pandemic onset and infant birthweight z-scores were unchanged (-0.004, 95% CI (-0.04, 0.03)).

Conclusion: Prenatal screening tests can be accurately ascertained using BC insurance billing data. Changes in GDM screening completion and in screening methods accounted for most of the increase in GDM diagnosis in BC since 2005. Covid-19 pandemic countermeasures were associated with an increase in pregnancy weight gain but not infant birthweight. Public health and future researchers should understand how screening changes can directly affect disease prevalence.

LAY SUMMARY

Gestational diabetes is a temporary state of high blood sugar that affected 7% of pregnancies in British Columbia (BC) in 2005 and rose to 14% in 2019. It is diagnosed by glucose screening tests but the specific tests have changed over the past 15 years. This work evaluated a new method to identify screening test data in BC and explained how changes in screening alone accounted for most of the rising rates of gestational diabetes. This thesis also demonstrated that the COVID-19 pandemic led to an increase in weight gain during pregnancy but no change in infant birthweights.

PREFACE

This thesis presents the results of a program of research including two projects, that I identified and designed in consultation with my thesis committee. I independently applied for and obtained data access for both projects and designed data collection tools and conducted all primary data collection. In consultation with my thesis committee, I selected the research questions and selected analytic methods, based on my own review of the literature and original thought. In all work presented herein, I assembled and analyzed all data, conducted all statistical analyses, interpreted the results and drafted manuscripts for the research chapters. My thesis committee members collaborated with me, as lead researcher and author, on the research chapters presented in this thesis.

The research projects conducted in my thesis were approved by the University of British Columbia's Clinical Research Ethics Board, under ethics certificate #H20-00741, and data access was approved through a Student Data Access Request under Data Access Request #Janssen-21-018 via Population Data BC. All inferences, opinions, and conclusions drawn in this thesis are those of the authors, and do not reflect the opinions or policies of the Data Steward(s). Approval for data from the Obstetrical Care Outcomes Assessment Program (OB COAP) was granted by the OB COAP Research committee and the study protocol was also reviewed and approved under the University of British Columbia's Clinical Research Ethics Board ethics certificate #H20-00741.

A version of Chapter 3 has been published [Nethery E, Hutcheon JA, Law MR, Janssen PA. Validation of insurance billing codes for monitoring antenatal screening. Epidemiology. 2022, In press]. I was the lead investigator, responsible for designing the study, writing and obtaining ethics approval, obtaining administrative data access, conducting all data collection, analyzing the data, writing the manuscript, and interpreting the results. Hutcheon JA and Janssen PA were involved in designing the study and analytic approaches. All co-authors contributed to manuscript edits and interpretation. I was responsible for all manuscript reviews and editing in the peer-review process.

A version of Chapter 6 has been published [Nethery E, Hutcheon JA, Kotaska A, Law MR, Janssen PA. Weight gain in pregnancy and infant birthweight after the onset of the COVID-19 pandemic: An interrupted time series analysis. The American Journal of Clinical Nutrition. 2022, In press]. I was the lead investigator, responsible for designing the study, obtaining administrative data access, analyzing the data, writing the manuscript and interpreting the results. Law MR, Hutcheon JA and Janssen PA were involved in designing the study and analytic approaches. All co-authors contributed to manuscript edits and interpretation. I was responsible for all manuscript reviews and editing in the peer-review process.

TABLE OF CONTENTS

Abstract iii
Lay Summary iv
Preface v
Table of contents vi
List of Tables viii
List of Figures x
List of Abbreviations xii
Acknowledgements xiv
Dedication xv
1 Introduction 1
1.1 Overarching theme and overview 1
1.2 Gestational diabetes mellitus 2
1.3 Pregnancy weight gain and infant birthweight 6
1.4 Research questions and hypotheses 9
1.5 Thesis overview 9
1.6 Significance and knowledge gaps 10
1.7 Disclaimer 11
2 Literature review of gestational diabetes 12
2.1 Overview 12
2.2 Risk-based v universal screening 12
2.3 Glucose tests 13
2.4 A one-step v two-step approach 13
2.5 History of screening and diagnostic guidelines 14
2.6 Canadian context 17
2.7 US context 19
2.8 International context 20
2.9 Being Unscreened 20
2.10 Prevalence of GDM 21
2.11 Perceptions of GDM screening and diagnosis among pregnant people 22
2.12 Summary 23
2.13 Tables 24
3 A validation of using insurance billings data to assess antenatal screening data against medical records data 28
3.1 Synopsis 28
3.2 Background 29
3.3 Methods 30
3.4 Analysis 31
3.5 Results 32
3.6 Discussion 34
3.7 Tables 36
4 Trends in Gestational diabetes screening practices in British Columbia: a descriptive study 39
4.1 Synopsis 39
4.2 Background 40
4.3 Methods 41
4.4 Results 43
4.5 Interpretation 44
4.6 Tables 47
4.7 Figures 51
5 The impact of changes in screening completion, screening methods and population demographics on the increase in gestational diabetes 53

5.1 Synopsis 53
5.2 Background 54
5.3 Methods 55
5.4 Results 56
5.5 Discussion 57
5.6 Tables 58
5.7 Figures 59
6 Weight gain in pregnancy and infant birthweight after the onset of the COVID-19 pandemic: an interrupted time series analysis 61
6.1 Synopsis 61
6.2 Introduction 63
6.3 Methods 64
6.4 Results 67
6.5 Discussion 70
6.6 Tables 73
6.7 Figures 76
7 The case for “complete case”: A brief review of missing data in Chapter 6 79
7.1 Synopsis 79
7.2 Background 80
7.3 Methods 81
7.4 Results 82
7.5 Discussion 83
7.6 Tables 84
7.7 Figures 88
8 Conclusion 90
8.1 Gestational diabetes screening and diagnoses 90
8.2 COVID-19 pandemic, pregnancy weight gain and infant birthweight 92
8.3 Significance and contribution 93
8.4 Strengths and limitations 95
8.5 Applications of these findings 97
8.6 Future research 98
8.7 Conclusion 100
8.8 Figures 101
Bibliography 102
A. Validation study supplemental 115
A.1 Supplemental methods 115
A.2 Tables 119
A.3 Figures 134
B. Descriptive study supplemental 141
B.1 Tables 141
B.2 Figures 147
C. Gestational diabetes study supplemental 158
C.1 Methods 158
C.2 Tables 159
C.3 Figures 166
D. Covid-19 Pandemic, weight gain and infant birthweight supplemental 181
D.1 Methods 181
D.2 Sensitivity analyses 183
D.3 Conditional quantile regression 185
D.4 A re-analysis of the COVID-19 pandemic study using excess or inadequate pregnancy weight gain according to the Institute of Medicine criteria 186
D.5 Tables 188
D.6 Figures 199

LIST OF TABLES

Table 2.1 Glucose tests used in gestational diabetes screening and diagnosis 24
Table 2.2 Major diagnostic and screening criteria for GDM (1960-2010) 24
Table 2.3 Key studies and randomized trials impacting GDM screening and diagnosis in the early 2000's 25
Table 2.4 Overview of selected international and national guidelines for GDM diagnosis and screening.....26
Table 3.1 Population characteristics in a validation study of antenatal screening in BC, Canada 2014-2019.....36
Table 3.2 Antenatal screening test outcomes for medical records and billing codes data in a validation study in British Columbia, Canada 2014-2019 37
Table 3.3 Antenatal screening test validation parameters for billing codes compared to medical records data in a validation study in British Columbia, Canada 2014-2019.....38
Table 4.1 Prevalence of any glucose test v no test (unscreened) by subgroups and time periods in British Columbia, Canada, for glucose test dates or 28th week of pregnancy between June 1, 2004 and May 31, 2019.....47
Table 4.2 Prevalence of three gestational diabetes screening approaches among subgroups and time periods in British Columbia, Canada for glucose test dates from June 1, 2004 and May 31, 2019 (n=525,720).....49
Table 5.1 Gestational diabetes diagnosis, screen completion, methods and population characteristics for selected years.....58
Table 6.1 Pregnancy cohort demographics and outcomes by pre-pandemic (Jan 1, 2016 to Feb 23, 2020) and pandemic (Mar 23, 2020 to Dec 28, 2020) time periods for a Washington State cohort (n=77,411 pregnancies).....73
Table 6.2. Infant cohort demographics and outcomes by pre-pandemic (Jan 1, 2016 to Feb 23, 2020) and pandemic (Mar 23, 2020 to Dec 28, 2020) pre-pandemic and pandemic (March 23, 2020) time periods for a Washington State cohort (n=104,936 infants) 74
Table 6.3. Quantile regression results for 90th percentiles using an interrupted time series analyses of the effect of the COVID-19 pandemic onset in a Washington State cohort (January 1, 2016 to December 28, 2020) 75
Table 7.1 Missing data patterns: Demographics for excluded cases, complete cases and full study population.....84
Table 7.2 Demographics comparing final cohort to excluded cases by pandemic time periods.....85
Table 7.3 Pooled model estimates from analysis using imputed datasets (20) and complete cases 86
Table 7.4 Descriptive results for un-restricted weight gain cohort compared to complete case cohort.....86
Table 7.5 ITS model results for unrestricted weight gain cohort v complete case cohort 87

Table A.1 Detailed definitions of billing codes used from BC MSP for coding antenatal screening tests.....119
Table A.2 Pregnancy and obstetric characteristics for all linked records, records with incomplete insurance and final validation group (unweighted %) 120
Table A.3 Validation parameters for all screening tests using billing code derived screening tests compared to medical records abstracted data (gold standard) in subgroups.....122
Table A.4 Cross-tabulations of medical records data against billings-based screening data for records available for a validation analysis of antenatal screening tests (n=127).....124
Table A.5 Study cohort characteristics and demographics comparing screened to unscreened for 3 antenatal screening tests (n=135 records) (unweighted %).....125
Table A.6 Completion rates for secondary variables by data source (Chart-abstracted v. PDR) 127
Table A.7 Descriptive results for secondary variables by data source (Medical records abstracted v. PDR) 128
Table A.8 Comparison of selected secondary variables with sample weighted results (medical records v BC-PDR) 129
Table A.9 Comparison of secondary variables (categorical) from BC PDR against medical records data (unweighted results) 129
Table A.10 Comparison of secondary variables (continuous) from BC PDR against medical records data (unweighted).....129
Table A.11 Detailed data dictionary and coding for medical records data 130
Table A.12 Detailed data dictionary and coding for MSP billing variables for antenatal health care professional type 131
Table A.13 Detailed definitions of billing fee codes used for prenatal care utilization.....132
Table A.14 Data dictionary for PDR variables used for validation (secondary variables) 133
Table B.1 Population demographics by gestational diabetes screening methods, BC, Canada, 2004-2019.....141
Table B.2 Crude and adjusted Relative Risks (RR) for one-step gestational diabetes screening, BC, Canada, 2005-2019 143

Table B.3 Gestational diabetes diagnosis and treatment type by screening methods in BC, Canada, 2011-2019 (after one-step was implemented) 144
Table B.4 One-step gestational diabetes screening rates by region in subgroups, time periods and by year 145
Table B.5 One-step gestational diabetes screening rates by year, BC, Canada, 2005-2019 146
Table C.1 Model estimated risk of gestational diabetes in each study year (n=551,457) 159
Table C.2 Population characteristics by gestational diabetes diagnosis in BC, Canada from 2005 to 2019 (n=551,457) 160
Table C.3 Population characteristics by gestational diabetes diagnosis in BC, Canada from 2005 to 2019 comparing full available study years to excluded groups for different reasons compared to the included cohort 162
Table C.4 Annual gestational diabetes counts and diagnoses (%) in excluded groups and full cohort 164
Table C.5 Annual gestational diabetes diagnoses in excluded groups and full cohort with 95% confidence intervals 164
Table C.6 Gestational diabetes counts and diagnoses, screening status in excluded groups and full cohort 165
Table C.7 Gestational diabetes counts and diagnoses, screening status in excluded groups and full cohort, rates with 95% CIs 165
Table D.1 Model estimates from interrupted time series analyses of the effect of the COVID-19 pandemic onset in a Washington State cohort (January 1, 2016 to December 28, 2020) (Primary analyses) 188
Table D.2 Demographics and characteristics of excluded cases for a study of the effect of the COVID-19 pandemic onset in a Washington State cohort (January 1, 2016 to December 28, 2020) 189
Table D.3 Summary of sensitivity analyses results Covid-19 study 190
Table D.4 Complete model terms for pregnancy weight gain models (kg) with sensitivity anlayses 190
Table D.5 Complete model terms for pregnancy weight gain z-score models with sensitivity analyses 191
Table D.6 Complete model terms for all infant birthweight z-score models with sensitivity analyses 192
Table D.7 Quantile regression for 90th percentiles using an interrupted time series analyses of the effect of the COVID-19 pandemic onset in a Washington State cohort 193
Table D.8 Quantile regression and mean regression results stratified by pregestational BMI (body mass index) categories for a study of the effect of the COVID-19 pandemic onset in a Washington State cohort (January 1, 2016 to December 28, 2020) 194
Table D.9 Model estimates from sensitivity analyses for increasing exposure to the pandemic by excluding births from February 23, 2020 to April 27, 2020 (9 weeks) and from February 23, 2020 to June 8, 2020 (15 weeks) from interrupted time series analyses of the effect of the COVID-19 pandemic onset in a Washington State cohort 195
Table D.10 Baseline weight and other characteristics stratified by pregestational BMI categories 196
Table D.11 Institute of Medicine (2009) pregnancy weight gain classifications and pregestational BMI 197
Table D.12 Full ITS model results for IOM excess or inadequate weight gain 198

LIST OF FIGURES

Figure 4.1 Monthly rates of gestational diabetes screening aggregated by month of screening tests, for a cohort of pregnancies in BC, Canada from June 2004 to May 2019.....51
Figure 4.2 Rates of gestational diabetes screening using a one-step method (75g glucose test only and IADPSG criteria) in BC from Jun 1, 2004 to May 31, 2019 in subgroups 52
Figure 5.1 Gestational diabetes screening and diagnosis by screening method in BC, Canada 59
Figure 5.2 Predicted gestational diabetes diagnosis risk using adjusted models 60
Figure 6.1 Flow of study population and exclusions for a Washington State study of gestational weight gain, infant birthweight and the COVID-19 pandemic (January 1, 2016 to December 28, 2020).....76
Figure 6.2 Interrupted time series graphs for pregnancy weight gain, z-score and infant birthweight z-score showing predicted trends and the COVID-19 pandemic onset (March 23, 2020) in a Washington State cohort (January 1, 2016 to December 28, 2020) 77
Figure 6.3 Average pregnancy weight gain, z-score and infant birthweight z-score by month of conception across study years for a Washington State cohort (January 1, 2016 to December 28, 2020) 78
Figure 7.1 Un-restricted weight gain cohort exclusions 88
Figure 7.2 Unrestricted weight gain cohort: Interrupted time series graphs and results.....89
Figure 8.1 Rates of gestational diabetes in Canada (excluding Quebec), 2017, from the Public Health Agency of Canada based on CIHI-DAD data 101

Figure A.1 Flowchart for linkage of chart-abstracted study data and administrative data.....134
Figure A.2 Decision tree for 1st trimester ultrasound completion (screened, unscreened, missing) abstracted from medical records (n=127 for validation study).....135
Figure A.3 Decision tree for gestational diabetes screen completion (screened, unscreened, missing) abstracted from medical records (n=127 linked for validation study).....136
Figure A.4 Decision tree for gestational diabetes screen methods (one-step or two-step) abstracted from medical records (n=127 linked for validation study).....137
Figure A.5 Decision tree for Group B streptococcus test abstracted from medical records 138
Figure A.6 Decision tree for billings derived antenatal screening test results for 1st trimester ultrasound, GDM screening and GBS screening (screened v unscreened v missing) for n=135 records.....139
Figure A.7 Decision tree for billings derived antenatal screening test results for gestational diabetes screening method (one-step or two-step) (n=135 records).....140
Figure B.1 Study population derivation and exclusions 147
Figure B.2 Rates of GDM one-step screening by region and pre-pregnancy BMI.....148
Figure B.3 Rates of GDM one-step screening by region and health care professional type.....149
Figure B.4 Rates of GDM one-step screening by region and history of GDM.....150
Figure B.5 Rates of GDM one-step screening by region and birth region of mother/birthing person.....151
Figure B.6 Rates of GDM one-step screening by region and planned home birth 152
Figure B.7 Rates of GDM one-step screening by region and adequacy of prenatal care usage index.....153
Figure B.8 Rates of GDM one-step screening by region and Health services delivery areas.....154
Figure B.9 Gestational diabetes diagnoses rates by screening type.....155
Figure B.10 Rates of one-step gestational diabetes screening in BC regions in 4 time periods by date of 1st glucose screening test for gestational diabetes by BC local health area 156
Figure B.11 Rates of gestational diabetes diagnoses in BC regions in 4 time periods by date of 1st glucose screening test for gestational diabetes.....157
Figure C.1 Study population flow chart and exclusions 166
Figure C.2 Gestational diabetes screening and diagnosis rates with two-step by C-C and DC-2013 criteria.....167
Figure C.3 Gestational diabetes rates modeled with addition of prior history of gestational diabetes (sensitivity analysis).....168
Figure C.4 Models with covariates added in reverse order.....168
Figure C.5 Sensitivity analyses 2007 start year.....169
Figure C.6 Sensitivity analyses 2008 start year.....170
Figure C.7 Sensitivity analyses 2010 start year.....171
Figure C.8 Sensitivity analyses 2018 end year 172
Figure C.9 Sensitivity analyses exclude 2011 (transition year).....173
Figure C.10 Sensitivity analyses use monthly rates instead of year 174

Figure C.11 Sensitivity analyses use monthly rates excluding transition period where methods changed.....175
Figure C.12 Sensitivity analyses use two variables for two-step screening to account for change in diagnostic criteria after IADPSG adopted in 2010 (change from C-C to DC-2013 for two-step) 176
Figure C.13 Sensitivity analyses GDM screening rates in health regions over time 177
Figure C.14 Sensitivity analyses GDM diagnosis risk in health regions over time.....178
Figure C.15 Predicted risk of GDM diagnosis by year (modeled) in stratified analyses by health region 179
Figure C.16 Predicted risk of GDM diagnosis by year (modeled) in stratified analyses by alternate region classification 180
Figure D.1 COVID-19 policy indices (Containment Health Index, Stringency Index and Government Response Index) for Washington State, U.S. in 2020 using data from the Oxford COVID-19 Government Response Tracker 199
Figure D.2 Directed acyclic graph for COVID-19 pandemic and pregnancy weight gain or infant birthweight 200
Figure D.3 Seasonal trends year-by-year comparing conception and delivery month.....201
Figure D.4 Quantile regression modeled level change parameters across percentiles of pregnancy weight gain (model adjusted for gestational age at delivery and seasonality) and z-score (adjusted for seasonality) 202
Figure D.5 Subgroup analyses of pregnancy weight gain (kg) by pregestational BMI adjusted using an interrupted time series for a Washington State cohort (January 1, 2016 to December 28, 2020) 203
Figure D.6 Subgroup analyses of pregnancy weight gain z-score by Distressed Communities Index using an interrupted time series for a Washington State cohort.....204
Figure D.7 Subgroup analyses of weight gain z-score by Race/ethnicity using an interrupted time series for a Washington State cohort.....205
Figure D.8 Subgroup analyses of pregnancy weight gain z-score by pregestational BMI using an interrupted time series for a Washington State cohort 206
Figure D.9 Subgroup analyses of pregnancy weight gain z-score by insurance payor using an interrupted time series for a Washington State cohort 207
Figure D.10 Subgroup analyses of pregnancy weight gain z-score by Parity using an interrupted time series for a Washington State cohort.....207
Figure D.11 Subgroup analyses of infant birthweight z-score by Distressed Communities Index using an interrupted time series for a Washington State cohort 208
Figure D.12 Subgroup analyses of infant birthweight z-score by Race/ethnicity using an interrupted time series for a Washington State cohort.....209
Figure D.13 Subgroup analyses of infant birthweight z-score by Race/ethnicity and parity adjusted using an interrupted time series for a Washington State cohort.....210
Figure D.14 Subgroup analyses of infant birthweight z-score by insurance payor using an interrupted time series for a Washington State cohort.....211
Figure D.15 Subgroup analyses of infant birthweight z-score by parity using an interrupted time series for a Washington State cohort.....211
Figure D.16 Subgroup analyses of infant birthweight z-score by pregestational BMI using an interrupted time series for a Washington State cohort 212
Figure D.17 Comparison of primary analyses and Intergrowth 21 standards for weight gain and infant birthweight z-scores 213
Figure D.18 Infant birthweight z-scores for primary cohort (infants) compared to a matched group with valid pregnancy weight gain.....214
Figure D.19 Parity-adjusted infant z-scores compared to primary outcome.....214
Figure D.20 Rate of monthly Covid-19 Positive pregnancies in complete dataset.....215
Figure D.21 Interrupted time series plots excluding any known Covid-19 Positive cases 216
Figure D.22 Interrupted time series for random sampled 1 birth per person for repeated pregnancies 217
Figure D.23 Excess and Inadequate weight gain using IOM criteria (full cohort, adjusted for weeks): Interrupted time series plots 218
Figure D.24 Excess and Inadequate weight gain using IOM criteria (>=37wks GA only): Interrupted time series plots 219

LIST OF ABBREVIATIONS

ACHOIS	The Australian Carbohydrate Intolerance Study in Pregnant Women
ACOG	American College of Obstetricians and Gynecologists
ADA	American Diabetes Association
ADIPS	Australasia Diabetes in Pregnancy Study Group
AIC	Akaike's Information Criterion
APNCU	Adequacy of Prenatal Care Utilization Index
ARR	Adjusted Relative risk
BC	British Columbia
BC-PDR	British Columbia Perinatal Data Registry
BMI	Body Mass Index, a ratio of weight (kg) /height $(m)^2$
BSD	Sociedade Brasileira de Diabetes/Brazilian Society of Diabetes
CA/CMA/DA	CA census agglomeration, CMA census metropolitan area, DA dissemination area
C-C	Carpenter-Coustan
CI	Confidence Interval
CIHI	Canadian Institute for Health Information
COVID-19	SARS-COV-19
DC / CDA	Diabetes Canada (formerly, Canadian Diabetes Association or CDA)
DCI	Distressed Communities Index
DIPSI	Diabetes in Pregnancy Study Group of India
EASD	European Association for the Study of Diabetes
FP	Family practice physician
FPG	Fasting plasma glucose
GA	Gestational age
GBS	Group B streptococcus
GCT	Glucose challenge test
GDM	Gestational diabetes mellitus
HAPO	Hyperglycemia Adverse Pregnancy Outcomes
HbA1c	Hemoglobin A1c test
HIC	High-income countries
HSDA	Health Services Delivery Area
IADPSG	International Association of Diabetes in Pregnancy Study Group
ICD 10-CA	International Classification of Diseases Version 10 (Canadian Edition)
IOM	Institute of Medicine
IQR	Interquartile range
ITS	Interrupted time series
JSOG	Japan Society of Obstetricians and Gynecologists
LGA	Large-for-gestational-age
LHA	Local Health Area
LIC	Low-income countries
LMIC	Low-middle income countries
MAR	Missing at random
MCAR	Missing completely at random
MI	Multiple imputation
MSP	Medical Services Plan
NA	Not applicable
NDDG	National Diabetes Data Group
NICE	National Institute for Health and Care Excellence
NICHD	National Institute of Child Health and Human Development
NPV	Negative predictive value
NZSSD	New Zealand Society for the Study of Diabetes
OB	Obstetrician
OGTT	Oral glucose tolerance test
OR	Odds ratio
OxCGRT	Oxford Covid-19 Government Response Tracker
PPV	Positive predictive value
PSBC	Perinatal Services British Columbia

RM	Registered Midwife
RR	Relative Risk
RUCA	Rural-urban commuting areas
SD	Standard deviation
SEMDSA	Society for Endocrinology, Metabolism and Diabetes of South Africa
SGA	Small-for-gestational-age
SOGC	Society of Obstetricians and Gynecologists of Canada
UK	United Kingdom
US	United States
WA	Washington State
wAG	weighted Average Glucose
WHO	World Health Organization

ACKNOWLEDGEMENTS

With gratitude, I acknowledge support over the years of my dissertation studies from the following individuals and institutions:

- Dr. Patti Janssen, my thesis supervisor, for her patience, guidance, support and mentorship
- My committee members: Dr. Jennifer Hutcheon for the 'best critiques' – contributing immensely to the rigour and foundation of this work; Dr. Michael Law for insight and general guidance especially for interrupted time series; and Dr. Andrew Kotaska for excellent general and clinical feedback.
- Vanier Canada Graduate Scholars program for providing the funding that supported my studies.
- The University of British Columbia and School of Population and Public Health for the 4-year graduate fellowship additional funding.
- Population Data BC for a student waiver for data access fees.

I also gratefully acknowledge assistance from the following organizations, staff and individuals for the projects in this thesis:

- Staff from Fraser Health (FH) and Provincial Health Services Authority (PHSA) who assisted with obtaining approvals and access to medical records used for the validation study.
- The Foundation for Health Care Quality and OB COAP for with in-kind contributions for data extracts for the Washington State study. Specifically, Kristin Sitcov, Dr. Vivian Souter.
- Staff from Population Data BC who have assisted with data access and approvals.

Last, I am deeply thankful for the support, mentorship and invaluable feedback throughout my studies from:

- Dr. Laura Schummers
- Jennifer Murray
- Dr. Susan Kennedy

To Nathan,

Thank you for your love and support
on this journey.

For Sage and Kai,

Always reminding me what's
truly important.

1 INTRODUCTION

1.1 Overarching theme and overview

Antenatal health care[1–3] is designed to optimize health for the pregnant person, the developing fetus and the neonate(s). A variety of screening tests and procedures are recommended[1–3] during pregnancy, to monitor for, and diagnose, conditions that could adversely impact health.

Important aspects of antenatal care include promotion of healthy weight gain and screening for gestational diabetes. Gestational diabetes is a temporary state of high blood sugar that occurs for the first time during pregnancy and is linked, in part, to maternal nutrition. Screening for this condition is usually recommended at the end of the second trimester (24-28 weeks gestation) as part of routine antenatal care. Pregnancy weight gain is also an important indicator of maternal nutrition and is generally screened for as part of routine care. Both excess weight gain and hyperglycemia in pregnancy have been associated with adverse perinatal and neonatal outcomes.[4–6] My thesis examines how changes in policy and practice in antenatal care can affect health outcomes in pregnant women and birthing people. Two types of changes that I assessed in this work are 1) direct policy or guideline changes and 2) the onset of the COVID-19 pandemic. Both of these changes could directly impact pregnancy and birth outcomes.

Specifically, I examined 1) impacts of gestational diabetes screening practices on gestational diabetes diagnosis and 2) impacts of a system-level event (the COVID-19 pandemic) on pregnancy weight gain and infant birthweight.

The majority of this thesis is from a series of linked studies of gestational diabetes in British Columbia (BC), Canada that I designed and conducted. This project included primary data collection for the purposes of a validation study, and several follow-up studies using linked administrative datasets. In view of anticipated delays in access to BC's administrative datasets during the recent COVID-19 pandemic, I utilized a clinical dataset from Washington State to study the effect of COVID-19 pandemic on pregnancy weight gain and infant birthweight.

This chapter provides an overview of the thesis, the two topic areas, the study context for each topic and the primary research questions and hypotheses.

A brief note on gender-inclusive language

Health outcomes discussed in my thesis are about people who experienced pregnancy. This can include people who identify as female (cis-women), as well as people who identify as male or non-binary. While a majority of those who become pregnant identify as female, other people (trans-men and non-binary people) may also experience pregnancy. None of the data sources used in my thesis captured information on gender identity, thus, I do not identify the study population as 'women' only. Throughout my thesis, in accordance with recent recommendations,[7] I use the terms "pregnant women and other pregnant people", "pregnant individuals", "pregnant people", "pregnant person" or "women and birthing people" to include all people who may become pregnant and who are included in my study groups.

"We can recognize that this [pregnancy] impacts women while also recognizing that it also impacts other groups. Those things are not mutually exclusive."

– Dr. Khiara Bridges, Professor-UC Berkeley School of Law, July 12, 2022, speaking to the U.S. Senate Judiciary Committee

1.2 Gestational diabetes mellitus

Gestational diabetes mellitus (GDM) is a pregnancy-associated condition which is usually screened for between 24-28 weeks of pregnancy[6] and is broadly defined as any glucose intolerance resulting in a transient hyperglycemia (elevated glucose) with first onset during pregnancy.[8] This is a temporary condition and is distinct from pre-existing type 1 or type 2 diabetes. GDM occurs during pregnancy and generally resolves after delivery, although, a history of a GDM diagnosis is associated with a 10-fold increased relative risk of developing type 2 diabetes post-partum compared to those without this condition.[9,10] Physiologically, normal pregnancy is characterized by a progressive increase in insulin resistance designed to conserve glucose for the growing fetus.[11] One explanation for gestational diabetes is that it represents an 'unmasking' of an underlying metabolic abnormality which results in excess insulin resistance during pregnancy which then precipitates a maternal state of hyperglycemia. As a result of this hyperglycemia, an excess of glucose is available to the fetus which can lead to fetal overgrowth.[12]

Gestational diabetes is one of the most commonly diagnosed pregnancy complications. A recent report by the International Diabetes Federation Atlas (2021) estimated the global standardized prevalence of GDM to be 14.2%,[13] but in specific regions or subgroups, reported rates vary from 2% to 45% of pregnant individuals.[14–17] By comparison, in 2011-2020, the global prevalence of pre-existing diabetes in pregnancy was estimated at 1.0%, with a regional range of 0.5% (Europe) to 2.4% (Middle East and North Africa).[18]

Despite extensive research efforts over the past 60 years, there remains widespread controversy regarding GDM.[19–22] In this section, I introduce some of these controversies and discuss how they have impacted gestational diabetes research. In Chapter 2, I present a detailed literature review of topics related to GDM, specifically, the evolution of diagnostic and screening practices for GDM, the Canadian and international standards and guidelines, and an overview of qualitative research on patient experiences with GDM and screening.

How to define gestational diabetes is a topic of substantial debate. GDM represents a heterogeneous group of metabolic disorders with varying levels of hyperglycemia[12] and the underlying pathophysiology is complex.[22] For example, current diagnostic approaches for GDM use blood test results from both a fasting state and after a glucose tolerance test (after a measured 'loading' of glucose is consumed). There is evidence that GDM in people with an abnormal fasting glycemia is more likely to represent one type of pathology, namely impaired β-cell function.[23] This may be linked with an increased genetic susceptibility to type 2 diabetes. On the other hand, glycemia after a tolerance test may represent a different pathology, related to an underlying insulin sensitivity due to pre-existing inflammatory pathways triggered by obesity, unhealthy diet, environmental exposures or limited physical activity. Despite these apparent differences in the pathologies of GDM, the diagnostic label is applied uniformly. Further, there can be underlying differences in the severity of hyperglycemia and in whether the hyperglycemia is able to be controlled with diet/exercise, or requires medication. As Landon & Gabbe described it, "Gestational diabetes represents a heterogeneous group of metabolic disorders, which result in varying degrees of maternal hyperglycemia and pregnancy-associated risk."[12]

A second controversy is around the overall benefit of GDM screening and treatment, especially for people with lower levels of hyperglycemia.[24–26] In 2003, the Canadian Medical Association Journal (CMAJ) published an editorial[27] stating that a number of physicians in Canada did not believe this condition exists, while others feel its importance is so low that screening is not justified. Some of this controversy stems from the fact that GDM presents with no overt symptoms. One perspective, is that hyperglycemia in pregnancy (*not* overt diabetes), is simply a risk factor that requires more intensive observation and testing to promote health.[28] The other perspective is that gestational diabetes is an important condition, similar to

pre-existing diabetes in pregnancy, that conveys increased perinatal and postpartum risks. Furthermore, treatment of GDM decreases risks of shoulder dystocia, hypertensive disorders of pregnancy (e.g. pre-eclampsia) and having a large-for-gestational age infant.[29,30]

Both of these issues, how to define GDM and appropriate treatment are inextricably linked. For example, if diagnostic criteria are not well characterized, or heterogeneous, then it is difficult to conduct well-designed and robust research studies to identify treatments. It is also important to remember that the majority of the cases of GDM-associated adverse outcomes (large fetal size, shoulder dystocia and hypertensive disorders) occur in people who are normoglycemic, and factors such as maternal weight and weight gain may confer greater risk of these poor outcomes than GDM alone.[31]

Methodologically, the early studies of the association between GDM and perinatal health outcomes used inconsistent definitions of GDM with limited control for confounding by underlying factors such as pregestational nutritional status (BMI) and weight gain during pregnancy. Further, researchers over the past decades have struggled to agree on a definition of GDM, because they disagreed on the objectives related to a diagnosis. Was it to identify women who would be likely to develop later diabetes (adult-onset diabetes mellitus) or to identify those at risk for maternal and fetal adverse outcomes during pregnancy? Early criteria for GDM diagnosis were based solely on the prevention of adult-onset diabetes,[32] therefore, diagnostic criteria were based on a relatively high threshold of hyperglycemia. In the late 1990's, researchers began to examine both immediate maternal and fetal risks during pregnancy as well as future health risks.[33,34] Others investigated GDM associations with pre-pregnancy obesity, pregnancy weight gain and fetal growth.[35–37] In combination, these findings suggested that high levels of hyperglycemia in pregnancy conferred some adverse neonatal or pregnancy risks, but the effects of pregestational BMI and pregnancy weight gain were not always well controlled for.

In 2008, a large multicenter study, the Hyperglycemia and Adverse Outcomes in Pregnancy (HAPO) Study, was the first well-designed study to find a continuous association between maternal glucose concentrations and some adverse pregnancy and infant outcomes. This led to a re-assessment in the GDM world as this study indicated that low levels of hyperglycemia also conferred some increased risk. In absence of a natural threshold, experts developed a new criteria[38] for diagnosis of GDM. Unfortunately, application of this new criteria, in some regions, increased GDM diagnostic rates as high as 40% without a clear relationship of this diagnosis to adverse pregnancy outcomes.[39] Therefore, the cost-benefit of adopting these new criteria continues to be the subject of much debate.[40]

Over the past 50 years, [20,39,41] numerous guidelines have been developed to define, and re-define, diagnostic criteria for gestational diabetes.[15,42] If gestational diabetes is viewed as a spectrum of metabolic

abnormalities, then choice of guideline and diagnostic thresholds, will influence which individuals are diagnosed. Universal recommendations for diagnostic and screening criteria for GDM remain elusive and the most recent recommendations from the International Federation of Obstetrics and Gynecology (FIGO)[43,44] favor a pragmatic approach that allows for regional variation within uniform guiding principles. This may be the best compromise for GDM in the international context.

From an epidemiologic perspective, changing diagnostic guidelines and screening criteria are important to consider when comparing research studies done in different decades, or in regions where different standards are applied. Unfortunately, large population-based datasets that are often used for prevalence studies or surveillance rarely have any data on screening method or diagnostic criteria, therefore, are unable to account for these potential sources of bias. For example, screening is rarely conducted in all of the eligible pregnant population, a fact that is usually overlooked. Second, depending on which screening method and guidelines are followed, GDM is diagnosed at different thresholds of hyperglycemia.

This leads to two problems with research on perinatal outcomes related to gestational diabetes; first, the population of those who are assumed to be negative for gestational diabetes may include people who were never screened at all, thus biasing the population of 'normo-glycemic' individuals. Second, the population of those who are diagnosed with GDM represents a range of severity of hyperglycemia *and*, depending on the time period or region, that range could have shifted during the study period. Careful study design and attention to information and selection biases are critical in future epidemiologic studies of gestational diabetes, particularly given the different guidelines used for screening and diagnosis.

1.2.1 Study context for GDM research in this thesis

British Columbia (BC) is the westernmost province of Canada, with a population in 2019 of approximately 4.9 million people. As with all Canadian provinces, BC has a universal single-payor health insurance system, publicly-funded by the province, called the BC-Medical Services Plan (BC-MSP). All BC residents, with some exceptions, are covered by BC-MSP and have a province-wide Personal Health Number (PHN) which links health data and services throughout the province.

Rates of GDM have increased across Canada,[42,45,46] with the national prevalence increasing from 4.0% in 2004 to 9.0% in 2017.[46] According to national hospitalization data, the province of British Columbia (BC) has the highest rate of GDM in Canada.[47] Specifically, in 2017, the Canada-wide rate of GDM was 9%, compared to 13.2% in BC. BC is the only province (excluding Quebec, as no data was available for that province), where the GDM rate exceeded the national average. There is relatively little published research on inter-provincial variability in GDM.

In Alberta, GDM prevalence was reported as 4.9% from 2008-2012.[48] A study of GDM among Chinese and South Asian populations in BC and Alberta (two western-most provinces of Canada) from 2004-2010 reported an overall GDM prevalence of 4.8% in Alberta and 7.2% in BC and concluded that differences in diagnostic practices likely contributed to this geographic difference in prevalence.[49] One study in BC from Kong et al., reported that BC had changed diagnostic approaches in 2010, and the pre-2010 prevalence of GDM was 7.9% compared (2009) to 9.4% after the policy change (2011). A study from Ontario reported an age-adjusted prevalence in 2010 of 5.6% in that province.

Perinatal health research in BC is strengthened by the linked administrative datasets available through Population Data BC.[50] After a detailed data review process, Population Data BC may provide approved researchers with access to health insurance billings (from BC's Medical Services Plan (MSP), perinatal data (from BC's Perinatal Data Registry BC-PDR), vital statistics (birth certificate data) and other administrative databases that represent all individuals in the province. External, researcher-collected data, may also be linked to administrative sources within strict criteria for privacy considerations. All data are linked using BC's Personal Health Numbers (PHNs) and other identifiers (date of birth, names, sex and postal codes) and de-identified prior to research access via a secure, remote platform.[51]

A broad range of perinatal health data, including gestational diabetes diagnoses and other demographic data, are available through the BC-PDR. However, as with most administrative datasets, the BC-PDR only reports gestational diabetes diagnoses and lacks data on gestational diabetes screening. To address this lack, I proposed to use BC-MSP laboratory insurance billings to capture gestational diabetes screening using a novel approach that I also planned to validate as part of this work.

I chose to examine gestational diabetes and screening in the BC context, in part, because of the high prevalence compared to the rest of Canada, the availability of high-quality population-based datasets for research, the possibility of using insurance billings to obtain screening data and the previously described screening policy change in 2010. Within this context, this thesis addresses a research gap in understanding how changes in GDM screening directly impacts gestational diabetes diagnosis risk in a population.

1.3 Pregnancy weight gain and infant birthweight

During pregnancy, a woman or birthing person's body changes to accommodate the fetus, placenta, increased blood volume and other physiologic changes. One way to monitor for nutritional status and pregnancy health can include measuring weight gain over the course of a pregnancy.[2,52] Serial weight gain measurements in pregnancy are not considered a perfect diagnostic or screening tool as these are

generally poor predictors, on their own, of adverse perinatal outcomes.[52] However, despite limitations, high levels of pregnancy weight gain have been associated with poor outcomes compared to weight gain within recommendations.[4,5] Deviations in maternal weight gain could be considered useful indicators of social or biological factors that relate to poor pregnancy or fetal outcomes. Further, recent research demonstrated that associations between fetal size and pregnancy weight gain are casual.[53] This supports the consideration of pregnancy weight gain as a modifiable risk factor for impacting fetal size.

Recommendations for weight gain in pregnancy are controversial. In the U.S in the 1960's, clinicians recommended restricted weight gain, preferably to 15 lbs (6.8 kg) to reduce risks of 'difficult births' and toxemia.[52] This was followed by a period of adjustment after this approach was linked to infant mortality, low birthweight and other poor outcomes. Later, the Institute of Medicine (IOM) defined target pregnancy weight gains by pre-pregnancy body mass index (BMI).[54] These criteria remain in use today, although they are also widely criticized.[55] Some argue the IOM guidelines are too high, especially for higher BMI categories and that they promote poor outcomes in this group.[55,56] Further, only 30-40% of most North American pregnant individuals gain weight within this criteria.[57] However, weight gain within IOM criteria is associated with lower rates of poor pregnancy outcomes than weight gain outside these ranges.[57,58] Excess weight gain in pregnancy, perhaps most importantly, is also associated with postpartum weight retention and can have long term health implications for development of diabetes and cardiovascular disease.[59]

Other research has focused on the trajectory of weight gain in pregnancy and whether increased weight gain in some trimester(s) is more impactful for perinatal outcomes.[60–62] Interactions between pre-pregnancy body mass index, gestational diabetes and weight gain are also widely investigated.[36,63] Current evidence points to minimal or no weight gain in pregnancy as the best recommendation for women with very high BMI to reduce risks of poor pregnancy outcomes.[55,57,64] Whether or not serial weight gain monitoring is useful on an individual level, from a population health surveillance perspective, pregnancy weight gain is a relatively simple measure that is associated with a range of maternal and fetal health outcomes.[65]

1.3.1 Study context for pregnancy weight gain and infant birthweight research in this thesis

Following the COVID-19 pandemic onset in 2020, governments, health systems and policies changed rapidly to respond to concerns about infection risk.[66,67] These policies and processes impacted people in different ways. Some examples include: reducing individuals' mobility through lock-downs and 'stay-at-home' orders, closing schools and workplaces, restricting public events, and closing gyms or public recreation facilities. Health systems also changed dramatically with reductions in routine health care visits

and shift to telehealth, shortened hospital stays and cancellation of elective or non-urgent procedures. Some changes with potential benefit also occurred, such as, reduced commuting, more at-home cooking and more time with family.

Early research following the initial months of the pandemic demonstrated weight increases among children and adults usually following pandemic-associated 'lock-downs'.[66,68–72] There is some limited local evidence that pregnant women and people also changed nutritional behaviors or increased food intake[73,74] but the impact of the pandemic on weight gain in pregnant women or infants birthweight is not well studied.

The Obstetrical Care Outcomes Assessment Program (OB COAP) is a research and quality improvement program in Washington, U.S.A. This database is abstracted from hospital and community-based medical records and currently represents approximately 1/3 of the hospitals in Washington State. While other perinatal data sources may have some data on pre-pregnancy weight, these data are often missing and may be inadequate for research purposes. Importantly, the OB COAP database contained relatively complete weight data for both an early and late pregnancy weight, along with a date indicator for when each value was collected. Further, this database is regularly updated on a quarterly basis, thus it was possible to obtain a dataset that contained a contemporaneous cohort of births until the end of 2020. Lastly, I was able to obtain deidentified OB COAP data with births by week of delivery for my study cohort. This was a key feature required for feasibility to conduct a time series analysis.

The pandemic has provided a unique 'natural experiment' that is of interest to public health. Quasi-experimental methods are well suited to studying the effects of natural experiments or other policy interventions. To explore a research gap on the effect of the pandemic on pregnancy weight gain and infant birthweight, I used the OB COAP dataset from Washington State to conduct an interrupted time series analysis. This dataset provided granular clinical data including data on weight gain, was recently updated, and could be used for a time-series analysis at the week level.

1.4 Research questions and hypotheses

The main objectives of my thesis were to answer the following 4 research questions:

Research question 1: Is screening test completion and screening methods as assessed using laboratory insurance billing data valid when compared with medical records data in British Columbia (BC), Canada?

> ***Hypothesis 1:*** Laboratory insurance billings data can be used accurately obtain data on antenatal screening tests for gestational diabetes, early 1st trimester screening ultrasounds and Group B streptococcus screening tests.

Research question 2: How did gestational diabetes screening practices change over time and within subgroups in BC, Canada following several policy and professional association guideline changes regarding gestational diabetes screening from 2005-2019?

> ***Hypothesis 2a:*** Gestational diabetes screening changed following policy and professional association guideline changes regarding methods of assessment.
>
> ***Hypothesis 2b:*** Gestational diabetes screening varied across population subgroups and following guideline changes.

Research question 3: What was the relative contribution of gestational diabetes screening practices (screening rates and methods) and population demographics to increasing the risk of gestational diabetes?

> ***Hypothesis 3:*** Changes in screening practices explain most of the increase in gestational diabetes diagnoses rather than changes in population characteristics or changes in other unknown characteristics.

Research question 4: What was the impact of the COVID-19 pandemic and associated public health countermeasures on pregnancy weight gain and infant birthweight?

> ***Hypothesis 4:*** COVID-19 associated policies and countermeasures that may have changed individual behaviors and changed prenatal care led to an increase in pregnancy related weight gain and infant birthweights.

1.5 Thesis overview

This thesis is presented in seven chapters. Chapters 3 to 6 are written in the form of manuscripts for peer-reviewed journals. Thus, topic headings within each chapter align with different journal requirements.

Chapter 2 presents a more detailed literature review of topics related to GDM screening and diagnosis. **Chapter 3** describes the validation study, answering my first research question. The validation study included primary data collection that I completed as part of this thesis. This included a chart review of medical records from 3 BC hospitals. The medical records data were linked through individual identifiers to provincial perinatal and administrative (billings) data for a validation analysis. **Chapter 4** presents a descriptive analysis of gestational diabetes screening data in BC pregnancies and addresses the second research question related to changes in gestational diabetes screening over time. **Chapter 5** examines how gestational diabetes screening methods impacted diagnosis in BC and addresses the third research question regarding the attribution of change in screening methods. **Chapter 6** examines the fourth research question related to pregnancy weight gain during the COVID-19 using the cohort from Washington State. **Chapter 7** presents additional analyses on missing data for the COVID-19 project.

The final chapter (**Conclusion**) provides a general discussion and interpretations for the overall thesis. This chapter also discusses some implications of this work for policy, clinical practice and research.

1.6 Significance and knowledge gaps

This research targets knowledge gaps related to: 1) gestational diabetes mellitus screening and diagnosis and 2) COVID-19 pandemic-associated impacts on pregnancy weight gain and infant birthweight.

First, I address a gap in knowledge on gestational diabetes screening completion and methods, and the impact of screening on diagnoses. Most large administrative datasets used in population studies lack any data on screening. Thus, there is a gap in understanding how screening completion or screening methods could impact measurement of gestational diabetes prevalence, especially on a population level. In this thesis, I developed a novel approach to capture gestational diabetes screening data using administrative data sources, validated this method using medical records data (Chapter 3), applied this screening data to describe how policy changes impacted screening practices in BC (Chapter 4), and, last, quantified the impact of screening practices on the rising prevalence of gestational diabetes in BC over the past 15 years (Chapter 5).

Second, I used a quasi-experimental study design to assess the impact of the COVID-19 pandemic on pregnancy weight gain and infant birthweight (Chapter 5). This study used rigorous analytic methods, an interrupted time series analysis, that improves over before-and-after study designs to examine an understudied topic area. Chapter 6 presents a brief review of issues with missing data in the study from Chapter 5.

1.7 Disclaimer

Regarding data accessed through Population Data BC (BC data): Access to data provided by the Data Steward(s) is subject to approval, but can be requested for research projects through the Data Steward(s) or their designated service providers. All inferences, opinions, and conclusions drawn in this publication are those of the author(s), and do not reflect the opinions or policies of the Data Steward(s).

2 LITERATURE REVIEW OF GESTATIONAL DIABETES

2.1 Overview

Current expert opinion supports the diagnosis and treatment of hyperglycemia in pregnancy to reduce risks of fetal overgrowth, neonatal hypoglycemia (a state of low-glucose that occurs in the neonate after delivery), associated delivery complications and maternal hypertensive disorders.[8,38,75,76] However, criteria for diagnosis of gestational diabetes remain controversial, lack international consensus, and have shifted repeatedly since the first screening criteria were derived in the 1960's.[15] This leads to a complex landscape for interpreting both current and past research evidence. There remains significant debate on the key issues in gestational diabetes screening and diagnosis during pregnancy: 1) universal vs. risk-based screening programs;[77] 2) which screening test to use, timing of screening[78] and usefulness of early screening prior to 24 weeks;[21] 3) screening approach (one-step v. two-step)[79]; 4) the most appropriate diagnostic test;[15,80] 5) the glucose thresholds that should be used for diagnosis;[42] or 6) the number of abnormal values required to constitute a diagnosis.[42,79,81,82] Further sections will expand on these issues.

2.2 Risk-based v universal screening

Both selective or risk-based screening and universal screening are used for gestational diabetes screening.[77] Selective screening means that only populations considered at risk of diabetes should be screened and low risk women and birthing people are exempt from screening. Low risk definitions vary, but generally include: younger age ($\leq$ 25 years old), no prior GDM, no first-degree relatives with diabetes, no prior macrosomic infant, pre-pregnancy body mass index ($\leq$28 kg/m^2), and belonging to a racial/ethnic group with a low prevalence of diabetes.[77] Universal screening, where all pregnant individuals are recommended for screening, is most commonly used worldwide. However, current UK guidelines[83] still use risk-based screening, as do some lower-resource settings.[41]

This change from selective to universal screening is important to consider for observational studies on gestational diabetes. Specifically, the proportion of people who are screened (v. unscreened), and the underlying risk profile of the group who are screened, differs between jurisdictions where universal screening is implemented compared to jurisdictions where risk-based screening is used. For example, a 2010 review of risk-based v. universal screening in 11 countries reported the proportion of people who would be exempt from screening according to risk-based criteria ranged from 5% to 86% in these different jurisdictions.[84] Further, the proportion of GDM positive individuals who would be missed by risk-based screening varied from 46% to 1.3%.[84]

2.3 Glucose tests

There are several test types used in gestational diabetes screening and diagnosis (Table 2.1). Most gestational diabetes screening and diagnoses criteria use either a glucose challenge test (GCT) or an oral glucose tolerance test (OGTT). Both tests use a glucose "challenge" approach whereby the person consumes a measured amount of glucose, and then blood tests are used to quantify the individual's glycemic response. Other tests used to screen for and/or diagnose pre-gestational or gestational diabetes are: a fasting glucose test, a random glucose test or a HbA1c test. A fasting glucose test refers to a blood glucose test that is taken in a fasting state; after the person has refrained from eating for 8 to 12 hours. A random glucose is a glucose test taken at any time. A hemoglobin A1c test (abbreviated as HbA1c) measures the amount of glucose that is attached to hemoglobin and is considered to represent an average amount of glucose over the past 3 months (roughly the life-span of a red blood cell). The validity of a HbA1c in pregnancy is unclear; however, it is still recommended in some criteria for early first-trimester screening for pre-existing diabetes.[8] HbA1c, random or fasting glucose tests are less commonly used for gestational diabetes diagnoses and screening and do not require a challenge component. A random or fasting glucose test is occasionally offered as an alternative for those who cannot tolerate the glucose drink, who decline recommended screening or who start prenatal care late in pregnancy.[85,86] During the COVID-19 pandemic, some regions recommended these non-challenge tests as alternative methods of GDM screening to minimize potential infection risk and time spent in out-patient laboratories.[87]

A glucose challenge test (GCT) requires a 50g oral glucose load (in a standardized drink) and then a single blood sample taken 1-hour afterwards. An oral glucose tolerance test (OGTT) consists of consumption of a larger oral glucose load (100g or 75g), usually after fasting, and includes multiple blood samples. Specifically, an OGTT test usually includes a fasting sample and then several more samples taken after the glucose drink (e.g., at 1-hour, 2-hours and 3-hours). In all cases, samples are analyzed for glucose concentrations (mmol/L). The other tests use a single blood test only. A HbA1c is more commonly used to diagnose pre-existing diabetes in a non-pregnant person but some guidelines recommend this test for early pregnancy (prior to 24 weeks) testing for pre-existing diabetes.[21]

2.4 A one-step v two-step approach

Screening for GDM can be broadly categorized as using either a **two-step approach** (a screening test followed by a diagnostic test if screen positive) or a **one-step approach** (a single diagnostic test)[15]. According to some guidelines, if extremely elevated results are identified on a screening test, then a diagnosis of either overt diabetes or gestational diabetes, may be made based on that test alone. A one-step approach has the advantage that everyone has only one diagnostic test. The disadvantage is that

diagnostic tests for GDM are generally more time-consuming, uncomfortable and costly than screening tests.[88,89]

Some argue that a one-step screening approach improves screening uptake rates since pregnant individuals only have to attend one laboratory visit for both screening and diagnosis.[90–92] However, they must fast before and make time for at least a 2-hour visit. By contrast, a two-step screening program requires two visits, albeit only for the proportion of people who screen positive on the first test (usually 20%). Others have demonstrated good adherence with a two-step screening program within a universally funded health care system,[78] but this may differ in health systems where individual or insurance costs vary.[91]

2.5 History of screening and diagnostic guidelines

The early criteria for diagnosis of hyperglycemia in pregnancy (O'Sullivan, Table 2.2) were derived to identify pregnant women and people who would be at high risk of developing type 2 diabetes later in life.[32,93] These criteria were generally used with risk-based screening programs. In the late 1970's and early 1980's, changes in laboratory techniques meant that samples were now analyzed in serum plasma rather than in whole blood. Two criteria for diagnosis were defined during this time period: the National Diabetes Data Group (NDDG) criteria[94] and the Carpenter-Coustan (C-C) criteria.[95] The former was designed to mimic the O'Sullivan criteria but adjusted the criteria for use in a serum plasma sample, the C-C criteria also lowered the diagnostic thresholds based on new research.[95] The C-C criteria used a two-step approach with a 50g-GCT screening test, followed by a diagnostic test using a 100g, 3-hour OGTT.

Over the following decades, a two-step approach with C-C diagnostic criteria was most commonly used in North America whereas the World Health Organization (WHO) criteria[96] were more commonly used in Asia and in Europe. The early WHO criteria (Table 2.4**)** were based on thresholds from non-pregnant populations and were widely viewed to be invalid in pregnancy. During this time period, there was ongoing debate about the relevance of screening and treating gestational diabetes as it was defined and, specifically, debate about the importance of treating milder levels hyperglycemia than those that were diagnosed using existing criteria. Existing criteria (C-C/O'Sullivan) were derived based on identifying a pre-diabetic condition in the pregnant person rather than identifying those at risk of adverse perinatal outcomes.[28] While there was evidence that untreated hyperglycemia was associated with fetal overgrowth[97,98], there was debate as to whether hyperglycemia/GDM should be considered a risk factor or a unique metabolic abnormality/disease process.

Two randomized trials[99,100] (Table 2.3) that examined whether treatment of hyperglycemia in pregnancy improved perinatal outcomes both demonstrated a benefit of treatment. It is important to note that one trial[99] included individuals at thresholds much higher than current standards, whereas the other trial's criteria[100] were similar to the C-C standards. The Australian Carbohydrate Intolerance Study in Pregnant Women (ACHOIS) trial reported a reduced risk for their primary outcome (a perinatal composite), an increased risk of induction, and no change for cesarean delivery or shoulder dystocia in the untreated group compared with the treatment group.[99] They also reported a lower risk of large for gestational age (LGA) (birthweight > 90th percentile by gestational age) in the treatment group. The second trial, by the National Institute of Child Health and Human Development (NICHD), found no difference in their primary perinatal composite outcome, but did find a reduction in LGA, cesarean birth, shoulder dystocia and hypertensive disorders.[100] Both trials, however, had statistically significant reductions in pregnancy weight gain in the treatment groups.[28,53,60] While weight gain is appropriately considered an intermediate variable (on the causal pathway) between a GDM diagnosis and perinatal adverse outcomes and should not be adjusted for, none of these studies presented sensitivity analyses with stratification on the intermediate variable (weight gain). Thus, it is unclear which treatment aspects of a GDM diagnosis (i.e. medication and glucose monitoring or nutritional/lifestyle counselling or simply a decrease in weight gain) confers health benefits.[24,25]

The studies also differed in the composition of racial/ethnic groups in their study populations. Specifically, the ACHOIS study population was reported as >75% White, 17% Asian and 8% "Other" and the NICHD study was reported as >55% Hispanic, 25% White, 11% Black and 5% Asian. The association between hyperglycemia and fetal growth varies by different racial/ethnic groups, this could be an important concern with generalizability for both studies.[101,102] However, the authors of both studies concluded that treatment of moderate hyperglycemia in pregnancy was beneficial.

A third large multi-center study (The Hyperglycemia and Adverse Pregnancy Outcomes (HAPO) Study)[33] was intended to clarify the risk of adverse outcomes by studying a continuum of hyperglycemia at levels lower than those considered to represent overt diabetes in pregnancy and by examining a range of perinatal outcomes. This study reported continuous associations between increasing hyperglycemia in pregnancy as measured by a 75g OGTT (one-step, 2-hour test) method and increasing risk(s) of cesarean delivery, neonatal hypoglycemia, LGA and cord C-peptide levels. Importantly, HAPO did not find clear evidence of a threshold at which risks increased, leading to debate about how to incorporate these findings into contemporary practice.

Following the publication of the HAPO Study, the International Association of Diabetes in Pregnancy Study Group (IADPSG) consensus panel derived thresholds based on an increased risk relative to the

study mean values for the fasting, 1-hour and 2-hour glucose measurements.[38] They defined a new diagnostic criteria for gestational diabetes based on an Odds Ratio (OR) of 1.75 relative to the mean glucose values as the reference group. However, the IADPSG authors acknowledged that the new criteria would result in an 17.8% incidence of gestational diabetes in the HAPO population. They also considered a threshold using an OR of 2.0 which had a modest increase in the risk of adverse outcomes (compared to the HAPO-OR1.75 threshold) but would decrease the incidence of GDM diagnosis to 10.5%. Nevertheless, the consensus recommendation was based on a HAPO-OR 1.75 thresholds and used a one-step screening approach with a 75g-OGTT (Table 2.3). The IADPSG criteria were published in 2010 and were subsequently adopted by many other professional association(s) guidelines and standards worldwide. Substantial increases in the prevalence of gestational diabetes after implementing the IADPSG criteria have been since demonstrated in numerous studies and systematic reviews.[15,39,79,86,103–105] On average, switching to the IADPSG criteria increases diagnoses by at least 1.75-fold, although some regions have reported much larger increases.[106,107]

As one example, McIntyre and Jensen reported that applying the IADPSG criteria in Denmark would have resulted in an increase in GDM from 2.3% to >40% of all pregnancies.[39] The authors found limited evidence of increased maternal or fetal risks in the Danish cohort who had 'untreated' GDM using the IADPSG criteria. Thus, they concluded that using the IADPSG criteria for GDM was inappropriate for Denmark and "would classify an unmanageable number of women as having GDM who are at low absolute risk of pregnancy complications and divert health resources from other areas."[39] On the other hand, a study in Spain reported fewer adverse outcomes after implementation of the IADPSG standards for GDM diagnosis and concluded that this change was cost-effective despite a 3.5-fold increase in prevalence.[103] In part because of inconsistent results demonstrating improved perinatal outcomes after the switch to IADPSG criteria,[39,86,108] GDM diagnostic criteria remain widely debated.[15,108] A recent systematic review reported 15 national and international standards for diagnosis of gestational diabetes.[15]

Selected guidelines in Canada, the US and internationally (Table 2.4) demonstrate the variability in guidelines that still exists today. A few trends are notable. Most countries, with the exception of the UK (NICE guidelines)[22,83], now recommend universal screening for GDM. Over time, more standards have adopted IADPSG criteria and diagnostic thresholds are decreasing (to capture more cases). Both one-step and two-step screening approaches are in widespread use today with some guidelines recommending either approach.[109] A 50g-GCT is the most commonly used screening test, but some countries use a single 2-hour blood test after a 75g OGTT (non-fasting) as a screening test[15,41] and others use a single fasting test.[110]

A recent 2022 study proposed a new diagnostic criteria for GDM using a weighted Average Glucose (wAG) that combined the results from a fasting, 1-hr and 2-hr result into one value and then assigned the wAG to 4 distinct diagnostic categories: Normal gestational glycemia (NGG), Impaired gestational glycemia (IGG), Gestational diabetes (GDM), and High risk GDM (hGDM).[111] These four categories identified pregnant people at higher risk of immediate complications and subsequent development of post-pregnancy diabetes as validated with previously-collected data. This could be a new diagnostic tool to consider for future guidelines on GDM.

2.6 Canadian context

In Canada, regional policies and professional association guidelines for GDM screening have changed several times in the past 20 years (Table 2.4).[42] In the late 1990's and early 2000's, Canadian guidelines recommended selective (aka risk-based) screening. This meant that low-risk pregnant people were exempt from screening. "Low risk" was defined as less than 25 years old, having a non-obese pre-pregnant body mass index, no prior history of gestational diabetes or macrosomia, no family history of diabetes in first-degree relatives and not belonging to an ethnic group with high diabetes prevalence.[42] Later Canadian guidelines (Diabetes Canada 2003, SOGC 2016)[42] recommended universal screening. One study[112] reported a 9-fold increase in GDM prevalence across Canada, from 0.3% in 1984 to 2.7% in 1996, after universal screening was implemented but noted this was likely an artifact of increased screening with no evidence of beneficial effects on pregnancy outcomes.

In Canada, the two largest professional associations who have written guidelines for management and treatment of diabetes in pregnancy are Diabetes Canada (DC) (formerly known as the Canadian Diabetes Association (CDA)) and the Society of Obstetricians and Gynecologists of Canada (SOGC). Prior to the HAPO Study, Canadian guidelines[113] used screening and diagnostic criteria generally comparable or the same as the C-C criteria. Following HAPO, Diabetes Canada in 2013 (DC-2013) recommended the use of a two-step screening approach (50g GCT followed by 75g OGTT) as the "preferred" option, with the alternate option being a one-step 75g OGTT using the IADPSG-2010 criteria.[114] Interestingly, the DC-2013 guidelines specified diagnostic thresholds for the two-step "preferred" method using HAPO-OR 2.0 criteria. In the same guidelines, the alternate option specified the HAPO-OR 1.75 thresholds for diagnosis (as used in the IADPSG-2010 standards). Therefore, according to the DC-2013 guidelines, if an individual was screened with a 50g-GTT (two-step approach) they would be diagnosed with different 75g-OGTT criteria (HAPO-OR 2.0) than if they were not screened (one-step approach) (HAPO-OR 1.75). Thus, using one-step screening would result in a higher diagnostic prevalence than using two-step

screening. This was the first example of two *different* diagnostic criteria specified in the same guideline and within the same country.

SOGC guidelines were updated in 2016[8] to match the DC-2013 criteria. Since then, the Canadian guidelines are generally aligned[8,114], but allow for a preferred and alternate option for screening which means that characterizing screening method could be especially important in Canada because two different screening approaches are both accepted.[42] I was unable to locate any Canadian research that describes relative uptake of the two guidelines-based screening approaches in practice. Thus, it is unknown to what extent different regions, provinces or health care professionals in Canada use the preferred or alternate screening approaches. If there are large regional differences in uptake of the different screening methods, this could have implications for both surveillance and health resource planning (i.e., access to diabetes clinics, nutritionists, and/or specialist physicians) across Canada.

In British Columbia, the province eliminated the 100g OGTT with C-C criteria in 2010 and switched to offer only a 75g diagnostic OGTT using IADPSG diagnostic criteria.[105] This change was in direct response to the HAPO Study and the IADPSG guidelines. Of interest, despite this provincial policy change, relevant Canadian professional association guidelines still referenced the C-C criteria and two-step screening. Canadian organizations did not endorse the IADPSG criteria until the Diabetes Canada 2013 guidelines.

Following the 2010 policy in BC, clinicians were recommended to use a one-step screening approach with the 75g-OGTT and diagnostic criteria as per the IADPSG guidelines. However, the 50g-GTT was not eliminated, and clinicians could continue to use a two-step screening approach, albeit with a 75g-OGTT for diagnosis. One study, Kong et al.,[105] used a before-and-after design to assess maternal and fetal outcomes following the change in policy in BC. They assessed births in two, 6-month blocks, from April 1 to September 30 in 2009 and in 2011 and found an increase in GDM prevalence from 7.9% to 9.4%. The authors did not find any statistically significant differences in maternal or fetal outcomes after the change in policy. In their discussion, they note the GDM prevalence in BC (9.4%), after the change to a policy recommending the one-step IADPSG screening, was lower than expected based on the HAPO Study (16%). These authors hypothesize that screening tests were likely under utilized (i.e. not everyone was screened)[115] and that guidelines were not consistently followed, leading to lower than expected rates. However, this study lacked any information on screening, therefore they were unable to verify these hypotheses.

In Alberta, Donovan et al. published two studies on gestational diabetes screening in this province. In one study,[78] they examined primiparous pregnant individuals from 2008-2012 for gestational diabetes

screening completion. They found that 91% received a 50g-GTT screening test and that two-step screening was widely accepted and implemented in a timely manner within their universally funded health system. In this province, laboratory data was linked to population-level health data to allow screening uptake to be assessed. A second study[48] examined perinatal outcomes in subgroups of different glucose test results after a two-step screening method and noted that a negative screening result using two-step screening with HAPO-OR 2.0 (DC-2013) criteria was associated with a low risk of adverse pregnancy outcomes.

Several Canadian studies[116] examined perinatal outcomes by glucose measurements according to different diagnostic criteria and report an increase in prevalence according to IADPSG criteria. However, none of these studies have examined regional or other differences in current screening practices, within current Canadian guidelines.

2.7 US context

In the US, the two main professional associations have differing criteria on GDM diagnosis and screening.[117] Following HAPO, in 2011, the American Diabetes Association (ADA) changed their guidelines to recommend only the IADPSG-2010 criteria (one-step 75g OGTT). By contrast, the American College of Obstetricians and Gynecologists (ACOG) (2013 and 2018 guidelines) has not adopted the IADPSG criteria and recommends screening with a two-step approach using a 50g GTT and 100g OGTT with *either* C-C or NDDG criteria for diagnosis. Likely to provide some coherence with ACOG, the 2014, 2018 and 2021 ADA guidelines include two options: *either* the IADPSG-2010 criteria (one-step 75g approach) *or* ACOG's criteria (two-step with either NDGG or C-C). Thus, three different GDM diagnostic criteria could be used in the US, today, all of which would meet national professional association guidelines.

Despite findings from the HAPO Study, the US has not widely adopted IADPSG criteria. A 2015 survey of obstetricians[118] reported that 90.1% recommended a two-step screening for GDM (v. one-step). The majority of two-step screening used C-C criteria, but 12% used NDDG criteria. There were also significant regional differences in screening with higher use of one-step (24%) in the Western region. A 2021 systematic review and evidence update for the US Preventative Services Task Force[117] examined 5 new randomized controlled trials (RCTs)[81,82,109,119,120] (4/5 with US study groups) that compared universal screening with one-step IADPSG criteria to two-step C-C criteria. Their meta-analysis showed that one-step screening was significantly associated with a diagnosis of GDM in 11.5% v. 4.9% of pregnancies but was not associated with any differences in fetal/neonatal or maternal outcomes. These authors conclude

that the greater prevalence of GDM resulting from increased use of one-step screening may have led to overdiagnosis and overtreatment without associated benefits.

2.8 International context

The diagnosis and treatment of GDM varies widely outside North America (Table 2.4).[13] Because low and middle income countries (LIC and LMIC) may have limited health system resources,[13,121] some use risk-based screening only or diagnostic criteria that result in much lower prevalence than the IADPSG-2010 criteria.[122] This is a deliberate decision in many regions, stemming from access to limited resources for monitoring and treating gestational diabetes. For example, in high-income-countries, a GDM diagnosis is accompanied by referrals for additional services usually through a diabetes-based clinic. These often involve extra prenatal visits and follow-up, daily blood sugar monitoring using a glucometer, dietary and lifestyle counselling and referral to an endocrinologist or specialist for medication, if needed. In regions where there are other more pressing perinatal health concerns (i.e., pre-eclampsia, postpartum hemorrhage, malnutrition, infectious diseases, maternal or neonatal mortality) and health resources are scarce, lower diagnostic thresholds for GDM is not seen as a beneficial use of public health resources.

This is one of the many reasons why standardized international criteria for GDM remain elusive. Many argue that cost-effectiveness and benefit of GDM treatment needs to be re-evaluated with carefully done randomized trials, before considering widespread use of standard diagnostic thresholds. As stated by Bilous et al., "each health care service [should] adopt diagnostic criteria based upon local available data on clinical and cost-effectiveness, practicality of test, and local resources."[26] Finally, ethnic and genetic variability in the effects of hyperglycemia in pregnancy on perinatal outcomes or long term outcomes is not well understood.[123] This represents key knowledge gap when considering global standardization of GDM criteria.

2.9 Being Unscreened

With risk-based screening, only those deemed at risk are screened. However, even in regions with recommended universal screening, 100% of the pregnant population is not screened in practice.[78] First, there are people with pre-pregnancy diabetes (<1%) and other medical complications (e.g. bariatric surgery) for whom an OGTT is contraindicated and are not recommended for GDM screening.[8] Second, there may be barriers that limit access to screening. For example, these could include travel distance to a laboratory for testing, language or cultural barriers in understanding screening information, not being able to take the time (off work or childcare) for testing, costs of testing or being unable to tolerate the test protocol because of nausea or vomiting.[124] Third, pregnant people may decline screening (personal beliefs

or values),[125] may decline the glucose drink (i.e. cultural, religious, personal, dietary reasons) and/or request alternative glucose loads (licorice, candy, honey tea, food)[126,127]. Finally, some pregnant people may elect to be tested and/or diagnosed with methods outside local guidelines such as self-monitoring with a glucometer[128] or using a fasting blood glucose test.[129] All of these could be classified as unscreened according to primary guidelines. While there is relatively little research on screening uptake,[85,91,115] some estimates are that between 4-50% of pregnant people may be unscreened,[78,115,125] even in the context of universal screening.

Decision-making about screening is also influenced by the guidance given by health care professionals when discussing screening tests.[130] While many pregnant women see a physician for health care during pregnancy, midwives and nurses may also provide prenatal care in many countries. In Canada, most pregnant people receive prenatal care from physicians, either general practice or obstetricians. Midwives in Canada are autonomous professionals who can care for women and birthing people during pregnancy, birth and postpartum and are involved with 30% of pregnancies in BC, ~10% across Canada.[131] Midwifery care has a strong focus on the principles of informed choice and midwives are trained to engage in discussions with pregnant people about all aspects of prenatal care; including routine screening tests.[132] Guidelines from midwifery organizations highlight the equivocal research evidence for screening and treatment of GDM[133–136] but note that "all pregnant women should be *offered* screening between 24 to 28 weeks gestation." In contrast, obstetric or physician-guidelines recommend universal screening and treatment based on evidence from expert consensus and state "all pregnant women not known to have pre-existing diabetes *should be screened* for GDM at 24-28 weeks of gestation."[8,114] Differences between midwifery and physician-led care have not been previously examined as a potential contributor to GDM screening uptake or screening method and is a research gap that I addressed in this work.

2.10 Prevalence of GDM

Gestational diabetes risk, as measured in observational studies, appears to have increased in many jurisdictions over recent decades.[14–16] Since hyperglycemia in pregnancy is also associated with maternal pre-pregnancy body mass index, maternal age and other maternal complications,[137] population-level increases in these factors could be linked to rising prevalence of gestational diabetes. However, widespread changes in GDM screening criteria (Table 2.4) and in who is screened (i.e. risk-based v. universal screening) are also important.[42]

Unfortunately, many population-based data sources used for surveillance only capture information on gestational diabetes diagnosis. Often, these data sources use a 'chart-by-exception' approach, whereby only diagnoses are captured. Thus, population-level data to identify if people are unscreened, or how they

were screened (i.e., screening method or diagnostic criteria) is not readily available. In this thesis, these are gaps that I addressed, first, in developing a method to capture screening data for large population datasets and second, examining the contribution of screening to rising prevalence of GDM.

2.11 Perceptions of GDM screening and diagnosis among pregnant people

There is relatively limited qualitative research on experiences with GDM screening in pregnancy.[138,139] Side effects, experienced by up to 20% of people from glucose challenge tests, include: nausea, dizziness, syncope and hypoglycemia.[81,140] In two qualitative studies specifically on screening (Germany[138], Australia[139]), however, the majority of participants reported positive experiences with screening. Those who screened positive did report a negative psychological impact after diagnosis. The German study considered experiences of people who had a one-step approach compared to those who had a two-step approach and reported positive experiences after the non-fasting screening (two-step) test. Barriers to completing screening identified using qualitative and mixed methods include travel distance[141], social/mental health issues, discomfort with the test, socio-economic barriers,[138] and preference/choice[85,124,142]. A recent qualitative study in BC on the experiences of declining care in pregnancy, reported that gestational diabetes screening was declined in over 12% of pregnancies in their sample.[125] This was the most commonly declined *recommended* prenatal test (slightly fewer than those who declined prenatal genetic testing which is considered optional/offered in BC).

Last, Edwell and Jack[89] published an important qualitative, rhetorical and narrative analysis of the overall debate around GDM. They reviewed scientific literature and patient-led blog posts to present both clinical and patient perspectives. The scientific literature, they noted, follows a "deferred quest" narrative trajectory as there are frequent references to how future research and data will eventually lead to medical consensus. On the other hand, patients' perspectives showed that when they became aware of the lack of scientific consensus on GDM, this led to a rupture of trust in medical authorities. This perspective contributed to a general distrust in the medical system and has important implications for patient-provider relationships. These authors concluded, in part, that health care professionals should openly acknowledge the different diagnostic standards and lack of consensus to their patients, and explain why they adhere to a particular approach. Pregnant people who are diagnosed with a medical condition often seek to understand their diagnosis by gathering information from multiple sources. If they have not previously been exposed to the complexity and controversy in GDM by their health care team, this could lead to further distrust in biomedicine and have implications for long term health care.

While there is relatively little qualitative research on GDM screening alone, the experiences of pregnant people who were diagnosed with GDM[143,144] or who experienced diabetes (type 1 or 2) in

pregnancy[143,145,146] are more well-studied. Other qualitative studies examined the experiences of treatment, socio-cultural implications[147] and post-partum follow-up care.[142]

According to some qualitative research, the experience of a GDM diagnosis is profound and can result in an emotionally distressing pregnancy.[148] Themes that emerged in the UK on the experiences of people with GDM diagnoses included: the disrupted pregnancy, projected anxiety, reproductive asceticism, women as baby machines, perceived stigma, lack of shared understanding and postpartum abandonment.[146] Similar themes are reported in other studies, thus, it is important to acknowledge the deep impact this diagnosis can have for individual people. Some racialized participants reported that experiencing GDM treatment was especially difficult as it conflicted with their cultural food needs and felt they had received biased treatment by professionals.[146]

A Canadian qualitative study[149] among an ethnically diverse group found both positive and negative themes. Negative effects included feeling pressured to fill multiple roles, financial impacts related to increasing costs of food to meet dietary requirements and a disconnect between the diabetes recommendations and their cultural practices. Positive effects were that women felt motivated to make health behavior changes after a diagnosis. Overall, the experience of GDM can be life-changing for women and other pregnant people. Experiences of screening alone are not well studied.

2.12 Summary

Despite decades of research into gestational diabetes screening, diagnosis and treatment, there remains significant debate and lack of consensus on how best to screen and diagnose GDM. Importantly, universal v. risk-based screening, screening approaches (one-step v two-step), screening criteria and guidelines, as well as timing of early screening are all key issues that should be reported in epidemiologic studies of GDM. Knowing how people are screened/diagnosed (i.e., which guidelines are used) as well as whether or not they are screened are both critical when comparing GDM rates across groups or over time. Well-designed epidemiologic studies of GDM are needed that accurately control for screening status and screening method in order to understand population-level changes in GDM diagnoses and associated perinatal outcomes.

2.13 Tables

Table 2.1 Glucose tests used in gestational diabetes screening and diagnosis

Test type	Glucose load	Timing of blood sample(s) usually associated with this test
Glucose challenge test (GCT)	50g	1-hour (after load)
Oral glucose tolerance test (OGTT)	75g or 100g	Fasting (before load) 1-hour (after load) 2-hour (after load) 3-hour (after load)
Hemoglobin A1c (HbA1c)	None	1 sample (anytime)
Fasting glucose test	None	1 sample (after fast)
Random glucose	None	1 sample (anytime)

Table 2.2 Major diagnostic and screening criteria for GDM (1960-2010)

Major criteria (1960-2010)	Year	Criteria defined for population to screen	Overall screening approach	Screening method (positive cut-off ≥)	OGTT glucose load	Criteria for diagnosis (≥ mmol/L) after OGTT				≥ values for diagnosis of GDM
						fasting	1-hr	2-hr	3-hr	
O'Sullivan[93] [a]	1964	Clinical risk	One-step		100g	5.0	9.2	8.1	6.9	2
O'Sullivan + Mahan[32] [a]	1973	Clinical risk	Two-step	50g-GCT (7.2)	100g	5.0	9.1	8.0	6.9	2
NDDG[94] [b]	1979		Two-step	50g-GCT (7.8)	100g	5.8	10.5	9.1	8.0	2
Carpenter-Coustan[95]	1982		Two-step	50g-GCT (7.8)	100g	5.3	10.0	8.6	7.8	2
IADPSG (HAPO OR-1.75)[38]	2010	Universal	One-step		75g	5.1	10.0	8.5		1

a. Criteria for diagnosis based on samples in whole blood

b. Abbreviations: National Diabetes Data Group = NDDG, Oral Glucose Tolerance Tests = OGTT, Glucose Challenge Test = GCT, International Association of Diabetes in Pregnancy Study Group =IADPSG, Hyperglycemia Adverse Pregnancy Outcomes =HAPO, OR = Odds Ratio

Table 2.3 Key studies and randomized trials impacting GDM screening and diagnosis in the early 2000's

Key studies	**Year(s) of study**	**Sample size**	**Criteria defined for population to screen**	**Overall screening approach**	**Screening method (positive cut-off ≥)**	**OGTT glucose load**	**Criteria for inclusion in RCT (≥ mmol/L) after OGTT**				**Criteria for treatment**
							Fasting[b]	1-hr	2-hr	3-hr	
ACHOIS[a] (Crowther RCT)[99]	2002-2007	485 / 473 treated / untreated	Either clinical risk OR positive on screen positive on GTT	Two-step	50g-GTT (7.8)	75g	≤ 7.8		7.8 to 11		2-hour within criteria
NICHD[a] (Landon RCT)[100]	1993-2003	490/510 treated / untreated	Universal	Two-step	50g-GTT (7.5-11.1)	100g	≤ 5.3	≥10	≥8.6	≥7.8	2 or 3 non-fasting values exceed criteria
HAPO[a] Study[33]	2000-2006	23,316	Universal	One-step		75g	≤5.8		≤11.1		

a. Acronyms: The Australian Carbohydrate Intolerance Study in Pregnant Women = ACHOIS, National Institute of Child Health and Human Development = NICHD, Hyperglycemia Adverse Pregnancy Outcomes =HAPO

b. Fasting plasma glucose (FPG)

Table 2.4 Overview of selected international and national guidelines for GDM diagnosis and screening

Organization or country	Year	Criteria defined for population to screen	Overall screening approach	Screening method (positive cut-off ≥)	OGTT glucose load	Criteria for diagnosis (≥ mmol/L) after OGTT				# ≥ for diag.	Standard criteria
						fasting	1-hr	2-hr	3-hr		
International[15,41,96]											
WHO	1980	NS	Two-step		100g	5.8	10.6	9.2	8.1	2	
WHO	1985	NS	Two-step		100g	7.0		11.1		1	
WHO	1999	NS	One-step		75g	6.1		7.8		1	
WHO	2006	Universal	One-step		75g	6.1		7.8		1	
WHO	2013	Universal	One-step		75g	5.1	10.0	8.5		1	**IADPSG**
US[117,150]											
ACOG	2013, 2018	Universal	Two-step	50g-GCT (7.2, 7.5 or 7.8)	100g	5.3 or 5.8	10 or 10.5	8.6 or 9.1	7.8 or 8	2	**C-C or NDDG**
ADA "Option 1"	2003	All but low risk	Two-step	50g-GCT (7.8)	100g	5.3	10.0	8.6	7.8	2	
ADA "Option 2"	2003	All but low risk	One-step		75g	5.3	10.0	8.6		2	
ADA	2011	Universal	One-step		75g	5.1	10.0	8.5		1	**IADPSG**
ADA "Option 1"	2014, 2018, 2021	Universal	One-step		75g	5.1	10.0	8.5		1	**IADPSG**
ADA "Option 2"	2014, 2018, 2021	Universal	Two-step	50g-GCT (7.2, 7.5 or 7.8)	100g					2	**C-C**
Canada[8,42,114,151–153]											
DC "Preferred"	1998	Clinical risk	Two-step	50g-GCT (7.8)	75g	5.3	10.6	8.9		2	
DC "Alternate"	1998	Clinical risk	Two-step	50g-GCT (7.8)	100g	5.3	10.0	8.6	7.8	2	**C-C**
DC	2003	Universal	Two-step	50g-GCT (7.8)	75g	5.3	10.6	8.9		2	
DC	2008	Universal	Two-step	50g-GCT (7.8)	75g	5.3	10.6	8.9		2	
DC "Preferred" (HAPO OR 2.0)	2013 & 2018	Universal	Two-step	50g-GCT (7.8 - 10.3)	75g	5.3	10.6	9.0		1	**HAPO OR 2.0**
DC "Alternate"	2013 & 2018	Universal	One-step		75g	5.1	10.0	8.5		1	**IADPSG**
SOGC	1992	Universal	Two-step	50g-GCT (7.8)	100g	5.3 or 5.8	10 or 10.5	8.6 or 9.1	7.8 or 8	2	**C-C or NDDG**
SOGC-Option 1	2002	Clinical risk	Two-step	50g-GCT (7.8)	100g	5.3 or 5.8	10 or 10.5	8.6 or 9.1	7.8 or 8	2	**C-C or NDDG**
SOGC-Option 2	2002	Clinical risk	Two-step	50g-GCT (7.8)	75g	5.3	10.6	8.9		2	**DC-2003**
SOGC "Preferred"	2016 & 2019	Universal	Two-step	50g-GCT (7.8)	75g	5.3	10.6	9.0		1	**HAPO OR 2.0**
SOGC "Alternate"	2016 & 2019	Universal	One-step		75g	5.1	10	8.5		1	**IADPSG**
Europe[15,83,154,155]											
EASD 1996	1996	NS	One-step			6.0		9.0		1	
NICE (UK)	2015	**Clinical risk**	One-step		75g	5.6		7.8		1	
Sweden-no standard criteria	2000-2015	Mixed	One-step		75g			12.2, 10 or 8.6	1		
Australasia[156]											
ADIPS	1998					5.5		8.0		1	
ADIPS	2013 & 2014	Universal	One-step		75g	5.1	10.0	8.5		1	**IADPSG 2010**

Organization or country	Year	Criteria defined for population to screen	Overall screening approach	Screening method (positive cut-off ≥)	OGTT glucose load	Criteria for diagnosis (≥ mmol/L) after OGTT				# ≥ for diag.	Standard criteria
						fasting	1-hr	2-hr	3-hr		
NZSSD 2004	1998, 2004	Universal				5.5		9.0			
NZ-MoH guideline	2014	Universal	One-step		75g	5.5		9.0		1	
Asia[15,41,157,158]											
Chinese Medical Association	2007		Two-step	50g-GCT (7.8)	100g or 75g					2	**ADA 2003 (either C-C or NDDG)**
Chinese Ministry of Health-preferred	2011	Universal	One-step		75g	5.1	10.0	8.5		1	**IADPSG 2010**
Chinese Ministry of Health-alternate	2011	Universal	Two-step	FPG	75g	5.1	10.0	8.5		1	**IADPSG 2010**
Chinese guidelines-preferred	2014	Universal	One-step		75g	5.1	10.0	8.5		1	**IADPSG 2010**
Chinese guidelines-alternate, low-resource	2014	Universal	Two-step	FPG (4.4-5.1)	75g	5.1	10.0	8.5		1	**IADPSG 2010 (two-step)**
DIPSI	2009	NS	One-step (non-fasting)		75g (*)			7.8		1	
JSOG/JDS	1984	Universal	Two-step	OGTT 75g any GA	75g	5.5	10.0	8.3		2	
JSOG	2013/2010	Universal	Two-step	OGTT 75g any GA	75g	5.1	10.0	8.5		1	
South America[110,159]											
BSD	2007	Universal		FPG (4.7)	75g		7.0				
BSD	2016	Universal		FPG (5.1-6.9) (1st trimester<20wks)	75g	5.1	10.0	8.5		1	**IADPSG 2010**
Chile Ministry of Health	previous and 2015	Universal	One-step		75g	5.6		7.8			
Africa[121,160]											
Nigeria- no standard	2021	Mixed	Mixed								
SEMDSA (not approved by OB group)	2007	Universal	One-step		75g	5.1	10.0	8.5		1	IADPSG 2010

a. Abbreviations: World Health Organization=WHO; American College of Obstetricians and Gynecologists = ACOG; American Diabetes Association = ADA; Diabetes Canada = DC (formerly, Canadian Diabetes Association or CDA); Society of Obstetricians and Gynecologists of Canada = SOGC; European Association for the Study of Diabetes = EASD; National Institute for Health and Care Excellence = NICE; Australasia Diabetes in Pregnancy Study Group = ADIPS; New Zealand Society for the Study of Diabetes = NZSSD; Diabetes in Pregnancy Study Group of India = DIPSI; Japan Society of Obstetricians and Gynecologists= JSOG; Sociedade Brasileira de Diabetes/Brazilian Society of Diabetes = BSD; Society for Endocrinology, Metabolism and Diabetes of South Africa= SEMDSA

3 A VALIDATION OF USING INSURANCE BILLINGS DATA TO ASSESS ANTENATAL SCREENING DATA AGAINST MEDICAL RECORDS DATA

To obtain data on gestational diabetes screening in BC, I planned to use billings data from BC's Medical Services Plan. However, before billings data could be used in applied epidemiologic research, it was critical to understand their accuracy. Billings data are not collected for research purposes, and in some contexts, may not accurately define clinical conditions of interest. This study was the first of which we are aware to validate the use of antenatal screening and gestational diabetes screening billings data for epidemiologic research in Canada. Our finding that laboratory billings data for gestational diabetes screening and other antenatal screening tests have excellent validity against a gold standard of medical chart review opens up new avenues for researchers to advance our understanding of gestational diabetes. A version of this chapter is in In-press in the journal Epidemiology.

3.1 Synopsis

Background: Prevalence statistics for pregnancy complications identified through screening such as gestational diabetes usually assume universal screening. However, rates of screening completion in pregnancy are not available in many birth registries or hospital databases. We validated screening test completion by comparing public insurance laboratory and radiology billing records with medical records at three hospitals in British Columbia, Canada.

Methods: We abstracted a random sample of 140 medical records (2014-2019), and successfully linked 127 to valid provincial insurance billings and maternal-newborn registry data. Billing records for gestational diabetes screening, any ultrasound before 14 weeks gestational age, and Group B streptococcus screening during each pregnancy were compared to the gold standard of medical records by calculating sensitivity and specificity, positive predictive value, negative predictive value and prevalence with 95% confidence intervals (CIs).

Results: Gestational diabetes screening (screened v. unscreened) in billing records had a high sensitivity (98% [95% CI: 93, 100]) and specificity (>99% [95% CI: 86, 100]). The use of specific glucose screening approaches (two-step v. one-step) were also well characterized by billing data. Other tests showed high sensitivity (ultrasound 97% [95% CI: 92, 99]; Group B streptococcus 96% [95%CI: 89, 99]) but lower negative predictive values (ultrasound 64% [95%CI: 33, 99]; Group B streptococcus 70% [95%CI: 40, 89]). Lower negative predictive values were due to the high prevalence of these screening tests in our sample.

Conclusions: Laboratory and radiology insurance billing codes accurately identified those who completed routine antenatal screening tests with relatively low false positive rates.

3.2 Background

Routine health care during pregnancy involves a number of screening tests and procedures[1] to optimize the health of the woman or pregnant person, and the developing fetus. Three recommended procedures and tests include: a first trimester ultrasound (<14 weeks) for gestational age estimation, a gestational diabetes screening test (usually between 24-28 weeks)[8] and a Group B streptococcus test (recommended between 35-37 weeks of a term pregnancy).[2] Most data sources for monitoring perinatal complications use a 'chart by exception' approach whereby individuals are assumed to not have a given condition unless specifically noted in their medical record. For conditions in which case status is established through screening, this approach makes the assumption that the population is 100% screened. However, screening uptake decreases when tests are uncomfortable, time-consuming, or controversial, or when individuals experience barriers to health care.[85,124,141,161] As a result, if rates of a disease or condition ascertained by screening increase or decrease, public health officials cannot determine if this change is an artefact of changes in screening practices or a true change in disease prevalence. Accurate data on screening rates during pregnancy is critical to disentangle these factors.

Recommendations for gestational diabetes screening, in particular among antenatal tests, have shifted repeatedly.[42,78,105] Furthermore, rates of gestational diabetes have been increasing over time, for reasons which are not clearly understood.[14,42,162] The reported prevalence of gestational diabetes assumes universal screening; however screening rates differ among populations.[124,163,164] As a result, it is unclear whether current prevalence estimates are accurately reflecting population-level screening rates.

We hypothesized that billing records from radiology and laboratory services with test-specific codes could potentially be used to monitor antenatal screening rates for routinely recommended pregnancy screening tests. Billing records have been previously used to characterize cancer screenings among non-pregnant groups[165,166], for infectious disease screening during pregnancy[167–169] and for post-partum diabetes screening.[170] Billings from a commercial claims database in the United States have been used to characterize guideline-based routine antenatal screening tests; however, no validation of this method was cited.[161] Therefore, we compared administratively-collected insurance billings data on the completion of three recommended antepartum screening tests conducted across different trimesters of pregnancy (1st trimester ultrasound, gestational diabetes screening and a Group B streptococcus test) with medical records in British Columbia, Canada to validate the use of billings records to characterize these antepartum screening tests.

3.3 Methods

3.3.1 Data

3.3.1.1 Medical records

We obtained a stratified random sample of 140 medical records from births at 3 hospitals in British Columbia (BC), Canada from Jan 1, 2014 to Dec 31, 2019. This included two of five health regions in the province, and two high-volume urban teaching hospitals and one small rural hospital. The number of records was based on being able to calculate a 95% confidence interval with a precision of +/- 5% for an estimated prevalence of 90% for screening. Hospitals were selected to provide variability in case-mix, region and demographics while limiting to two health regions for feasibility. The requested records were evenly stratified by health care professional type at delivery (either Registered Midwife, Family Practice Physician, or Obstetrician) (Appendix A, Antenatal health care professional type coding). Data abstraction was performed by a BC Registered Midwife. This project was approved by the University of British Columbia Research Ethics Board (#H20-00741).

3.3.1.2 Administrative data

Population Data BC is a multi-university data platform that provides researchers with access to population-level datasets for British Columbia. For this study, we accessed claims data from BC's Medical Services Plan (MSP) and the Perinatal Data Registry (a chart-abstracted, quality-controlled dataset of all births >500g and >20 weeks)[171,172]. The universal Medical Services Plan covers all eligible residents except for a small population who are insured by the Federal government (estimated at <5% of total BC population)[173].

Antenatal care visits, out-patient laboratory, and hospital laboratory services are billed to the public health insurance plan through a fee-for-service model. Abstracted medical records from this study were linked to the administrative datasets by personal health number and date of birth, and deidentified by Population Data BC prior to analysis. We extracted billing codes for each pregnancy in the medical records study group.

3.3.2 Measures

3.3.2.1 Antenatal screening tests

We assessed screening test status (screened/unscreened/missing) from medical records and from billing codes (Table A.1) for: any ultrasound prior to 14 weeks,[174] any gestational diabetes screening, and any Group B streptococcus test by vaginal-rectal swab.[175] We also assessed screen completion for two gestational diabetes screening methods as per current Canadian guidelines: either a "two-step" approach

("preferred"), or a "one-step" approach ("alternate"). A "two-step" involved a preliminary 50g glucose challenge test, and if positive, a second diagnostic test with a 75g 2-hour fasting glucose tolerance test. The "one-step" approach required a single 75g 2-hour fasting test (details in Appendix A. Additional information on administrative data sources and linkages in this study).[8]

For each medical record, we examined any antenatal, labor or delivery records, consultant notes, or laboratory or radiology reports to ascertain completion of screening tests (Figure A.2, Figure A.3, Figure A.5 and Figure A.6 for detailed decision trees used to derive screening test status from medical records). To resolve any discrepancies in the medical record, we used primary sources such as laboratory reports. If there were no data on a test, a clear indication that a test was declined, or no antenatal care, this was coded as "unscreened". If we were unable to determine test status due to missing or incomplete records, then the test result was coded as "missing".

To derive screening status from administrative data using billing codes (Figure A.6 and Figure A.7), we searched each pregnancy's billing claims for the presence of specific fee codes. One-step screening was assigned if only a 75g test was billed, or if the 75g service date was before other glucose testing. Two-step screening was assigned if there was only a 50g test or if the 50g service date was within 45 days before a 75g test. If there was no billing for the specific test, and health insurance registration was active for this pregnancy, then screening status was set to "unscreened". If health insurance was inactive, then the screening status was set to "missing".

3.3.2.2 Other clinical data

We used clinical and demographic data from the BC Perinatal Data Registry[176] (BC-PDR) to stratify the results by subgroups. Antenatal health care professional type ("Family practice physician", "Obstetrician" or "Registered Midwife", or "Unknown and/or <3 visits") was defined using billing codes via a previously published method.[177] Generally, this required a minimum of 3 antenatal care visits or one full trimester of care with the specified provider type (Table A.12, Table A.13). Additional data for pregnancy characteristics was also extracted from the medical records and from the BC-PDR (Table A.11).

3.4 Analysis

We present basic clinical characteristics, antenatal screening test results, and completion rates as abstracted from medical records and derived from billing codes. Tests for association used chi-squared and Fisher's exact tests (when expected cell counts <5). We considered medical records as the gold standard as this reflected the primary record of patient care and use of billings to ascertain screening data

was a new approach. Using medical records as the gold standard, we calculated the sensitivity (probability of being identified as screened using billings, given a true screened result in medical records), specificity (probability of being identified as and unscreened using billings, given a true unscreened result in medical records), negative predictive value (probability that being unscreened by billings represents a true 'unscreened' case), and positive predictive value (probability that being screened by billings represents a true 'screened' case).[178] Sensitivity and specificity were based on non-missing data from medical records. We also calculated the true prevalence as the percentage of pregnancies screened (v unscreened) for each test from the medical records data. For all our calculations, we derived sampling weights to account for our stratified sampling scheme (by care provider type at delivery) and applied weights to all calculations to enable our results to reflect the hospital populations from which they were sampled (see Appendix A. Sample size, strata and sample weights). Results are presented with 95% confidence intervals[179,180] and analyses were performed using R (v 4.0.5)[181].

To inform future probabilistic bias analyses, we also calculated validation parameters with 95% confidence intervals by subgroups: antenatal health care professional type[177], body mass index ($\geq$30 kg/m^2 v. <30 kg/m^2), maternal age (<35 years v. 35+) and parity (nulliparous v. multiparous). This could be used to quantify the contribution of systematic errors to research based on screening data.

To discuss how having data on screening completion could impact diagnostic prevalence, we calculated true prevalence (excluding those unscreened) compared to an observed prevalence (including all individuals in the denominator regardless of screening status) for both gestational diabetes diagnoses and Group B streptococcus positivity ascertained from medical records.

Some additional obstetric variables captured in the perinatal data registry were also validated although this was not the primary focus of this manuscript as these have been previously validated elsewhere[176]. Additional variables were validated with similar approaches for categorical results and calculated intraclass correlation coefficients for continuous results (e.g., infant birthweight, gestational age at delivery, weeks on 1st trimester ultrasound). We also compared gestational diabetes diagnosis, treatment method (diet or medication), Group B strep positivity, delivery outcomes and care provider type as ascertained from the perinatal data compared to medical records.

3.5 Results

While 140 medical records were abstracted, only 135 medical records were linked to administrative data (Figure A.7). Unlinked records resulted from inconsistencies with personal health numbers or dates of birth between data sources (identifiers). The final sample for calculating sensitivity, specificity, negative

and positive predictive values was further reduced due to missing data in either medical records or billings-based data. Eight records were missing billings-based screening data because of incomplete insurance status throughout the pregnancy (Figure A.1), leaving a maximum of 127 records for the validation analysis. Detailed ascertainment of screening test data (screened, unscreened, and missing) from medical records are shown in Figure A.2 to Figure A.5. Of interest, being classified as 'unscreened' was most frequent for gestational diabetes screening (n=16, of which 12 were 'declined'), followed by Group B strep screening (n=10 records, of which 9 were scheduled cesarean deliveries), and 1st trimester ultrasound (n=8, 4 declined). Demographics for the full sample (n=135) and those with complete insurance status (n=127) were similar (Table A.2). The study population was predominantly multiparous (63%), and slightly over half received care from a family practice physician (58%) (Table 3.1).

The prevalence of screening completion for all tests was similar using both methods (medical records v. billing codes) (Table 3.2). Billing codes-based screening results had high completion rates (>94%). Medical records indicated that gestational diabetes screening had been completed but did not include specific glucose screening tests results in 42% (53/125) of cases, therefore these were coded as missing for screening approach (one-step or two-step). As a result, gestational diabetes screening test type was more difficult to ascertain (57% completion) using medical records, but well-captured by billing codes (94% completion).

Billing codes methods (Table 3.3) had a high sensitivity and positive predictive (values between 92 to >99% depending on the screening test). For gestational diabetes screening, specificity (95 to >99% for different tests) and negative predictive values (95 to >99%) were also high. Billing codes-based 1st trimester ultrasounds had a lower specificity (78% [95% CI 33, 99]) and negative predictive value (64% [95% CI 33, 99]) than other tests. However, the overall prevalence of first trimester ultrasounds was very high (>94%) which decreases negative predictive values.

When examining validation results (Table A.3), sensitivity was generally high in all subgroups. Specificity in subgroups varied by screening test. Specificity for gestational diabetes screening test type was also high (>87 to 100%) for all subgroups. Screening prevalence (weighted) based on medical records suggested lower screening among multiparous individuals, and by antenatal care provider type; however, confidence intervals were overlapping in most cases.

The risk of diagnosis of gestational diabetes in our validation sample among those screened was 19% [95% CI 11, 27] compared to an observed risk of 14% [95% CI 9, 23] in the full sample. The true risk of positivity for Group B streptococcus was 25% [95% CI 15, 34] compared to an observed risk of 21% [95% CI 13, 29].

Additional validation of variables available from the BC-PDR for diagnosis of gestational diabetes and other obstetric characteristics are reported in the Appendices (Table A.6, Table A.7, Table A.9, Table A.10). Of note, completion rate for weight of pregnant person (kg) (50%) at hospital admission was particularly low in the perinatal data registry (BC-PDR), otherwise, completion was similar in the BC-PDR to medical records. Specificity of Group B streptococcus testing (screened v unscreened v missing) in the PDR was very low (16%). Completion of a 1st trimester ultrasound also had lower specificity (60%) but high sensitivity in the PDR compared to medical records. Gestational diabetes diagnosis showed 100% agreement across the two data sources; however, mode of treatment (medication or diet controlled) had lower sensitivity (92% for diet controlled, 85% for medication controlled) but high specificity (99%, both). Intraclass correlations for all continuous secondary variables we assessed were generally high (>90%) except for pre-pregnancy weight (kg) (ICC 56%).

3.6 Discussion

In this study, routinely-collected laboratory and radiology billing codes data accurately identified screening test completion for three recommended antenatal screening tests. Billing codes also accurately identified test completion of either a one-step or a two-step gestational diabetes screening approach in a population where both approaches could be used as per national guidelines.[42] These results support the use of billing codes data as a strategy to help monitor trends in screening-based pregnancy complications such as gestational diabetes, and better understand the impact that choice of screening approach has on apparent disease rates. For example, the observed risk of diagnosis of gestational diabetes in our sample was 14% using a chart-by-exception approach, whereas the true diagnostic risk appeared higher (19%) after accounting for screening status.

The study was limited to delivery-based medical records from only three hospitals. However, billings for laboratory tests or radiology are likely consistent across the province since all facilities, both outpatient laboratories and hospitals, bill for these tests using fee-for-service billings.[29] Other limitations include: record abstraction by a single individual and no data for race or ethnicity. Our sample was randomly allocated, used both paper and electronic records and we carefully assessed screening completion from records using detailed algorithms. Screening may be implemented differently in some subgroups or regions. For example, gestational diabetes risk can be assessed using non-standard methods such as doing 1 week of daily glucometer monitoring. This approach to screening would not be captured in billings data, therefore our study may not be generalizable to those screening situations. However, findings from this study should be generalizable to other health care systems where codes (e.g., Current procedural terminology CPT) identify billings for reimbursement and with similar screening practices. In a single-

payor system as in Canada, it is also important to consider that billings data is limited to those with active insurance registration.

Billing codes also performed well across subgroups by parity, antenatal care provider, pre-pregnancy obesity and age and did not display any clear directional biases across subgroups or test types. However, our subgroup analyses were restricted to small samples and billing codes may be less accurate in subgroups where private-pay options are accessed more frequently. In particular, assisted reproductive technologies are not covered by public insurance in British Columbia and may include early ultrasounds.[182] Thus, billing records may underestimate the prevalence of ultrasound completion prior to 14 weeks gestation in some subgroups, and we noted a low specificity (50%) in those with older maternal age at delivery.

Characterizing those who are unscreened is critical for estimating the true prevalence of antenatal conditions and complications that follow from screening. This approach could help identify populations with low screening uptake, target health professionals to improve the use shared decision-making and unbiased communication,[183,184] address screening barriers, or provide culturally appropriate resources.[185] Both barriers to care, as well as individual values and preferences can impact screening uptake. Of note, a recent survey study in British Columbia found that 305/2100 (14.5%) declined gestational diabetes screening in pregnancy.[125] The prevalence of gestational diabetes is increasing in many jurisdictions, but it is unclear whether this represents a true increase in disease incidence or an artefact of changes in screening practices, since the screening approach (one-step v. two-step) impacts prevalence (with a one-step screening having a lower diagnostic threshold).[42] This billing codes-based method provides a novel way to identify the impact of screening approach (one-step v two-step) on disease incidence where individual laboratory test data is not available. Given ongoing debate around best practices for gestational diabetes screening, one-step screening may have decreased during the COVID-19 pandemic, as this approach requires more in-person time in an outpatient laboratory.[186] Use of billing codes to capture screening approaches could be an important assessment tool for further studies on the impact of practice changes on gestational diabetes outcomes.

Overall, these results support the use of billing codes to capture completion of three antenatal screening tests, as well as two different approaches to screen for gestational diabetes. The method we developed and validated in this study could be used to reduce information and diagnostic bias in future studies that rely on gestational age ascertainment using early ultrasound, or in research on gestational diabetes or Group B streptococcus disease in newborns.

3.7 Tables

Table 3.1 Population characteristics in a validation study of antenatal screening in BC, Canada 2014-2019

Characteristic	Linked to administrative data **N = 135** n (%)	weighted (%)[a]
Parity		
P0	54 (40%)	(37%)
P1-P3	76 (56%)	(60%)
P4 or more	5 (4%)	(3%)
Age of birthing person at delivery (years)		
< 24	14 (10%)	(9.5%)
25-29	36 (27%)	(28%)
30-34	51 (38%)	(38%)
35-39	28 (21%)	(20%)
40+	6 (4%)	(5%)
Pre-pregnancy body mass index (BMI) (kg/m^2) [b]		
<24.9 (Underweight or Normal)	59 (44%)	(43%)
25-29.9 (Overweight)	30 (22%)	(20%)
30+ (Obese I, II, III)	19 (14%)	(15%)
missing data	27 (20%)	(22%)
Neighbourhood income quintiles per person[c]		
lowest income	29 (21%)	(23%)
mid-low income	28 (21%)	(20%)
middle income	18 (13%)	(16%)
mid-high income	33 (24%)	(24%)
highest income	13 (10%)	(9%)
missing or NA	14 (10%)	(10%)
Antenatal health care professional type[d]		
Family practice physician	54 (42%)	(58%)
Registered Midwife	52 (40%)	(23%)
Obstetrician	23 (18%)	(19%)
Unknown or ≤2 antenatal health care visits	6	
Multifetal pregnancy	<5[f]	(3%)
Gestational age at delivery		
preterm (<37 weeks)	12 (7%)	(8%)
term (37 + weeks)	123 (93%)	(92%)
Mode of delivery[e]		
Cesarean	46 (34%)	(35%)
Operative vaginal	13 (10%)	(11%)
Spontaneous vaginal	76 (56%)	(54%)

a. % weighted by sampling weights for stratified design as described in Appendix A Sample size, strata and sample weights.

b. Pre-pregnancy body mass index (BMI) was ascertained from medical records which record a pre-pregnancy weight and height. We calculated BMI and reported by categories as defined by the Institute of Medicine standards.38

c. Neighbourhood income quintiles (based on Statistics Canada data)39 represent the average income in the area (census tract). Census tracts were linked by the data stewards at the residential postal code level for the residence of the birthing person/mother.

d. Antenatal health care professional type was defined using billing codes27 and required a minimum of 3 routine antenatal care visits with the specified provider type. Consultation visits were not included. Number of visits were assessed using counts of prenatal care fee-for-service billing codes by professional type.

e. Mode of delivery, gestational age at delivery, parity, is reported from medical records. Age is reported from administrative data.

f. Cell sizes <5 suppressed as per Perinatal Services BC policy

Table 3.2 Antenatal screening test outcomes for medical records and billing codes data in a validation study in British Columbia, Canada 2014-2019

	Medical records data N = 135	**Billing codes data N = 135**	**Differences in screen prevalence p-value[a]**
Screening test	n screened/total non-missing (screened % in sample)	n screened/total non-missing (screened % in sample)	
First ultrasound at <14 weeks	114/123 (93%)	113/127 (89%)	0.31
Completion rate	91 %	94 %	
GDM screened	114/131 (87%)	107/127 (84%)	0.53
Completion rate	97 %	94 %	
Two-step GDM screening approach	28/77 (36%)	53/127 (42%)	0.45
Completion rate	57 %	94 %	
One-step GDM screening approach	32/77 (42%)	54/127 (43%)	0.89
Completion rate	57 %	94 %	
Screened for GBS at term	116/130 (89%)	113/127 (89%)	0.95
Completion rate	96 %	94 %	

a. Pearson's Chi-squared test

Table 3.3 Antenatal screening test validation parameters for billing codes compared to medical records data in a validation study in British Columbia, Canada 2014-2019

Screening test	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Prevalence in medical records data	Prevalence in billing codes data
Ultrasound at <14 weeks gestation	97 (92, 99)	78 (33, 99)	99 (92, 99)	64 (33, 99)	94 (87, 98)	90 (83, 95)
Gestational diabetes (GDM) screened	98 (93, 100)	100 (86, 100)[a]	100 (93, 100)[a]	88 (64, 97)	87 (79, 93)	84 (76, 90)
Two-step GDM screening approach	100 (80, 100)[a]	95 (80, 100)	93 (74, 98)	100 (80, 100)[a]	40 (27, 53)	40 (31, 50)
One-step GDM screening approach	92 (72, 99)	100 (80, 100)[a]	100 (71, 100)	95 (82, 100)	39 (27, 53)	44 (34, 54)
Group B streptococcus test	96 (89, 99)	79 (47, 96)	97 (89, 99)	70 (40, 89)	88 (80, 94)	87 (79, 93)

a. Confidence intervals reported with unweighted data because survey-weighted methods did not provide valid estimates due to 100% agreement.

4 TRENDS IN GESTATIONAL DIABETES SCREENING PRACTICES IN BRITISH COLUMBIA: A DESCRIPTIVE STUDY

Having demonstrated that laboratory billing data can accurately capture gestational diabetes screening, we could then confidently use British Columbia's population-level billing records to explore time trends and variability of gestational diabetes screening across subgroups. This study was the first of which we are aware to present descriptive data on gestational diabetes screening across BC, both by time period and in the context of known policy changes. We showed differences in screening among population subgroups with particular regional differences. Descriptive epidemiology can generate new hypotheses to further advance our understanding of GDM screening patterns, uptake and barriers. These data are also important for public health surveillance in BC.

4.1 Synopsis

Background: In October 2010, British Columbia shifted to recommending gestational diabetes screening use a one-step approach for all pregnant people. However, the province retained availability of a two-step approach. The shift to one-step screening was to align with new international guidelines and was expected to increase prevalence of GDM since the diagnostic threshold was lower than using a two-step approach. Later, in 2013, national guidelines recommended one-step as an alternate method only. The impact of these guideline and policy changes on rates of one-step screening is unknown and could differ by region or obstetric risk factors. Therefore, we assessed trends in one-step gestational diabetes screening over the study period and by subgroups.

Methods: We conducted a descriptive study using de-identified linked perinatal and laboratory billing data. We included all pregnancies, delivered after 28 weeks gestation with screening dates from June 1 2004 to May 31, 2019. We assessed screening method prevalence with 95% Confidence Intervals, plotted time trends, and examined risks in subgroups and by region.

Results: After BC's policy change in 2010, use of one-step screening increased sharply from 2.0% (95% CI 1.9, 2.0) to a peak of 53.9% (95% CI 53.4, 54.5) in 2013. Following the Diabetes Canada 2013 update, one-step screening decreased to 39.3% (95% CI 38.8, 39.8) in 2015. Higher use was observed for people with risk factors and in the southwest, urban regions.

Interpretation: One-step gestational diabetes screening uptake increased rapidly but did not reach 100%, despite provincial guidelines. Current gestational diabetes screening in BC demonstrates higher use of one-step screening among people with risk factors but there are strong regional disparities in screening practices. Since one-step screening increases diagnostic prevalence, more use of a one-step screening approach would require increased capacity for diabetes-associated treatment during pregnancy.

4.2 Background

Gestational diabetes is defined as any glucose intolerance resulting in a transient hyperglycemia with first onset during pregnancy[8] but specific thresholds to use for diagnosis are a subject of persistent debate.[39] Gestational diabetes is one of the most commonly diagnosed complications of pregnancy but its prevalence varies from 2 to 40%,[13] in part, based on screening and diagnostic practices in a particular region. Following the Hyperglycemia and Adverse Pregnancy Outcomes (HAPO) study in 2008[33], the International Association of Diabetes in Pregnancy Study Group (IADPSG) released new guidelines[38] recommending a one-step 75g diagnostic test for all pregnant people. In subsequent years, the IADPSG guidelines have been the subject of much controversy[15,187] as there is clear evidence that this increases prevalence by up to 2-fold.[15] Part of this debate stems from a desire to balance possible harms[89,144] and system-level costs[117] of diagnosing and treating a higher number of people with milder hyperglycemia against the potential reduction of some perinatal risks.[33]

In British Columbia, in October 2010, the Province switched from using a two-step screening approach to recommending a one-step approach using the IADPSG criteria for *all* pregnant people.[105] However, two-step screening was still available at the patients' or providers' preference and the extent to which this policy recommendation (for one-step) was followed is not known. No Canadian guidelines or standards at this time specified one-step screening.[42]

In April 2013, Diabetes Canada revised their guidelines (DC-2013) with two-step screening as the "preferred" option (using updated set of thresholds) and one-step as an "alternative" (using IADPSG criteria).[42,105] In July 2016, the Society of Obstetricians and Gynecologists of Canada updated their guidelines (SOGC-2016) for the first time since 2002 to align with the 2013 Diabetes Canada guidelines. Thus, there were three policy and guideline changes that may have impacted gestational diabetes screening practices in British Columbia between 2010 and 2016.

Screening for gestational diabetes is not captured by perinatal data registries in this province, or in most jurisdictions, thus screening patterns are not well characterized. Understanding screening use, especially in response to guideline changes, could provide critical insights about system or individual-level barriers to care, provider practice patterns and/or opportunities for education or outreach. Therefore, we assessed the uptake of one-step screening across BC by region, health care professional type and other patient subgroups.

4.3 Methods

4.3.1 Data source

We obtained data via Population Data BC, a multi-university platform[50] that provides researchers with access to deidentified and linked population-level administrative datasets for British Columbia. For this study, we accessed insurance billing records from BC Medical Services Plan (MSP), chart-abstracted perinatal data from the BC Perinatal Data Registry[176] (pregnancies resulting in liveborn infants or still-births ≥20 weeks and ≥500g), birth certificate data, and the MSP consolidation file that links individuals to census-derived data.[50] Using MSP billing records, we defined active health insurance status if active coverage was maintained for over 90% of the duration of the pregnancy. The study population was restricted to linked pregnancies (> 28 weeks gestational age at birth), birthing parents or mothers who resided within the province, who had active health insurance, no pre-pregnancy diabetes, were screened for gestational diabetes and whose first prenatal care visit (by billings) occurred prior to the 7th month of pregnancy. We restricted to active provincial health insurance because our method to assess gestational diabetes screening required complete billings data for the pregnancy. The study population included pregnant individuals whose gestational diabetes screening test occurred between June 1, 2004 and May 31, 2019.

4.3.2 Measures

Primary outcomes were gestational diabetes screening with either a one-step, two-step or an 'other glucose test' approach. A one-step approach was defined by billings for only a diagnostic glucose test which did *not* occur within 45 days after a glucose screening test billing. The timing limitation was to exclude cases where an early glucose test was included with a prenatal blood panel as this "early" test is not part of the usual second trimester (24-28 weeks) gestational diabetes screening. A two-step approach was defined by the presence of any billing for a gestational diabetes glucose screening test. An 'other glucose test' was identified if neither a one-step or a two-step was coded, and billing records for either a HbA1c or a random plasma glucose test were present. Our method to characterize gestational diabetes screening was previously validated against medical records with high sensitivity and specificity (Chapter 3).

We obtained individual-level obstetric and demographic characteristics from the BC Perinatal Data Registry[50,176] for parity (P0, P1-3, P4 or more), age at delivery (less than 25 years, 25-34 years, 35+ years), pre-pregnancy body mass index (in kg/m^2, by Institute of Medicine criteria[54]), a measure of low/moderate medical and obstetric risk (yes v. no),[177] local health region (rural v urban) and planned

home births (yes v. no). The risk variable was based on criteria derived by McRae[177] with the inclusion of no prior adverse fetal/neonatal outcome (no prior congenital anomaly, neonatal death or stillbirth).

Using antenatal billings from MSP, we derived prenatal care utilization using the Adequacy of Prenatal Care Utilization Index criteria[177,188] and the antenatal health care professional (HCP) type during prenatal care ("Family practice physician", "Obstetrician", "Registered Midwife" or "missing") using a previously developed approach.[177] The HCP criteria required a minimum of three antenatal care visits with that HCP type and was intended to represent care provided during the time gestational diabetes screening would normally occur (24-28 weeks). The "missing" group included those with a low number of antenatal care visits (<3 visits billed or <1 full trimester of midwifery care) or who could not be assigned. We also classified birth region of mother/birthing person (Canada or USA v. Asia or Arab countries v. All others) using country indicated on the infant birth certificate.[50]

We classified region of residence (mapped by Population Data BC at the postal code level) of birthing person at the local health area (LHA) level in four groups to represent different levels of access to health services (Metro Vancouver or Victoria v. Northern v. Other southern cities v. Rest of province). Local health areas are geographic regions defined by the BC Ministry of Health. The "Other southern cities" group included medium sized cities outside of the Vancouver/Victoria area that also have a tertiary or regional hospital located in their city. The "Northern" group included all of the northern health region. We also reported neighbourhood income quintiles (based on Statistics Canada)[50] representing the average income in the area (census tract). Rural (v. urban) was indicated by LHA having a population < 10,000 people. Last, we identified individuals with prior pregnancies in the study cohort and created a variable for the current pregnancy that represented a history of a gestational diabetes diagnoses for any prior pregnancy (any history of GDM, no previous GDM, unknown). Because this could only be assessed for a subset of pregnancies who had a prior delivery in BC during the study years, we maintained a separate category for those who could not be assessed.

4.3.3 Statistical analysis

We calculated screening rates with 95% confidence intervals for each gestational diabetes screening approach and for those unscreened, in the whole study population and among subgroups defined by individual-level, health care systems and regional characteristics of interest.

Monthly and yearly rates were defined using the date of the glucose test of interest for the identified screening approach. Thus, plots are based on the date of the first screening test for gestational diabetes. Using monthly rates, we plotted time trends for all screening approaches. We plotted annual one-step screening rates in subgroups by parity, age, body mass index, health care professional type, health region,

rural status and antepartum risk. Yearly rates were calculated for June 1 to May 31 in each year to report annual rates from the start and end dates of the study.

On all plots, we also indicated dates of *three* policy and guideline changes: a BC-only policy change to using a one-step approach (October 2010)[105], the Diabetes Canada 2013 guidelines (April 2013)[189] and the SOGC 2016 guidelines (July 2016)[152]. We report prevalence rates of the one-step approach in four time periods relative to each guideline change and mapped regional trends at the Health Services Delivery Area level. Statistical analysis and mapping were done using R 4.0.6.[181]

Additional descriptive data for rates of gestational diabetes diagnosis and treatment, by screening approach, are reported from 2011 after one-step screening was included. We also mapped screening and diagnoses rates by health region. Sensitivity analyses were undertaken to confirm that descriptive results were not substantially altered after adjusting for multiple confounders. We also modeled univariate and adjusted relative risks (RR) for one-step gestational diabetes screening for each subgroup characteristic using a modified Poisson binomial[190] regression approach.

4.4 Results

A total of 525,720 pregnant people were screened for gestational diabetes after excluding 51,021 (8.8%) who were classified as unscreened (Table 4.1, Table B.1). Overall screening prevalence with any glucose test was 91.2% (95%CI 91.1, 91.2) and increased over the study period (from 89% to 95%). Screening prevalence was lower for those with high parity (P4 or more) (77.5%), inadequate antepartum care (77%) or who had midwife-led care (80%) (Table 4.1). Among those screened, prevalence of the two-step method was 69.4% (95%CI 69.2, 69.5), prevalence of the one-step method was 25.8% (95%CI 25.6, 25.9) and 4.9% (95%CI 4.8, 4.9) for other glucose methods (Table 4.1).

Among all screened pregnancies, one-step screening uptake was lowest in the Northern region (4.1%), among rural residents (11.1%) and younger people (< 25 years old at delivery) (15.8%) (Table B.4). By contrast, one-step screening uptake was high for individuals with known risk factors for gestational diabetes: specifically, a previous diagnosis of gestational diabetes (51.1%), pre-pregnancy body mass index greater or equal to 35 kg/m^2 (Obese II or III[54]) (34.3%), age $\geq$ 35 years (30.8%), birthing parent born in Asia or Arabia (33.1%) and with moderate/high antepartum medical or obstetric risk (31.7%). An "other glucose test" was used more frequently for parous people (15.4% for P4 or more), midwife-led care (13.5%), inadequate prenatal care (11.6%) or planned home births (26.5%).

After October 2010 (Figure 4.1) use of the one-step screening method increased from 2% to over 50% of the screens conducted by the beginning of 2012. After the DC-2013 guidelines were published (specifying one-step an "alternate" method), one-step screening rapidly declined from 60% in early 2013 to 40% by 2014 (Table B.5). After the SOGC 2016 guidelines, one-step further declined to 37%. Following both guidelines publication dates, there appeared to be a 4-month delay before screening methods changed.

One-step screening by subgroups revealed differences over time (Figure 4.2, Table 4.1). During the initial time period after BC's policy change, there was less difference in uptake of one-step screening across risk strata. However, after the DC-2013 report was released, one-step uptake remained highest for those *with* risk factors for gestational diabetes (prior GDM, older age, higher pre-pregnancy BMI, medical risk (Figure B.3, Figure B.4, Figure B.5, Figure B.6, Figure B.7, Figure B.8). Irrespective of any changes in guideline, one-step screening was low across all subgroups in the northern region (~2-6%).

All health care professional groups increased use of a one-step approach following the BC policy change but use only remained high (>50%) among obstetricians after the DC-2013 and SOGC-2016 guideline changes (Figure B.3). By 2013, (Figure 4.2) one-step screening was highest (66%) in the large urban cities (Vancouver and Victoria), lower in the other Southern cities and rural areas (33%) and lowest (3%) in the Northern region. Subgroups within regions showed similar trends to the full population relative to the baseline uptake in each region. The only characteristic that had substantially higher uptake of one-step screening across all regions was a prior history of gestational diabetes. Maps showed similar trends and that rates of diagnosis were also highest in the southern, urban regions (Figure B.10 and Figure B.11). Multiple regression analyses did not alter overall findings (Table B.2). Among those screened with a one-step method, 18% were diagnosed with gestational diabetes compared to 9% of those screened with a two-step approach. (Table B.3 and Figure B.9)

4.5 Interpretation

Following a 2010 province-wide policy that recommended one-step screening approach for *all* pregnant people,[105] only about 50% of eligible pregnancies were screened using this approach by 2012. Subsequently, the 2013 Diabetes Canada guideline countered the BC policy by labelling two-step as a "preferred" approach compared to one-step as an "alternate". This led to a rapid decline of one-step screening to 40% of eligible people, and a trend towards a risk-based implementation of this screening option. The northern region had low uptake of one-step screening across all time periods, compared with high uptake in the urban centers (Vancouver and Victoria) and moderate uptake in the rest of BC.

Over the study period, 92% of pregnant people completed at least one glucose test during pregnancy and could be considered screened for gestational diabetes. We observed lower completion of any testing for Northern and rural residents, suggesting that these groups may be experiencing unique barriers compared to the rest of the province. Screening completion was also lower among midwife-led care. This could reflect both the low obstetric risk status of individuals under midwifery care and also the impact of a model of care which emphasizes principles of informed choice.[132] Practice guidelines from midwifery organizations also have subtle differences in language (offer screening v should be screened) and content which may impact how care providers counsel clients on this topic.[134,152,191]

From October 2010 to March 2013, while a single approach (one-step) was recommended in BC, screening rates were similar across subgroups (BMI, age, risk composite, health care professional). In regions where one-step was implemented, most individuals were screened in accordance with the BC-2010 change, and personal or health care professional recommendations (based on risk status or other factors) may have had less effect on a choice of screening approach. However, the BC-2010 change had no/little impact in the northern region, suggesting that this change was generally not applied in this health region.

Prior research has shown that patient experience[89] and health system impacts/costs[40] differ for a one-step, two-step or 'other' screening approach. Rural BC also experienced decreased access to prenatal care services.[192] Perhaps rural or northern laboratories could not offer the longer, more involved one-step test as a routine option. Alternately, providers or pregnant people may prefer the two-step approach because the initial screening test is relatively brief. Given that northerners and rural people often have to travel long distances to/from health care services,[193] a shorter test duration may be important in promoting *any* screening.

Between 20-30% of people report significant side effects and inability to complete screening due to nausea or emesis from the glucose load, fainting or discomfort from repeated blood samples.[124,127] We found rates of one-step screening, a test which is generally more invasive and time-consuming than a two-step approach, were low for those with high parity. People who were previously screened for gestational diabetes and who screened negative, could be choosing, in collaboration with their physician or midwife, screening approaches based on their presumably 'lower risk' status.

During our study period, use of a random plasma glucose or a HbA1c ('other glucose tests') for gestational diabetes screening was not a recommended method. Thus, use of this screening approach is likely a result of patient or health care professional choice. Our findings of elevated rates of non-standard gestational diabetes screening for high parity, midwifery clients and planned home births suggest these

groups may be engaging with midwifery principles of informed choice in their prenatal care.[194] There are more people under midwifery care who decline usual care[195,196]. Women and birthing people who plan a midwife-attended birth at home, rather than at the hospital, may want fewer interventions and tests in prenatal care, and in labor.[197] Of note, despite the fact that an alternate screening was not standard during our study period, the SOGC recently endorsed the use of only a random plasma glucose or a HbA1c if health system resources are limited because of the COVID-19 pandemic.[87]

4.5.1 Limitations

Specific data on barriers to care (i.e., travel distance, access to laboratory services, individual-level socio-economic indicators) or provider or patient decision-making were not available in our data sources and suggest some areas for future study. Finally, we did not have information on race or ethnicity thus we cannot explore potential associations between screening and racialized care.

4.5.2 Conclusion

Our study demonstrates how changes in health policies and practice guidelines impacted gestational diabetes screening practices. Public health should be aware that changes in guidelines and policies may exacerbate rural-urban disparities in health care services. Gestational diabetes prevalence increases when more people are screened with a one-step v. a two-step screening approach.[86] Thus, characterizing screening practices is critically important in understanding changes in gestational diabetes prevalence across BC.

4.6 Tables

Table 4.1 Prevalence of any glucose test v no test (unscreened) by subgroups and time periods in British Columbia, Canada, for glucose test dates or 28th week of pregnancy between June 1, 2004 and May 31, 2019

Characteristic	Any glucose screening test completed N = **525,720** % (95% CI)	No glucose test (unscreened) N = 51,021 % (95% CI)
All pregnancies	91.2% (91.1, 91.2)	8.8% (8.8, 8.9)
Time period for guidelines on GDM screening		
Period 1 (Jun 1, 2004 – Sep 30, 2010) – Two-step	88.8% (88.6, 88.9)	11.2% (11.1, 11.4)
Period 2 (Oct 1, 2010 – Mar 31, 2013) – BC 2010 one-step IADPSG	90.5% (90.3, 90.6)	9.5% (9.4, 9.7)
Period 3 (Apr 1, 2013 – Jun 30, 2016) – DC 2013 guidelines	92.6% (92.5, 92.8)	7.4% (7.2, 7.5)
Period 4 (Jul 1, 2016 – May 31, 2019) – SOGC 2016 guidelines	95.1% (95.0, 95.3)	4.9% (4.7, 5.0)
Parity[a]		
P0	93.4% (93.4, 93.5)	6.6% (6.5, 6.6)
P1-P3	89.6% (89.5, 89.7)	10.4% (10.3, 10.5)
P4 or more	77.5% (76.7, 78.3)	22.5% (21.7, 23.3)
Age of birthing person/mother (years)		
less than 25	87.7% (87.4, 87.9)	12.3% (12.1, 12.6)
25-34	91.6% (91.5, 91.7)	8.4% (8.3, 8.5)
35+	91.9% (91.8, 92.1)	8.1% (7.9, 8.2)
Pre-pregnancy body mass index (kg/m^2)[54]		
Under or normal (<24.9)	90.0% (89.8, 90.1)	10.0% (9.9, 10.2)
Overweight (25.0-29.9)	93.6% (93.5, 93.8)	6.4% (6.2, 6.5)
Obese I (30.0-34.9)	94.9% (94.7, 95.2)	5.1% (4.8, 5.3)
Obese II & III (>=35.0)	96.4% (96.1, 96.6)	3.6% (3.4, 3.9)
Missing data	90.2% (90.1, 90.4)	9.8% (9.6, 9.9)
Region of birth of mother/birthing parent[b]		
Canada or USA	89.4% (89.3, 89.5)	10.6% (10.5, 10.7)
Asia or Arabia	96.9% (96.8, 97.0)	3.1% (3.0, 3.2)
All other regions	90.7% (90.4, 90.9)	9.3% (9.1, 9.6)
Antepartum medical or obstetric risk[c]		
No/low risk	91.1% (91.0, 91.1)	8.9% (8.9, 9.0)
Moderate/high risk	92.1% (91.8, 92.4)	7.9% (7.6, 8.2)
History of gestational diabetes in previous pregnancy		
no	93.5% (93.4, 93.6)	6.5% (6.4, 6.6)
no prior pregnancy in data	88.8% (88.7, 89.0)	11.2% (11.0, 11.3)
yes	95.5% (95.1, 95.8)	4.5% (4.2, 4.9)
Antenatal health care professional type[177]		
Family practice	93.4% (93.3, 93.5)	6.6% (6.5, 6.7)
Registered Midwife	79.9% (79.7, 80.2)	20.1% (19.8, 20.3)
Obstetrician	95.2% (95.1, 95.4)	4.8% (4.6, 4.9)
Missing or <2 antenatal visits	51.4% (49.7, 53.2)	48.6% (46.8, 50.3)
Planned home birth		
Planned hospital (all births)	92.1% (92.0, 92.1)	7.9% (7.9, 8.0)
Planned home (only available for RM care)	64.8% (64.1, 65.5)	35.2% (34.5, 35.9)
Adequacy of prenatal care utilization index[188]		
Adequate Plus	95.4% (95.2, 95.5)	4.6% (4.5, 4.8)
Adequate	93.7% (93.6, 93.8)	6.3% (6.2, 6.4)
Intermediate	88.2% (88.0, 88.3)	11.8% (11.7, 12.0)
Inadequate	76.8% (76.4, 77.2)	23.2% (22.8, 23.6)
Region of residence of birthing person/mother[d]		
Metro Vancouver or Victoria	92.2% (92.2, 92.3)	7.8% (7.7, 7.8)
Northern region	87.7% (87.4, 88.0)	12.3% (12.0, 12.6)
Other southern cities	90.2% (90.0, 90.4)	9.8% (9.6, 10.0)
Rest of province	87.9% (87.6, 88.2)	12.1% (11.8, 12.4)

Characteristic	Any glucose screening test completed N = **525,720** % (95% CI)	No glucose test (unscreened) N = 51,021 % (95% CI)
Rural or urban residence by local health area region[e]		
Urban	91.2% (91.2, 91.3)	8.8% (8.7, 8.8)
Rural	88.3% (87.8, 88.7)	11.7% (11.3, 12.2)
Neighbourhood income quintiles per person[f]		
lowest income quintile	91.0% (90.8, 91.1)	9.0% (8.9, 9.2)
mid-low income quintile	91.8% (91.7, 92.0)	8.2% (8.0, 8.3)
middle income quintile	91.4% (91.3, 91.6)	8.6% (8.4, 8.7)
mid-high income quintile	91.5% (91.3, 91.6)	8.5% (8.4, 8.7)
highest income quintile	90.1% (89.9, 90.3)	9.9% (9.7, 10.1)
missing or NA	87.7% (87.0, 88.4)	12.3% (11.6, 13.0)

a. Missing parity for n=17 pregnancies.

b. Data obtained from infant birth certificate. Missing data for n=2423 (<1%) pregnancies.

c. Antepartum medical or obstetric risk defined using methods proposed by McRae et al. with the addition of a history of fetal complications from BC-PDR data (prior neonatal death, stillbirth or anomaly). Full definition includes: CIHI discharge table ICD-10 codes: O991 O994 O99803/04/09 O101-4 O109 O266 O981 O984-9 O360 O361 and PDR: Prior prescription for anti-hypertensive medication, prior neonatal death, anomaly, stillbirth or 2 or more prior cesarean births.

d. Regions derived as follows: Metro Vancouver or Victoria includes all local health areas within the greater Vancouver and Victoria metropolitan areas; Northern region includes all of the Northern health region; Other southern cities included all cities with regional or tertiary hospitals located in the city; Rest of province = all other local health regions.

e. Rural (v. urban) was indicated by LHA having a population < 10,000 people.

f. Neighbourhood income quintiles (based on Statistics Canada)[50] represent the average income in the area (census tract).

Table 4.2 Prevalence of three gestational diabetes screening approaches among subgroups and time periods in British Columbia, Canada for glucose test dates from June 1, 2004 and May 31, 2019 (n=525,720)

Characteristic	One-step N = 135,427 % (95% CI)	Two-step N = 364,698 % (95% CI)	Other glucose test N = 25,595 % (95% CI)
All pregnancies	25.8% (25.6, 25.9)	69.4% (69.2, 69.5)	4.9% (4.8, 4.9)
Time period for guidelines on GDM screening			
Period 1 (Jun 1, 2004 – Sep 30, 2010) – Two-step	2.0% (1.9, 2.1)	93.1% (93.0, 93.2)	4.9% (4.8, 5.0)
Period 2 (Oct 1, 2010 – Mar 31, 2013) – BC 2010 one-step IADPSG	45.2% (44.9, 45.6)	50.2% (49.8, 50.5)	4.6% (4.5, 4.7)
Period 3 (Apr 1, 2013 – Jun 30, 2016) – DC 2013 guidelines	42.8% (42.5, 43.1)	51.9% (51.6, 52.2)	5.4% (5.2, 5.5)
Period 4 (Jul 1, 2016 – May 31, 2019) – SOGC 2016 guidelines	37.7% (37.4, 38.0)	57.7% (57.4, 58.0)	4.5% (4.4, 4.7)
Parity[a]			
P0	26.6% (26.5, 26.8)	69.8% (69.6, 70.0)	3.5% (3.5, 3.6)
P1-P3	25.1% (25.0, 25.3)	69.1% (68.9, 69.2)	5.8% (5.7, 5.9)
P4 or more	19.5% (18.6, 20.4)	65.1% (64.0, 66.2)	15.4% (14.6, 16.2)
Age of birthing person/mother (years)			
less than 25	15.8% (15.5, 16.0)	77.9% (77.6, 78.3)	6.3% (6.1, 6.5)
25-34	25.8% (25.7, 26.0)	69.6% (69.4, 69.8)	4.6% (4.5, 4.6)
35+	30.8% (30.5, 31.0)	64.3% (64.1, 64.6)	4.9% (4.8, 5.0)
Pre-pregnancy body mass index (kg/m^2)[54]			
Under or normal (<24.9)	26.3% (26.2, 26.5)	68.7% (68.6, 68.9)	4.9% (4.8, 5.0)
Overweight (25.0-29.9)	28.5% (28.2, 28.8)	67.2% (66.9, 67.5)	4.3% (4.2, 4.4)
Obese I (30.0-34.9)	30.7% (30.3, 31.2)	64.4% (63.9, 64.9)	4.8% (4.6, 5.1)
Obese II & III (>=35.0)	34.3% (33.7, 34.9)	59.5% (58.8, 60.2)	6.2% (5.9, 6.5)
Missing data[b]	20.4% (20.2, 20.6)	74.7% (74.4, 74.9)	4.9% (4.8, 5.0)
Region of birth of mother/birthing parent[c]			
Canada or USA	22.9% (22.8, 23.1)	71.2% (71.0, 71.3)	5.9% (5.8, 6.0)
Asia or Arabia	33.1% (32.8, 33.3)	64.9% (64.6, 65.1)	2.0% (2.0, 2.1)
All other regions	27.7% (27.3, 28.1)	67.7% (67.2, 68.1)	4.6% (4.4, 4.8)
Antepartum medical or obstetric risk[d]			
No/low risk	25.3% (25.1, 25.4)	70.0% (69.8, 70.1)	4.8% (4.7, 4.8)
Moderate/high risk	31.7% (31.2, 32.1)	62.4% (61.9, 62.8)	5.9% (5.7, 6.2)
History of gestational diabetes in previous pregnancy			
no	26.6% (26.4, 26.8)	69.9% (69.7, 70.1)	3.5% (3.4, 3.6)
no prior pregnancy in data	23.4% (23.2, 23.5)	70.8% (70.7, 71.0)	5.8% (5.7, 5.9)
yes	51.1% (50.3, 51.8)	38.7% (38.0, 39.4)	10.2% (9.8, 10.7)
Antenatal health care professional type[177]			
Family practice	22.1% (21.9, 22.2)	74.6% (74.5, 74.8)	3.3% (3.2, 3.4)
Registered Midwife	32.2% (31.8, 32.5)	54.3% (53.9, 54.6)	13.6% (13.3, 13.8)
Obstetrician	36.8% (36.4, 37.1)	60.2% (59.8, 60.5)	3.1% (2.9, 3.2)
Missing or <2 antenatal visits	12.2% (10.7, 13.9)	60.3% (58.0, 62.7)	27.4% (25.3, 29.7)
Planned home birth			
Planned hospital (all births)	25.8% (25.7, 25.9)	69.8% (69.7, 70.0)	4.3% (4.3, 4.4)
Planned home (only available for RM care)	23.1% (22.3, 23.8)	50.4% (49.5, 51.3)	26.5% (25.7, 27.3)
Adequacy of prenatal care utilization index[188]			
Adequate Plus	28.4% (28.1, 28.7)	67.3% (67.0, 67.7)	4.3% (4.1, 4.4)
Adequate	26.6% (26.4, 26.7)	69.7% (69.5, 69.9)	3.7% (3.6, 3.8)
Intermediate	24.2% (24.0, 24.5)	69.8% (69.6, 70.0)	6.0% (5.9, 6.1)
Inadequate	19.8% (19.3, 20.2)	68.6% (68.1, 69.1)	11.6% (11.3, 12.0)
Region of residence of birthing person/mother[e]			
Metro Vancouver or Victoria	31.4% (31.3, 31.6)	64.4% (64.3, 64.6)	4.1% (4.1, 4.2)
Northern region	4.1% (3.9, 4.3)	89.0% (88.7, 89.3)	6.9% (6.7, 7.2)
Other southern cities	14.9% (14.6, 15.2)	78.3% (78.0, 78.7)	6.8% (6.6, 7.0)
Rest of province	17.5% (17.2, 17.7)	76.5% (76.2, 76.8)	6.1% (5.9, 6.2)
Rural or urban residence by local health area region[f]			
Urban	26.2% (26.1, 26.4)	69.0% (68.8, 69.1)	4.8% (4.7, 4.9)
Rural	11.1% (10.7, 11.6)	81.7% (81.1, 82.3)	7.1% (6.7, 7.5)

Characteristic	One-step N = 135,427 % (95% CI)	Two-step N = 364,698 % (95% CI)	Other glucose test N = 25,595 % (95% CI)
Neighbourhood income quintiles per person[g]			
lowest income quintile	25.5% (25.2, 25.7)	69.3% (69.0, 69.6)	5.3% (5.1, 5.4)
mid-low income quintile	26.2% (25.9, 26.4)	69.1% (68.8, 69.4)	4.7% (4.6, 4.9)
middle income quintile	26.3% (26.0, 26.6)	69.0% (68.7, 69.2)	4.7% (4.6, 4.9)
mid-high income quintile	26.5% (26.2, 26.7)	68.9% (68.6, 69.2)	4.6% (4.5, 4.8)
highest income quintile	24.0% (23.7, 24.3)	71.1% (70.8, 71.4)	4.9% (4.7, 5.0)
missing or NA	25.0% (24.0, 26.1)	68.7% (67.6, 69.8)	6.3% (5.7, 6.9)

a. Missing parity for n=18 pregnancies

b. Missing pre-pregnancy body mass index data for n=135,789 pregnancies (26%), therefore this was considered as an independent category for reporting

c. Data obtained from infant birth certificate. Missing data for n=1914 (<1%) pregnancies

d. Antepartum medical or obstetric risk defined using methods proposed by McRae et al. with the addition of a history of fetal complications from BC-PDR data (prior neonatal death, stillbirth or anomaly). Full definition includes: CIHI discharge table ICD-10 codes: O991 O994 O99803/04/09 O101-4 O109 O266 O981 O984-9 O360 O361 and PDR: Prior prescription for anti-hypertensive medication, prior neonatal death, anomaly, stillbirth or 2 or more prior cesarean births

e. Regions derived as follows: Metro Vancouver or Victoria includes all local health areas within the greater Vancouver and Victoria metropolitan areas; Northern region includes all of the Northern health region; Other southern cities included all cities with regional or tertiary hospitals located in the city; Rest of province = all other local health regions

f. Rural (v. urban) was indicated by LHA having a population < 10,000 people.

g. Neighbourhood income quintiles (based on Statistics Canada)[50] represent the average income in the area (census tract).

4.7 Figures

Figure 4.1 Monthly rates of gestational diabetes screening aggregated by month of screening tests, for a cohort of pregnancies in BC, Canada from June 2004 to May 2019

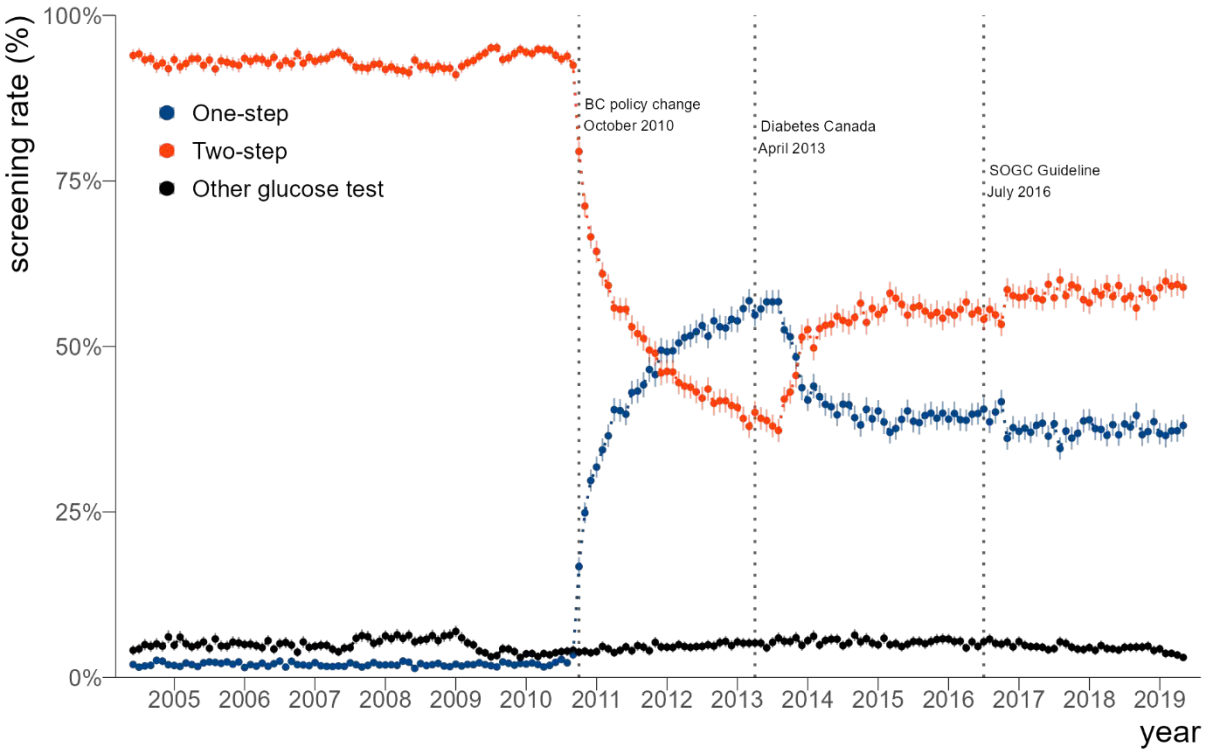
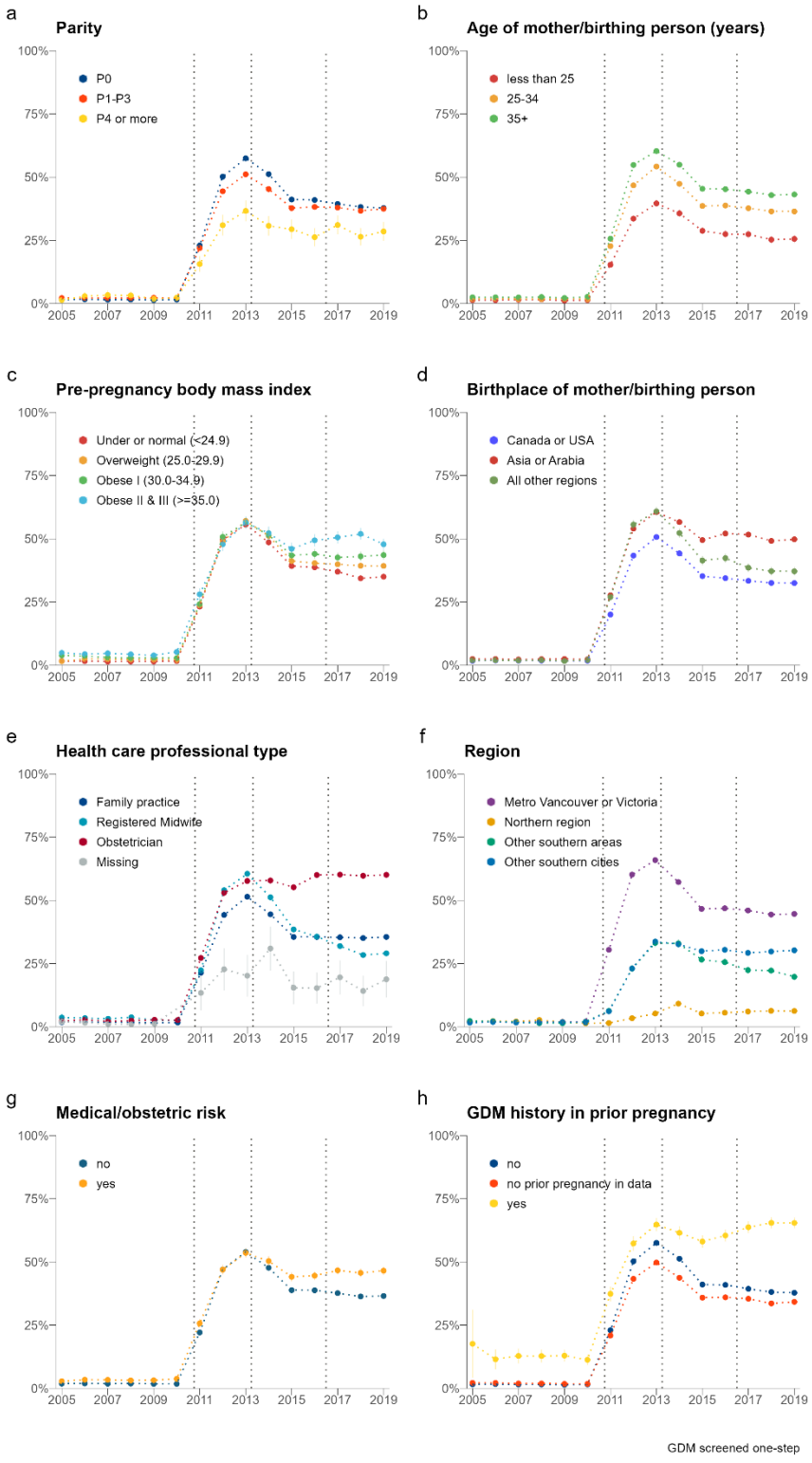


Figure 4.2 Rates of gestational diabetes screening using a one-step method (75g glucose test only and IADPSG criteria) in BC from Jun 1, 2004 to May 31, 2019 in subgroups



5 THE IMPACT OF CHANGES IN SCREENING COMPLETION, SCREENING METHODS AND POPULATION DEMOGRAPHICS ON THE INCREASE IN GESTATIONAL DIABETES

Having demonstrated that laboratory billing records can accurately capture gestational diabetes screening and having characterized screening trends in BC, we could then confidently use British Columbia's population-level linked datasets to explore the reasons for the province's rising rate of gestational diabetes. The rate of gestational diabetes in BC is not only increasing, but is among the highest in the country. As we demonstrated in Chapter 4, use of a one-step screening method has also increased in BC. This study is the first of which we know to examine the attribution of screening and population characteristics to rising rates of gestational diabetes. Our findings of a spurious association between screening method changes and rising incidence of GDM are important for public health as well as for future research.

5.1 Synopsis

Importance: Gestational diabetes is increasing in British Columbia, Canada, but the reasons for these increases are poorly understood.

Objective: To examine the relative contribution of gestational diabetes screening practices (screening completion and methods) and population demographics to rises in gestational diabetes risk.

Design: Retrospective, population-based cohort linking a provincial perinatal data registry with population-based laboratory billing records.

Setting: British Columbia, Canada, 2005-2019.

Participants: All pregnancies without pre-existing diabetes, delivered >28 weeks gestational age.

Interventions or exposures: Gestational diabetes screening completion, screening method (one-step 75g glucose test or two-step approach [50g glucose screening test followed by a diagnostic test if screen positive]), and population-level risk factors including maternal age, pre-pregnancy BMI, and maternal country of birth.

Main outcomes or measures: Predicted annual gestational diabetes risk (relative to baseline 2005) sequentially adjusted with modified Poisson binomial regression, for screening completion, screening method and risk factors.

Results: Gestational diabetes risk more than doubled from 7.2% in 2005 to 14.7% in 2019 (n=550,783 pregnancies). Screening completion increased from 87.2% in 2005 to 95.5% in 2019. Use of a one-step screening approach increased from 0% in 2005 to 40% by 2019. Crude risk of gestational diabetes increased by 2-fold (95% CI: 1.9 to 2.1) in 2019 (vs. 2005). The magnitude of this estimated increase lessened to 1.9 (95% CI: 1.8 to 2.0) after controlling for changes in screening completion and to 1.34 (95% CI: 1.3 to 1.4) after further controlling for changes in screening method. Changes in screening methods had the largest impact on the increase in risk. Further adjustment for population factors had a small impact (1.25-fold increase, 95% CI: 1.2 to 1.3).

Conclusions or relevance: In this population-based cohort, most of the apparent increase in gestational diabetes prevalence was attributable to changes in screening practices (primarily changes in screening methods). Changing population factors were not a large contributor to the increase. Accurate data on screening completion and methods are critical for population health surveillance efforts to monitor trends in gestational diabetes and identify true increases in risk.

5.2 Background

Gestational diabetes is increasing worldwide.[15] In the U.S., gestational diabetes increased from 4.8% in 2011 to 6.4% in 2019, a 33% increase in less than a decade.[16] Although it is speculated that the rise in risk may be due to changing demographics and lifestyle (such as increasing maternal age, changes in racial/ethnic composition of the population, decreased physical activity and poor diet quality), increases have been observed in all racial/ethnic groups in the U.S. after adjusting for increases in maternal age over time.[16,198] The reasons for the continued increased risk of diagnosis remain poorly understood.

An initial diagnosis of gestational diabetes is dependant on completion of an antenatal glucose screening test. Most population-based studies of gestational diabetes, however, lack data on screening completion. Therefore, the rise in gestational diabetes diagnoses could reflect increased uptake of screening. Further, glucose screening options have expanded in recent years and professional organizations differ on recommended methods.[80] Two-step screening (a 1-hour-50 g glucose challenge test followed by a diagnostic test using either a 3-hour-100g or a 2-hour-75g oral glucose tolerance test if screened positive) is the most commonly used method in the U.S. and is recommended by the American College of Obstetricians and Gynecologists.[80] More recently, one-step screening (a single 2-hour-75g oral glucose tolerance test using International Association of Diabetes in Pregnancy Study Groups (IADPSG) diagnostic criteria) was recommended by the American Diabetes Association[80] and as an “alternate” screening test in Canada.[42] As one-step screening is more sensitive, increased use of this method is expected to increase the diagnostic prevalence of gestational diabetes.[15]

Whether rising risk of gestational diabetes are explained by changes in screening practices or changes in population characteristics remains unknown. Therefore, we studied relative contributions of screening completion, screening method and changing population-level characteristics to rising risk of gestational diabetes.

5.3 Methods

5.3.1 Data source

We identified all births at or beyond 28 weeks gestation in the Canadian province of British Columbia (BC), using the population-based BC Perinatal Data Registry (BC-PDR) and included all pregnancies between July 1, 2004 and June 30, 2019 (by screening date or 7th month if unscreened). We linked these records with public health insurance billings (BC Medical Services Plan), vital statistics data and census-derived data via Population Data BC[199] using provincial health numbers. We excluded individuals with pre-existing diabetes (0.6%), late antenatal care (after 7th month) and inactive insurance status for >10% of the pregnancy (by month)[50]. This study was approved by University of British Columbia Research Ethics Board (#H20-00741).

5.3.2 Measures

Gestational diabetes diagnosis was defined by an ICD 10-CA (code O24.8) in the discharge summary of the delivery hospitalization and from the BC-PDR. We obtained screening completion and type of gestational diabetes screening test using billings data via a validated method.

Screen completion was defined by completion of a recommended gestational diabetes test versus having no screening test(s) (unscreened or unknown). Screen method was either a two-step approach (50g glucose challenge test followed by a diagnostic test) or a one-step approach (75g oral glucose tolerance test with IADPSG criteria).[38] In October 2010 in BC, policy changed to recommend a one-step screening for all pregnancies.[105]

We also examined population characteristics associated with gestational diabetes risk:[176] parity, age at delivery, pre-pregnancy body mass index, multi-fetal pregnancy, pre-existing medical/obstetric conditions composite, mother's country of birth (all Asian or Arabian peninsula v. all others v. Canada/USA), antenatal care by a midwife and "Inadequate" prenatal care using the Adequacy of Prenatal Care Utilization Index.[200]

5.3.3 Statistical analysis

We modeled annual gestational diabetes risk using generalized linear regression with a modified Poisson binomial approach. We built four nested models, which were sequentially adjusted for potential determinants of gestational diabetes to understand the contribution of each to temporal trends in prevalence:

- Model (1): temporal trend: adjusted for each year as fixed, independent predictor
- Model (2): adjusted for year + screen completion (screened v unscreened)
- Model (3): adjusted for year + screen completion + method (two-step v one-step)
- Model (4): adjusted for year + screen completion + method + population characteristics

To assess the contribution of screening completion, method and population characteristics to temporal trends, we used model coefficients to predict yearly risk with 95% confidence intervals with all characteristics fixed at 2005 mean levels, and compared these to the observed 2005 risk (Model 1) by calculating risk ratios (RR). Thus, if a model explained *all* of the year-to-year variability in gestational diabetes risk, then there we would expect no increase in the predicted risk for each year relative to that observed for 2005. Additional sensitivity analyses and characteristics of excluded cases are described in the Supplemental.

5.4 Results

Gestational diabetes diagnoses increased from 7.2% in 2005 to 14.7% in 2019 (n=550,783 pregnancies) (Figure 5.1 and Table 5.1). Screening completion increased from 87% in 2005 to 96% in 2019. Screening method changed over the study period: use of one-step screening increased from 0% in 2005 to 51% in 2012, then decreased to 40% in 2019. Some population characteristics changed from 2005 to 2019: pre-pregnancy body mass index over 30 kg/m^2 increased from 11% to 16%; age 35+ years at delivery increased from 22% to 29%; medical/obstetric complications increased from 7% to 8%; mothers birth location in Asia or Arab countries increased from 22% to 27%; midwifery care increased from 4% to 26%.

Unadjusted models estimated a 2-fold increase (95% CI 1.9 to 2.1) in gestational diabetes risk for 2019 compared with 2005 (Figure 5.2, Table C.1). After accounting for the increase in screening completion over time (Model 2), gestational diabetes in 2019 remained 1.9-fold higher (95% CI 1.8 to 2.0). Screening method (Model 3) explained more of the yearly increase than any other factors (1.34-fold increase for 2019 v. 2005; 95% CI 1.3 to 1.4). Further adjustment for trends in population characteristics had only a small impact on rising risk (1.25-fold increase; 95% CI 1.2 to 1.3). None of the sensitivity analyses altered the overall results (Appendix C. Gestational diabetes study supplemental).

5.5 Discussion

In this population-based cohort from British Columbia, Canada, the increase in gestational diabetes from 2005 to 2019 was explained primarily by changes in screening and not by temporal changes in population characteristics. Despite global concerns over increases in high body mass index, older maternal age, and obstetric risk factors, these were not associated with annual increases in gestational diabetes in BC.

Recent studies have examined trends in gestational diabetes worldwide.[16,45,198,201–203] In jurisdictions where screening methods were unchanged, risks were relatively stable[201,202] and/or increases have been explained by population changes (e.g. body mass index, age, ethnicity). In jurisdictions with variable screening practices, risks of diagnosis doubled or tripled, even when controlled for population changes.[16,45,198] These increases persisted across subgroups.[16,204]

This study is limited by a lack of data on racialized/ethnic groups and incomplete data for body mass index. Strengths include having validated data for both gestational diabetes screening methods and completion in a large study population.

Our findings lend support to the hypothesis that increases in the incidence of gestational diabetes may be spurious – caused by changes in screening practices rather than changes in true disease incidence. It is possible that our findings are not generalizable and that other regions have a true rise in rates; however, our study highlights the importance of having data on screening methods and completion to better understand the rising incidence of gestational diabetes in other jurisdictions.

5.6 Tables

Table 5.1 Gestational diabetes diagnosis, screen completion, methods and population characteristics for selected years

Gestational diabetes % (95% CI[a])	2005 N = 33,340	2009 N = 37,702	2012 N = 37,158	2015 N = 37,089	2019 N = 36,414
Diagnosis	7.2% (6.9 to 7.5)	8.0% (7.8 to 8.3)	10.3% (10.0 to 10.7)	11.9% (11.6 to 12.3)	14.7% (14.3 to 15.0)
Screening completion	87.2% (86.9 to 87.6)	89.0% (88.6 to 89.3)	90.2% (89.9 to 90.5)	92.3% (92.0 to 92.5)	95.5% (95.3 to 95.7)
Screening method					
Two-step	87.2% (86.9 to 87.6)	89.0% (88.6 to 89.3)	44.7% (44.2 to 45.2)	54.0% (53.5 to 54.5)	57.8% (57.3 to 58.3)
One-step (IADPSG[b])	0.0% (0.0 to 0.0)	0.0% (0.0 to 0.0)	45.5% (45.0 to 46.0)	38.3% (37.8 to 38.8)	37.7% (37.2 to 38.2)
Not screened/no data	12.8% (12.4 to 13.1)	11.0% (10.7 to 11.4)	9.8% (9.5 to 10.1)	7.7% (7.5 to 8.0)	4.5% (4.3 to 4.7)
One step (IADPSG criteria) (among screened only)	0.0% (0.0 to 0.0)	0.0% (0.0 to 0.0)	50.5% (49.9 to 51.0)	41.5% (41.0 to 42.0)	39.5% (39.0 to 40.0)
Population characteristics % (95% CI)					
Nulliparous	45.7% (45.1 to 46.2)	46.4% (45.9 to 46.9)	46.1% (45.6 to 46.6)	46.8% (46.3 to 47.3)	46.4% (45.9 to 46.9)
Pre-pregnancy body mass index (kg/m2) (non-missing data)					
<24.9	68.3% (67.7 to 68.9)	66.2% (65.6 to 66.8)	66.1% (65.5 to 66.6)	65.1% (64.5 to 65.6)	60.4% (59.9 to 61.0)
25.0-29.9	20.3% (19.8 to 20.9)	21.2% (20.7 to 21.7)	21.0% (20.5 to 21.5)	21.2% (20.7 to 21.7)	23.8% (23.3 to 24.2)
30.0-34.9	7.1% (6.8 to 7.5)	7.9% (7.6 to 8.2)	8.1% (7.8 to 8.5)	8.4% (8.1 to 8.8)	9.6% (9.3 to 10.0)
>35.0	4.2% (4.0 to 4.5)	4.7% (4.5 to 5.0)	4.8% (4.6 to 5.1)	5.3% (5.0 to 5.5)	6.2% (5.9 to 6.5)
Missing body mass index	29.1% (28.6 to 29.6)	33.3% (32.8 to 33.8)	24.9% (24.4 to 25.3)	22.8% (22.4 to 23.2)	18.9% (18.5 to 19.4)
Age of mother/birthing person at delivery					
Less than 25 years	17.3% (16.9 to 17.7)	16.1% (15.7 to 16.5)	13.2% (12.9 to 13.6)	11.1% (10.8 to 11.4)	8.4% (8.1 to 8.7)
25-34 years	60.7% (60.2 to 61.3)	60.7% (60.2 to 61.2)	63.0% (62.5 to 63.4)	64.1% (63.6 to 64.5)	62.5% (62.0 to 63.0)
35+ years	22.0% (21.6 to 22.4)	23.2% (22.7 to 23.6)	23.8% (23.4 to 24.3)	24.9% (24.4 to 25.3)	29.2% (28.7 to 29.6)
Multifetal pregnancy (v. singleton)	1.5% (1.3 to 1.6)	1.5% (1.4 to 1.6)	1.6% (1.4 to 1.7)	1.5% (1.4 to 1.7)	1.4% (1.3 to 1.5)
Medical/obstetric complications (composite)[c]	4.3% (4.1 to 4.5)	4.5% (4.3 to 4.7)	5.0% (4.7 to 5.2)	5.8% (5.6 to 6.1)	7.0% (6.7 to 7.2)
Mother/birthing person's region of birth (by country on infant birth certificate)					
All other regions	8.8% (8.5 to 9.1)	8.5% (8.3 to 8.8)	8.9% (8.6 to 9.2)	8.4% (8.1 to 8.7)	9.4% (9.1 to 9.7)
Asia or Arabia	21.6% (21.1 to 22.0)	21.9% (21.5 to 22.3)	23.3% (22.9 to 23.8)	24.4% (23.9 to 24.8)	26.9% (26.5 to 27.4)
Canada or USA (or missing)[d]	69.6% (69.1 to 70.1)	69.6% (69.1 to 70.0)	67.8% (67.3 to 68.2)	67.2% (66.8 to 67.7)	63.7% (63.2 to 64.2)
Registered midwife prenatal care	3.7% (3.5 to 4.0)	11.2% (10.9 to 11.6)	16.4% (16.0 to 16.7)	21.1% (20.6 to 21.5)	26.3% (25.9 to 26.8)
Inadequate prenatal care (v. all other)[200]	8.7% (8.4 to 9.0)	6.8% (6.5 to 7.0)	6.5% (6.2 to 6.7)	5.8% (5.6 to 6.1)	5.7% (5.5 to 6.0)

a. CI = Confidence Interval using binomial proportions

b. IADPSG = International Association of Diabetes in Pregnancy Study Groups screening criteria using a one-step 75g oral glucose tolerance test (OGTT)

c. Medical/obstetric complications composite includes: pre-existing hypertension, pregnancy complicating conditions or diseases, previous stillbirth, neonatal death or anomaly. (ICD-10-CA codes in Appendix Table C.2).

d. Missing data <0.5%

5.7 Figures

Figure 5.1 Gestational diabetes screening and diagnosis by screening method in BC, Canada

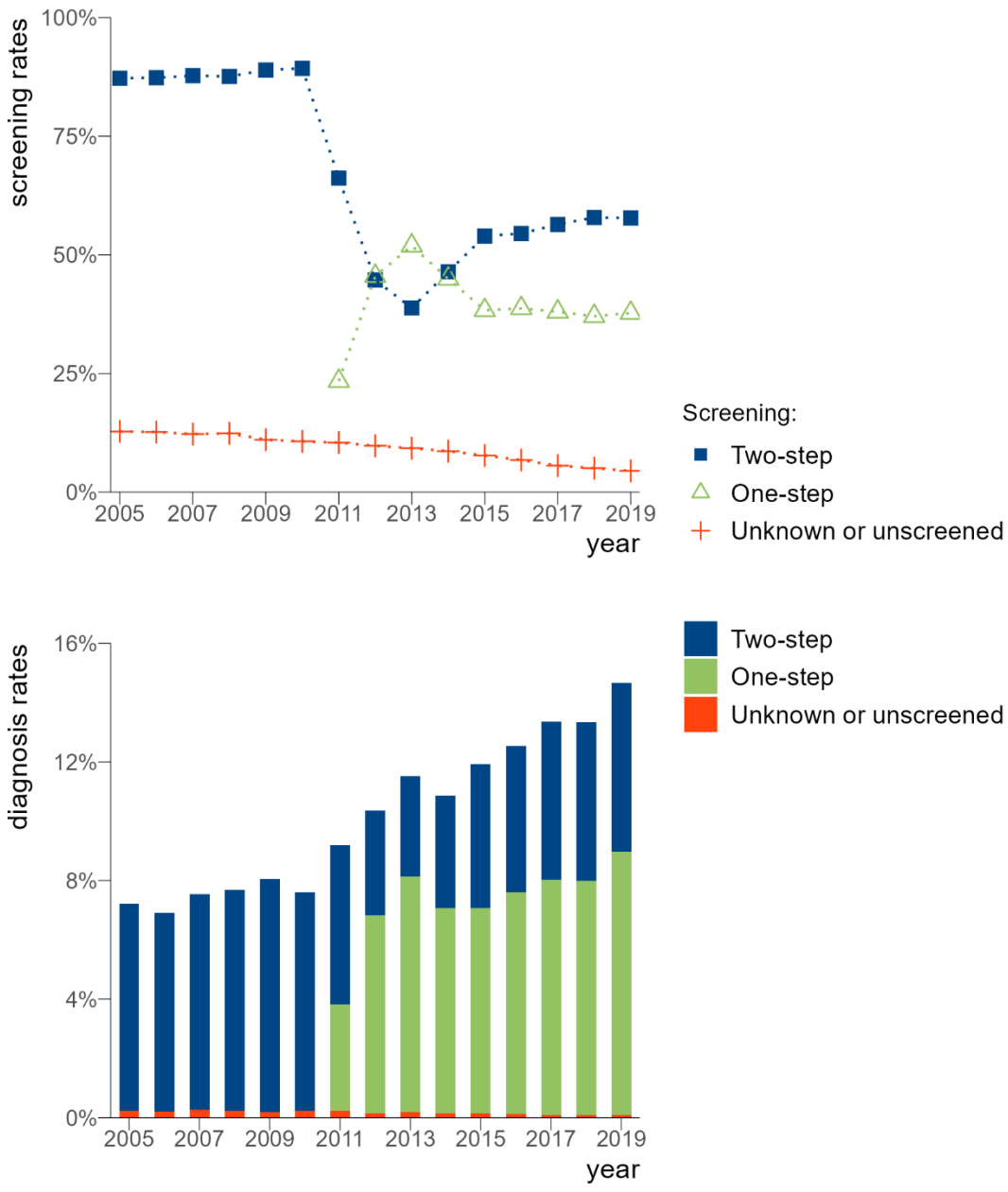
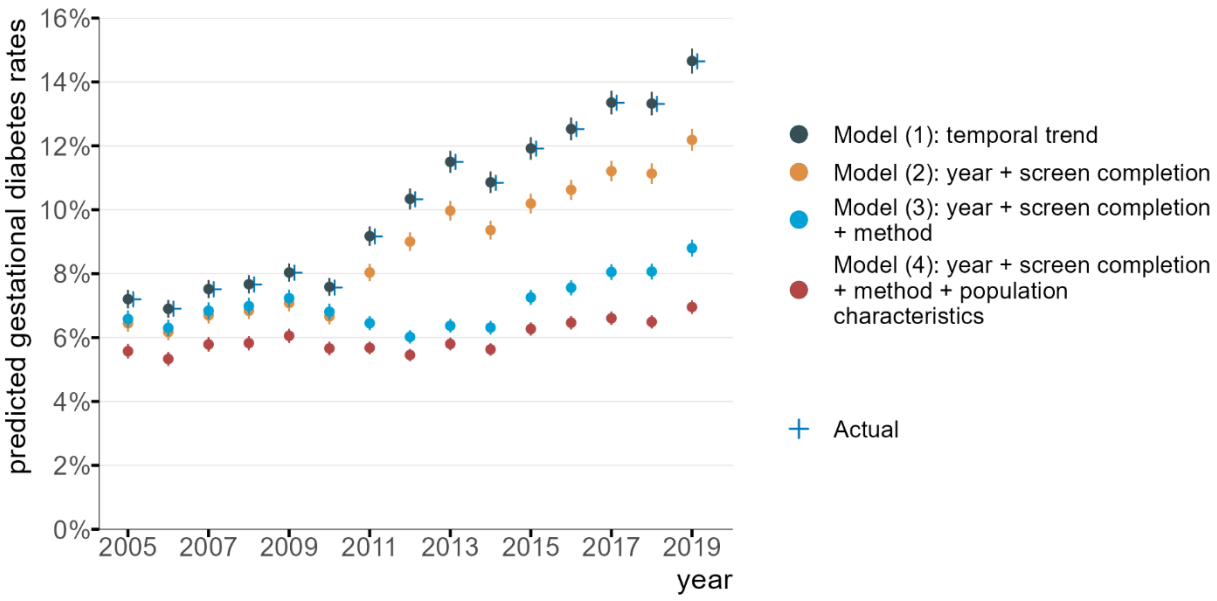


Figure 5.2 Predicted gestational diabetes diagnosis risk using adjusted models



6 WEIGHT GAIN IN PREGNANCY AND INFANT BIRTHWEIGHT AFTER THE ONSET OF THE COVID-19 PANDEMIC: AN INTERRUPTED TIME SERIES ANALYSIS

The COVID-19 pandemic and its associated countermeasures had profound consequences for provision of antenatal care. While the experience of pandemic-associated 'lock-downs' led to increases in weight gain for children and adults, little is known about the effects on pregnant people. This study was the first we know of to use a robust quasi-experimental design, interrupted time series, to examine this issue. Our findings of a modest pandemic-associated increase in weight gain, across all pregestational BMI categories, but no change in infant birthweight provide more information about how this global pandemic affected pregnancy. A version of this chapter is in In-press at the American Journal of Clinical Nutrition.

6.1 Synopsis

Background: Increased weight gain and decreased physical activity has been reported for some populations since the COVID-19 pandemic but this has not been well characterized in pregnant populations.

Objectives: Our objective was to characterize the impact of the COVID-19 pandemic and associated countermeasures on pregnancy weight gain and infant birthweight in a U.S. cohort.

Design: Washington State pregnancies and births (Jan 1, 2016 to Dec 28, 2020) from a multi-hospital quality improvement organization were examined for pregnancy weight gain, pregnancy weight gain z-score adjusted for pregestational body mass index (BMI) and gestational age, and infant birthweight z-score, using an interrupted time series design which controls for underlying time –trends. We used mixed effects linear regression models, controlled for seasonality and clustered at the hospital level, to model weekly time trends and changes at March 23, 2020, the onset of local COVID-19 countermeasures.

Results: Our analysis included 77,411 pregnant people and 104,936 infants with complete outcome data. The mean pregnancy weight gain was 12.1kg (z-score -0.14) during a pre-pandemic time period (March-December 2019) and increased to 12.4kg (z-score -0.09) after the onset of the pandemic (March-December 2020). Our time series analysis found that after the pandemic onset, mean weight gain increased by +0.49 kg (95% CI 0.25, 0.73), weight gain z-score increased by 0.080 (95% CI 0.031, 0.125) with no changes in the baseline yearly trend and infant z-scores (-0.004, 95% CI (-0.04, 0.03)) were unchanged. Overall results were unchanged in analyses stratified by pregestational BMI categories.

Conclusions: We observed a modest increase in weight gain after the onset of the pandemic among pregnant people, but no changes in infant birthweights. This modest weight change could be clinically most relevant for people with high pregestational BMI who are recommended a lower total weight gain during pregnancy.

6.2 Introduction

In response to the COVID-19 pandemic, leaders introduced sweeping changes to health systems and service delivery, policies restricting individuals' travel outside the home, and closures of schools and workplaces[205]. These have been associated with changes in exercise and nutrition, weight gain and weight loss [68,206–208] and worsening mental health [209,210], when compared to pre-pandemic time periods. Effects of the pandemic have not been uniform, with disproportionate impacts being felt by those living in poverty, those with existing chronic health conditions and racialized groups[211].

For pregnant people, the COVID-19 pandemic disrupted lifestyles and increased stress[209].Antenatal stress may alter weight gain in pregnancy [5,212,213]; furthermore, pandemic-related stress could have unique impacts [214] on weight change trajectories during pregnancy [4]. Along with increased stress and disrupted lifestyles, health care delivery in the United States changed, with an increased reliance on telehealth and longer spacing between prenatal care visits [215]. These may have decreased access to nutritional counseling and serial weight assessments during prenatal care. At the same time, food insecurity increased in the United States after the onset of the pandemic [216] and families may have had to increase their reliance on shelf-stable processed foods [217,218]. This may have been particularly important for families living in poverty as both food insecurity and increased use of processed foods have been linked to higher rates of obesity [219].

Weight gain during pregnancy is used as an indicator of nutritional health. Excess pregnancy weight gain is associated with a higher risk of large birthweight infants [53,57], pregnancy related diseases (e.g. hypertensive disorders of pregnancy and gestational diabetes) [220,221] and is a strong determinant of longer-term obesity [54]. We hypothesized that the pandemic-associated countermeasures and stresses, which have impacted weight status among non-pregnant people [68,206–208], may have altered pregnancy weight gain and infant birthweights when compared to pre-pandemic time periods. Increases in maternal obesity or infant birthweights could have long term health consequences by impacting rates of post-pregnancy obesity, childhood obesity and chronic diseases such as diabetes. Therefore, we studied births from a multi-hospital initiative in Washington State, where some of the earliest U.S. cases of COVID-19 were detected. We aimed to assess the combined impact of the COVID-19 pandemic, pandemic-related policies, and health system disruptions on changes in weight during pregnancy and on infant birthweight.

6.3 Methods

6.3.1 Subjects

We used data from a perinatal quality improvement initiative, the Obstetrical Care Outcomes Assessment Program (OB COAP), from January 1, 2016 through December 31, 2020, representing approximately one third of the births in Washington State, United States. The database was populated through both electronic health records and chart abstraction with real-time quality checks and validation [222]. This study was reviewed by the University of British Columbia Harmonized Ethics Review Board and approved as a minimal risk study (#H20-00741) and was also approved by the OB COAP research committee.

We restricted to singleton pregnancies with births that occurred at or beyond 24 weeks gestation. We excluded records with missing or implausible weight measurements (<30kg or >350kg), with no early or pre- pregnancy weight measurement (<14+0 weeks), with a last measured weight taken more than 28 days from delivery, and with missing or implausible gestational weight gain z-score (>6SD or < -6SD) using the z-score reference of Santos et al [223]. We excluded infants with missing birthweight or sex, implausible infant birthweight according to criteria from Alexander [224] and z-scores (using the z-score chart from Aris [225]) as per the approach of Basso & Wilcox [226] (<5SD or >-5SD for term, >4SD or <-3SD for preterm).

6.3.2 Study context

The first confirmed case of COVID-19 in the United States was in Washington State on January 21, 2020. By March 12, 2020, social gatherings were banned, all educational institutions were closed, and on March 23, 2020, the state governor issued a 2 week ‘stay-at-home’ order. Most broad restrictions on public life remained until early June 2020, followed by a temporary loosening of some restrictions until September 2020 when there was a resurgence of COVID-19 cases. Schools were closed for in-person learning throughout 2020. Hospital-level and health-care provider-level infection control countermeasures were based on guidelines from national professional associations.[227] COVID-19 public health and policy actions in Washington State were quantified using publicly available data from the Oxford Covid-19 Government Response Tracker (OxCGRT)[205] to identify three time periods of interest: 1) a pre-pandemic period (January 1, 2016 to February 23, 2020), 2) a transition period where new policies were rapidly implemented (February 24, 2020 to March 23, 2020) and 3) a steady state period where a few pandemic measures were relaxed but most policies were maintained consistently across the state (March 24, 2020 – December 28, 2020) (Figure D.1).

6.3.3 Measurements

6.3.3.1 Pregnancy weight gain, z-scores and infant birthweight z-scores

We examined pregnancy weight gain using two different measures: 1) total pregnancy weight gain in kilograms, defined as the difference between the last weight before delivery (within 28 days of delivery) and pre- or early pregnancy weight (<14+0 weeks) and 2) pregnancy weight gain z-scores which were standardized for pregestational body mass index (BMI) and gestational age using a weight-gain for gestational age chart[223,228] that was derived from over 200,000 pregnant people from 33 cohorts in Europe, North America and Oceania. Pre- or early pregnancy weight was based on a self-reported pre-pregnancy weight or the measured weight at the first prenatal visit. The last pregnancy weight before delivery was recorded at the time of admission in labor. We calculated pregestational BMI using the pre- or early pregnancy weight and height (cm) [229]. We calculated infant birthweight z-scores, standardized for gestational week at birth and infant sex, using the U.S. natality-based reference charts of Aris et al.[225,230]

6.3.3.2 Demographic and obstetric characteristics

We obtained chart-abstracted data for self-reported race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Hispanic/Latinx, Asian or Pacific Islander, Native, Other or mixed race), maternal age at delivery (years), parity (nulliparous (no prior term delivery) or multiparous), pregestational body mass index (kg/m^2), height (cm), gestational age at delivery (weeks, based on obstetric estimated due date), hospital site of delivery, insurance payor type (Medicaid v. others), rural-urban commuting areas (RUCA)[231] collapsed to 2-levels (rural v. non-rural)[232] and the Distressed Communities Index[233] (DCI) quintiles (Prosperous, Comfortable, Mid-tier, At risk, Distressed) from the data registry. The DCI quintiles combine seven socioeconomic indicators into a measure of economic well-being in each zip-code relative to its peers.[233] Pregestational body mass index was categorized as underweight or normal ($\leq$24.9 kg/m^2), overweight (25-29.9 kg/m^2), and grades 1 (30-34.9 kg/m^2), 2 (35-39.9 kg/m^2), and 3 ($\geq$40 kg/m^2) obesity.

6.3.4 Statistical analyses

We used an interrupted time series design[234,235] to assess pandemic-associated changes in the outcomes while controlling for underlying trends by week of study time. Interrupted time series is one of the strongest quasi-experimental designs to evaluate the effects of a policy, an intervention or a wide-spread systems impact. In this analysis, a time series establishes the underlying trend and two line segments are fitted simultaneously, separated by the onset of the COVID-19 pandemic. The hypothetical scenario if the impact had not occurred is referred to as the 'counterfactual'.

The time period of our study was January 1, 2016 to December 28, 2020 (261 complete weeks). We chose the COVID-19 pandemic onset as beginning on March 23, 2020 which we identified as the start of

a ‘steady-state’ of pandemic-related policies and restrictions in Washington State. Births in a 4-week period[235] from February 24 to March 22, 2020 were excluded for two reasons. First, we hypothesized that an effect of the pandemic on either weight gain or infant birthweight would not occur immediately; and that at least 2 weeks of pandemic-associated policies would be needed to observe meaningful and detectable weight gain. Second, there were rapid changes in COVID-19 policies during this time segment. Excluding births in this 4-week period meant that for pregnant people who delivered after March 23, their total weight gain would include at least 2 weeks of the pandemic. We hypothesized the pandemic could cause both a change in level and in the time trend[235] in our outcomes because the impact of the pandemic on weight at the population level could be immediate if diet or activity changed immediately, or delayed if there was a more gradual overall change in behavior.

Potential confounders were identified using a directed acyclic graph (Figure D.2) and from prior studies.[236–238] Pregnancy weight gain was adjusted a priori for gestational age at delivery, since gestational duration directly impacts an individual’s opportunity to gain weight.[239] Neither weight gain z-scores or infant z-scores models were adjusted for gestational age since z-scores were gestational age specific. We considered Medicaid insurance payor, rural residence, distressed community indices, race/ethnicity, age, parity, antenatal health care professional type (midwife v. family practice v obstetrician) and pregestational body mass index (BMI) (in kg/m^2) as potential confounders and plotted time series of all potential confounders. If we noted discontinuities at the pandemic onset and there was no plausible association between that factor and the pandemic, this justified inclusion in the model.

We also adjusted for seasonal trends[240,241] for both pregnancy weight gain and infant birthweight.[238,242] Seasonality can be an important confounder in perinatal outcomes, as it may impact both birth rates and exposure-outcome relationships.[243] We used week of conception[243] rather than week of delivery to estimate the impact of season (Figure D.3). We also plotted mean data by month of conception and superimposed by year. Adjustment for seasonal trends used a single sine term, as this provided the best model fit based on lowest Akaike’s Information Criterion (AIC) compared to other approaches (multiple sine-cosine pairs, month indicator variables).

We included, a priori, random effect terms for hospital intercept, slope and residuals to allow for hospital-level variation in baseline outcomes and over time. To account for sampling uncertainty and repeated measures within the sample study population, parametric bootstrapping techniques were used to calculate confidence intervals. All models were run as generalized linear regression mixed effect models in R.[181] Final model specification is detailed in the online supplement.

6.3.5 Sensitivity analyses

We hypothesized that the pandemic might differentially impact those who were at the higher end of the population distribution of pregnancy weight gain. To assess this, we examined the 90th percentile of all outcomes in quantile regression models[244] using similar interrupted time series models. We also repeated pregnancy weight gain z-score and infant birthweight z-score analyses in subgroups (Distressed Communities Index quintiles, Medicaid status, parity, body mass index and by race/ethnicity). Last, we ascertained likely COVID-19 cases (identified via open-text fields as COVID-positive, COVID symptomatic and presumed positive or COVID-positive in pregnancy) and repeated our analyses excluding known cases. We also repeated the analyses stratified by pregestational BMI categories. Lastly, we examined the effect of increased duration of exposure to the pandemic by excluding 9 weeks of births, from Feb 23 to April 27, 2020, and 15 weeks, from Feb 23 to June 8, 2020, thereby including pregnancies with a longer exposure to pandemic-associated countermeasures.

6.4 Results

Study population (Figure 6.1)

There were 107,062 singleton pregnancies and infants (>24 weeks gestational age) during the study period. Overall, 21.7% (n=23,277) of pregnancies were missing weight gain data because their weight data was collected after 14 weeks of pregnancy and/or more than 28 days before delivery and 6.2% (n=5214) were excluded due to missing or implausible weight data. Only 0.5% (n=515) of infants were excluded due to missing or implausible birthweight data. The final sample included 77,411 pregnancies and 104,936 infants. Excluded cases were not biased by the pandemic time period (Table D.2).

Population characteristics **(**Table 6.1 and Table 6.2):

The demographics of the pregnancy and infant cohorts showed some minor differences between the time periods. Specifically, the pandemic period included a greater proportion of nulliparas, individuals beginning pregnancy with obesity, and individuals with older age at delivery. Time-series graphs for demographic or obstetric covariates revealed that any apparent differences were due to gradual trends over time rather than abrupt changes at the pandemic onset, thus no additional covariates were included in regression models.

Pregnancy weight gain and infant birthweight: pre-pandemic compared to post-pandemic

We compared the 40 weeks post-pandemic (March 23-Dec 28, 2020) to the same period in 2019. From March-December 2019, the mean pregnancy weight gain was 12.13 kg 95% CI (12.02, 12.24) and z-score was -0.14 95% CI (-0.16, -0.12) compared to the mean pregnancy weight gain 12.39 kg 95% CI (12.28,

12.51) and z-score -0.092 95% CI (-0.11, -0.07) in the post-pandemic period (March-December 2020). Infant birthweight z-scores were unchanged (0.075 95% CI 0.063, 0.086) compared to the post-pandemic period (0.068 95% CI 0.044, 0.091). Interrupted time series (Figure 6.2**,** Table D.1) models showed a decreasing yearly trend before the pandemic in both pregnancy weight gain (-0.12 kg/year 95%CI (-0.21, -0.03)) and z-score (-0.016, 95%CI (-0.03, 0.00) /year) which represents roughly 2% of the study population in 2019 having lower pregnancy weight gain when compared to 2016.

Despite this yearly decrease in pregnancy weight gain, infant birthweight z-scores were stable (0.001, 95% CI (-0.01, 0.01) /year). Our models estimated that at the onset of the COVID-19 pandemic mean pregnancy weight gain increased (+0.49 kg, 95% CI (0.25, 0.73)) and pregnancy weight gain z-scores increased (0.08, 95% CI (0.04, 0.12)), but infant z-scores (-0.004, 95% CI (-0.04, 0.03)) were unchanged. We found no statistically significant change in the yearly time trends in infant z-scores after the pandemic onset.

Seasonal effects

Seasonal plots (Figure 6.3) revealed higher pregnancy weight gain and pregnancy weight gain z-scores for pregnancies conceived in the late spring (May-June) compared to those conceived in the late fall (November-December). Models estimated a seasonal trend where the difference from the maximum weight gain (births in the last week in February) to the minimum (births in the first week in September) was 0.32 kg 95% CI (0.26, 0.38) for weight gain, 0.066 (95% CI 0.055, 0.078) for weight gain z-score (~3 percentiles change) and non-significant (-0.002, 95% CI -0.010, 0.007) for infant z-score.

Pregnancy weight gain at 90th percentile of distribution

Examining the upper end of the weight gain distribution (90th percentile) identified an almost three-fold increase in both pregnancy weight gain (1.20 kg 95% CI (0.75, 1.65)) and pregnancy weight gain z-scores (0.20, 95% CI (0.12, 0.28)) only, after the pandemic onset, compared to the population average models (Figure D.4**,** Table D.7).

Subgroup results

Our observed finding of an increase in pregnancy weight gain z-score after the onset of the pandemic remained within quintiles of the Distressed Communities Index, although only the largest subgroup, “Prosperous” (0.12, 95% CI (0.061, 0.186)) had confidence intervals that excluded the null (Figure D.6).

Subgroups by race and ethnicity (Figure D.7) showed a pandemic-related increased weight-gain z-score in the largest subgroup (Non-Hispanic, White) (0.12, 95% CI (0.060, 0.184) and marginally, in the Non-Hispanic Black and Other or mixed-race subgroups, despite small sample sizes. In the Asian, Pacific

Islander subgroup, there was a significant trend change (0.223 z-score/year, 95% CI (0.03, 0.42)) (almost a 9 percentile change per year) suggesting a gradual, rather than instantaneous, effect of the pandemic on increasing pregnancy weight gain z-scores. We observed no significant pandemic-related changes in the Hispanic/Latinx subgroup.

Unlike the mean population models where infant birthweight z-scores were unaffected by the pandemic, in the DCI "Prosperous" subgroup (Figure D.11) the pandemic impact increased infant birthweight z-scores (0.056, 95% CI (0.001, 0.111)) and in the "Comfortable" DCI group, decreased infant birthweight z-scores (-0.069, 95% CI (-0.141, 0.002)). Infant birthweight z-scores were unchanged after the pandemic for all race-ethnicity groups (Figure D.12**,** Figure D.13) except in the Non-Hispanic Black subgroup (0.198, 95% CI (0.024, 0.371)) and in the Asian, Pacific-Islander subgroup (-0.087, 95% CI (-0.165, -0.008)).

Stratifying by Medicaid payor demonstrated a stronger pandemic impact in the "not Medicaid" group (Figure D.9). Mean pregnancy weight gain z-scores were markedly different by parity, with mean z-scores near 0 in the nulliparous subgroup compared to -0.2 in the multiparous group (Figure D.10).

For infant birthweight z-scores, none of the additional subgroup models (Figure D.14, Figure D.15, Figure D.16) showed statistically significant changes at the pandemic time point either for level or trend changes. Birthweight z-scores increased across subgroups by increasing pre- or early-pregnancy body mass index (Figure D.16).

Excluding known Covid-19 positive cases (n=232), did not alter findings for the pandemic onset and key outcomes (pregnancy weight gain 0.506 kg, 95% CI (0.27, 0.75); pregnancy weight gain z-score 0.083, 95% CI (0.04, 0.13)) (Table D.4, Table D.5, Table D.6, Figure D.21).

<u>Results stratified by pregestational BMI:</u>

Stratified results for pregnancy weight gain by pregestational BMI (<25: +0.42 kg; 25-<30: +0.43; 30+: +0.49) were generally unchanged from the main results (+0.49 kg, 95% CI (0.25, 0.73)) by point estimates, although confidence intervals included 0 in the higher BMI categories with small sample sizes (Figure D.8). Results for z-scores and infant birthweight were also similar to the primary models. Stratified quantile regression results for the 90th percentiles of weight gain were also consistent across pregestational BMI categories (Table D.8, Figure D.5). Of interest, the model-predicted seasonal trend was most pronounced among those with normal or under-weight body mass index, suggesting that weight gain in this subgroup is most impacted by seasonality.

<u>Increased duration of exposure to the pandemic:</u>

Overall results for all three outcomes were similar when excluding 9 or 15 weeks of births, although point estimates for the level change effect for weight gain and weight gain z-score moved away from the null (Table D.9). Additional sensitivity analyses (Appendix D) did not alter the overall findings.

6.5 Discussion

Using rigorous analytic methods that control for underlying time trends, we found a modest (0.5 kg) increase in pregnancy weight gain and in pregnancy z-scores after the onset of the COVID-19 pandemic in a cohort of deliveries in Washington State. Pandemic-associated changes in pregnancy weight gain were more pronounced in people above the 90th percentile of weight gain. Despite pandemic-associated changes in pregnancy weight gain in this study group, and in subgroups, we found no pandemic-associated changes in infant birthweight z-scores at the population level. Results were consistent across pregestational BMI categories.

The COVID-19 pandemic, and changes in health services, policies and governmental countermeasures have been linked to increases in stillbirth, maternal deaths and maternal depression and a decrease in preterm birth among high-income countries only [209]. Weight increases after the pandemic have been reported for non-pregnant study groups (adults and children) [206,245] however, research on this topic has focused on qualitative measures [246], short post-pandemic time periods [54,73], 'lock-downs' [246] and used "pre-post" designs [247]. Some countries reported fewer low-birthweight infants after 'lockdowns' [248] but these results have not been confirmed in pooled meta-analyses [209,249,250]. Notably, one meta-analysis reported increased infant birthweights (mean 17g) after the pandemic [249].

While our study found a statistically significant change, the magnitude of the mean increase in pregnancy weight gain (total of 0.5kg or 1.1lbs per pregnancy) was relatively small. Our findings are of interest for several reasons. First, this modest increase in pregnancy weight gain could be a part of the causal pathway for pandemic-associated decreases in low birthweight infants [209,249] noted in other settings. Despite no apparent shift in mean infant birthweight z-scores in our cohort, it is possible that a modest increase in pregnancy weight gain contributed to decreases in low birthweight seen elsewhere. Second, increased pregnancy weight gain could alter the trajectory of weight gain throughout pregnancy. For example, an higher trajectory of first trimester pregnancy weight gain has been associated with an increased risk of gestational diabetes [60]. Third, this modest change in weight gain impacts the entire population [251], which could shift a relatively large number of people towards 'excess' weight gain and thus increase rates of chronic diseases such as hypertension and diabetes [252]. For example, we noted a stronger pandemic impact (1.1 kg) for those who were already gaining "excess" pregnancy weight which may further impact chronic health risks. Importantly, the magnitude of both the pandemic-associated mean pregnancy weight

gain (0.5kg) and for the 90th percentile of weight gain (1.1 kg) was similar across all pregestational BMI categories. Therefore, pandemic-associated effects on weight gain may be most important for people with higher pregestational BMI for whom a lower overall weight gain is recommended (5-9kg) [54]. Nevertheless, our findings are also generally reassuring, and suggest that the pandemic did not have a major impact on weight gain in pregnancy and/or that any effect was counteracted by decreases in commuting or other lifestyle changes [253].

We also found a seasonal effect in pregnancy weight gain with 0.3 kg higher mean weight gain for pregnancies conceived in late winter compared to early summer conceptions. This seasonal effect highlights the importance of controlling for seasonality in weight gain research [243]; otherwise, exposure-outcome or exposure-gestational age [254] relationships could be confounded by season – an issue which is critical when examining time-varying exposures, as in our case. While seasonal trends in weight gain [242,255] and infant birthweight [255] have most often been reported in countries where nutritional intake is correlated with the growing season, seasonal patterns also occurred in the U.S. [238,255] In our study, seasonal weight gain could be caused by changes in physical activity due to environmental factors; the fall-winter months in the Pacific Northwest are generally rainy and colder compared to summer months with moderate outdoor temperatures.

Our analysis did not identify any changes in infant birthweight z-scores, either from the pandemic or from seasonality. It is possible that time-varying or neighbourhood-level exposures (e.g. air pollution) attenuated the impact of weight gain on infant birthweight in our cohort [256,257] or, more likely, that the small magnitudes of weight gain we observed were not sufficient to meaningfully impact infant birthweights.

Strengths of this study include: an interrupted time series analysis which controls for underlying time trends, adjustment for seasonality [243], a large sample size, and a longer post-pandemic time period than many prior analyses. We also had several limitations. First, we restricted to those with valid weight measurements in the first trimester and near to delivery. However, the proportion of excluded cases was consistent in pre-pandemic and post-pandemic time periods. We do not expect that the association between the pandemic and either weight gain or infant birthweight is different in those excluded or included in the study, thus, this should not lead to substantial bias in our primary findings. Second, we were unable to control for individual-level factors such as diet, exercise, employment or stress. However, we see no indication that these factors would have changed in the population for reasons *other* than the pandemic onset which means our study is appropriately characterizing pandemic impacts on our outcomes. Last, our study population represents a single U.S. state where pandemic-associated

countermeasures were relatively widespread. This may impact generalizability to other U.S. regions where there were relatively few countermeasures that restricted physical activity or movement.

Our study has implications for public health planning for future potential pandemic time periods where antenatal care and lifestyles are broadly disrupted. Virtual exercise programs [258] or fewer restrictions on the use of outdoor spaces (e.g. playgrounds and parks) with a low level of infection risk [259] could be two avenues to help promote physical activity and healthy pregnancies in any future pandemics. While the weight gain effect overall was modest, individuals with higher pregestational BMI were equally impacted, therefore public health efforts to promote healthy lifestyles after widespread disruptions such as the COVID-19 pandemic could be most relevant in this specific population.

6.6 Tables

Table 6.1 Pregnancy cohort demographics and outcomes by pre-pandemic (Jan 1, 2016 to Feb 23, 2020) and pandemic (Mar 23, 2020 to Dec 28, 2020) time periods for a Washington State cohort (n=77,411 pregnancies)

Characteristic	**Pre-pandemic Jan 1 2016- Feb 23, 2020 N=65,214 mean± SD or n (%)**	**Pandemic Mar 23-Dec 28, 2020 N=12,197 mean± SD or n (%)**
Nulliparous	26,631 (40.8)	5256 (43.1)
Race and ethnicity of birthing women/person:		
Non-Hispanic White	34,515 (52.9)	5967 (48.9)
Non-Hispanic Black	2670 (4.1)	512 (4.2)
Hispanic or Latinx	10713 (16.4)	2046 (16.8)
Asian or Pacific Islander	13,060 (20.0)	2548 (20.9)
Native American or Native Alaskan	696 (1.1)	103 (0.8)
Other or mixed race	1963 (3.0)	372 (3.0)
Missing	1597 (2.4)	649 (5.3)
Rural zip code	5310 (8.1)	920 (7.5)
Missing rural indicator	1649 (2.5)	351 (2.9)
Medicaid insurance	19537 (30.0)	3351 (27.5)
Missing insurance	2313 (3.5)	66 (0.5)
Distressed Communities Index:		
Prosperous	29,543 (45.3)	5576 (45.7)
Comfortable	16,137 (24.7)	3040 (24.9)
Mid-tier	5931 (9.1)	1155 (9.5)
At risk	10,097 (15.5)	1765 (14.5)
Distressed	2839 (4.4)	534 (4.4)
Missing	667 (1.0)	127 (1.0)
Age of birthing person (year)	30.4 ± 5.4	30.8 ±5.4
Pregestational body mass index (kg/m2)	27.1 ± 6.6	27.4 ±6.7
Pregestational body mass index (kg/m2) categories		
Underweight or Normal weight (<24.9)	30,128 (46.2)	5454 (44.7)
Overweight (25.0-29.9)	17,794 (27.3)	3288 (27.0)
Obese class I (30.0-34.9)	9362 (14.4)	1809 (14.8)
Obese class II (35.0-39.9)	4595 (7.0)	935 (7.7)
Obese class III (>=40.0)	3335 (5.1)	711 (5.8)
Height of birthing person (cm)	163.1 ±7.2	163.0 ±7.1
Total pregnancy weight gain (kg)	12.3 ± 6.1	12.4 ±6.5
Subgroup: pregestational BMI <24.9	13.8 ± 5.0	14.0 ± 5.2
Subgroup: pregestational BMI 25-<30	12.6 ± 5.9	12.8 ± 6.3
Subgroup: pregestational BMI 30+	9.3 ± 6.9	9.4 ± 7.3
Total pregnancy weight gain (kg)	12.3 ± 6.1	12.4 ±6.5
Total pregnancy weight gain z-score	-0.1 ± 1.1	-0.1 ±1.2
Gestational age at delivery (weeks)	38.8 ± 1.7	38.7 ±1.7
Infant birthweight (g)	3367.5 ±538.3	3354.0 ±533.4

Table 6.2. Infant cohort demographics and outcomes by pre-pandemic (Jan 1, 2016 to Feb 23, 2020) and pandemic (Mar 23, 2020 to Dec 28, 2020) pre-pandemic and pandemic (March 23, 2020) time periods for a Washington State cohort (n=104,936 infants)

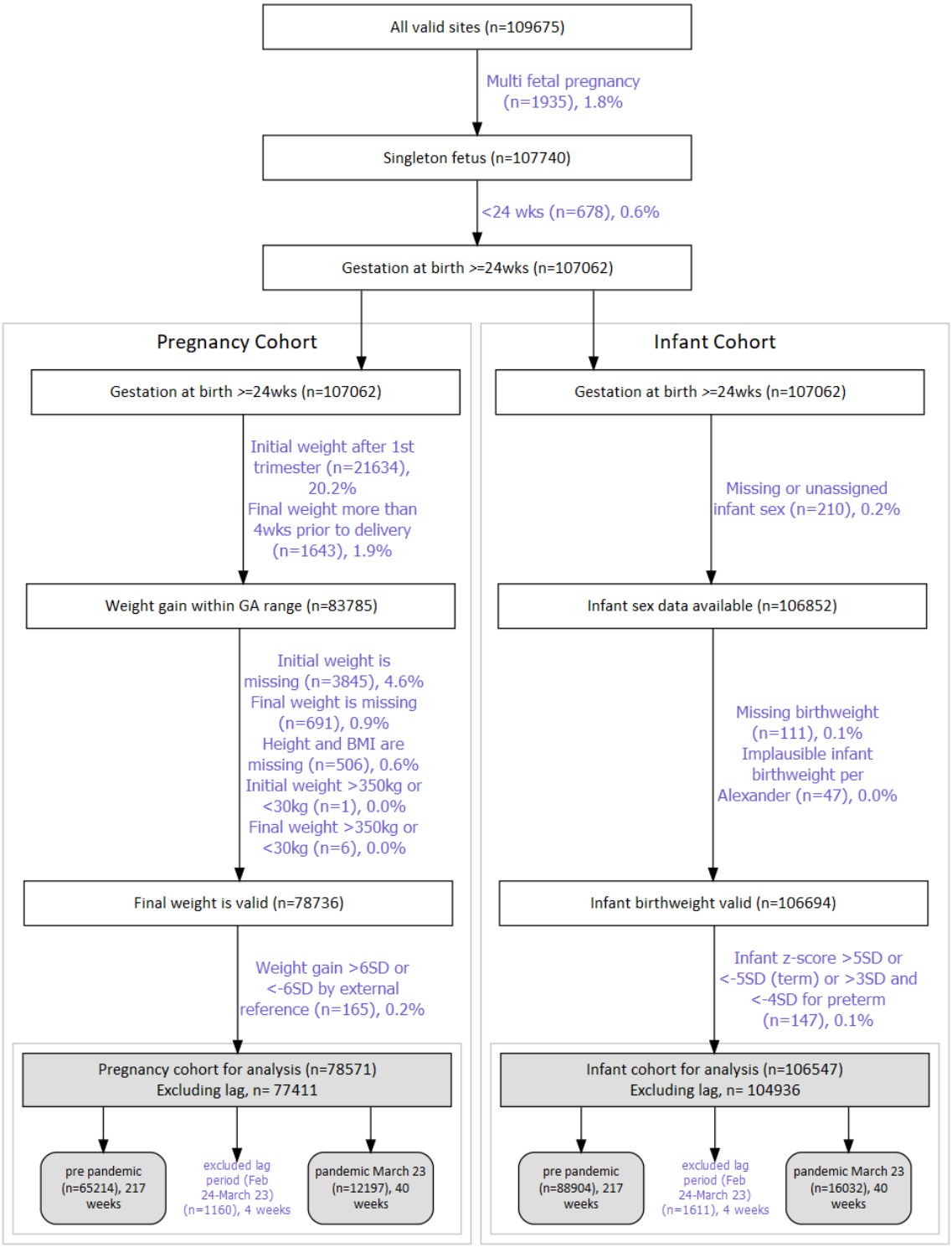
	Pre-pandemic Jan 1 2016- Feb 23, 2020 N=88,904 mean± SD or n (%)	**Pandemic Mar 23-Dec 28, 2020 N= 16,032 mean± SD or n (%)**
Nulliparous pregnancy	35,722 (40.2)	6798 (42.4)
Race or ethnicity of birthing person/woman:		
Non-Hispanic White	46,023 (51.8)	7571 (47.2)
Non-Hispanic Black	4310 (4.8)	754 (4.7)
Hispanic or Latinx	15,024 (16.9)	2702 (16.9)
Asian or Pacific Islander	17,017 (19.1)	3058 (19.1)
Native American or Native Alaskan	1241 (1.4)	197 (1.2)
Other or mixed race	3113 (3.5)	547 (3.4)
Missing	2176 (2.4)	1203 (7.5)
Rural zip code:	7306 (8.2)	1285 (8.0)
Missing rural indicator	2460 (2.8)	480 (3.0)
Medicaid Insurance	30,921 (34.8)	5169 (32.2)
Missing Insurance	2464 (2.8)	89 (0.6)
Distressed Communities Index:		
Prosperous	37,144 (41.8)	6677 (41.6)
Comfortable	22,308 (25.1)	4106 (25.6)
Mid-tier	8981 (10.1)	1729 (10.8)
At risk	14,906 (16.8)	2548 (15.9)
Distressed	4415 (5.0)	767 (4.8)
Missing	1150 (1.3)	205 (1.3)
Age of birthing person (year)	30.2 ±5.6	30.5 ±5.6
Gestational age at delivery (weeks)	38.7 ±1.9	38.6 ±1.8
Infant birthweight (g)	3342.2 ±563.9	3332.0 ±556.4
Infant birthweight z-score	0.1 ±1.1	0.1 ±1.0

Table 6.3. Quantile regression results for 90th percentiles using an interrupted time series analyses of the effect of the COVID-19 pandemic onset in a Washington State cohort (January 1, 2016 to December 28, 2020)

Model terms	**Quantile regression (90th percentile) Estimate (95% CI)**
Pregnancy weight gain (kg) (n= 77, 411)	
Level change	1.20, 95%CI (0.75, 1.65)
Trend change	-0.72, 95%CI (-1.72, 0.27)
Pregnancy weight gain z-score (n=77,411)	
Level change	0.20, 95%CI (0.12, 0.28)
Trend change	-0.11, 95%CI (-0.28, 0.06)
Infant birthweight z-score (n=104,936)	
Level change	-0.04, 95%CI (-0.10, 0.02)
Trend change	0.07, 95%CI (-0.06, 0.20)

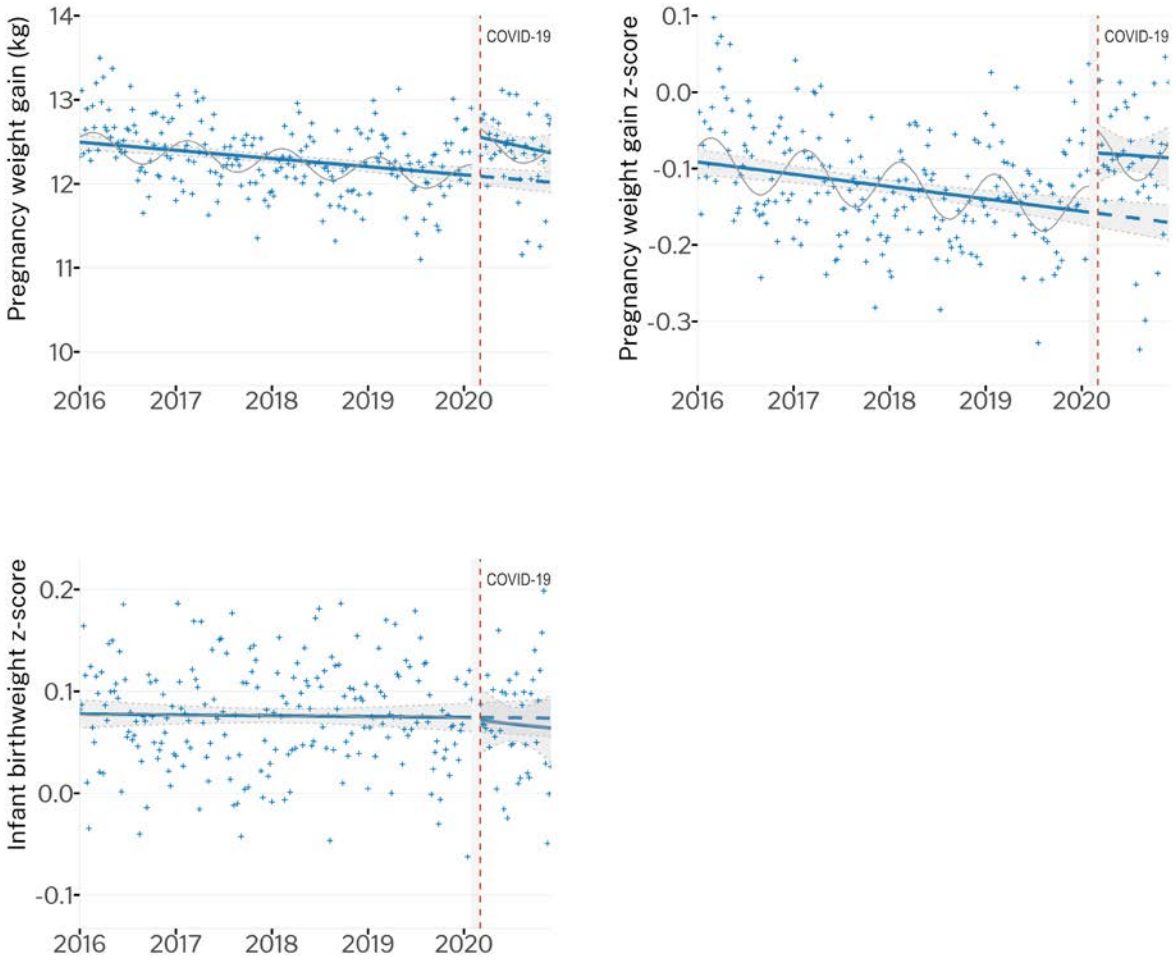
6.7 Figures

Figure 6.1 Flow of study population and exclusions for a Washington State study of gestational weight gain, infant birthweight and the COVID-19 pandemic (January 1, 2016 to December 28, 2020).



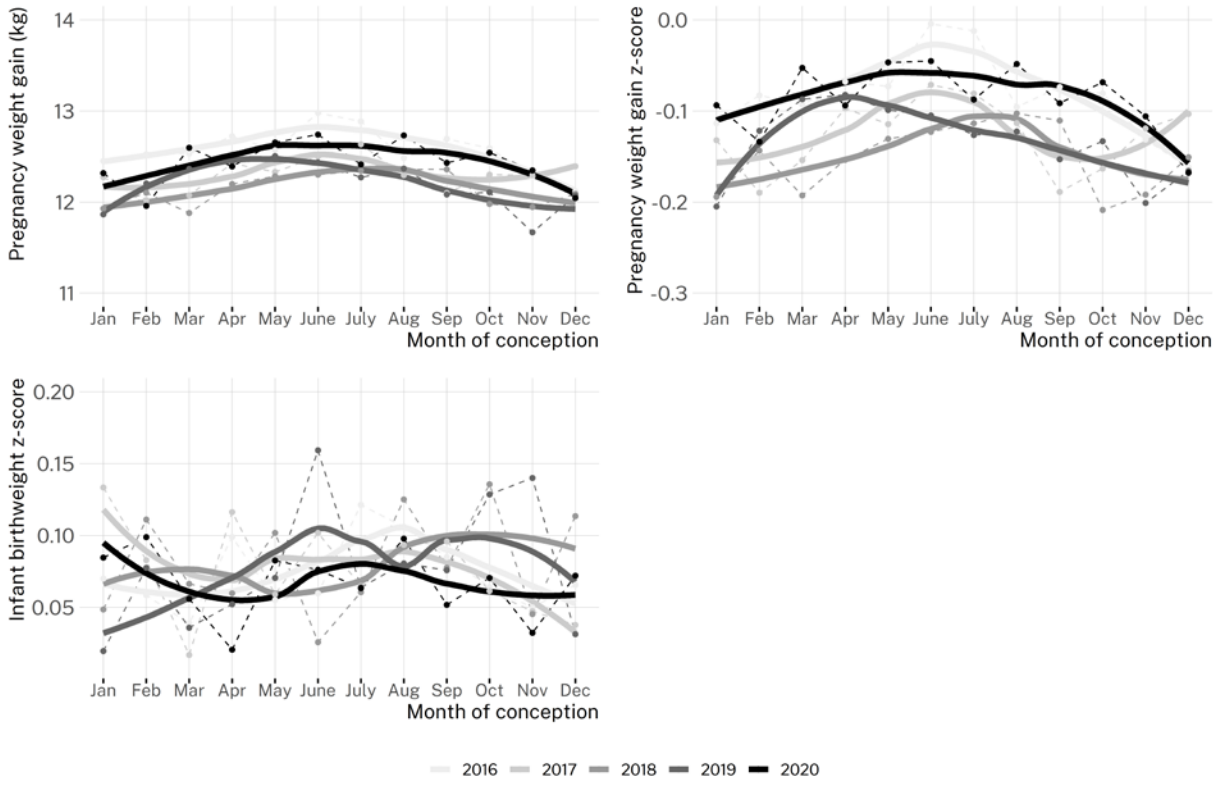
(Excluded data in blue text)

Figure 6.2 Interrupted time series graphs for pregnancy weight gain, z-score and infant birthweight z-score showing predicted trends and the COVID-19 pandemic onset (March 23, 2020) in a Washington State cohort (January 1, 2016 to December 28, 2020)



Points (+) represent mean outcome by study week, modeled (predicted) trend is a solid line; counterfactual is dashed line; seasonal modeled effect is solid thin line; 95% confidence interval for modeled trends in light grey shading. Plotted trendlines are drawn based on models unadjusted by random effects.

Figure 6.3 Average pregnancy weight gain, z-score and infant birthweight z-score by month of conception across study years for a Washington State cohort (January 1, 2016 to December 28, 2020)



7 THE CASE FOR "COMPLETE CASE": A BRIEF REVIEW OF MISSING DATA IN CHAPTER 6

Missing weight gain data was an important limitation in the study presented in Chapter 6. This chapter explores this issue in detail and presents several approaches to address missing data in the Washington State interrupted time series analysis of COVID-19 impacts on pregnancy weight gain and infant birthweight.

7.1 Synopsis

Background: In the analysis in Chapter 5, the final cohort was restricted to pregnancies with complete and valid data (>22% of cases excluded). A "complete case" approach may lead to biased results; therefore, multiple imputation techniques are often used to address missing data and may yield valid results with correctly estimated standard errors. In this analysis, the missing data was in the outcome variable (weight gain) which is a special case.

Objective: The aims of this section were to review the literature on multiple imputation with a lens to the specifics of imputing an outcome variable, to identify the type of the missing weight gain data (missing at random (MAR) or missing completely at random (MCAR)), to implement a multiple imputation (MI) approach if appropriate and recommend the use of either complete case or MI for this study.

Methods: Patient data for excluded cases, complete cases and the full study population were compared descriptively and by pandemic time periods. A multiple imputation approach was implemented according to recommended methods and the interrupted time series analyses (ITS) (from Chapter 5) were repeated using the imputed datasets. Similar analyses were also repeated in sample without exclusions for 'invalid' weight gain data.

Results: Based on the literature on imputation for outcome data, complete case analysis is preferred, unless missing data meet MCAR criteria. Missingness in this dataset did not meet criteria for MCAR as there was a higher proportion of Medicaid recipients in the missing cases. Using an MI approach, the overall findings were similar to Chapter 5, but standard errors increased and results did not reach statistical significance. By contrast, using an un-restricted cohort, the results were more pronounced (biased away from the null).

Conclusions: Because the missing data did not meet MCAR criteria, complete case is preferred over an MI approach. Additional exploratory analyses also point to bias in the MI implementation.

7.2 Background

There is a large body of literature on dealing with missing data in epidemiologic analyses.[260,261] In general, there are two possible ways to deal with missing data: 1) restrict to a population with complete data (complete case analysis) or 2) use some form of "imputation" to replace missing values with plausible data. Statistical approaches to impute data range from very simple (aka replacement with a mean value) to complex (fully-conditional regression-based approaches, also known as multiple imputation (MI)). The decision to use complete case as compared to imputation is specific to each analysis. Some key issues are: whether missing data occurred at random (or not), if missingness is in the independent (X) or dependent variables (Y), and whether missing data techniques can be used with the proposed analysis. This section will expand on the decision to use a complete case approach as compared to multiple imputation using chained equations (fully conditional approach) which is often assumed to be the most robust approach to missing data.[262]

When assessing missing data for the study in Chapter 5, there were several unique considerations. First, this is an interrupted time series analysis, a specialized research design that has some features that differ from more standard approaches (e.g., linear or logistic regression). Multiple imputation has not been widely used for interrupted time series analysis, to date.[262–264]

Second, the missing data was in the dependent/outcome variable only. There has been some reluctance among epidemiologists to impute outcome data as this implies "treating cases in the analysis with unknown outcomes as if they were known"[265]; however, imputation is appropriate for dependent variables in many cases.[265–267] According to van Buuren[260] and Von Hippel[261], when missing data is limited to the dependent variable Y, either complete case analysis[260] or a multiple imputation with deletion (MID)[261] is preferred to a standard MI approach. An MID approach uses standard MI imputation followed by deletion of cases with imputed Y, while retaining any cases with imputed independent (X) data. In this analysis, there is no missing data in the independent (X) (the COVID-19 pandemic time point), thus an MID technique is not applicable.

Further, to use imputation for a dependent variable, if outcome data is missing at random (MAR), or missing completely at random (MCAR), then complete-case analysis is preferred. As noted by Little (1992) "if the Xs are complete and the missing values of Y are missing at random, then the incomplete cases contribute no information to the regression of Y on X1, ... ,Xp". Von Hippel agrees, "If the X's are complete and the missing values of Y are *missing at random*, then the incomplete cases contribute no information to the regression of Y on X".[261,268] And, as van Buuren [260] notes, "Suppose that the complete-data model is a regression with outcome Y and predictors X. If the missing data occur in Y only,

complete-case analysis and multiple imputation are equivalent, so then complete-case analysis is preferred since it is easier, more efficient and more robust. Quantities that depend on the correct marginal distribution of Y, such as the mean or R2, require the stronger MCAR assumption." The primary outcome for this analysis was a mean, thus meeting the stronger MCAR assumption would be required to justify using a MI approach. Therefore, it was critical to understand whether missing data in this study population met MCAR assumptions.

Last, the literature described one special case where MI may be advantageous over complete-case analysis when imputing outcome data and *may* lead to unbiased estimates when compared to a complete case analysis. This required additional predictors for Y, that are not part of the regression for Y on X.[260] Further, these additional predictors variables should not have high proportions of missing data as this could increase standard errors/decrease efficiency in imputed data.[260] The dataset used for the analysis in Chapter 5 did contain many potential auxiliary variables which could be used to impute Y, and which were not part of the regression. However, the ability of those auxiliary variables to usefully predict Y (weight gain) was unclear.

After reviewing the literature on multiple imputation with a lens towards the particular features of this dataset and the analysis presented in Chapter 4, this chapter aimed to 1) assess the data for criteria for MAR or MCAR; 2) implement an exploratory MI approach assuming this data falls within the 'special case' noted above (acknowledging the uncertainty in whether these auxiliary variables provide sufficient information for imputation); 3) re-analyze the dataset without an exclusion for 'valid' weight gain and 4) justify the decision to use complete case analysis for the primary study.

7.3 Methods

The complete case cohort (from Chapter 5) was derived by: a) excluding missing or implausible weight or body mass data and b) excluding weight gain outside the 'study criteria' (invalid weight gain). The 'study criteria' excluded cases with weight data, but where the initial weight measurement was *after* 14 weeks gestational age or the final weight was more than 4 weeks *prior* to delivery. To assess missing data patterns,[264,269] I examined descriptive data for demographics and other relevant variables in the full study population and in three subgroups: 1) Cases excluded for missing/implausible data 2) Cases excluded for study criteria 3) Complete case cohort. I also examined the complete case cohort compared to the excluded subgroup, stratified by pandemic time periods.

To impute missing data, I used an MI with chained equations approach[260,270] with all possible covariates (with an absolute correlation with the response/imputed variable > 0.1) as predictors for imputation.

Because this is a data registry with a large number of potential auxiliary variables, I considered only variables which were measured prior to the weight data. I used multiple imputation with chained equations to impute missing initial and final weight measurements for 20 datasets using the R package "mice" (v. 3.3.1).[260,270] After imputation, I recalculated weight gain and z-scores [223] and applied the same exclusion criteria as in the primary analysis, for 'out of range' weight gain or 'z-scores' (excluding cases with >6 standard deviations). For the 20 imputed datasets, I repeated the interrupted time series models (with random effect terms for hospital site as in the main analyses) for the imputed data sets and obtained pooled effect estimates for level and trend changes as reported in the main analyses using the R package "mitml".

To further investigate whether the study population was biased by the exclusion of cases outside the 'study criteria' for total pregnancy weight gain, I created an 'un-restricted' cohort that included cases that did not meet study criteria and repeated the primary ITS analysis.

7.4 Results

There were 107,062 singleton pregnancies, ≥24 weeks gestational age fetus available for weight gain analysis (Figure 7.1). There were 23,277/107,062 (21.7%) pregnancies excluded for weight gain outside the study criteria. A smaller group, 5214/107062 (4.9%) pregnancies, were excluded because of a calculated weight gain, body mass index or z-score that was missing, invalid or implausible (Table 7.1). There were 78,571 pregnancies in the 'complete case' cohort. There were several differences for the excluded cases compared to the final cohort (Table 7.1). Excluded cases had substantially higher rates of Medicaid (48% in excluded cases v. 30% in final sample) and slightly more with low socio-economic status (as indicated by the DCI variables). Thus, missing weight gain data does not meet criteria for missing completely at random (MCAR) but is likely missing at random (MAR).

Importantly for the ITS analysis, the proportion of cases relative to the exposure of interest (the pandemic) was similar for the complete case dataset (84% pre-pandemic and 16% pandemic cases) and the excluded cases (86% pre-pandemic, 14% pandemic) (Table 7.2). With the exception of missingness in race/ethnicity data, most characteristics were consistent in the excluded data across the pre-pandemic v. pandemic time periods.

After implementing an MI approach, level and trend change terms from the pooled ITS models compared to the primary analysis (Table 7.3) were similar with an increase in pregnancy weight gain (level change), and no change in trend. However, using imputed data, effect estimates were attenuated towards the null.

Notably, results for pregnancy weight gain z-score no longer reach statistical significance. Further, standard errors were increased in the imputed results when compared to a complete case analysis.

The 'un-restricted cohort' (Figure 7.1) (n=98,682) had a lower mean weight gain (11.3 kg) than the primary analytic cohort (12.3 kg) (Table 7.4). This is expected, since weight gain that did not meet study criteria includes people with weight gain over a shorter pregnancy time period. Overall findings were unchanged, but the magnitude of the level change almost doubled (0.12 (95%CI 0.08, 0.16) for pregnancy weight gain z-score) compared to the complete case cohort (0.05 (95%CI 06, 0.010) for pregnancy weight gain z-score) (Table 7.5).

7.5 Discussion

Missing data did not meet criteria for missing completely at random (MCAR) but was classified as missing at random (MAR). Proportions of excluded cases compared to final analytic cohort (valid/plausible data) were unchanged by the exposure of interest (pandemic onset) and population characteristic differences were unlikely to cause residual confounding in the main analysis. A review of the literature found that imputation of outcome data was not recommended, unless MCAR criteria was met, which was not the case in this analysis.

Using MI to impute missing data generally decreases standard errors, compared to complete case analysis, by increasing sample size and efficiency. In this analytic case, standard errors increased in the imputed results when compared to a complete case analysis. This suggests that the MI implementation in this context did not lead to improved efficiencies when compared to a complete-case analysis, as expected based on missing-at-random patterns [260,261,266]. This may be because of the use of race/ethnicity (with a high degree of missingness) in the imputation or because the auxiliary variables are insufficient to derive appropriate values for the outcome data (Y). Excluding missing data for weight gain did not introduce differential bias, if anything, using a complete case cohort biased findings towards the null. In summary, a complete case analysis was recommended, over an MI approach, for this particular analysis.

7.6 Tables

Table 7.1 Missing data patterns: Demographics for excluded cases, complete cases and full study population

	Excluded cases (outside study criteria) **N=23,277 (21.7%)** **N (%)**	**Excluded cases (missing or invalid data)** **N=5,214 (4.9%)** **N (%)**	**Complete case cohort N=78,571 (73.4%)** **N (%)**	**All available singleton pregnancies, ≥24 weeks, valid sites N=107,062** **N (%)**
Nulliparous	9073 (39.0)	1895 (36.3)	32395 (41.2)	43363 (40.5)
Race and ethnicity of birthing person:				
Non-Hispanic White	10894 (46.8)	2670 (51.2)	41107 (52.3)	54671 (51.1)
Non-Hispanic Black	1592 (6.8)	355 (6.8)	3226 (4.1)	5173 (4.8)
Hispanic or Latinx	4264 (18.3)	908 (17.4)	12934 (16.5)	18106 (16.9)
Asian or Pacific Islander	3965 (17.0)	616 (11.8)	15843 (20.2)	20424 (19.1)
Native American or Native Alaskan	551 (2.4)	111 (2.1)	808 (1.0)	1470 (1.4)
Other or mixed race	1091 (4.7)	289 (5.5)	2374 (3.0)	3754 (3.5)
Missing	**920 (4.0)**	**265 (5.1)**	2279 (2.9)	3464 (3.2)
Rural zip code:				
Yes	1820 (7.8)	671 (12.9)	6316 (8.0)	8807 (8.2)
Missing	658 (2.8)	301 (5.8)	2036 (2.6)	2995 (2.8)
Insurance payer:				
Medicaid	**11150 (47.9)**	**2563 (49.2)**	23182 (29.5)	36895 (34.5)
Missing	45 (0.2)	147 (2.8)	2381 (3.0)	2573 (2.4)
Distressed Communities Index:				
Prosperous	7529 (32.3)	1417 (27.2)	35674 (45.4)	44620 (41.7)
Comfortable	6084 (26.1)	1414 (27.1)	19451 (24.8)	26949 (25.2)
Mid-tier	2964 (12.7)	789 (15.1)	7194 (9.2)	10947 (10.2)
At risk	**4729 (20.3)**	**1109 (21.3)**	12027 (15.3)	17865 (16.7)
Distressed	**1605 (6.9)**	**271 (5.2)**	3422 (4.4)	5298 (4.9)
Missing	366 (1.6)	214 (4.1)	803 (1.0)	1383 (1.3)
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Age of birthing person (year)	29.4 (6.0)	29.6 (5.8)	30.5 (5.4)	30.2 (5.6)
Height of birthing person (cm)	162.6 (7.3)	162.8 (7.6)	163.1 (7.2)	163.0 (7.2)
Gestational age at delivery (weeks)	38.6 (2.1)	37.8 (3.1)	38.8 (1.7)	38.7 (1.9)
Weeks between weights (early or pre- and final weight) (pre-pregnancy weights assigned as time =0)	15.0 (8.1)	35.8 (4.8)	31.7 (4.6)	28.3 (8.9)
Infant birthweight (g)	3292.9 (603.4)	3166.1 (757.1)	3365.6 (537.3)	3340.1 (566.8)

Table 7.2 Demographics comparing final cohort to excluded cases by pandemic time periods

	All excluded cases N=28,034		**Complete case cohort N=77,411**	
	Pre-pandemic	**COVID-19 pandemic**	**Pre-pandemic**	**COVID-19 pandemic**
	N=24,144 (86%)	**N=3890 (14%)**	**N=65,214 (84%)**	**N=12,197 (16%)**
Nulliparous	9232 (38.2)	1559 (40.1)	26631 (40.8)	5256 (43.1)
Race and ethnicity of birthing person:				
Non-Hispanic White	11755 (48.7)	1625 (41.8)	34515 (52.9)	5967 (48.9)
Non-Hispanic Black	1667 (6.9)	245 (6.3)	2670 (4.1)	512 (4.2)
Hispanic or Latinx	4406 (18.2)	669 (17.2)	10713 (16.4)	2046 (16.8)
Asian or Pacific Islander	3999 (16.6)	517 (13.3)	13060 (20.0)	2548 (20.9)
Native American or Native Alaskan	556 (2.3)	96 (2.5)	696 (1.1)	103 (0.8)
Other or mixed race	1169 (4.8)	176 (4.5)	1963 (3.0)	372 (3.0)
Missing	592 (2.5)	562 (14.4)	1597 (2.4)	649 (5.3)
Rural zip code:				
Yes	2076 (8.6)	374 (9.6)	5310 (8.1)	920 (7.5)
Missing	815 (3.4)	130 (3.3)	1649 (2.5)	351 (2.9)
Insurance payor				
Medicaid	11624 (48.1)	1849 (47.5)	19537 (30.0)	3351 (27.5)
Missing	168 (0.7)	23 (0.6)	2313 (3.5)	66 (0.5)
Distressed Communities Index:				
Prosperous	7704 (31.9)	1115 (28.7)	29543 (45.3)	5576 (45.7)
Comfortable	6293 (26.1)	1081 (27.8)	16137 (24.7)	3040 (24.9)
Mid-tier	3117 (12.9)	584 (15.0)	5931 (9.1)	1155 (9.5)
At risk	4924 (20.4)	795 (20.4)	10097 (15.5)	1765 (14.5)
Distressed	1611 (6.7)	236 (6.1)	2839 (4.4)	534 (4.4)
Missing	495 (2.1)	79 (2.0)	667 (1.0)	127 (1.0)
Age of birthing person (year)	29.4 (5.9)	29.7 (6.1)	30.4 (5.4)	30.8 (5.4)
Height of birthing person (cm)	162.7 (7.4)	162.6 (7.2)	163.1 (7.2)	163.0 (7.1)
Gestational age at delivery (weeks)	38.4 (2.4)	38.3 (2.3)	38.8 (1.7)	38.7 (1.7)
Pregnancy weight gain (kg) **only cases with non-missing weight gain data (N=21,560)*	18,554 / 21,560 (86%)	3006 / 21,560 (14%)		
Median (IQR)	6.8 (2.7 – 11)	7.1 (2.5 – 11.7)	12.3 (8.6 – 15.9)	12.3 (8.6 – 16.3)

Table 7.3 Pooled model estimates from analysis using imputed datasets (20) and complete cases

	Pooled estimates from imputed datasets using MI			**Estimates from primary analysis (complete case analysis)**		
	Estimate (p-value)	95% CI	SE	Estimate (p-value)	95% CI	SE
Pregnancy weight gain (kg)						
Level change	0.232 (0.072)	-0.020, 0.484	0.128	0.348 (0.006)	0.102, 0.593	0.125
Trend change	0.001 (0.825)	-0.009, 0.011	0.005	0.001 (0.9)	-0.009, 0.011	0.005
Pregnancy weight gain z-score						
Level change	0.016 (0.568)	-0.040, 0.072	0.029	0.051 (0.028)	0.006, 0.096	0.023
Trend change	0.001 (0.314)	-0.001, 0.003	0.001	0.001 (0.4)	-0.001, 0.003	0.001

Table 7.4 Descriptive results for un-restricted weight gain cohort compared to complete case cohort

	Complete case cohort *N=77411*	**Un-restricted weight gain cohort** *N=98682*
Nulliparous	31887 (41.2)	40301 (40.8)
Race and ethnicity of birthing person:		
Non-Hispanic White	40482 (52.3)	50340 (51.0)
Non-Hispanic Black	3182 (4.1)	4666 (4.7)
Hispanic or Latinx	12759 (16.5)	16619 (16.8)
Asian or Pacific Islander	15608 (20.2)	19371 (19.6)
Native American or Native Alaskan	799 (1.0)	1304 (1.3)
Other or mixed race	2335 (3.0)	3295 (3.3)
Missing data	2246 (2.9)	3087 (3.1)
Payor is Medicaid:		
yes	22888 (29.6)	33001 (33.4)
missing	2379 (3.1)	2418 (2.5)
Distressed Communities Index:		
Prosperous	35119 (45.4)	42181 (42.7)
Comfortable	19177 (24.8)	24617 (24.9)
Mid-tier	7086 (9.2)	9782 (9.9)
At risk	11862 (15.3)	16147 (16.4)
Distressed	3373 (4.4)	4822 (4.9)
missing	794 (1.0)	1133 (1.1)
Age of birthing person (year)	30.5 (5.4)	30.3 (5.6)
BMI in early pregnancy (kg/m^2)	27.1 (6.6)	27.5 (6.7)
Height of birthing person (cm)	163.1 (7.2)	163.0 (7.2)
Pregnancy weight gain (kg)	**12.3 (6.2)**	**11.3 (6.5)**
weight gain z-score	**-0.1 (1.1)**	**-0.3 (1.2)**
Weeks between pre- or early pregnancy weight and final weight for weight gain calculation	**31.7 (4.6)**	**28.1 (8.8)**
Gestational age at delivery (weeks)	38.8 (1.7)	38.7 (1.8)
Infant birthweight (g)	3365.4 (537.5)	3349.5 (553.3)

Table 7.5 ITS model results for unrestricted weight gain cohort v complete case cohort

	Un-restricted weight gain cohort		**Complete case cohort**	
	Estimate (95% CI)	**p-value**	**Estimate (95% CI)**	**p-value**
Pregnancy weight gain (kg)				
Level change	0.688 (0.461, 0.915)	<0.001	0.348 (0.102, 0.593)	0.006
Trend change	0.004 (-0.006, 0.013)	0.4	0.001(-0.009, 0.011)	0.9
Pregnancy weight gain z-score				
Level change	0.120 (0.077, 0.163)	<0.001	0.051 (0.006, 0.096)	0.028
Trend change	0.001 (-0.001, 0.003)	0.2	0.001(-0.001, 0.003)	0.4

7.7 Figures

Figure 7.1 Un-restricted weight gain cohort exclusions

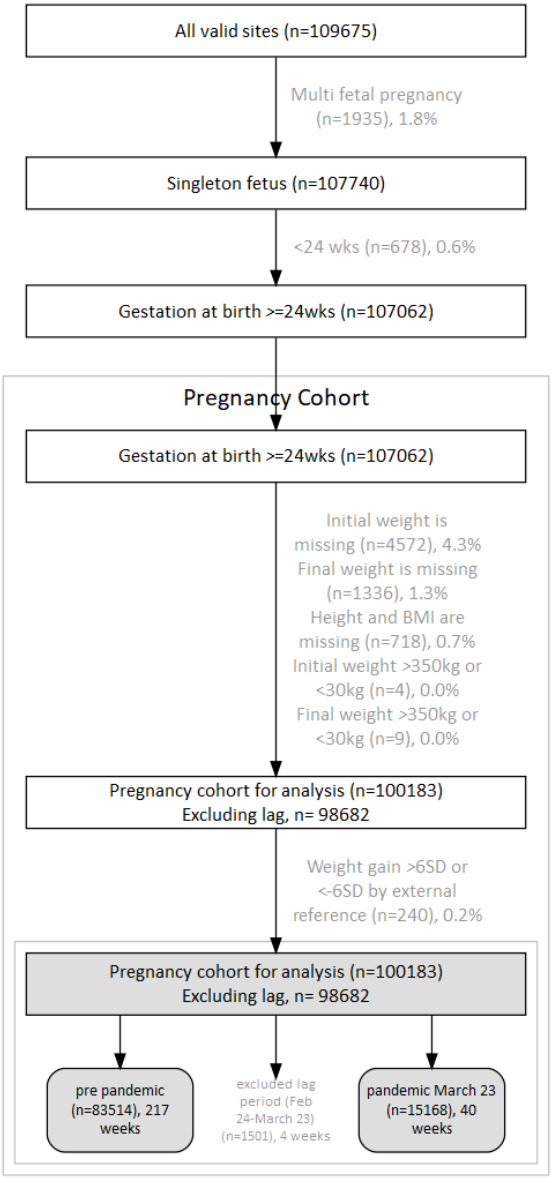
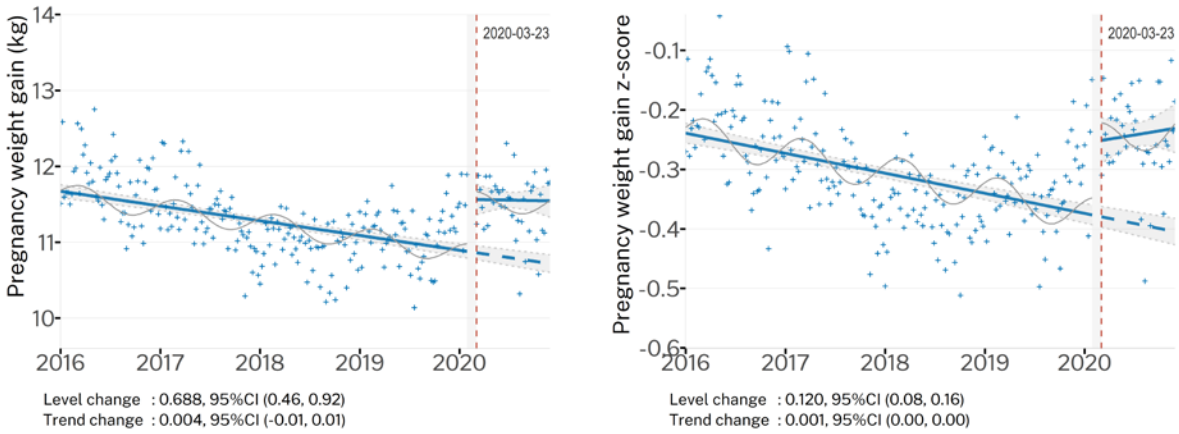


Figure 7.2 Unrestricted weight gain cohort: Interrupted time series graphs and results



8 CONCLUSION

The work presented in this thesis explored how policy changes during the time of antenatal care[1–3] can impact pregnancy health and highlight new directions for further research in these areas.

This theme was examined in the context of pregnancy nutrition and antenatal health care. My dissertation work included three studies on gestational diabetes in BC: (1) a validation of a novel approach to characterize antenatal screening data using insurance billings data; (2) a descriptive study of gestational diabetes screening patterns; (3) an analysis of the impacts of gestational diabetes screening completion, methods and population characteristics on rising rates of gestational diabetes. A final study (4) was an interrupted time series analysis of the impact of the COVID-19 pandemic on pregnancy weight gain and infant birthweight using a dataset with contemporary and detailed clinical data from hospitals in Washington State.

8.1 Gestational diabetes screening and diagnoses

8.1.1 (Chapter 3) A validation of using insurance billings data to assess antenatal screening data against medical records data

In our validation study, we demonstrated that laboratory insurance billing data for three antenatal screening tests' completion and methods were accurate when compared with medical record data. Specifically, billings data was able to capture screening completion for gestational diabetes, 1st trimester ultrasound and Group B streptococcus with high sensitivity (97 – 100%), specificity (68 – 100%), positive (97 – 100%), and negative (63 – 81%) predictive values. Gestational diabetes screening approaches (one-step or two-step) were also well characterized although 45% records did not report screening approach and thus sample size for validation was reduced. Validation parameters in subgroups did not point to key biases in the method but were generally consistent with the main results.

There are some examples of billing data being used to characterize antenatal screening tests in the literature,[161,167,168] but none report a formal validation of this approach. Both gestational diabetes and Group B streptococcus are widely studied conditions in perinatal epidemiology but issues of bias in screening completion are rarely discussed. In particular, most population-based gestational diabetes studies lack data on screening and note this as a significant limitation.[16]

While diagnostic codes based on billing or hospital discharge data (e.g., ICD-10 codes) have been validated,[271] procedure codes are less commonly used. One other validation study examined the use of a procedure code for ultrasound in a pregnant population. This study[272] validated a billing-based approach to ascertain prenatal conditions including GDM diagnosis and completion of ultrasound procedures in a

US setting. They did not examine GDM screening in this study. Similar to our findings, they reported a high sensitivity and PPV for both GDM diagnosis and ultrasounds.

8.1.2 (Chapter 4) A descriptive analysis of different approaches to gestational diabetes screening in BC, Canada

In our study of screening practices for gestational diabetes, we demonstrated substantial variability over time and by subgroups for the uptake of a one-step screening method. The 2010 policy change to use one-step screening in BC was based on updated international IADPSG criteria[38] but contemporaneous Canadian guidelines were not consistent[42] with those criteria. Thus, there was a discrepancy between the province's policy and Canadian professional association guidelines. Following the policy change in October 2010, one step screening uptake was concentrated in the large urban centers with over 70% of people receiving one step screening by 2012-2013. By contrast, rates in other areas increased slightly (~25%) or negligibly (5%) as compared with 2005-2009 (<2% across the province).

We also noted a trend towards universal early uptake of one-step screening, at least within regions where it was applied at all. This was expected, given the policy was intended to apply to all pregnancies. Updates in 2013 and 2016 to Canadian guidelines included the IADPSG criteria using a one-step method but classified it as an "alternate" approach. After this, uptake patterns changed and became more "risk-based". After 2013, one-step screening, which is a more sensitive approach to diagnosing people with GDM, was used primarily for people who also had underlying risk factors. Arguably, this is a reasonable and appropriate application of the current Canadian guidelines by clinicians who are recommending a one-step method for patients with additional risk factors for both gestational and type 2 diabetes.

While there are many studies[15,39,86,86,106,109] that demonstrate before-and-after effects of a change from two-step screening to one-step screening, most were done in closed systems, where one-step screening was applied uniformly, for example, without an alternate method or in a randomized trial where allocation was done by intent-to-treat. It is notable that several pragmatic studies reported lower adherence to *any* screening for groups that received a one-step method compared to a two-step method.[82,273] In one recent randomized trial in the US (Hillier at al.[82]), over 11,000 people were assigned to each study arm (one-step v. two-step) but only 70% in the one-step group adhered to this method. The authors noted that "factors related to lower adherence included both maternal and provider characteristics as well as provider reliance on non-fasting tests to ensure that gestational diabetes screening was completed at a visit."[82] By contrast, >97% in the two-step arm completed two-step screening.

Almost 9% of individuals in our BC cohort were not screened for gestational diabetes using recommended methods during the study period. This is similar to a 2008-2012 study in Alberta[78] that

reported 8% had neither two-step or one-step screening. We were unable to locate other population-level studies that reported substantial variation in gestational diabetes screening methods (relative use of one-step *and* two-step) as we noted in our study in BC. In the Alberta study (Donovan et al.[78]), 99% of those screened (with recommended methods), were screened using a two-step approach. Kong et al.[105] used a before-and-after design to assess changes in perinatal and neonatal outcomes in BC after the 2010 policy change, but they lacked any data on screening uptake. This was acknowledged as a limitation in their study.

The 2013 Canadian guidelines that allowed for *either* one-step and two-step screening were among the first published guidelines to recommend multiple different approaches (Table 2.4). However, the US also has a mix of screening practices, in part, because the two main organizations recommended different methods (American Diabetes Association v. ACOG). One survey of US maternal-fetal medicine physicians reported only 10% of American MFM physicians[118] preferred one-step screening, however regionally these preferences varied from 24% to <4%.

8.1.3 (Chapter 5) Changes in screening and population factors explained changes in diagnosis of GDM

In this analysis, we used the data on screening in BC to explore how temporal changes in screening have impacted GDM risks by year. This BC cohort was unusual in having data on screening practices that changed substantially over time, a large cohort and individual level health data. Other studies have rarely had data on all three of the domains we assessed: screening completion, screening method and population risk factors.

Prior research has demonstrated that where screening practices were stable, rates remained consistent and/or population level changes (increases in body mass index or older age) explained these changes.[201,202] Several other recent studies have shown increasing trends across all subgroups;[16,204] or increasing trends even after controlling for shifts in demographics.[16,45,198] This latter group are from regions where screening data was not available and where current practice represents a mix of screening methods. Our study results demonstrate that the substantial, unexplained, increase in gestational diabetes in BC could be spurious. Specifically, this is attributed to screening changes, primarily, rather than underlying risk factor changes.

8.2 COVID-19 pandemic, pregnancy weight gain and infant birthweight

This study reported a relatively modest (estimated as +0.49 kg) increase in weight gain after the onset of the COVID-19 pandemic in Washington state with no change in infant birthweights. However, we also

found a larger weight gain increase (1.13 kg) for the highest 90th percentile of weight gain. Pandemic-associated weight increases have been reported in other settings,[73,246,274] but not with rigorous quasi-experimental methods as in our study. Stratification by pregestational BMI did not demonstrate any differences in the main findings.

While both increases may appear relatively modest, this could contribute to changes in the trajectory of weight gain throughout a pregnancy. This altered trajectory has been associated with increase in risk of developing gestational diabetes. A recent study from Italy[275] reported a statistically significant temporal relationship between experiencing 'lock-down' (using interrupted time series methods) in the first trimester of pregnancy and later GDM risk. In their study, the GDM diagnosis rate in 2019 was 9% compared to 13.5% in 2020 and there was a strong increase in monthly diagnoses for those who experienced lock-down in their first trimester. While an analysis of COVID-19 associated impacts on GDM in the Washington State cohort was out of the scope of this dissertation, preliminary data suggests a similar trend with higher GDM rates in the 6-months after the COVID-19 pandemic. On the other hand, our results could be viewed in a reassuring light, since there was only minimal change in weight gain and this did not appear to have any effect on infant birthweight.

8.3 Significance and contribution

8.3.1 Validation

Validation studies are a critical component of epidemiologic research that is often under-utilized and important for addressing and mitigating information bias in epidemiologic analyses.[276] Importantly, validation parameters estimated in this analysis could be used to inform other studies where billing data is used to assess screening status.

In terms of the three screening tests validated in this study, each has specific applications in perinatal research. Ascertainment of gestational age at delivery is a critical component of clinical decision-making around timing of delivery and risk management in the context of obstetric complications.[277] Further, gestational age (GA) is an important confounder (or mediator)[243] in almost all perinatal outcomes. In clinical practice and in research, gestational age ascertained by an early (1st trimester) ultrasound is considered more accurate than either a last menstrual period or a later (2nd or 3rd trimester) ultrasound.[174,278,279] Therefore, ascertainment of early ultrasound completion could address information bias in a broad range of perinatal research that rely on gestational age ascertainment.

Characterizing screening status is also particularly important for studies where screening is directly associated with a diagnosis, such as with gestational diabetes. When a diagnosis is contingent on

screening, then it is crucial to correctly specify the denominator of the population at risk. Second, screening methods are rarely considered in epidemiologic studies of gestational diabetes despite known differences in screening methods. Therefore, the method we developed and validated in this study could be an important aspect of addressing information bias in future studies of gestational diabetes.

Best practices for identifying mothers/people at risk for Group B sepsis in newborns is also widely debated; specifically, whether to use risk-based criteria for treatment as compared to screening.[280] Therefore, application of our validated approach to identifying GBS screening status could also be informative to improving research in this domain.

8.3.2 Gestational diabetes

The field of research impact is a developing area of study that explores how research generates benefit (in multiple domains) and concerns itself with what research impacts are and how to measure them.[281] Descriptive research can contribute to the field of health policy and research impact by providing information about the population level effects of a policy change. There is relatively little available public documentation on the BC policy change in October 2010. For example, who decided on this policy? Was there consultation with experts, clinicians, patients or government? Was there some education or outreach across the province after it was implemented? Was there additional planning or resource allocation to address the increase in costs for laboratory testing and treatment (i.e., more diabetes would be diagnosed) after this policy was implemented? This could be an important example where research impact tools[281,282] could be applied to understand both the harms and benefits of changes in GDM screening across the population.

Importantly, the second gestational diabetes study (Chapter 5) demonstrates that current research on gestational diabetes-associated risk and any GDM-associated perinatal outcomes must consider underlying variability in screening practices. This is especially important given the mixed approach of Canadian guidelines. This may also have implications for large population studies in other countries as the impact of the IADPSG guidelines on clinical practice is highly variable. Some clinicians are strongly aligned with this guideline, whereas others remain skeptical. Despite over 14 years since the HAPO study was published, there is still no consensus about the best way to screen and diagnose GDM. In response to the two Canada-wide revisions of practice guidelines (2013 and 2016), there has been little published data on how this has impacted health systems across the country. While we have contributed information on this topic specific to British Columbia, our study also highlights a national-level research gap in this area.

8.3.3 COVID-19, pregnancy weight gain and infant birthweight

The study on COVID-19 contributes to our general understanding of how the pandemic has impacted pregnant people and points to a need for ongoing surveillance on down-stream effects of increased weight gain such as hypertension and diabetes. The increase in pandemic-associated weight gain was strongest for those who were already on a high trajectory of weight gain z-score (>90th percentile). Our overall findings for the effect of the pandemic were unchanged when stratified by pregestational body mass index subgroups. This suggests that the pandemic effect on weight gain was the same across the population, regardless of pre-pregnancy nutritional status. However, people who have a high BMI before pregnancy are recommended to gain less weight overall so the small COVID-associated increase could be most impactful in this population. Our findings about seasonality in weight gain are also highlight this as a key issue with perinatal epidemiology, in general.[239,243]

As the long-term effects of the COVID-19 pandemic are studied and understood in public health, we can hope to learn from both the good, and the bad. On the one hand, we found a stronger impact for those who were already gaining more weight but, on the other hand, the population change in weight gain was small overall.

8.4 Strengths and limitations

This research was strengthened by the completion of a validation study (Chapter 3) as the foundation of two analyses of gestational diabetes (Chapters 4 and 5). The potential for selection bias is minimized by the use of population-based data and billings from a universal health care system. Our analysis in Chapter 4 was strengthened by our access to individual-level health and screening data for the majority of the BC population over a 15-year period, representing over 500,000 pregnancies. We assessed the robustness of the gestational diabetes findings (Chapter 5) through multiple sensitivity analyses. The study on COVID-19 was strengthened by the use of a robust quasi-experimental study design and an interrupted time series analysis. This study also used z-scores to standardize the pregnancy weight gain for body mass index, gestational age. We also used a number of analytic approaches to investigate the robustness of the findings to different reference standards, selection bias, and missing data (Chapter 6).

Overall, the studies in Chapters 4 and 5 were limited by using observational designs. Because Chapter 4 is purely a descriptive analysis, these findings highlight patterns we observed in the data and can be used for hypothesis generating. Unmeasured confounding is possible in both cases, in particular, we have no information on race/ethnicity.

The method used to ascertain screening status in both studies was based on billings for health care services. If an individual used health care services outside the province or did not have current insurance health care during their pregnancy near the point of screening, their screening billing might not be captured leading to bias in the screening data. Therefore, we excluded people without active health insurance during the majority of their pregnancy, with prenatal care that appeared to begin (in BC) late in pregnancy, and who resided outside the province. We also excluded pre-existing diabetes and deliveries (<28 weeks) that occurred before routine GDM screening. Our exclusions may introduce selection bias towards a less transient and possibly healthier population because we excluded people with incomplete care. This is unavoidable since the method to ascertain screening would inaccurately code people as unscreened if they did not have current insurance or if they were screened outside the province. Thus, the prevalence of GDM we reported may not be comparable to other settings; unless they used similar exclusion criteria (i.e., gestational age, insurance status etc.). Overall, the characteristics of the full available births did not differ substantively from the analytic cohort after exclusions (Table C.3, Table C.4, Table C.5, Table C.6). This selection bias is unlikely to impact the internal validity of the findings in Chapter 5.

The key strengths of the COVID-19 study were the use of a quasi-experimental design and interrupted time series analysis. We also used a conception-time cohort rather than a delivery-date cohort to control for seasonality, employed bootstrapping to estimate confidence intervals, and used hospital-level random effects to account for systems-level variation. Additional sensitivity analyses assessed issues of missing data, reference standards, subgroup analyses and used conditional quantile regression to explore associations across the distribution of weight gain.

As with all regional studies, there may be specific regional population characteristics that could differ from other locations. This is always important to consider and could affect generalizability of these results to other populations. In particular, for the COVID-19 study, pandemic-associated countermeasures were relatively widespread in Washington State, and may have been more restrictive than some other US States but less restrictive than in some parts of Europe.

8.4.1 Specific limitations

In Chapter 4, one limitation of the validation study was the use of medical records from only three hospitals in BC. BC health services delivered by doctors and midwives are mostly on a fee-for-service basis, but there are some exceptions. However, we are unaware of any laboratories (either outpatient or in-hospital) that do not bill using a fee-for-service mode. This study was strengthened by the use of a stratified random sample of medical records from two different charting systems (paper charts and EMR)

from different health care regions. We also used sample-weights to adjust for underlying sample stratification.

In Chapter 4, we were limited by available data sources for geographic and other characteristics. While it could be informative to report gestational diabetes screening or diagnoses among subgroups by individual-level data for income, ethnicity, dietary factors, exercise or relative to the location of food deserts (regions with limited availability of grocery stores with fresh food), this data is simply not available for this cohort. We observed a substantial difference in screening in the northern region and it is possible that this could be due to a differential measurement bias in our underlying method. Based on personal communication with several clinicians in the northern health region, they reported that one-step screening for GDM was rarely used in this region.

In Chapter 5, a potential limitation of this analysis is unmeasured confounding, particularly by other underlying risk factors like family history of diabetes and race/ethnicity. Both are risk factors for GDM diagnosis and could be changing in the BC population. To address uncontrolled confounding by race/ethnicity, we used linked infants' birth certificate data and controlled for the mother's place of birth. While an imperfect indicator, we did observe screening differences by region of mother's birth which suggests this variable is capturing some of the effect of unmeasured confounding by race/ethnicity.

A key limitation of the COVID-19 study is selection bias due to the restriction to those with valid weight gain data as this excluded over 22% of pregnancies. In Chapter 7, I present a detailed review of this issue and argue that this bias is unlikely to be differential with respect to the intervention (the COVID-19 pandemic). We were also unable to control for unmeasured confounders but we see no reason that the key factors would have changed for reasons *other* than the pandemic, thus, our study is appropriately characterizing the pandemic impacts.

8.5 Applications of these findings

8.5.1 Applications to perinatal research and epidemiology

The research in this thesis validated a method of ascertaining antenatal screening data that could be used in future research and has broad applications in perinatal or other health research. For gestational diabetes research, the work in my thesis demonstrated the critical importance of screening in understanding patterns of diagnosis of GDM. This also has important implications for planning new studies where GDM is considered and/or when examining perinatal or long-term health sequelae associated with a GDM diagnosis.

As we know, the COVID-19 pandemic will likely have long-lasting health effects on populations due to a myriad of factors: health system changes, mental health changes and physical health changes. The slight pandemic health effects on weight gain could be important to consider as a possible confounder in future studies that use weight gain either as an exposure or outcome.

8.5.2 Applications to public health practice, clinicians or pregnant women/people

The descriptive data on GDM in BC may be helpful to public health and surveillance in the province and in health regions. This could inform health systems planning for gestational diabetes treatment services, clinician training and/or patient education or outreach. Follow-up re-screening in the first year after a gestational diabetes pregnancy is recommended, but there is little available data on this topic. This could be assessed using billing code methods, as we did in this study. Overall, the results and methods developed in this dissertation study could be applied to public health surveillance and to knowledge translation or dissemination tools at the hospital or community level.

The controversy around gestational diabetes is easily seen in public discourse (blog posts, social media) by pregnant women/people who are diagnosed with this condition. As clinicians, we may not engage deeply with this controversy when discussing screening recommendations; however, this may not be ideal. Minimizing the controversy around GDM may erode individuals' trust in traditional medical care.[89] Shared decision-making tools could be developed that draw on the information in this work.[184,283,284] Such tools could help pregnant people and health care professionals engage in a balanced and informed discussion about how, when and who to screen for gestational diabetes. For example, an excellent visual pamphlet on GDM published in 2014[285] (https://www.renaissancemidwifery.ca/docs/gdm_pamphlet.pdf) is no longer aligned with current clinical guidelines. This pamphlet describes a risk-based approach to screening and assumes only a two-step approach to screening and diagnosis. Up to date patient information for BC should be developed to reflect current screening guidelines and the BC context.

8.6 Future research

Validation studies are fundamental buildings blocks to future research studies. In this case, we hope that the method described and validated in this thesis could be applied in other regions. If applied in a region *without* universal health insurance/single-payor system, then there may be specific limitations for that context and additional validation could be useful. Alternately, other procedures that could be identified through billings (e.g., medication abortion, pap tests, intrauterine device (IUD) insertions, mammograms, cancer screening) can be characterized with a similar approach.

Using this cohort, we hope to study antenatal screening completion for all three antenatal procedures/tests, across BC. Further, this data can be applied to explore differences in perinatal outcomes among subgroups by screening status. Our method of capturing glucose tests using billing data could also be applied to understand the proportion of women in BC who receive a recommended post-partum diabetes screening in the first year after a gestational diabetes diagnosis.

Gestational diabetes remains a widely debated and controversial topic. Future research should also focus on evaluation of the health systems impacts of the current Canadian guidelines and the extent to which the current approach benefits Canadian women and birthing people. There are numerous conceptual frameworks[281,282] that could be applied to this explore question. Future research should also include mixed methods and/or qualitative methods to incorporate the views and preferences of birthing people in Canada with respect to gestational diabetes in pregnancy. Given the substantial personal and qualitative impacts of a gestational diabetes diagnosis[89,144], and new research showing equivocal perinatal benefit of a one-step approach (vs two-step)[81,82,117], arguably, we need to better understand the perspectives and values of Canadian women and birthing people on this topic. For mild hyperglycemia or diet-controlled GDM, in particular, explaining this diagnosis through a risk factor lens, rather than as a disease, may be helpful for pregnant people.[144]

Differences in screening across Canada may be important determinants of differences in prevalence. We described regional disparities in screening practices, possibly because of a concern about resource allocation or systems costs, but we lack any data to support this supposition. This would be an important hypothesis to test in future research in other Canadian regions.

Prevalence of gestational diabetes across Canada is increasing and is substantially higher in BC than in the other Canadian provinces included in CIHI data (excludes Quebec). Specifically, a Perinatal Health Indicators data table, available from the Public Health Agency of Canada, showed that for 2017, the rate gestational diabetes in BC was 13.2% as compared to 9.0% across the country (using CIHI-DAD data, Figure 8.1).[47] Using available 2019-2021 CIHI-DAD data from UBC's data repository (a 10% random sample of the full CIHI-DAD), I reproduced a comparable sample. The 2019-2021 rate of GDM was 13.9%, again, substantially higher than the national average (9.7%). In our study, the 2019 GDM diagnosis rate was 14.7% (95% CI 14.3, 15.0) after exclusions (non-standard GDM screening, insurance status, gestational age and pre-existing diabetes) for study design issues. Using the full available births for this time period, I calculated an observed GDM diagnosis rate in 2019 in BC was 14.3% (95% CI 13.9, 14.6).

Based on CIHI-DAD data,[47] and confirmed by the results from this study, BC has substantially higher rates of diagnosed GDM than other Canadian provinces. Another topic for future research would be to examine gestational diabetes screening practices across Canada and in subgroups such as First Nations or Inuit people. Differences in GDM screening could be a major cause of inter-provincial differences in GDM prevalence which could have a disproportionate burden, or benefit, across different health care systems.

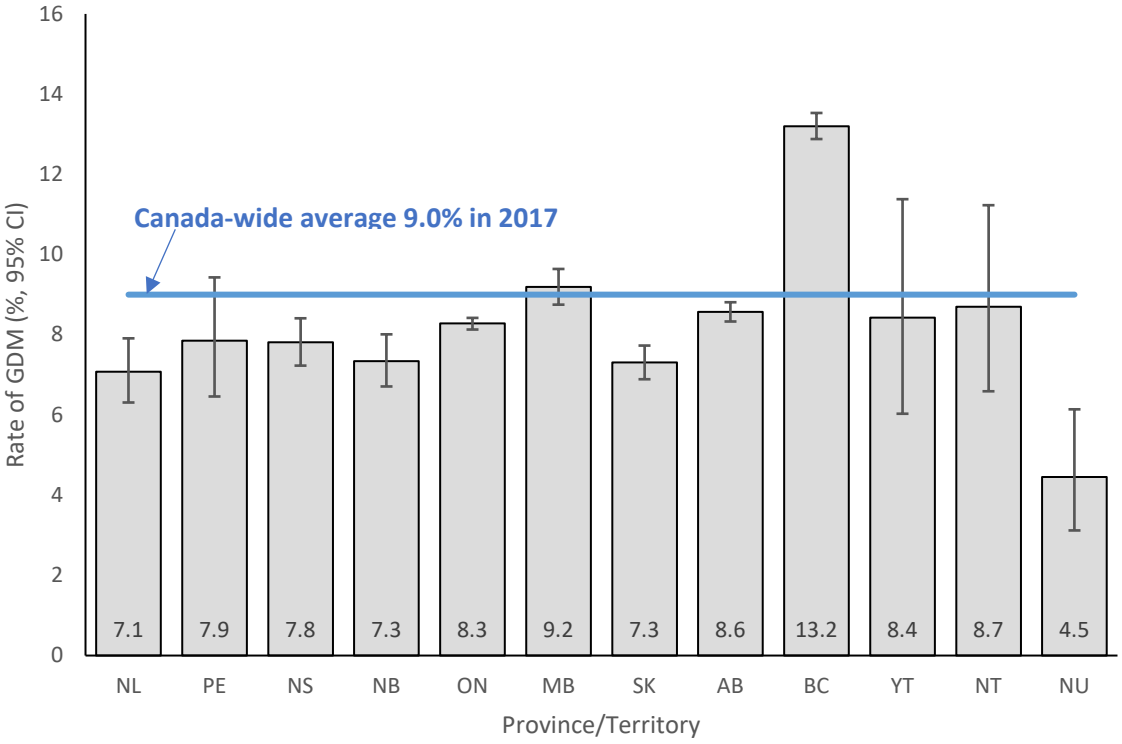
Drawing from the COVID-19 pandemic study, future research should explore the effect of any pandemic-associated weight gain on gestational diabetes. Further, using local nutrition data (i.e., grocery store data) or mobility data (i.e., from smartphones) could be an interesting and understand patterns of weight gain in pregnancy. Future research could also consider whether our results on seasonal trends in weight gain could be replicated using other data sources, for example, vital statistics data.

8.7 Conclusion

This thesis broadly examined two topics that link to pregnancy, nutrition and antenatal health care. One chapter was a validation study, two chapters used a population-based cohort with descriptive and analytic methods, and the fourth chapter used a quasi-experimental design and an interrupted time series analysis. In the first three chapters, I developed and validated a novel approach to identify antenatal screening and applied this method to examine gestational diabetes in BC. The descriptive chapter demonstrated potential disparities in access or uptake of screening by region and highlighted how policy and guideline changes shift clinical practice. The second chapter revealed how these screening changes directly led to rising gestational diabetes diagnoses in BC. BC has the highest provincial rate of GDM diagnosis in Canada and screening practices in this province may differ from the rest of Canada. The final research chapter found a modest COVID-19 pandemic associated change in pregnancy weight gain in Washington State. This demonstrated how global events can lead to small, measurable changes in pregnancy health and nutrition. Overall, this research highlights the critical importance of characterizing screening in studies of gestational diabetes. Further studies of gestational diabetes and other antenatal conditions could apply these methods to incorporate screening data in their analyses. Pregnant women and people, clinicians and health planners in BC should understand the extent to which screening method directly impacts diagnosis risk and incorporate this information for systems planning and clinical decision-making.

8.8 Figures

Figure 8.1 Rates of gestational diabetes in Canada (excluding Quebec), 2017, from the Public Health Agency of Canada based on CIHI-DAD data



BIBLIOGRAPHY

1. BC Perinatal Health Program. *BCPHP Obstetric Guideline Maternity Care Pathway*. Perinatal Services BC: Provincial Health Services Authority; 2010.
2. American Academy of Pediatrics and the American College of Obstetricians and Gynecologists, American Academy of Pediatrics, American College of Obstetricians and Gynecologists. *Guidelines for Perinatal Care*.; 2007.
3. Canada PHA of. Care during pregnancy: Family-centred maternity and newborn care national guidelines. Published February 8, 2021. Accessed July 28, 2022. https://www.canada.ca/en/public-health/services/publications/healthy-living/maternity-newborn-care-guidelines-chapter-3.html
4. Kapadia MZ, Gaston A, Van Blyderveen S, et al. Psychological antecedents of excess gestational weight gain: A systematic review. *BMC Pregnancy Childbirth*. 2015;15(1). doi:10.1186/s12884-015-0535-y
5. Bodnar LM, Wisner KL, Moses-Kolko E, Sit DKY, Hanusa BH. Prepregnancy body mass index, gestational weight gain, and the likelihood of major depressive disorder during pregnancy. *J Clin Psychiatry*. 2009;70(9):1290-1296. doi:10.4088/JCP.08m04651
6. Kampmann U, Madsen LR, Skajaa GO, et al. Gestational diabetes : A clinical update. *World J Diabetes*. 2015;6(8):1065-1072. doi:10.4239/wjd.v6.i8.1065
7. Rioux C, Weedon S, London-Nadeau K, et al. Gender-inclusive writing for epidemiological research on pregnancy. *J Epidemiol Community Health*. Published online June 27, 2022. doi:10.1136/jech-2022-219172
8. Keely E, Berger H, Feig DS. New Diabetes Canada Clinical Practice Guidelines for Diabetes and Pregnancy - What's Changed? *J Obstet Gynaecol Can*. 2019;40(11):1484-1489. doi:10.1016/j.jogc.2018.06.024
9. Vounzoulaki E, Khunti K, Abner SC, Tan BK, Davies MJ, Gillies CL. Progression to type 2 diabetes in women with a known history of gestational diabetes: systematic review and meta-analysis. *BMJ*. 2020;369:m1361. doi:10.1136/bmj.m1361
10. Diaz-Santana MV, O'Brien KM, Park YMM, Sandler DP, Weinberg CR. Persistence of Risk for Type 2 Diabetes After Gestational Diabetes Mellitus. *Diabetes Care*. 2022;45(4):864-870. doi:10.2337/dc21-1430
11. Mcintyre H, Catalano P, Zhang C, Desoye G, Mathiesen E, Damm P. Gestational diabetes mellitus. *Nat Rev Dis Primer*. 2019;5:47. doi:10.1038/s41572-019-0098-8
12. Landon MB, Gabbe SG. Gestational Diabetes Mellitus. *Obstet Gynecol*. 2011;118(6). Accessed July 21, 2022. https://oce.ovid.com/article/00006250-201112000-00025/PDF
13. Wang H, Li N, Chivese T, et al. IDF Diabetes Atlas: Estimation of Global and Regional Gestational Diabetes Mellitus Prevalence for 2021 by International Association of Diabetes in Pregnancy Study Group's Criteria. *Diabetes Res Clin Pract*. 2022;183. doi:10.1016/j.diabres.2021.109050
14. Behboudi-Gandevani S, Amiri M, Bidhendi Yarandi R, Ramezani Tehrani F. The impact of diagnostic criteria for gestational diabetes on its prevalence: a systematic review and meta-analysis. *Diabetol Metab Syndr*. 2019;11(1):11. doi:10.1186/s13098-019-0406-1
15. Saeedi M, Cao Y, Fadl H, Gustafson H, Simmons D. Increasing prevalence of gestational diabetes mellitus when implementing the IADPSG criteria: A systematic review and meta-analysis. *Diabetes Res Clin Pract*. 2021;172:108642. doi:10.1016/j.diabres.2020.108642
16. Shah NS, Wang MC, Freaney PM, et al. Trends in Gestational Diabetes at First Live Birth by Race and Ethnicity in the US, 2011-2019. *JAMA*. 2021;326(7):660-669. doi:10.1001/jama.2021.7217
17. Azeez TA, Abo-Briggs T, Adeyanju AS. A systematic review and meta-analysis of the prevalence and determinants of gestational diabetes mellitus in Nigeria. *Indian J Endocrinol Metab*. 2021;25(3):182-190. doi:10.4103/ijem.ijem_301_21
18. Chivese T, Hoegfeldt CA, Werfalli M, et al. IDF Diabetes Atlas: The prevalence of pre-existing diabetes in pregnancy – A systematic review and meta-analysis of studies published during 2010–2020. *Diabetes Res Clin Pract*. 2022;183. doi:10.1016/j.diabres.2021.109049
19. Meek CL. Natural selection? The evolution of diagnostic criteria for gestational diabetes. *Ann Clin Biochem*. 2017;54(1):33-42. doi:10.1177/0004563216674743
20. Carreiro MP, Nogueira AI, Jr AR oliveira. Controversies and Advances in Gestational Diabetes — An Update in the Era of Continuous Glucose Monitoring. *J Clin Med*. Published online 2018:1-13. doi:10.3390/jcm7020011
21. Huhn EA, Rossi SW, Hoesli I, Göbl CS. Controversies in Screening and Diagnostic Criteria for Gestational Diabetes in Early and Late Pregnancy. *Front Endocrinol*. 2018;9(November):5-12. doi:10.3389/fendo.2018.00696
22. Wexler DJ, Powe CE, Barbour LA, et al. Research Gaps in Gestational Diabetes Mellitus: Executive Summary of a National Institute of Diabetes and Kidney Diseases Workshop. *Obstet Gynecol*. 2018;132(2):496-505. doi:10.1097/AOG.0000000000002726

23. Hiersch L, Shah BR, Berger H, et al. Oral Glucose Tolerance Test Results in Pregnancy Can Be Used to Individualize the Risk of Future Maternal Type 2 Diabetes Mellitus in Women With Gestational Diabetes Mellitus. *Diabetes Care*. 2021;44(8):1860-1867. doi:10.2337/dc21-0659

24. Martis R, Crowther C, Shepherd E, Alswiler J, Downie M, Brown J. Treatments for women with gestational diabetes mellitus: an overview of Cochrane systematic reviews. *Cochrane Database Syst Rev*. 2018;(8). doi:10.1002/14651858.CD012327

25. Brown J, Alwan NA, West J, et al. Lifestyle interventions for the treatment of women with gestational diabetes. *Cochrane Database Syst Rev*. 2017;2017(5). doi:10.1002/14651858.CD011970.pub2

26. Bilous RW, Jacklin PB, Maresh MJ, Sacks DA. Resolving the Gestational Diabetes Diagnosis Conundrum: The Need for a Randomized Controlled Trial of Treatment. *Diabetes Care*. 2021;44(4):858-864. doi:10.2337/dc20-2941

27. Sermer M. Does screening for gestational diabetes mellitus make a difference? *CMAJ*. 2003;168(4):429-431.

28. Coustan DR. Diagnosis of Gestational Diabetes: What Are Our Objectives? *Diabetes*. 1991;40(Supplement_2):14-17. doi:10.2337/diab.40.2.S14

29. Horvath K, Koch K, Jeitler K, et al. Effects of treatment in women with gestational diabetes mellitus: systematic review and meta-analysis. *BMJ*. 2010;340:c1395. doi:10.1136/bmj.c1395

30. Kapur A, McIntyre HD, Divakar H, et al. Towards a global consensus on GDM diagnosis: Light at the end of the tunnel? *Int J Gynecol Obstet*. 2020;149(3):257-261. doi:10.1002/ijgo.13149

31. Hartling L, Dryden DM, Guthrie A, Muise M, Vandermeer B, Donovan L. Benefits and Harms of Treating Gestational Diabetes Mellitus: A Systematic Review and Meta-analysis for the U.S. Preventive Services Task Force and the National Institutes of Health Office of Medical Applications of Research. *Ann Intern Med*. 2013;159(2):123-129. doi:10.7326/0003-4819-159-2-201307160-00661

32. O'Sullivan J, Mahan C. Criteria for the Oral Glucose Tolerance Test in Pregnancy. *Diabetes*. 1964;13:278-285.

33. The HAPO Study Cooperative Research Group. Hyperglycemia and Adverse Pregnancy Outcomes. *N Engl J Med*. 2008;358(19):1991-2002.

34. Scholtens DM, Kuang A, Lowe LP, et al. Hyperglycemia and Adverse Pregnancy Outcome Follow-up Study (HAPO FUS): Maternal Glycemia and Childhood Glucose Metabolism. *Diabetes Care*. 2019;42(March):372-380. doi:10.2337/dc18-2021

35. Alberico S, Montico M, Barresi V, et al. The role of gestational diabetes, pre-pregnancy body mass index and gestational weight gain on the risk of newborn macrosomia: Results from a prospective multicentre study. *BMC Pregnancy Childbirth*. 2014;14(1). doi:10.1186/1471-2393-14-23; 10.1186/1471-2393-14-23

36. Kim SY, Sharma AJ, Sappenfield W, Wilson HG, Salihu HM. Association of Maternal Body Mass Index, Excessive Weight Gain, and Gestational Diabetes Mellitus With Large-for-Gestational-Age Births. *Obstet Gynecol*. 2014;123(4):737-744. doi:10.1097/AOG.0000000000000177

37. Graves E, Hill DJ, Evers S, et al. The Impact of Abnormal Glucose Tolerance and Obesity on Fetal Growth. *J Diabetes Res*. 2015;2015:e847674. doi:10.1155/2015/847674

38. International Association of Diabetes and Pregnancy Study Groups Consensus Panel. International Association of Diabetes and Pregnancy Study Groups recommendations on the diagnosis and classification of hyperglycemia in pregnancy. *Diabetes Care*. 2010;33(3):676-682. doi:10.2337/dc09-1848

39. Mcintyre HD, Jensen DM. Gestational Diabetes Mellitus : Does One Size Fit All ? A Challenge to Uniform Worldwide Diagnostic Thresholds. *Diabetes Care*. 2018;41(July):1339-1342. doi:10.2337/dc17-2393

40. Meltzer S, Snyder J, Penrod J, Nudi M, Morin L. Gestational diabetes mellitus screening and diagnosis: a prospective randomised controlled trial comparing costs of one-step and two-step methods. *BJOG Int J Obstet Gynaecol*. 2010;117(4):407-415. doi:10.1111/j.1471-0528.2009.02475.x

41. Agarwal MM. Gestational diabetes mellitus: An update on the current international diagnostic criteria. *World J Diabetes*. 2015;6(6):782-791. doi:10.4239/wjd.v6.i6.782

42. Mussa J, Meltzer S, Bond R, Garfield N, Dasgupta K. Trends in national canadian guideline recommendations for the screening and diagnosis of gestational diabetes mellitus over the years: A scoping review. *Int J Environ Res Public Health*. 2021;18(4):1-17. doi:10.3390/ijerph18041454

43. Hod M, Kapur A, Sacks DA, et al. The International Federation of Gynecology and Obstetrics (FIGO) Initiative on Gestational Diabetes Mellitus: A Pragmatic Guide for Diagnosis, Management, and Care. *Int J Gynecol Obstet*. 2015;131(3).

44. FIGO initiative on gestational diabetes (guidelines). World diabetes foundation. Published November 10, 2015. Accessed August 14, 2022. https://www.worlddiabetesfoundation.org/files/figo-initiative-gestational-diabetes-guidelines

45. Feig DS, Hwee J, Shah BR, Booth GL, Bierman AS, Lipscombe LL. Trends in Incidence of Diabetes in Pregnancy and Serious Perinatal Outcomes: A Large, Population-Based Study in Ontario, Canada, 1996–2010. *Diabetes Care*. 2014;37(6):1590-1596. doi:10.2337/dc13-2717

46. Metcalfe A, Sabr Y, Hutcheon JA, et al. Trends in obstetric intervention and pregnancy outcomes of Canadian women with diabetes in pregnancy from 2004 to 2015. *J Endocr Soc*. 2017;1(12):1540-1549. doi:10.1210/js.2017-00376

47. Centre for Surveillance and Applied Research, Public Health Agency of Canada. *Perinatal Health Indicators Data Tool*. 2020th ed. Public Health Agency of Canada; 2020. Accessed August 9, 2022. https://health-infobase.canada.ca/phi/data-tool/index?Dom=3

48. Donovan LE, Edwards AL, Savu A, et al. Population-Level Outcomes with a 2-Step Approach for Gestational Diabetes Screening and Diagnosis. *Can J Diabetes*. 2017;41(6):596-602. doi:10.1016/j.jcjd.2016.12.010

49. Yeung RO, Savu A, Kinniburgh B, et al. Prevalence of gestational diabetes among Chinese and South Asians : A Canadian population-based analysis. *J Diabetes Complications*. 2017;31(3):529-536. doi:10.1016/j.jdiacomp.2016.10.016

50. Central Demographics File (MSP Registration and Premium Billings, Client Roster and Census Geodata)/Consolidation file (MSP registration and premium billing) data set | Population Data BC. Accessed April 20, 2022. https://www.popdata.bc.ca/data/demographic/consolidation_file

51. The data linkage process | Population Data BC. Accessed September 11, 2022. https://www.popdata.bc.ca/index.php/datalinkage/process

52. Abrams B, Altman SL, Pickett KE. Pregnancy weight gain: Still controversial. *Am J Clin Nutr*. 2000;71(5 SUPPL.). doi:10.1093/ajcn/71.5.1233s

53. Hutcheon JA, Stephansson O, Cnattingius S, Bodnar LM, Johansson K. Is the Association between Pregnancy Weight Gain and Fetal Size Causal?: A Re-examination Using a Sibling Comparison Design. *Epidemiology*. 2019;30(2):234-242. doi:10.1097/EDE.0000000000000959

54. Institute of Medicine. *Weight Gain during Pregnancy: Reexamining the Guidelines*. (Rasmussen KM, Yaktine AL, eds.). National Academies Press; 2009.

55. Devlieger R, Ameye L, Nuyts T, Goemaes R, Bogaerts A. Reappraisal of Gestational Weight Gain Recommendations in Obese Pregnant Women: A Population-Based Study of 337,590 Births. *Obes Facts*. 2020;13(4):333-348. doi:10.1159/000508975

56. Mamun AA, Callaway LK, O'Callaghan MJ, et al. Associations of maternal pre-pregnancy obesity and excess pregnancy weight gains with adverse pregnancy outcomes and length of hospital stay. *BMC Pregnancy Childbirth*. 2011;11. doi:10.1186/1471-2393-11-62

57. Goldstein RF, Abell SK, Ranasinha S, et al. Association of gestational weight gain with maternal and infant outcomes: A systematic review and meta-analysis. *JAMA - J Am Med Assoc*. 2017;317(21):2207-2225. doi:10.1001/jama.2017.3635

58. Leonard SA, Abrams B, Main EK, Lyell DJ, Carmichael SL. Weight gain during pregnancy and the risk of severe maternal morbidity by prepregnancy BMI. *Am J Clin Nutr*. 2020;111(4):845-853. doi:10.1093/ajcn/nqaa033

59. Amorim AR, Rössner S, Neovius M, Lourenço PM, Linné Y. Does Excess Pregnancy Weight Gain Constitute a Major Risk for Increasing Long-term BMI? *Obesity*. 2007;15(5):1278-1286. doi:10.1038/oby.2007.149

60. MacDonald SC, Bodnar LM, Himes KP, Hutcheon JA. Patterns of gestational weight gain in early pregnancy and risk of gestational diabetes mellitus. *Epidemiology*. 2017;28(3):419-427. doi:10.1097/EDE.0000000000000629

61. Jarman M, Yuan Y, Pakseresht M, Shi Q, Robson PJ, Bell RC. Patterns and trajectories of gestational weight gain: a prospective cohort study. *CMAJ Open*. 2016;4(2):E338-E345. doi:10.9778/cmajo.20150132

62. Fontaine PL, Hellerstedt WL, Dayman CE, Wall MM, Sherwood NE. Evaluating body mass index-specific trimester weight gain recommendations: differences between black and white women. *J Midwifery Womens Health*. 2012;57(4):327-335. doi:10.1111/j.1542-2011.2011.00139.x

63. Ryan EA. Diagnosing gestational diabetes. *Diabetologia*. 2011;54(3):480-486. doi:10.1007/s00125-010-2005-4

64. Poston L, Bell R, Croker H, et al. Effect of a behavioural intervention in obese pregnant women (the UPBEAT study): a multicentre, randomised controlled trial. *Lancet Diabetes Endocrinol*. 2015;3(10):767-777. doi:10.1016/S2213-8587(15)00227-2

65. Martínez-Hortelano JA, Cavero-Redondo I, Álvarez-Bueno C, Garrido-Miguel M, Soriano-Cano A, Martínez-Vizcaíno V. Monitoring gestational weight gain and prepregnancy BMI using the 2009 IOM guidelines in the global population: a systematic review and meta-analysis. *BMC Pregnancy Childbirth*. 2020;20(1):649. doi:10.1186/s12884-020-03335-7

66. Akseer N, Kandru G, Keats EC, Bhutta ZA. COVID-19 pandemic and mitigation strategies: Implications for maternal and child health and nutrition. *Am J Clin Nutr*. 2020;112(2):251-256. doi:10.1093/ajcn/nqaa171

67. Aranda Z, Binde T, Tashman K, et al. Disruptions in maternal health service 19 pandemic in use during the COVID- - 2020 : experiences from 37 health facilities in low- - income and middle- - income countries. *BMJ Glob Health*. 2022;7:1-10. doi:10.1136/bmjgh-2021-007247

68. Bhutani S, Vandellen MR, Cooper JA. Longitudinal weight gain and related risk behaviors during the covid-19 pandemic in adults in the us. *Nutrients*. 2021;13(2):1-14. doi:10.3390/nu13020671

69. Almandoz JP, Xie L, Schellinger JN, et al. Impact of COVID-19 stay-at-home orders on weight-related behaviours among patients with obesity. *Clin Obes*. 2020;10. doi:10.1111/cob.12386

70. Drieskens S, Berger N, Vandevijvere S, et al. Short-term impact of the COVID-19 confinement measures on health behaviours and weight gain among adults in Belgium. *Arch Public Health*. 2021;79(1):1-10. doi:10.1186/s13690-021-00542-2

71. Chew HSJ, Lopez V. Global impact of covid-19 on weight and weight-related behaviors in the adult population: A scoping review. *Int J Environ Res Public Health*. 2021;18(4):1-32. doi:10.3390/ijerph18041876

72. Mulugeta W, Desalegn H, Solomon S. Impact of the COVID -19 pandemic lockdown on weight status and factors associated with weight gain among adults in Massachusetts. *Clin Obes*. 2021;(December 2020):1-8. doi:10.1111/cob.12453

73. Zhang J, Zhang Y, Huo S, et al. Emotional eating in pregnant women during the covid-19 pandemic and its association with dietary intake and gestational weight gain. *Nutrients*. 2020;12(8):1-12. doi:10.3390/nu12082250

74. Wang PH, Lee WL, Yang ST, Tsui KH, Chang CC, Lee FK. The impact of COVID-19 in pregnancy: Part I. Clinical presentations and untoward outcomes of pregnant women with COVID-19. *J Chin Med Assoc JCMA*. 2021;84(9):813-820. doi:10.1097/JCMA.0000000000000595

75. Billionnet C, Mitanchez D, Weill A, et al. Gestational diabetes and adverse perinatal outcomes from 716,152 births in France in 2012. *Diabetologia*. 2017;60(4):636-644. doi:10.1007/s00125-017-4206-6

76. Venkatesh KK, Lynch CD, Powe CE, et al. Risk of Adverse Pregnancy Outcomes Among Pregnant Individuals With Gestational Diabetes by Race and Ethnicity in the United States, 2014-2020. *JAMA*. 2022;327(14):1356-1367. doi:10.1001/jama.2022.3189

77. Miailhe G, Kayem G, Girard G, Legardeur H, Mandelbrot L. Selective rather than universal screening for gestational diabetes mellitus? *Eur J Obstet Gynecol Reprod Biol*. 2015;191(December 2010):95-100. doi:10.1016/j.ejogrb.2015.05.003

78. Donovan LE, Savu A, Edwards AL, Johnson JA, Kaul P. Prevalence and Timing of Screening and Diagnostic Testing for Gestational Diabetes Mellitus : A Population-Based Study in Alberta, Canada. *Diabetes Care*. 2016;39(January):55-60. doi:10.2337/dc15-1421

79. Feldman RK, Tieu RS, Yasumura L. Gestational Diabetes Screening: The IADPSG compared with Carpenter-Coustan Screening. *Obstet Gynecol*. 2016;127(1):10-17. doi:10.1097/AOG.0000000000001132

80. US Preventive Services Task Force. Screening for Gestational Diabetes: US Preventive Services Task Force Recommendation Statement. *JAMA*. 2021;326(6):531-538. doi:10.1001/jama.2021.11922

81. Davis EM, Abebe KZ, Simhan HN, et al. Perinatal Outcomes of Two Screening Strategies for Gestational Diabetes Mellitus. *Obstet Gynecol*. 2021;00(00):1-10. doi:10.1097/AOG.0000000000004431

82. Hillier TA, Pedula KL, Ogasawara KK, et al. A Pragmatic, Randomized Clinical Trial of Gestational Diabetes Screening. *N Engl J Med*. 2021;384(10):895. doi:10.1159/000128682

83. *Diabetes in Pregnancy: Management from Preconception to the Postnatal Period*. National Institute for Health and Care Excellence (NICE); 2020. Accessed July 27, 2022. http://www.ncbi.nlm.nih.gov/books/NBK555331/

84. Hiéronimus S, Le Meaux JP. Relevance of gestational diabetes mellitus screening and comparison of selective with universal strategies. *Diabetes Metab*. 2010;36(6, Part 2):575-586. doi:10.1016/j.diabet.2010.11.010

85. Lachmann EH, Fox RA, Dennison RA, Usher-Smith JA, Meek CL, Aiken CE. Barriers to completing oral glucose tolerance testing in women at risk of gestational diabetes. *Diabet Med*. 2020;37(9):1482-1489. doi:10.1111/dme.14292

86. Brown FM, Wyckoff J. Application of One-Step IADPSG Versus Two-Step Diagnostic Criteria for Gestational Diabetes in the Real World : Impact on Health Services , Clinical Care , and Outcomes. *Diabetes Pregnancy*. 2017;17(85):1-13. doi:10.1007/s11892-017-0922-z

87. Yamamoto JM, Donovan LE, Feig DS, Berger H. Temporary Alternative Screening Strategy for Gestational Diabetes Screening During the COVID-19 Pandemic—The Need for a Middle Ground. *Can J Diabetes*. 2022;46(2):204-206. doi:10.1016/j.jcjd.2021.08.008

88. He J, Chen X, Wang Y, Liu Y, Bai J. The experiences of pregnant women with gestational diabetes mellitus: a systematic review of qualitative evidence. *Rev Endocr Metab Disord*. 2021;22(4):777-787. doi:10.1007/s11154-020-09610-4

89. Edwell J, Jack J. Gestational Diabetes Testing, Narrative, and Medical Distrust. *J Bioethical Inq*. 2017;14(1):53-63. doi:10.1007/s11673-016-9762-9

90. Kong JM. Endorsement of Diabetes Canada's Alternative Approach to Diagnosis of Gestational Diabetes. *Can J Diabetes*. 2018;42(6):580. doi:10.1016/j.jcjd.2018.02.007

91. Blatt AJ, Nakamoto JM, Kaufman HW. Gaps in diabetes screening during pregnancy and postpartum. *Obstet Gynecol*. 2011;117(1):61-68. doi:10.1097/AOG.0b013e3181fe424b

92. Sievenpiper JL, McDonald SD, Grey V, Don-Wauchope AC. Missed follow-up opportunities using a two-step screening approach for gestational diabetes. *Diabetes Res Clin Pract*. 2012;96(2):6-9. doi:10.1016/j.diabres.2012.01.030

93. Wilkerson HLC, O'Sullivan JB, Thorner R. A Study of Glucose Tolerance and Screening Criteria in 752 Unselected Pregnancies. *Diabetes*. 1963;12(4):313-318. doi:10.2337/diab.12.4.313

94. National Diabetes Data Group. Classification and Diagnosis of Diabetes Mellitus and Other Categories of Glucose Intolerance. *Diabetes*. 1979;28(12):1039-1057. doi:10.2337/diab.28.12.1039

95. Carpenter MW, Coustan DR. Criteria for screening tests for gestational diabetes. *Am J Obstet Gynecol*. 1982;144(7):768.

96. World Health Organization. Diagnostic criteria and classification of hyperglycaemia first detected in pregnancy: A World Health Organization Guideline. *Diabetes Res Clin Pract*. 2014;103(3):341-363. doi:10.1016/j.diabres.2013.10.012

97. Pettitt DJ, Knowler W, Baird R, Bennett P. Gestational Diabetes: Infant and Maternal Complications of Pregnancy in Relation to Third-Trimester Glucose Tolerance in the Pima Indians | Diabetes Care | American Diabetes Association. *Diabetes Care*. 1980;3(3). Accessed July 18, 2022. https://diabetesjournals-org.eu1.proxy.openathens.net/care/article/3/3/458/20667/Gestational-Diabetes-Infant-and-Maternal

98. O'Sullivan JB, Charles D, Mahan CM, Dandrow RV. Gestational diabetes and perinatal mortality rate. *Am J Obstet Gynecol*. 1973;116(7):901-904. doi:10.1016/S0002-9378(16)33834-0

99. Crowther CA, Hiller JE, Moss JR, Mcphee AJ, Jeffries WS, Robinson JS. Effect of Treatment of Gestational Diabetes Mellitus on Pregnancy Outcomes. *N Engl J Med*. 2005;352(24):2477-2486.

100. Landon MB, Spong CY, Thom E, et al. A Multicenter, Randomized Trial of Treatment for Mild Gestational Diabetes. *N Engl J Med*. 2009;361(14):1339-1348.

101. Hedderson MM, Ehrlich S, Sridhar S, Darbinian J, Moore S, Ferrara A. Racial / Ethnic Disparities in the Prevalence of Gestational Diabetes Mellitus by BMI. *Diabetes Care*. 2012;35(February). doi:10.2337/dc11-2267

102. Read SH, Rosella LC, Berger H, et al. BMI and risk of gestational diabetes among women of South Asian and Chinese ethnicity: a population-based study. *Diabetologia*. 2021;64(4):805-813. doi:10.1007/s00125-020-05356-5

103. Duran A, Saenz S, Torrejon M, et al. Introduction of IADPSG Criteria for the Screening and Diagnosis of Gestational Diabetes Mellitus Results in Improved Pregnancy Outcomes at a Lower Cost in a Large Cohort of Pregnant Women : The St . Carlos Gestational Diabetes Study. *Diabetes Care*. 2014;37(September):2442-2450. doi:10.2337/dc14-0179

104. Catalano PM, Mcintyre HD, Cruikshank JK, et al. The Hyperglycemia and Adverse Pregnancy Outcome Study: Associations of GDM and obesity with pregnancy outcomes. *Diabetes Care*. 2012;35(4).

105. Kong JM, Lim K, Thompson DM. Evaluation of the International Association of the Diabetes in Pregnancy Study Group New Criteria : Gestational Diabetes Project. *Can J Diabetes*. 2015;39(2):128-132. doi:10.1016/j.jcjd.2014.09.007

106. Agarwal MM, Dhatt GS, Othman Y. Gestational diabetes: differences between the current international diagnostic criteria and implications of switching to IADPSG. *J Diabetes Complications*. 2015;29(4):544-549. doi:10.1016/j.jdiacomp.2015.03.006

107. Alfadhli E. Gestational diabetes in Saudi women identified by the International Association of Diabetes and Pregnancy Study Group versus the former American Diabetes Association criteria: a prospective cohort study. *Ann Saudi Med*. 2015;35(6):428-434. doi:10.5144/0256-4947.2015.428

108. Egan AM, Vellinga A, Harreiter J, et al. Epidemiology of gestational diabetes mellitus according to IADPSG / WHO 2013 criteria among obese pregnant women in Europe. *Diabetologia*. 2017;60:1913-1921. doi:10.1007/s00125-017-4353-9

109. Khalifeh A, Eckler R, Felder L, Saccone G, Caissutti C, Berghella V. One-step versus two-step diagnostic testing for gestational diabetes: a randomized controlled trial. *J Matern Fetal Neonatal Med*. 2020;33(4):612-617. doi:10.1080/14767058.2018.1498480

110. Sampaio Y, Porto LB, Lauand TCG, Marcon LP, Pedrosa HC. Gestational diabetes and overt diabetes first diagnosed in pregnancy: characteristics, therapeutic approach and perinatal outcomes in a public healthcare referral center in Brazil. *Arch Endocrinol Metab*. 2020;65:79-84. doi:10.20945/2359-3997000000310

111. Doi SAR, Bashir M, Sheehan MT, et al. Unifying the diagnosis of gestational diabetes mellitus: Introducing the NPRP criteria. *Prim Care Diabetes*. 2022;16(1):96-101. doi:10.1016/j.pcd.2021.08.006

112. Wen SW, Liu S, Kramer MS, et al. Impact of Prenatal Glucose Screening on the Diagnosis of Gestational Diabetes and on Pregnancy Outcomes. *Am J Epidemiol*. 2000;152(11):1009-1014. doi:10.1093/aje/152.11.1009

113. Buresi MC, Lee J, Gill S, Kong JM, Money DM, Yoshida EM. The Prevalence of Gestational Diabetes Mellitus and Glucose Abnormalities in Pregnant Women With Hepatitis C Virus Infection in British Columbia. *J Obstet Gynaecol Can*. 2010;32(10):935-941. doi:10.1016/S1701-2163(16)34680-1

114. Feig DS, Berger H, Donovan L, et al. Diabetes Canada Clinical Practice Guidelines Expert Committee. *Can J Diabetes*. 2018;42:S255-S282.

115. Yapa M, Simmons D. Screening for gestational diabetes mellitus in a multiethnic population in New Zealand. *Diabetes Res Clin Pract*. 2000;48(3):217-223. doi:10.1016/S0168-8227(99)00150-3

116. Bodmer-Roy S, Morin L, Cousineau J, Rey E. Pregnancy Outcomes in Women With and Without Gestational Diabetes Mellitus According to The International Association of the Diabetes and Pregnancy Study Groups Criteria. *Obstet Gynecol*. 2012;120(4):746-752. doi:10.1097/AOG.0b013e31826994ec

117. Pillay J, Donovan L, Guitard S, et al. Screening for Gestational Diabetes: Updated Evidence Report and Systematic Review for the US Preventive Services Task Force. *JAMA*. 2021;326(6):539-562. doi:10.1001/jama.2021.10404

118. Bimson BE, Rosenn BM, Morris SA, Sasso EB, Schwartz RA, Brustman LE. Current trends in the diagnosis and management of gestational diabetes mellitus in the United States. *J Matern Fetal Neonatal Med*. 2017;30(21):2607-2612. doi:10.1080/14767058.2016.1257603

119. Scifres CM, Abebe KZ, Jones KA, et al. Gestational Diabetes Diagnostic Methods (GD2M) Pilot Randomized Trial. *Matern Child Health J*. 2015;19(7):1472-1480. doi:10.1007/s10995-014-1651-4

120. Sevket O, Ates S, Uysal O, Molla T, Dansuk R, Kelekci S. To evaluate the prevalence and clinical outcomes using a one-step method versus a two-step method to screen gestational diabetes mellitus. *J Matern Fetal Neonatal Med*. 2014;27(1):36-41. doi:10.3109/14767058.2013.799656

121. Nicolaou V, Levitt N, Huddle K, Soepnel L, Norris SA. Perspectives on gestational diabetes mellitus in South Africa. *S Afr Med J*. 2022;112(3):196-200. doi:10.7196/SAMJ.2022.v112i3.16184

122. Khan S, Bal H, Khan ID, Paul D. Evaluation of the diabetes in pregnancy study group of India criteria and Carpenter-Coustan criteria in the diagnosis of gestational diabetes mellitus. *Turk J Obstet Gynecol*. 2018;15(2):75-79. doi:10.4274/tjod.57255

123. Yuen L, Wong VW, Simmons D, Simmons D. Ethnic Disparities in Gestational Diabetes. *Curr Diab Rep*. 2018;18(68).

124. Nielsen K, Kapur A, Damm P, de Courten M, Bygbjerg I. From screening to postpartum follow-up - the determinants and barriers for gestational diabetes mellitus (GDM) services, a systematic review. *BMC Pregnancy Childbirth*. 2014;14(1). http://www.biomedcentral.com/1471-2393/14/41

125. Stoll K, Wang JJ, Niles P, Wells L, Vedam S. I felt so much conflict instead of joy: an analysis of open-ended comments from people in British Columbia who declined care recommendations during pregnancy and childbirth. *Reprod Health*. 2021;18(1):79. doi:10.1186/s12978-021-01134-7

126. Racusin DA, Antony K, Showalter L, Sharma S, Haymond M, Aagaard KM. Candy twists as an alternative to the glucola beverage in gestational diabetes mellitus screening. *Am J Obstet Gynecol*. 2015;212(4):522.e1-522.e5. doi:10.1016/j.ajog.2014.11.010

127. Farrar D, Duley L, Dowswell T, Da L. Different strategies for diagnosing gestational diabetes to improve maternal and infant health (Review). *Cochrane Database Syst Rev*. 2017;(8). doi:10.1002/14651858.CD007122.pub4

128. Ardilouze A, Bouchard P, Hivert MF, et al. Self-Monitoring of Blood Glucose: A Complementary Method Beyond the Oral Glucose Tolerance Test to Identify Hyperglycemia During Pregnancy. *Can J Diabetes*. 2019;43(8):627-635. doi:10.1016/j.jcjd.2019.02.004

129. Nicklas JM, Zera CA, Lui J, Seely EW. Patterns of gestational diabetes diagnosis inside and outside of clinical guidelines. *BMC Pregnancy Childbirth*. 2017;17(1):11. doi:10.1186/s12884-016-1191-6

130. Attanasio LB, Kozhimannil KB, Kjerulff KH. Factors influencing women's perceptions of shared decision making during labor and delivery: Results from a large-scale cohort study of first childbirth. *Physiol Behav*. 2017;176(3):139-148. doi:10.1016/j.physbeh.2017.03.040

131. Canadian Association of Midwives. *Canadian Association of Midwives Annual Report 2015/16.*; 2016.

132. Sandall J, Soltani H, Gates S, Shennan A, Devane D. Midwife-led continuity models versus other models of care for childbearing women. *Cochrane Database Syst Rev*. 2016;(4). doi:10.1002/14651858.CD004667.pub5

133. Kehler S, Macdonald T, Meuser A. *Gestational Diabetes Mellitus: A Review for Midwives*.; 2016.

134. Association of Ontario Midwives. No 7 - Screening for Gestational Diabetes. Published online 2006.

135. Gunn C, Bernstein J, Bokhour B, McCloskey L. Narratives of Gestational Diabetes Provide a Lens to Tailor Postpartum Prevention and Monitoring Counseling. *J Midwifery Womens Health*. 2020;65(5):681-687. doi:10.1111/jmwh.13122

136. Mattenley A, Cheng LA, Cooper F, et al. Gestational Diabetes Mellitus. 2017;(June 2015):1-6.

137. Abarca-Gómez L, Abdeen ZA, Hamid ZA, et al. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. *The Lancet*. 2017;390(10113):2627-2642. doi:10.1016/S0140-6736(17)32129-3

138. Görig T, Schneider S, Bock C, Maul H, Kleinwechter H, Diehl K. Screening for gestational diabetes mellitus in Germany: A qualitative study on pregnant women׳s attitudes, experiences, and suggestions. *Midwifery*. 2015;31(11):1026-1031. doi:10.1016/j.midw.2015.07.001

139. Daniells S, Grenyer BFS, Davis WS, Coleman KJ, Burgess JAP, Moses RG. Gestational Diabetes Mellitus : Is a diagnosis associated with an increase in maternal anxiety and stress in the short and intermediate term? *Diabetes Care*. 2003;26(2):385-389. doi:10.2337/diacare.26.2.385

140. Jagannathan R, Neves JS, Dorcely B, et al. The Oral Glucose Tolerance Test: 100 Years Later. *Diabetes Metab Syndr Obes Targets Ther*. 2020;13:3787-3805. doi:10.2147/DMSO.S246062

141. Cullinan J, Gillespie P, Owens L, Dunne F. Accessibility and screening uptake rates for gestational diabetes mellitus in Ireland. *Health Place*. 2012;18(2):339-348. doi:10.1016/j.healthplace.2011.11.001

142. Nielsen JH, Olesen CR, Kristiansen TM, Bak CK, Overgaard C. Reasons for women's non-participation in follow-up screening after gestational diabetes. *Women Birth*. 2015;28(4):e157-e163. doi:10.1016/j.wombi.2015.04.006

143. Costi L, Lockwood C, Munn Z, Jordan Z. Women's experience of diabetes and diabetes management in pregnancy: a systematic review of qualitative literature: *JBI Database Syst Rev Implement Rep*. 2014;12(1):176-280. doi:10.11124/jbisrir-2014-1304

144. Craig L, Sims R, Glasziou P, Thomas R. Women's experiences of a diagnosis of gestational diabetes mellitus: A systematic review. *BMC Pregnancy Childbirth*. 2020;20(1):1-15. doi:10.1186/s12884-020-2745-1

145. Marchetti D, Carrozzino D, Fraticelli F, Fulcheri M, Vitacolonna E. Quality of Life in Women with Gestational Diabetes Mellitus : A Systematic Review. *J Diabetes Res*. 2017;2017.

146. Parsons J, Sparrow K, Ismail K, Hunt K, Rogers H, Forbes A. Experiences of gestational diabetes and gestational diabetes care: A focus group and interview study. *BMC Pregnancy Childbirth*. 2018;18(1):1-12. doi:10.1186/s12884-018-1657-9

147. Faal Siahkal S, Javadifar N, Najafian M, Iravani M, Zakerkish M, Heshmati R. The psychosocial challenges associated with gestational diabetes mellitus: A systematic review of qualitative studies. *Prim Care Diabetes*. 2022;16(1):11-26. doi:10.1016/j.pcd.2021.09.003

148. Parsons J, Ismail K, Amiel S, Forbes A. Perceptions Among Women With Gestational Diabetes. *Qual Health Res*. 2014;24(4):575-585. doi:10.1177/1049732314524636

149. Kaptein S, Evans M, McTavish S, et al. The Subjective Impact of a Diagnosis of Gestational Diabetes Among Ethnically Diverse Pregnant Women: A Qualitative Study. *Can J Diabetes*. 2015;39(2):117-122. doi:10.1016/j.jcjd.2014.09.005

150. ACOG Committee on Obstetric Practice. ACOG Practice Bulletin No. 190 Summary: Gestational Diabetes Mellitus. *Obstet Gynecol*. 2018;131(2):406-408. doi:10.1097/AOG.0000000000002498

151. Berger H, Crane J, Farine D. Screening for Gestational Diabetes Mellitus. *SOGC Clin Pract Guidel*. 2002;(121):1-10.

152. Berger H, Gagnon R, Sermer M. Diabetes in Pregnancy: Clinical Practice Guideline. *J Obstet Gynaecol Can*. 2016;38(7):667-680. doi:10.1016/j.jogc.2016.04.002

153. Berger H, Gagnon R, Sermer M. Guideline No. 393-Diabetes in Pregnancy. *J Obstet Gynaecol Can*. 2019;41(12):1814-1825.e1. doi:10.1016/j.jogc.2019.03.008

154. Lindqvist M, Persson M, Lindkvist M, Mogren I. No consensus on gestational diabetes mellitus screening regimes in Sweden: pregnancy outcomes in relation to different screening regimes 2011 to 2012, a cross-sectional study. *BMC Pregnancy Childbirth*. 2014;14(1):185. doi:10.1186/1471-2393-14-185

155. Claesson R, Ekelund M, Berntorp K. The potential impact of new diagnostic criteria on the frequency of gestational diabetes mellitus in Sweden. *Acta Obstet Gynecol Scand*. 2013;92(10):1223-1226. doi:10.1111/aogs.12209

156. Laurie JG, McIntyre HD. A Review of the Current Status of Gestational Diabetes Mellitus in Australia—The Clinical Impact of Changing Population Demographics and Diagnostic Criteria on Prevalence. *Int J Environ Res Public Health*. 2020;17(24):9387. doi:10.3390/ijerph17249387

157. He Z, Xie H, Liang S, et al. Influence of different diagnostic criteria on gestational diabetes mellitus incidence and medical expenditures in China. *J Diabetes Investig*. 2019;10(5):1347-1357. doi:10.1111/jdi.13008

158. Iwama N, Sugiyama T, Metoki H, et al. Difference in the prevalence of gestational diabetes mellitus according to gestational age at 75-g oral glucose tolerance test in Japan: The Japan Assessment of Gestational Diabetes Mellitus Screening trial. *J Diabetes Investig*. 2019;10(6):1576-1585. doi:10.1111/jdi.13044

159. Nicolosi BF, Souza RT, Mayrink J, et al. Incidence and risk factors for hyperglycemia in pregnancy among nulliparous women: A Brazilian multicenter cohort study. *PLOS ONE*. 2020;15(5):e0232664. doi:10.1371/journal.pone.0232664

160. Onyenekwe BM, Young EE, Nwatu CB, Okafor CI, Ugwueze CV, Chukwu SN. Prevalence of Gestational Diabetes in South East Nigeria Using the Updated Diagnostic Guidelines. *Dubai Diabetes Endocrinol J*. 2019;25(1-2):26-32. doi:10.1159/000500089

161. Gourvevitch RA, Natwick T, Chaisson CE, Weiseth A, Shah NT. Variation in Guideline-Based Prenatal Care in a Commercially Insured Population. *Am J Obstet Gynecol*. Published online 2021. doi:10.1016/j.ajog.2021.09.038

162. Pouliot A, Elmahboubi R, Adam C. Incidence and Outcomes of Gestational Diabetes Mellitus Using the New International Association of Diabetes in Pregnancy Study Group Criteria in Hôpital Maisonneuve-Rosemont. *Can J Diabetes*. 2019;43(8):594-599. doi:10.1016/j.jcjd.2019.10.003

163. Boyle DIR, Versace VL, Dunbar JA, et al. Results of the first recorded evaluation of a national gestational diabetes mellitus register: Challenges in screening, registration, and follow-up for diabetes risk. *PLoS ONE*. 2018;13(8):1-15. doi:10.1371/journal.pone.0200832

164. Persson M, Winkvist A, Mogren I. Surprisingly low compliance to local guidelines for risk factor based screening for gestational diabetes mellitus - A population-based study. *BMC Pregnancy Childbirth*. 2009;9:1-10. doi:10.1186/1471-2393-9-53

165. Fenton JJ, Zhu W, Balch S, Smith-Bindman R, Fishman P, Hubbard RA. Distinguishing screening from diagnostic mammograms using medicare claims data. *Med Care*. 2014;52(7):1-18. doi:10.1097/MLR.0b013e318269e0f5

166. Paszat L, Sutradhar R, Luo J, Tinmouth J, Rabeneck L, Baxter NN. Uptake and Short-term Outcomes of High-risk Screening Colonoscopy Billing Codes: A Population-based Study Among Young Adults. *J Can Assoc Gastroenterol*. 2022;5(2):86-95. doi:10.1093/jcag/gwab014

167. Ross CE, Tao G, Patton M, Hoover KW. Screening for Human Immunodeficiency Virus and Other Sexually Transmitted Diseases Among U.S. Women With Prenatal Care. *Obstet Gynecol*. 2015;125(5). Accessed May 17, 2022. https://oce.ovid.com/article/00006250-201505000-00031/HTML

168. Kolasa MS, Tsai Y, Xu J, Fenlon N, Schillie S. Hepatitis B Surface Antigen Testing Among Pregnant Women, United States 2014. *Pediatr Infect Dis J*. 2017;36(7):e175-e180. doi:10.1097/INF.0000000000001516

169. Leung J, Cannon MJ, Grosse SD, Bialek SR. Laboratory testing for cytomegalovirus among pregnant women in the United States: a retrospective study using administrative claims data. *BMC Infect Dis*. 2012;12(1):334. doi:10.1186/1471-2334-12-334

170. Hale NL, Probst JC, Liu J, Martin AB, Bennett KJ, Glover S. Postpartum Screening for Diabetes among Medicaid-Eligible South Carolina Women with Gestational Diabetes. *Womens Health Issues*. 2012;22(2):e163-e169. doi:10.1016/j.whi.2011.08.003

171. British Columbia Ministry of Health. Vital Events Births. Published online 2021. Accessed February 25, 2022. http://www.popdata.bc.ca/data

172. Perinatal Services BC. British Columbia Perinatal Data Registry. Published online 2021. Accessed February 25, 2022. http://www.popdata.bc.ca/data

173. Morgan SG, Cunningham CM, Hanley GE. Individual and Contextual Determinants of Regional Variation in Prescription Drug Use: An Analysis of Administrative Data from British Columbia. Ross JS, ed. *PLoS ONE*. 2010;5(12):e15883. doi:10.1371/journal.pone.0015883

174. Barr WB, Pecci CC. Last menstrual period versus ultrasound for pregnancy dating. *Int J Gynaecol Obstet Off Organ Int Fed Gynaecol Obstet*. 2004;87(1):38-39. doi:10.1016/j.ijgo.2004.06.008

175. Allen VM, Yudin MH, Bouchard C, et al. Management of group B streptococcal bacteriuria in pregnancy. *J Obstet Gynaecol Can JOGC J Obstétrique Gynécologie Can JOGC*. 2012;34(5):482-486.

176. Frosst G, Hutcheon J, Joseph KS, Kinniburgh B, Johnson C, Lee L. Validating the British Columbia Perinatal Data Registry: A chart re-abstraction study. *BMC Pregnancy Childbirth*. 2015;15(1):1-11. doi:10.1186/s12884-015-0563-7

177. McRae DN, Janssen PA, Vedam S, et al. Reduced prevalence of small-for-gestational-age and preterm birth for women of low socioeconomic position: A population-based cohort study comparing antenatal midwifery and physician models of care. *BMJ Open*. 2018;8(10):1-11. doi:10.1136/bmjopen-2018-022220

178. Benchimol EI, Manuel DG, To T, Griffiths AM, Rabeneck L, Guttmann A. Development and use of reporting guidelines for assessing the quality of validation studies of health administrative data. *J Clin Epidemiol*. 2011;64(8):821-829. doi:10.1016/j.jclinepi.2010.10.006

179. Tsai WY, Chi Y, Chen CM. Interval estimation of binomial proportion in clinical trials with a two-stage design. *Stat Med*. 2008;27(1):15-35. doi:10.1002/sim.2930

180. Stevenson, Mark, Sergeant, Evan. epiR: Tools for the Analysis of Epidemiological Data version 2.0.46 from CRAN. Accessed April 21, 2022. https://rdrr.io/cran/epiR/

181. R Core Team. R: A language and environment for statistical computing. Published online 2021. https://www.r-project.org

182. Bouzayen R, Eggertson L. In vitro fertilization: A private matter becomes public. *CMAJ Can Med Assoc J*. 2009;181(5):243-243. doi:10.1503/cmaj.091344

183. Nieuwenhuijze MJ, Korstjens I, de Jonge A, de Vries R, Lagro-Janssen A. On speaking terms: A Delphi study on shared decision-making in maternity care. *BMC Pregnancy Childbirth*. 2014;14(1):1-11. doi:10.1186/1471-2393-14-223

184. Kotaska A. Informed consent and refusal in obstetrics: A practical ethical guide. *Birth*. 2017;44(3):195-199. doi:10.1111/birt.12281

185. Altman MR, Oseguera T, McLemore MR, Kantrowitz-Gordon I, Franck LS, Lyndon A. Information and power: Women of color's experiences interacting with health care providers in pregnancy and birth. *Soc Sci Med*. 2019;238:112491. doi:10.1016/j.socscimed.2019.112491

186. McIntyre HD, Moses RG. The Diagnosis and Management of Gestational Diabetes Mellitus in the Context of the COVID-19 Pandemic. *Diabetes Care*. 2020;43(7):1433-1434. doi:10.2337/dci20-0026

187. Curtis AM, Farmer AJ, Roberts NW, Armitage LC. Performance of guidelines for the screening and diagnosis of gestational diabetes mellitus during the COVID-19 pandemic: A scoping review of the guidelines and diagnostic studies evaluating the recommended testing strategies. *Diabetes Epidemiol Manag*. 2021;3:100023. doi:10.1016/j.deman.2021.100023

188. Kotelchuck M. An evaluation of the Kessner Adequacy of Prenatal Care Index and a proposed Adequacy of Prenatal Care Utilization Index. *Am J Public Health*. 1994;84(9):1414-1420. doi:10.2105/AJPH.84.9.1414

189. Bhattacharyya OK, Shah BR, Booth GL. Canadian Diabetes Association guidelines 2013 full report. *Can J Diabetes*. 2013;179(9):920-926. doi:10.1503/cmaj.080554

190. Zou G. A modified poisson regression approach to prospective studies with binary data. *Am J Epidemiol*. 2004;159(7):702-706. doi:10.1093/aje/kwh090

191. Mattenley A, Cheng LA, Cooper F, et al. *Gestational Diabetes Mellitus*. BC Women's Hospital & Health Centre; 2017:1-6.

192. Grzybowski S, Stoll K, Kornelsen J. Distance matters: a population based study examining access to maternity services for rural women. *BMC Health Serv Res*. 2011;11:147. doi:10.1186/1472-6963-11-147

193. Jazdarehee A, Parajulee A, Kornelsen J. The experiences of rural British Columbians accessing surgical and obstetrical care. *Patient Exp J*. 2021;8(1):126-134. doi:10.35680/2372-0247.1505

194. College of Midwives of British Columbia. Policy on informed choice. Published online 2017:1-2.

195. Niles PM, Stoll K, Wang JJ, Black S, Vedam S. "I fought my entire way": Experiences of declining maternity care services in British Columbia. *PLOS ONE*. 2021;16(6):e0252645. doi:10.1371/journal.pone.0252645

196. Dixon V, Burton N. Are midwifery clients in Ontario making informed choices about prenatal screening? *Women Birth*. 2014;27(2):86-90. doi:10.1016/j.wombi.2014.02.003

197. Butler MM, Sheehy L, Kington MM, et al. Evaluating midwife-led antenatal care: Choice, experience, effectiveness, and preparation for pregnancy. *Midwifery*. 2015;31(4). doi:10.1016/j.midw.2014.12.002

198. Lavery J, Friedman A, Keyes K, Wright J, Ananth C. Gestational diabetes in the United States: temporal changes in prevalence rates between 1979 and 2010. *BJOG Int J Obstet Gynaecol*. 2017;124(5):804-813. doi:10.1111/1471-0528.14236

199. British Columbia Ministry of Health, Perinatal Services BC. Consolidation File (MSP Registration & Premium Billing), Medical Services Plan (MSP) Payment Information File, Vital Events Births, British Columbia Perinatal Data Registry. Published online Years Provided (-2019 2004. Accessed February 22, 2022. http://www.popdata.bc.ca/data

200. Alexander GR, Kotelchuck M. Quantifying the adequacy of prenatal care: A comparison of indices. *Public Health Rep*. 1996;111(5):408-419.

201. Ignell C, Claesson R, Anderberg E, Berntorp K. Trends in the prevalence of gestational diabetes mellitus in southern Sweden, 2003–2012. *Acta Obstet Gynecol Scand*. 2014;93(4):420-424. doi:10.1111/aogs.12340

202. Yan B, Yu Y, Lin M, et al. High, but stable, trend in the prevalence of gestational diabetes mellitus: A population-based study in Xiamen, China. *J Diabetes Investig*. 2019;10(5):1358-1364. doi:10.1111/jdi.13039

203. Su FL, Lu MC, Yu SC, et al. Increasing trend in the prevalence of gestational diabetes mellitus in Taiwan. *J Diabetes Investig*. 2021;12(11):2080-2088. doi:10.1111/jdi.13595

204. Gregory C.W. E, Danielle M. E. *Trends and Characteristics in Gestational Diabetes: United States, 2016–2020*. National Center for Health Statistics (U.S.); 2022. doi:10.15620/cdc:118018

205. Hale T, Angrist N, Goldszmidt R, et al. A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker). *Nat Hum Behav*. 2021;5(4):529-538. doi:10.1038/s41562-021-01079-8

206. Chew HSJ, Lopez V. Global impact of covid-19 on weight and weight-related behaviors in the adult population: A scoping review. *Int J Environ Res Public Health*. 2021;18(4):1-32. doi:10.3390/ijerph18041876

207. Deschasaux-Tanguy M, Druesne-Pecollo N, Esseddik Y, et al. Diet and physical activity during the coronavirus disease 2019 (COVID-19) lockdown (March-May 2020): Results from the French NutriNet-Santé cohort study. *Am J Clin Nutr*. 2021;113(4):924-938. doi:10.1093/ajcn/nqaa336

208. Mulugeta W, Desalegn H, Solomon S. Impact of the COVID -19 pandemic lockdown on weight status and factors associated with weight gain among adults in Massachusetts. *Clin Obes*. 2021;(December 2020):1-8. doi:10.1111/cob.12453

209. Chmielewska B, Barratt I, Townsend R, et al. Effects of the COVID-19 pandemic on maternal and perinatal outcomes: a systematic review and meta-analysis. *Lancet Glob Health*. 2021;9(6):e759-e772. doi:10.1016/S2214-109X(21)00079-6

210. Brülhart M, Klotzbücher V, Lalive R, Reich SK. Mental health concerns during the COVID-19 pandemic as revealed by helpline calls. *Nature*. 2021;600(7887):121-126. doi:10.1038/s41586-021-04099-6

211. Green H, Fernandez R, MacPhail C. The social determinants of health and health outcomes among adults during the COVID-19 pandemic: A systematic review. *Public Health Nurs*. 2021;(July):1-11. doi:10.1111/phn.12959

212. Badon SE, Hedderson MM, Hyde RJ, Quesenberry CP, Avalos LA. Pre-and Early Pregnancy Onset Depression and Subsequent Rate of Gestational Weight Gain. *J Womens Health*. 2019;28(9):1237-1245. doi:10.1089/jwh.2018.7497

213. Molyneaux E, Poston L, Khondoker M, Howard LM. Obesity, antenatal depression, diet and gestational weight gain in a population cohort study. *Arch Womens Ment Health*. 2016;19(5):899-907. doi:10.1007/s00737-016-0635-3

214. Bridgland VME, Moeck EK, Green DM, et al. Why the COVID-19 pandemic is a traumatic stressor. *PLoS ONE*. 2021;16(1 January):1-15. doi:10.1371/journal.pone.0240146

215. Onwuzurike C, Meadows AR, Nour NM. Examining Inequities Associated with Changes in Obstetric and Gynecologic Care Delivery during the Coronavirus Disease 2019 (COVID-19) Pandemic. *Obstet Gynecol*. 2020;136(1):37-41. doi:10.1097/AOG.0000000000003933

216. Gundersen C, Hake M, Dewey A, Engelhard E. Food Insecurity during COVID-19. *Appl Econ Perspect Policy*. 2021;43(1):153-161. doi:10.1002/aepp.13100

217. Niles M, Bertmann F, Belarmino E, Wentworth T, Biehl E, Neff R. The Early Food Insecurity Impacts of COVID-19. *Nutrients*. Published online 2020. doi:10.1101/2020.05.09.20096412

218. Leddy AM, Weiser SD, Palar K, Seligman H. A conceptual model for understanding the rapid COVID-19-related increase in food insecurity and its impact on health and healthcare. *Am J Clin Nutr*. 2020;112(5):1162-1169. doi:10.1093/ajcn/nqaa226

219. Sartorelli DS, Crivellenti LC, Zuccolotto DCC, Franco LJ. Relationship between minimally and ultra-processed food intake during pregnancy with obesity and gestational diabetes mellitus. *Cad Saude Publica*. 2019;35(4):e00049318. doi:10.1590/0102-311X00049318

220. Crane JMG, White J, Murphy P, Burrage L, Hutchens D. The Effect of Gestational Weight Gain by Body Mass Index on Maternal and Neonatal Outcomes. *J Obstet Gynaecol Can*. 2009;31(1):28-35. doi:10.1016/S1701-2163(16)34050-6

221. Holowko N, Chaparro MP, Nilsson K, et al. Social inequality in pre-pregnancy BMI and gestational weight gain in the first and second pregnancy among women in Sweden. *J Epidemiol Community Health*. 2015;69(12):1154-1161. doi:10.1136/jech-2015-205598

222. Kauffman E, Souter VL, Katon JG, Sitcov K. Cervical Dilation on Admission in Term Spontaneous Labor and Maternal and Newborn Outcomes. *Obstet Gynecol*. 2016;127(3):481-488. doi:10.1097/AOG.0000000000001294

223. Santos S, Eekhout I, Voerman E, Gaillard R, Barros H, Charles M aline. Gestational weight gain charts for different body mass index groups for women in Europe , North America , and Oceania. Published online 2018:1-15.

224. Alexander GR, Himes JH, Kaufman RB, Mor J, Kogan M. A united states national reference for fetal growth. *Obstet Gynecol*. 1996;87(2):163-168. doi:10.1016/0029-7844(95)00386-x

225. Aris IM, Kleinman KP, Belfort MB, Kaimal A, Oken E. A 2017 US reference for singleton birth weight percentiles using obstetric estimates of gestation. *Pediatrics*. 2019;144(1). doi:10.1542/peds.2019-0076

226. Basso O, Wilcox A. Mortality risk among preterm babies: Immaturity versus underlying pathology. *Epidemiology*. 2010;21(4):521-527. doi:10.1097/EDE.0b013e3181debe5e

227. Stephens AJ, Barton JR, Bentum NAA, Blackwell SC, Sibai BM. General Guidelines in the Management of an Obstetrical Patient on the Labor and Delivery Unit during the COVID-19 Pandemic. *Am J Perinatol*. 2020;37(8):829-836. doi:10.1055/s-0040-1710308

228. Ismail LC, Bishop DC, Pang R, et al. Gestational weight gain standards based on women enrolled in the Fetal Growth Longitudinal Study of the INTERGROWTH-21st project: A Prospective longitudinal cohort study. *BMJ Online*. 2016;352. doi:10.1136/bmj.i555

229. Rangel Bousquet Carrilho T, M. Rasmussen K, Rodrigues Farias D, et al. Agreement between self-reported pre-pregnancy weight and measured first-trimester weight in Brazilian women. *BMC Pregnancy Childbirth*. 2020;20(1):734. doi:10.1186/s12884-020-03354-4

230. Duryea EL, Hawkins JS, McIntire DD, Casey BM, Leveno KJ. A revised birth weight reference for the United States. *Obstet Gynecol*. 2014;124(1):16-22. doi:10.1097/AOG.0000000000000345

231. WWHAMI Rural Health Research Center. Rural Urban Commuting Area Codes Data. Published 2011. Accessed September 9, 2014. http://depts.washington.edu/uwruca/ruca-data.php

232. Nethery E, Gordon W, Bovbjerg ML, Cheyney M. Rural community birth : Maternal and neonatal outcomes for planned community births among rural women in the United. *Birth Issues Perinat Care*. 2018;45:120-129. doi:10.1111/birt.12322

233. Economic Innovation Group. *EIG' s Distressed Communities Index*.; 2020.

234. Kontopantelis E, Doran T, Springate DA, Buchan I, Reeves D. Regression based quasi-experimental approach when randomisation is not an option: Interrupted time series analysis. *BMJ Online*. 2015;350:1-4. doi:10.1136/bmj.h2750

235. Bernal JL, Cummins S, Gasparrini A. Interrupted time series regression for the evaluation of public health interventions: A tutorial. *Int J Epidemiol*. 2017;46(1):348-355. doi:10.1093/ije/dyw098

236. Herring S, Rose M, Skouteris H, Oken E. Optimizing weight gain in pregnancy to prevent obesity in women and children. *Diabetes Obes Metab*. 2012;14:195-203.

237. Johansson K, Linné Y, Rössner S, Neovius M. Maternal predictors of birthweight: The importance of weight gain during pregnancy. *Obes Res Clin Pract*. 2007;1(4):243-252. doi:10.1016/j.orcp.2007.09.001

238. Currie J, Schwandt H. Within-mother analysis of seasonal patterns in health at birth. *Proc Natl Acad Sci*. 2013;110(32):13228-13228. doi:10.1073/pnas.1313401110

239. Hutcheon JA, Moskosky S, Ananth C V., et al. Good practices for the design, analysis, and interpretation of observational studies on birth spacing and perinatal health outcomes. *Paediatr Perinat Epidemiol*. 2019;33(1):O15-O24. doi:10.1111/ppe.12512

240. Hategeka C, Ruton H, Karamouzian M, Lynd LD, Law MR. Use of interrupted time series methods in the evaluation of health system quality improvement interventions: A methodological systematic review. *BMJ Glob Health*. 2020;5(10):1-13. doi:10.1136/bmjgh-2020-003567

241. Bhaskaran K, Gasparrini A, Hajat S, Smeeth L, Armstrong B. Time series regression studies in environmental epidemiology. *Int J Epidemiol*. 2013;42(4):1187-1195. doi:10.1093/ije/dyt092

242. Fahey CA, Chevrier J, Crause M, Obida M, Bornman R, Eskenazi B. Seasonality of antenatal care attendance, maternal dietary intake, and fetal growth in the VHEMBE birth cohort, South Africa. *PLoS ONE*. 2019;14(9):1-15. doi:10.1371/journal.pone.0222888

243. Neophytou AM, Kioumourtzoglou MA, Goin DE, Darwin KC, Casey JA. Educational note: Addressing special cases of bias that frequently occur in perinatal epidemiology. *Int J Epidemiol*. 2021;50(1):337-345. doi:10.1093/ije/dyaa252

244. Koenker R, Hallock KF. Quantile regression. *J Econ Perspect*. 2001;15(4):143-156. doi:10.1257/jep.15.4.143

245. Lin AL, Vittinghoff E, Olgin JE, Pletcher MJ, Marcus GM. Body Weight Changes during Pandemic-Related Shelter-in-Place in a Longitudinal Cohort Study. *JAMA Netw Open*. 2021;4(3):17-20. doi:10.1001/jamanetworkopen.2021.2536

246. Kirchengast S, Hartmann B. Pregnancy outcome during the first covid 19 lockdown in Vienna, Austria. *Int J Environ Res Public Health*. 2021;18(7):1-14. doi:10.3390/ijerph18073782

247. Du M, Yang J, Han N, Liu M, Liu J. Association between the COVID-19 pandemic and the risk for adverse pregnancy outcomes: A cohort study. *BMJ Open*. 2021;11(2). doi:10.1136/bmjopen-2020-047900

248. Philip RK, Purtill H, Reidy E, et al. Unprecedented reduction in births of very low birthweight (VLBW) and extremely low birthweight (ELBW) infants during the COVID-19 lockdown in Ireland: a 'natural experiment' allowing analysis of data from the prior two decades. *BMJ Glob Health*. 2020;5(9):e003075. doi:10.1136/bmjgh-2020-003075

249. Yang J, D'Souza R, Karrat A, et al. COVID-19 pandemic and population-level pregnancy and neonatal outcomes: a living systematic review and meta-analysis. *Acta Obstet Gynecol Scand*. 2021;100:1756-1770. doi:10.1111/aogs.14206

250. Vaccaro C, Mahmoud F, Aboulatta L, Aloud B, Eltonsy S. The impact of COVID-19 first wave national lockdowns on perinatal outcomes: a rapid review and meta-analysis. *BMC Pregnancy Childbirth*. 2021;21(1):1-14. doi:10.1186/s12884-021-04156-y

251. Doyle YG, Furey A, Flowers J. Sick individuals and sick populations: 20 Years later. *J Epidemiol Community Health*. 2006;60(5):396-398. doi:10.1136/jech.2005.042770

252. Vivian Ukah U, Bayrampour H, Sabr Y, et al. Association between gestational weight gain and severe adverse birth outcomes in Washington State, US: A population-based retrospective cohort study, 2004-2013. *PLoS Med*. 2019;16(12):2004-2013. doi:10.1371/journal.pmed.1003009

253. van der Werf ET, Busch M, Jong MC, Hoenders HJR. Lifestyle changes during the first wave of the COVID-19 pandemic: a cross-sectional survey in the Netherlands. *BMC Public Health*. 2021;21(1):1226. doi:10.1186/s12889-021-11264-z

254. Darrow LA, Strickland MJ, Klein M, et al. Seasonality of Birth and Implications for Temporal Studies of Preterm Birth. *Epidemiology*. 2009;20(5):699-706. doi:10.1097/EDE.0b013e3181a66e96

255. Chodick G, Flash S, Deoitch Y, Shalev V. Seasonality in birth weight: Review of global patterns and potential causes. *Hum Biol*. 2009;81(4):463-477. doi:10.3378/027.081.0405

256. Brauer M, Lencar C, Tamburic L, Koehoorn M, Demers P, Karr C. A Cohort Study of Traffic-Related Air Pollution Impacts on Birth Outcomes. *Environ Health Perspect*. 2008;116(5):680-686. doi:10.1289/ehp.10952

257. Miranda ML, Edwards SE, Keating MH, Paul CJ. Making the environmental justice grade: the relative burden of air pollution exposure in the United States. *Int J Environ Res Public Health*. 2011;8(6):1755-1771. doi:10.3390/ijerph8061755

258. Silva-Jose C, Sánchez-Polán M, Diaz-Blanco Á, Coterón J, Barakat R, Refoyo I. Effectiveness of a Virtual Exercise Program During COVID-19 Confinement on Blood Pressure Control in Healthy Pregnant Women. *Front Physiol*. 2021;12(March):1-9. doi:10.3389/fphys.2021.645136

259. Cusack L, Sbihi H, Larkin A, et al. Residential green space and pathways to term birth weight in the Canadian Healthy Infant Longitudinal Development (CHILD) Study. *Int J Health Geogr*. 2018;17(1):1-12. doi:10.1186/s12942-018-0160-x

260. van Buuren S. *Flexible Imputation of Missing Data*. 2nd ed. Chapman & Hall/CRC; 2018.

261. von Hippel PT. Regression with missing Ys: An improved strategy for analyzing multiply imputed data. *Sociol Methodol*. 2007;37(1):83-117.

262. Hughes RA, Heron J, Sterne JAC, Tilling K. Accounting for missing data in statistical analyses: Multiple imputation is not always the answer. *Int J Epidemiol*. 2019;48(4):1294-1304. doi:10.1093/ije/dyz032

263. van Ginkel JR, Linting M, Rippe RCA, van der Voort A. Rebutting Existing Misconceptions About Multiple Imputation as a Method for Handling Missing Data. *J Pers Assess*. 2020;102(3):297-308. doi:10.1080/00223891.2018.1530680

264. Bazo-Alvarez JC, Morris TP, Carpenter JR, Petersen I. Current practices in missing data handling for interrupted time series studies performed on individual-level data: A scoping review in health research. *Clin Epidemiol*. 2021;13:603-613. doi:10.2147/CLEP.S314020

265. Johnson DR, Young R. Toward best practices in analyzing datasets with missing data: Comparisons and recommendations. *J Marriage Fam*. 2011;73(5):926-945. doi:10.1111/j.1741-3737.2011.00861.x

266. Sullivan TR, Lee KJ, Ryan P, Salter AB. Multiple imputation for handling missing outcome data when estimating the relative risk. *BMC Med Res Methodol*. 2017;17(1):1-10. doi:10.1186/s12874-017-0414-5

267. Donders ART, van der Heijden GJMG, Stijnen T, Moons KGM. Review: A gentle introduction to imputation of missing values. *J Clin Epidemiol*. 2006;59(10):1087-1091. doi:10.1016/j.jclinepi.2006.01.014

268. Little RJA. Regression with missing X's: A review. *J Am Stat Assoc*. 1992;87(420):1227-1237. doi:10.1080/01621459.1992.10476282

269. Bazo-Alvarez JC, Morris TP, Pham TM, Carpenter JR, Petersen I. Handling missing values in interrupted time series analysis of longitudinal individual-level data. *Clin Epidemiol*. 2020;12:1045-1057. doi:10.2147/CLEP.S266428

270. Buuren S van, Groothuis-Oudshoorn K. **mice** : Multivariate Imputation by Chained Equations in *R. J Stat Softw*. 2011;45(3). doi:10.18637/jss.v045.i03

271. Bowker SL, Savu A, Lam NK, Johnson JA, Kaul P. Validation of administrative data case definitions for gestational diabetes mellitus. *Diabet Med*. 2017;34(1):51-55. doi:10.1111/dme.13030

272. Andrade SE, Moore Simas TA, Boudreau D, et al. Validation of algorithms to ascertain clinical conditions and medical procedures used during pregnancy. *Pharmacoepidemiol Drug Saf*. 2011;20(11):1168-1176. doi:10.1002/pds.2217

273. Fuller KP, Borgida AF. Gestational Diabetes Mellitus Screening Using the One-Step Versus Two-Step Method in a High-Risk Practice. *Clin Diabetes Publ Am Diabetes Assoc*. 2014;32(4):148-150. doi:10.2337/diaclin.32.4.148

274. Woolford S, Sidell M, Li X, Young D, Resnicow K, Koebnick C. Changes in Body Mass IndexAmong Children andAdolescents During the COVID-19 Pandemic. *JAMA*. Published online 2021. doi:doi:10.1001/jama.2021.15036

275. Zanardo V, Tortora D, Sandri A, Severino L, Mesirca P, Straface G. COVID-19 pandemic: Impact on gestational diabetes mellitus prevalence. *Diabetes Res Clin Pract*. 2022;183:109149. doi:10.1016/j.diabres.2021.109149

276. Fox MP, Lash TL, Bodnar LM. Common misconceptions about validation studies. *Int J Epidemiol*. 2020;49(4):1392-1396. doi:10.1093/ije/dyaa090

277. Methods for Estimating the Due Date. Accessed August 8, 2022. https://www.acog.org/en/clinical/clinical-guidance/committee-opinion/articles/2017/05/methods-for-estimating-the-due-date

278. Demianczuk N, Van den Hof M. The Use of first trimester ultrasound. *SOGC Clin Pract Guidel*. 2003;(135):1-6.

279. Savitz D a., Terry JW, Dole N, Thorp JM, Siega-Riz AM, Herring AH. Comparison of pregnancy dating by last menstrual period, ultrasound scanning, and their combination. *Am J Obstet Gynecol*. 2002;187(6):1660-1666. doi:10.1067/mob.2002.127601

280. Rao GG, Khanna P. To screen or not to screen women for Group B Streptococcus (Streptococcus agalactiae) to prevent early onset sepsis in newborns: recent advances in the unresolved debate. *Ther Adv Infect Dis*. 2020;7:2049936120942424. doi:10.1177/2049936120942424

281. Greenhalgh T, Raftery J, Hanney S, Glover M. Research impact: a narrative review. *BMC Med*. 2016;14(1):78. doi:10.1186/s12916-016-0620-8

282. Banzi R, Moja L, Pistotti V, Facchini A, Liberati A. Conceptual frameworks and empirical approaches used to assess the impact of health research: an overview of reviews. *Health Res Policy Syst*. 2011;9(1):26. doi:10.1186/1478-4505-9-26

283. Edmonds BT. Shared decision-making and decision support: Their role in obstetrics and gynecology. *Curr Opin Obstet Gynecol*. 2014;26(6):523-530. doi:10.1097/GCO.0000000000000120

284. Gee RE, Corry MP. Patient engagement and shared decision making in maternity care. *Obstet Gynecol*. 2012;120(5):995-997. doi:http://10.1097/AOG.0b013e31827046ac

285. Montanez A. Gestational diabetes. Published online 2014.

286. D'Angelo D. Patterns of Health Insurance Coverage Around the Time of Pregnancy Among Women With Live-Born Infants—Pregnancy Risk Assessment Monitoring System, 29 States, 2009. *Am J Public Health*. 2016;106(4):e1-e2. doi:10.2105/AJPH.2016.303133

287. Korn EL, Graubard BI. Confidence intervals for proportions with very small expected number of positive counts estimated from survey data – ScienceOpen. *Surv Methodol*. 1998;24(2). Accessed August 20, 2022. https://www.scienceopen.com/document?vid=2cd14e72-eac5-43fd-9a0d-d38ffc59f992

288. McRae DN. *Antenatal Midwifery Care and Reduced Prevalence of Small-for-Gestational-Age Birth and Other Adverse Infant Birth Outcomes for Women of Low Socioeconomic Position A Population Based Cohort Study Comparing Midwifery and Physician-Led Models of Care*. PhD Dissertation. University of Saskatchewan; 2017.

289. McRae DN, Muhajarine N, Janssen PA. Improving birth outcomes for women who are substance using or have mental illness: a Canadian cohort study comparing antenatal midwifery and physician models of care for women of low socioeconomic position. *BMC Pregnancy Childbirth*. 2019;19(1). doi:10.1186/s12884-019-2428-y

290. IOM (Institute of Medicine). *An Update on Research Issues in the Assessment of Birth Settings: Workshop Summary*. The National Academies Press; 2013. doi:10.17226/18368

291. Thompson D, Berger H, Feig D, et al. Diabetes and Pregnancy. *Can J Diabetes*. 2013;37(SUPPL.1):S168-S183. doi:10.1016/j.jcjd.2013.01.044

292. Tilden EL, Snowden JM. The causal inference framework: a primer on concepts and methods for improving the study of well-woman childbearing processes. *J Midwifery Womens Health*. 2019;63(6):700-709. doi:10.1111/jmwh.12710.The

293. Hernán MA, Robins JM. *Causal Inference, Pt. I*. Chapman & Hall/CRC, Forthcoming; 2019. doi:10.4324/9781315542287-6

294. Lusa L, Ahlin Č. Restricted cubic splines for modelling periodic data. *PLoS ONE*. 2020;15(10 October):1-17. doi:10.1371/journal.pone.0241364

295. Perperoglou A, Sauerbrei W, Abrahamowicz M, Schmid M. A review of spline function procedures in R. *BMC Med Res Methodol*. 2019;19(1):1-16. doi:10.1186/s12874-019-0666-3

296. Lokken EM, Taylor GG, Huebner EM, et al. Higher severe acute respiratory syndrome coronavirus 2 infection rate in pregnant patients. *Am J Obstet Gynecol*. 2021;225(1):75.e1-75.e16. doi:10.1016/j.ajog.2021.02.011

297. Centers for Disease Control and Prevention. CDC Covid Pregnancy Information 2021. Published online 2021. https://www.cdc.gov/nchs/covid19/technical-linkage.htm

298. Stirnemann J, Villar J, Salomon LJ, et al. International estimated fetal weight standards of the INTERGROWTH-21st Project. *Ultrasound Obstet Gynecol*. 2017;49(4):478-486. doi:10.1002/uog.17347

299. Fay E, Hugh O, Francis A, et al. Customized GROW vs INTERGROWTH-21st birthweight standards to identify small for gestational age associated perinatal outcomes at term. *Am J Obstet Gynecol MFM*. 2022;4(2):1-6. doi:10.1016/j.ajogmf.2021.100545

300. Johansson K, Hutcheon JA, Stephansson O, Cnattingius S. Pregnancy weight gain by gestational age and BMI in Sweden: A population-based cohort study. *Am J Clin Nutr*. 2016;103(5):1278-1284. doi:10.3945/ajcn.115.110197

A. Validation study supplemental

A.1 Supplemental methods

Additional information on administrative data sources and linkages in this study

The administrative data for this validation study came from three data sources[50]. These included 1) BC Perinatal Data Registry (BC-PDR), 2) Medical Services Plan billings records (MSP-billings) and 3) the Medical Services Plan registration file (MSP-registration).

1) The BC-PDR is a validated perinatal data registry[176] that contains over 300 data elements including obstetric and neonatal outcome data. Unfortunately, the BC-PDR captures diagnosis of GDM but does not capture screening status, either completion or method. The BC-PDR does capture 1st trimester ultrasound and Group B strep screening and diagnosis status. Race and ethnicity data are not captured in this data registry, nor is it collected on most standard medical records in BC, therefore we were unable to report data on race or ethnicity. Pregnancies and births (live and stillbirths) are only captured in the BC-PDR if they happen ≥20 weeks gestational age or if birthweight of fetus or newborn is ≥500g. The BC-PDR does not include data for deliveries that are therapeutically or spontaneously delivered at <20 weeks gestation and are <500 grams fetal birth weight. This registry also includes all hospital births, all home births attended by Registered Midwives in BC and all births (e.g., en-route or unplanned home births) where hospital or emergency services were involved. Births outside of the hospital that were unattended, or not attended by a registered medical provider (aka "freebirth" or an intended home birth with an unlicensed attendant) in BC are not captured in the PDR. Since Registered Midwives in BC attend home births, are covered by insurance, and legal/licensed by the province (since 1998), we estimate that the proportion of unattended home births in BC is very small.

2) MSP-billings report all fees and procedures billed to the public health insurance system for each individual study id during all years. We restricted to billing records for services during each pregnancy time period and then identified all billings relevant to the codes of interest (listed in eTable1).

3) The MSP-registration file reports the start and end day of the year of active insurance registration for each person and year. Utilising this data, we identified months of active health insurance during the duration of the pregnancy. We did not count the first 2 months of the pregnancy, because we anticipated some error in our ascertainment of pregnancy start month and because most prenatal care services would not happen until after this point. We calculated a percentage of pregnancy months with active insurance coverage and considered those with less than 90% of months with active insurance as having "incomplete insurance for the pregnancy". MSP covers all eligible BC residents except for a small population who are

insured by the Federal government (estimated at <5% of total BC population)[173]. These are: 'Status Indians'[1] (First Nations and Inuit), veterans, active-duty military and Royal Canadian Mounted Police (RCMP) who have separate (federally funded) health insurance. However, the billings file includes billings for these other federal payors, therefore these groups are included in the study population. Additionally, there a waiting period (at least 3 months) before people can register for BC-MSP for all new residents in the province. This applies to anyone with valid residency: Canadian citizens moving from another province, temporary workers on visas, refugees, new immigrants, students with valid visas. Interruptions in health insurance coverage are not uncommon in pregnancy.[286] Last, there are people who pay directly or out-of-pocket. This may include citizens of other countries, who do not have residency status in BC.

Uncertainty in linkage between the 3 data sources is not uncommon depending on the specific time period or cohort. For example, all births in the province are included in the BC-PDR, but not everyone is registered in the health insurance plan, therefore, some PDR records are completely unlinked to billings data. Further, some individuals have incomplete insurance coverage during their pregnancy, therefore their billings may not accurately contain all tests or screening procedures during their whole pregnancy. For example, if their insurance became active in the 6th month of pregnancy, then they may have paid out of pocket for lab services early in pregnancy, or they may have been covered by a different health insurance plan for part of their pregnancy before their BC insurance became active.

Sample size, strata and sample weights

Sample size was based on an estimated proportion (prevalence) between 90-95% for GDM screening and achieving a precision of +/- 4% and we requested a random sample evenly stratified by health care professional type at delivery (1/3 of cases by Registered Midwife, Family Practice Physician, or Obstetrician).

A study in Alberta, Canada reported a screening completion rate[78] for any diabetes screening in a population-based study of pregnant women of ~95% when including all possible tests. While we anticipated a similar population-based screening rate in BC, we anticipated lower screening completion rates among midwife-led care,[125] thus we planned to oversample among Registered Midwife clients. While the proportion of midwife-involved care as of 2020 is roughly 30% in BC, the requested sample will oversample in the midwife group because we estimate a lower screening prevalence in this care provider group. A large chart validation study in BC from 2010-12 reported 100% completion for Group

[1] 'Status Indian' is a legal term referring to the Indigenous identity of people registered under the Canadian government's Indian Act and eligible for certain government benefits and services.

B Strep screening[176] but only 83% had valid screening data. Therefore, we anticipated a true prevalence of GBS screening completion between 100-83%.

Health authorities who provided the random sample identified health care professional type and pregnancy year from hospital discharge records. We used data from the full BC population (using administrative data) from 2014-2019 and calculated the total number of births in each sampling strata according to the health care professional groups from hospital discharge records. We calculated sample weights and applied these weights for validation statistics and sample demographics. This enabled our results to reflect the hospital populations from which they were sampled.

Survey weighted methods (R library survey) were used to calculate all proportions reported for the validation and demographics, confidence intervals were calculated using an incomplete beta function (option "beta") with an effective sample size based on the estimated variance of the proportion.[287] In a few cases, R could not compute valid intervals and we re-calculated confidence intervals using proc surveyfreq in SAS (v 9.4) using design-based Clopper-Pearson confidence limits which apply a similar approach.[287]

Medical records chart abstraction procedure

All medical records were abstracted by the first author of the study who is also a Registered Midwife in BC. We derived all procedures for data coding of screening data from charts, decision trees and an MS Access database (secured) with internal data checking/validation *prior* to beginning data abstraction. The variables and coding procedures for abstraction were reviewed by study co-authors prior to abstraction and also reviewed by two hospital ethics approval committees and the data stewards for the administrative datasets as part of their approvals process.

Medical records from one hospital were paper-based while medical records at the other two hospitals were via an electronic medical records system (EMR). Prior to chart abstraction, training was provided for chart-based records by the medical records manager; however, the first author had previously had hospital privileges and was attending births at this site so was familiar with these medical records. For the EMR system, the health authority required completion of several online training modules before granting access to the EMR system.

Background on screening and diagnosis of gestational diabetes in BC

In Canada, the two main guidelines for management and treatment of diabetes in pregnancy are from Diabetes Canada (DC) (formerly known as the Canadian Diabetes Association (CDA)) and the Society of Obstetricians and Gynecologists of Canada (SOGC).[42] Presently, both recommend a two-step screening approach (50g GCT followed by 75g OGTT) as the "preferred" option, with the "alternate" option being a

one-step 75g OGTT using the International Association of Pregnancy Study Groups (IADPSG) criteria.[114] Thresholds for diagnosis of gestational diabetes differ depending on which approach: One-step screening is diagnosed when blood glucose levels exceed the IADPSG criteria (fasting 5.1, 1-hr 10.0, 2-hr 8.5 mmol/L) after a 75g OGTT. Two-step screening is diagnosed with a higher threshold (fasting 5.3, 1-hr 10.6, 2-hr 9.0 mmol/L) after the diagnostic 75g OGTT. There is no available data on prevalence of different screening approaches in Canada.

Antenatal health care professional type coding

We used a previously defined algorithm [177,288,289] to define health care professional type using billings data. The purpose of this criteria was to establish a minimum level of exposure to a single health care professional-type, as has been done in other comparison studies of midwifery v physician care. Details of this are: antenatal care with a family practice physician (FP) was defined as greater than or equal to three routine antenatal visits with this provider type, and less than or equal to one routine antenatal visit with an obstetrician (OB), or less than or equal to one partial trimester of midwifery care. Antenatal care with an OB was operationalised as greater than or equal to three routine antenatal visits with an OB, and less than or equal to one routine antenatal visit with FP, or less than or equal to one partial trimester of midwifery care. Antenatal midwifery care was operationalised as greater than or equal to two partial or full trimesters of midwifery care (equivalent to a minimum exposure of three routine antenatal physician visits), and less than or equal to one routine GP or OB antenatal visit. OB consultations were not included as routine antenatal visits. The "missing" or $\underline{\leq 2}$ antenatal visits category was defined by cases when the algorithm could not identify a single care provider with 3 or more visits or where there were $\underline{\leq}$ 2 visits overall.

A.2 Tables

Table A.1 Detailed definitions of billing codes used from BC MSP for coding antenatal screening tests

Code	Code description	Antenatal screening test coded
8655	OBS. B-SCAN - LESS THAN 14 WKS.	1st trimester ultrasound
96782	APB OBS-B-SCAN UNDER 14 WEEKS GESTATION	1st trimester ultrasound
96785	APB OBS-B-SCAN <14WKS/NUCHAL TRANSLUCENCY-ADD FETU	1st trimester ultrasound
96786	APB OBS-B-SCAN <14WKS/NUCHAL TRANSLUCENCY-ADD FETU	1st trimester ultrasound
91690	GLUCOSE, GESTATIONAL ASSESSMENT	50g glucose test (GCT) (used for two-step screening)
91695	GLUCOSE TOLERANCE TEST-GESTATIONAL PROTOCOL	75g OGTT (used for both one-step and two-step)
91715	GLUCOSE TOLERANCE TEST, 2 - 5 HOURS	75g OGTT
91716	GLUCOSE TOLERANCE TEST > 6 HOURS	75g OGTT
90739	COMBINED VAGINO-ANORECTAL OR VAGINAL CULTURE	Group B streptococcus test

Table A.2 Pregnancy and obstetric characteristics for all linked records, records with incomplete insurance and final validation group (unweighted %)

Characteristic n (%)	**linked to administrative data N = 135[1]**	**available for validation N = 127**	**incomplete insurance N = 8**	**p-value[a]**
Parity				0.13
P0	54 (40%)	48 (38%)	6 (75%)	
P1-P3	76 (56%)	74 (58%)	<5[f]	
P4 or more	5 (3.7%)	5 (3.9%)	<5	
Age of birthing person at delivery (years)				0.61
< 24	14 (10%)	13 (10%)	<5	
25-29	36 (27%)	32 (25%)	<5	
30-34	51 (38%)	49 (39%)	<5	
35-39	28 (21%)	27 (21%)	<5	
40+	6 (4.4%)	6 (4.7%)	<5	
Pre-pregnancy body mass index (kg/m^2)[b]				0.95
<24.9	59 (44%)	56 (44%)	<5	
25-29.9	30 (22%)	28 (22%)	<5	
30+	19 (14%)	18 (14%)	<5	
missing data	27 (20%)	25 (20%)	<5	
Neighbourhood income quintiles per person[c]				0.53
lowest income	29 (21%)	27 (21%)	<5	
mid-low income	28 (21%)	26 (20%)	<5	
middle income	18 (13%)	18 (14%)	<5	
mid-high income	33 (24%)	32 (25%)	<5	
highest income	13 (9.6%)	11 (8.7%)	<5	
missing or NA	14 (10%)	13 (10%)	<5	
Antenatal health care professional type[d]				0.33
Family practice physician	54 (42%)	53 (43%)	<5	
Registered Midwife	52 (40%)	50 (40%)	<5	
Obstetrician	23 (18%)	21 (17%)	<5	
Missing or ≤2 antenatal health care visits	6	<5	<5	
Multifetal pregnancy	12 (7%)	11 (7%)	<5	0.44
Gestational age at delivery:				
preterm (<37 weeks)	123 (93%)	116 (93%)	7 (88%)	
Mode of delivery[e]				
Cesarean	46 (34%)	43 (34%)	<5	>0.99
Operative vaginal	13 (9.6%)	13 (10%)	<5	
Spontaneous vaginal	76 (56%)	71 (56%)	5 (62%)	

a. Fisher's exact test

b. Pre-pregnancy BMI was ascertained from medical records. Standard medical records in BC collect data for a pre-pregnancy weight and height, we calculated BMI and reported by categories as defined by the Institute of Medicine standards.[290]

c. Neighbourhood income quintiles (based on Statistics Canada)[50] represent the average income in the area (census tract). Census tracts were linked by the data stewards at the residential postal code level for the residence of the birthing person/mother. This data was obtained from administrative sources. For example, an individual living in the highest income quintile region is living in an overall 'wealthier' neighbourhood.

d. Antenatal health care professional type ("Family practice physician", "Obstetrician" or "Registered Midwife", or "Unknown and/or <3 visits") was defined using billing codes via a previously published method.[177] Generally, this required a minimum of 3 routine antenatal care visits with the specified provider type. Consultation visits were not included. Number of visits were assessed using counts of prenatal care fee-for-service billing codes by professional type.

e. Mode of delivery, gestational age at delivery, parity, is reported from medical records. Age and labour type is reported from the perinatal data registry.

f. Cell sizes <5 suppressed as per Perinatal Services BC reporting guidelines.

Table A.3 Validation parameters for all screening tests using billing code derived screening tests compared to medical records abstracted data (gold standard) in subgroups

Subgroup	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Prevalence in medical records data	Prevalence in billing codes data
Ultrasound at <14 weeks gestation						
Antenatal health care professional type						
Midwife	96 (86, 100)	80 (23, 100)	98 (86, 100)	67 (23, 100)	91 (79, 97)	87 (75, 95)
Family Practice	97 (89, 100)	77 (11, 100)	98 (89, 100)	63 (11, 100)	93 (81, 99)	88 (76, 95)
Obstetrician	100	NA	100	NA	100	100
Parity						
Nulliparous	96 (85, 100)	NA	100 (85, 100)	25 (0, 100)	99 (93, 100)	94 (85, 99)
Multiparous	98 (92, 100)	76 (29, 99)	98 (92, 100)	76 (29, 99)	91 (81, 97)	88 (77, 95)
Body mass index						
<30 kg/m^2	96 (89, 99)	100	100 (89, 100)	40 (0, 84)	97 (93, 99)	92 (85, 96)
≥30 kg/m^2	100	NA	100	NA	100	100
missing	100	69 (12, 99)	92	100 (12, 100)	77 (49, 94)	77 (51, 93)
Age						
<35 years	100	100	100	100	95 (86, 99)	92 (83, 97)
≥35 years	88 (71, 97)	50 (6, 94)	94 (71, 97)	33 (6, 94)	90 (75, 97)	83 (66, 93)
GDM screening (one or two-step)						
Antenatal health care professional type						
Midwife	100	100	100	100	83 (69, 93)	84 (69, 93)
Family Practice	97 (89, 100)	100	100 (89, 100)	83 (72, 95)	87 (74, 95)	81 (68, 91)
Obstetrician	100	NA	100	NA	95 (74, 100)	95 (75, 100)
Parity						
Nulliparous	95 (83, 99)	100	100 (83, 100)	33 (0, 100)	98 (91, 100)	93 (82, 98)
Multiparous	100	100	100	100	82 (70, 90)	79 (68, 88)
Body mass index						
<30 kg/m^2	100	100	100	100	95 (87, 98)	95 (87, 98)
≥30 kg/m^2	100	100	100	100	72 (41, 93)	62 (34, 85)
missing	90 (67, 99)	100	100 (67, 100)	76	76 (52, 92)	69 (45, 87)
Age						
<35 years	97 (91, 100)	100	100 (91, 100)	83 (58, 100)	89 (80, 95)	84 (74, 92)
≥35 years	100	100	100	100	83 (62, 95)	83 (62, 95)
Two-step GDM screening						
Antenatal health care professional type						
Midwife	100	95 (73, 100)	92 (73, 100)	100 (73, 100)	37 (18, 58)	51 (36, 66)
Family Practice	100	93 (66, 100)	92 (75, 100)	100 (66, 100)	46 (27, 65)	43 (30, 58)
Obstetrician	100	100	100	100	23 (5, 55)	14 (3, 37)
Parity						
Nulliparous	100	100	100	100	46 (23, 71)	40 (24, 57)
Multiparous	100	93 (74, 99)	89 (72, 100)	100 (74, 100)	37 (22, 54)	40 (29, 53)
Body mass index						
<30 kg/m^2	100	90 (64, 99)	90 (74, 100)	100 (64, 100)	47 (30, 65)	47 (35, 60)
≥30 kg/m^2	100	100	100	100	17 (3, 46)	19 (4, 47)
missing	100	100	100	100	36 (12, 67)	34 (15, 58)
Age						
<35 years	100	100	100	100	46 (30, 62)	43 (32, 55)
≥35 years	100	87 (54, 99)	72 (26, 100)	100 (54, 100)	26 (9, 51)	31 (15, 52)

Subgroup	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Prevalence in medical records data	Prevalence in billing codes data
One-step GDM screening						
Antenatal health care professional type						
Midwife	90 (52, 100)	100	100 (52, 100)	95 (85, 100)	33 (16, 55)	33 (19, 48)
Family Practice	88 (47, 100)	100	100 (47, 100)	95 (81, 100)	32 (16, 52)	38 (24, 52)
Obstetrician	100	100	100	100	69 (38, 91)	81 (57, 95)
Parity						
Nulliparous	100	100	100	100	50 (26, 74)	53 (36, 70)
Multiparous	87 (56, 99)	100	100 (56, 100)	94 (84, 100)	35 (20, 51)	39 (27, 52)
Body mass index						
<30 kg/m^2	88 (57, 99)	100	100 (57, 100)	92 (73, 100)	43 (26, 61)	47 (35, 60)
≥30 kg/m^2	100	100	100	100	43 (15, 74)	43 (18, 71)
missing	100	100	100	100	29 (8, 58)	35 (16, 58)
Age						
<35 years	100	100	100	100	35 (20, 52)	41 (30, 53)
≥35 years	80 (38, 99)	100	100 (38, 100)	84 (56, 100)	50 (26, 73)	52 (32, 72)
GBS screening						
Antenatal health care professional type						
Midwife	100	100	100	100	96 (87, 100)	96 (87, 100)
Family Practice	92 (81, 98)	70 (30, 95)	95 (81, 98)	60 (30, 95)	86 (73, 94)	85 (72, 93)
Obstetrician	100	100	100	100	85 (61, 97)	86 (63, 97)
Parity						
Nulliparous	93 (77, 99)	NA	100 (77, 100)	27 (0, 100)	98 (87, 100)	91 (76, 98)
Multiparous	97 (89, 100)	77 (44, 96)	95 (89, 100)	83 (44, 96)	83 (71, 91)	85 (74, 93)
Body mass index						
<30 kg/m^2	94 (84, 98)	69 (4, 100)	99 (84, 98)	32 (4, 100)	96 (87, 99)	91 (81, 97)
≥30 kg/m^2	100	67 (4, 100)	94 (80, 100)	100 (4, 100)	83 (56, 97)	90 (66, 99)
missing	100	87 (42, 100)	94 (83, 100)	100 (42, 100)	68 (44, 87)	74 (50, 91)
Age						
<35 years	95 (86, 99)	68 (27, 95)	96 (86, 99)	63 (27, 95)	89 (79, 95)	89 (79, 95)
≥35 years	96 (81, 100)	100	100 (81, 100)	82 (37, 100)	85 (66, 96)	82 (63, 94)

Abbreviations: GBS = Group B strep, GDM = gestational diabetes mellitus,

Note: NA results occurred for subgroups with 100% agreement or because numbers in cell for validation statistic calculations were very small (<5) leading to modeled confidence intervals that exceeded relevant ranges and/or could not be calculated using survey-weighted methods.

Table A.4 Cross-tabulations of medical records data against billings-based screening data for records available for a validation analysis of antenatal screening tests (n=127)

Billings-based data	Medical records data			Total
	yes	unscreened	Unknown	
1st trimester ultrasound completed				
yes	104	2	7	113
no (unscreened)	4	6	4	14
Total, n	108	8	11	127
GDM screened				
yes	105	0	2	107
no (unscreened)	2	16	2	20
Total, n	107	16	4	127
Two-step GDM screening approach				
yes	27	2	24	53
no (unscreened)	0	42	32	74
Total, n	27	44	56	127
One-step GDM screening approach				
yes	26	0	28	54
no (unscreened)	2	43	28	73
Total, n	28	43	56	127
GBS screened				
yes	105	3	5	113
no (unscreened)	4	10	0	14
Total, n	109	13	5	127

Note: All validation calculations and prevalence results used weights based on sampling strata (health care professional type).

Table A.5 Study cohort characteristics and demographics comparing screened to unscreened for 3 antenatal screening tests (n=135 records) (unweighted %)

Characteristic n (%)	**1st trimester ultrasound completed**			**Gestational diabetes screened**			**Group B streptococcus test completed**		
	yes N = 114	**no** N = 9	**p-value**[a]	**yes** N = 114	**no** N = 17	**p-value**[a]	**yes** N = 116	**no** N = 14	**p-value**[a]
Parity			<.001			<.001			.003
P0	48 (42%)	<5[f]		50 (44%)	<5		51 (44%)	<5	
P1-P3	65 (57%)	<5		63 (55%)	10 (59%)		63 (54%)	9 (64%)	
P4 or more	<5	<5		<5	<5		<5	<5	
Age of birthing person at delivery (years)			0.031			0.91			0.76
< 24	10 (8.8%)	<5		12 (11%)	<5		12 (10%)	<5	
25-29	32 (28%)	<5		30 (26%)	<5		31 (27%)	<5	
30-34	47 (41%)	<5		43 (38%)	6 (35%)		44 (38%)	5 (36%)	
35-39	20 (18%)	5 (56%)		23 (20%)	5 (29%)		23 (20%)	5 (36%)	
40+	5 (4.4%)	<5		6 (5.3%)	<5		6 (5.2%)	<5	
Pre-pregnancy body mass index (BMI) (kg/m^2) [b]			0.037		<5	0.026			0.001
<24.9	50 (44%)	<5		53 (46%)	5 (29%)		55 (47%)	<5	
25-29.9	27 (24%)	<5		28 (25%)	<5		28 (24%)	<5	
30+	19 (17%)	<5		13 (11%)	<5		15 (13%)	<5	
missing data	18 (16%)	5 (56%)		20 (18%)	7 (41%)		18 (16%)	8 (57%)	
Neighbourhood income quintiles per person[c]			0.46			0.35			0.95
lowest income	22 (19%)	<5		25 (22%)	<5		24 (21%)	<5	
mid-low income	24 (21%)	<5		25 (22%)	<5		24 (21%)	<5	
middle income	16 (14%)	<5		14 (12%)	<5		16 (14%)	<5	
mid-high income	27 (24%)	<5		26 (23%)	6 (35%)		28 (24%)	<5	
highest income	11 (9.6%)	<5		10 (8.8%)	<5		11 (9.5%)	<5	
missing or NA	14 (12%)	<5		14 (12%)	<5		13 (11%)	<5	
Antenatal health care professional type			0.17			0.36			0.24
Family practice physician	46 (41%)	<5		47 (42%)	5 (36%)		45 (40%)	6 (55%)	
Registered Midwife	46 (41%)	5 (83%)		43 (39%)	8 (57%)		49 (43%)	<5	
Obstetrician	19 (17%)	<5		21 (19%)	<5		19 (17%)	<5	
Missing or ≤2 antenatal health care visits	<5	<5		<5	<5		<5	<5	
Multifetal pregnancy	<5	<5	>0.99	<5	<5	>0.99	<5	<5	0.37
Gestational age at delivery			0.44			0.31			>0.99
preterm (<37 weeks)	104 (94%)	7 (88%)		106 (94%)	14 (88%)		107 (93%)	12 (92%)	
term (37 + weeks)	7 (6.3%)	<5		7 (6.2%)	<5		8 (7.0%)	<5	
Unknown	<5	<5		<5	<5		<5	<5	
Labour type			0.45			0.071			<.001
Induced	36 (32%)	<5		38 (33%)	<5		39 (34%)	<5	
No labor (scheduled cesarean)	17 (15%)	<5		14 (12%)	5 (29%)		11 (9.5%)	9 (64%)	
Spontaneous	61 (54%)	6 (67%)		62 (54%)	10 (59%)		66 (57%)	<5	
Mode of delivery[e]			>0.99			0.25			0.015
Cesarean	41 (36%)	<5		36 (32%)	8 (47%)		35 (30%)	10 (71%)	
Operative vaginal	10 (8.8%)	<5		13 (11%)	<5		13 (11%)	<5	
Spontaneous vaginal	63 (55%)	5 (56%)		65 (57%)	9 (53%)		68 (59%)	<5	

a. Bold indicates p>0.05 by Fisher's exact test

b. Pre-pregnancy BMI was ascertained from medical records. Standard medical records in BC collect data for a pre-pregnancy weight and height, we calculated BMI and reported by categories as defined by the Institute of Medicine standards.[290]

c. Neighbourhood income quintiles (based on Statistics Canada)[50] represent the average income in the area (census tract). Census tracts were linked by the data stewards at the residential postal code level for the residence of the birthing person/mother. This data was obtained from administrative sources. For example, an individual living in the highest income quintile region is living in an overall 'wealthier' neighbourhood.

d. Antenatal health care professional type ("Family practice physician", "Obstetrician" or "Registered Midwife", or "Unknown and/or <3 visits") was defined using billing codes via a previously published method.[177] Generally, this required a minimum of 3 routine antenatal care visits with the specified provider type. Consultation visits were not included. Number of visits were assessed using counts of prenatal care fee-for-service billing codes by professional type.

e. Mode of delivery, gestational age at delivery, parity, is reported from medical records. Age and labour type is reported from the perinatal data registry.

f. Cell sizes <5 suppressed as per Perinatal Services BC reporting requirements.

Table A.6 Completion rates for secondary variables by data source (Chart-abstracted v. PDR)

Characteristic	Medical records N = 135	BC-PDR N = 135	p-value[1]
Prenatal care provider type	99 %	100 %	0.50
Parity	100 %	100 %	
Parity -Number of previous liveborn infants	100 %	100 %	
Pre-pregnancy weight (kg)	90 %	82 %	0.080
Hospital admission weight (kg)	65 %	50 %	0.010
Height (cm)	79 %	90 %	0.013
Dx: pre-existing diabetes	100 %	100 %	
Dx: gestational diabetes	84 %	100 %	<0.001
Dx: diet-controlled gestational diabetes	84 %	100 %	<0.001
Dx: medication-controlled gestational diabetes	84 %	100 %	<0.001
Screening: First ultrasound (GA in wks.)	86 %	87 %	0.72
Dx: GBS Positive at term	87 %	87 %	>0.99
Screening: screened for GBS at term	96 %	89 %	0.020
Delivery: Mode	99 %	100 %	>0.99
Delivery: CS scheduled or elective	34 %	34 %	>0.99
Infant: birthweight (g)	96 %	99 %	0.21
Infant: Sex	99 %	100 %	0.50
Infant: GA at birth by best OB estimate	97 %	100 %	0.12

[1] Fisher's exact test; Pearson's Chi-squared test

Table A.7 Descriptive results for secondary variables by data source (Medical records abstracted v. PDR)

Characteristic	**Medical records** N = 135	**PDR** N = 135	**p-value**[a]
Prenatal care provider type, n/N (%)			<0.001
FP	44/133 (33%)	n/a	
OB	35/133 (26%)	n/a	
Other[b]	<5	83/135 (61%)	
RM	54/133 (41%)	52/135 (39%)	
Parity, n/N (%)			0.90
Multiparous	83/135 (61%)	82/135 (61%)	
Nulliparous	52/135 (39%)	53/135 (39%)	
Pre-pregnancy weight (kg), Mean (SD)	68 (15)	67 (15)	0.68
Hospital admission weight (kg), Mean (SD)	82 (16)	83 (14)	0.52
Height (cm), Mean (SD)	164 (7)	163 (7)	0.91
Pre-existing diabetes, n/N (%)	<5	<5	>0.99
Gestational diabetes, n/N (%)	20/114 (18%)	20/135 (15%)	0.56
Diet-controlled gestational diabetes, n/N (%)	12/114 (11%)	12/135 (8.9%)	0.66
Medication-controlled gestational diabetes, n/N (%)	8/114 (7.0%)	8/135 (5.9%)	0.73
Screening: First ultrasound (GA in weeks), Mean (SD)	9.4 (2.0)	9.9 (2.4)	0.27
Screening: First ultrasound at <14 weeks completed, n/N (%)	114/123 (93%)	111/118 (94%)	0.67
GBS Positive at term among screened, n/N (%)	25/117 (21%)	28/117 (24%)	0.64
Screening: screened for GBS at term, n/N (%)	116/130 (89%)	117/120 (98%)	0.009
Delivery: Mode, n/N (%)			>0.99
CS	46/134 (34%)	46/135 (34%)	
OVD	13/134 (9.7%)	13/135 (9.6%)	
SVB	75/134 (56%)	76/135 (56%)	
Delivery: CS scheduled or elective, n/N (%)	21/46 (46%)	15/46 (33%)	0.20
Infant: birthweight (g), Mean (SD)	3,407 (589)	3,383 (619)	0.84
Infant: Sex, n/N (%)			0.82
F	74/133 (56%)	77/135 (57%)	
M	59/133 (44%)	58/135 (43%)	
Infant: GA at birth by best OB estimate, Mean (SD)	38.7 (2.1)	38.4 (2.0)	0.087

a. Pearson's Chi-squared test; Wilcoxon rank sum test; Fisher's exact test

b. 'Other' for the PDR includes records not coded as "Midwife involved" in the BC-PDR

b. Cell sizes <5 suppressed as per Perinatal Services BC reporting requirements.

Table A.8 Comparison of selected secondary variables with sample weighted results (medical records v BC-PDR)

Comparison	Sensitivity	Specificity	PPV	NPV	True Prevalence	PDR Prevalence
Group B streptococcus test	99 (94, 100)	16 (1, 53)	95 (94, 100)	50 (1, 53)	88 (80, 94)	98 (94, 100)
GBS Positive result	100	99 (93, 100)	96	100 (93, 100)	23 (14, 33)	27 (17, 37)
US 1st trimester completed	100	60 (6, 99)	99	100 (6, 99)	94 (87, 98)	96 (90, 99)
GDM diagnosis	100	100	100	100	18 (10, 27)	15 (9, 23)
GDM diagnosis diet-controlled	92 (59, 100)	99 (94, 100)	92 (59, 100)	99 (94, 100)	12 (6, 21)	10 (5, 18)
GDM diagnosis medication-controlled	85 (35, 100)	99 (94, 100)	85 (35, 100)	99 (94, 100)	6 (2, 13)	5 (2, 11)

Table A.9 Comparison of secondary variables (categorical) from BC PDR against medical records data (unweighted results)

Comparison (Records v. BC-PDR)	N	Sensitivity	Specificity	PPV	NPV	True prevalence	PDR prevalence
First trimester ultrasound done	104	100 (98, 100)	75 (28, 97)	99 (95, 100)	100 (46, 100)	96 (91, 99)	97 (93, 99)
GDM diagnosis	107	100 (87, 100)	100 (97, 100)	100 (87, 100)	100 (97, 100)	17 (11, 25)	17 (11, 25)
GDM diet-controlled	107	91 (65, 99)	99 (95, 100)	91 (65, 99)	99 (95, 100)	10 (6, 17)	10 (6, 17)
GDM med-controlled	107	86 (50, 98)	99 (95, 100)	86 (50, 98)	99 (95, 100)	7 (3, 12)	7 (3, 12)
DM pre-pregnancy	127	100 (15, 100)	100 (98, 100)	100 (15, 100)	100 (98, 100)	1 (0, 4)	1 (0, 4)
GBS screened	107	99 (95, 100)	33 (8, 71)	96 (91, 99)	67 (18, 96)	94 (89, 98)	97 (93, 99)
GBS positive	101	100 (89, 100)	99 (94, 100)	96 (81, 100)	100 (97, 100)	22 (15, 31)	23 (15, 32)
Nulliparous	127	99 (94, 100)	98 (90, 100)	99 (94, 100)	98 (90, 100)	63 (54, 71)	63 (54, 71)
RM involved care	126	96 (88, 99)	100 (97, 100)	100 (95, 100)	97 (92, 99)	40 (32, 49)	39 (31, 48)
SV delivery	126	100 (96, 100)	100 (96, 100)	100 (96, 100)	100 (96, 100)	56 (47, 64)	56 (47, 64)
CS delivery	126	100 (94, 100)	100 (97, 100)	100 (94, 100)	100 (97, 100)	34 (26, 43)	34 (26, 43)
Operative vaginal delivery	126	100 (83, 100)	100 (98, 100)	100 (83, 100)	100 (98, 100)	10 (6, 17)	10 (6, 17)
Labor induction	111	91 (78, 97)	91 (83, 96)	81 (66, 91)	96 (90, 99)	30 (22, 39)	33 (25, 42)
No labor or scheduled CS	127	86 (67, 96)	99 (96, 100)	95 (78, 99)	97 (93, 99)	17 (11, 24)	15 (10, 22)
Infant sex	125	99 (94, 100)	94 (86, 98)	96 (89, 99)	98 (91, 100)	57 (48, 65)	58 (50, 67)

Table A.10 Comparison of secondary variables (continuous) from BC PDR against medical records data (unweighted)

Comparison (Chart v. PDR)	ICC	Lin's CCC
Gestational age of fetus at 1st ultrasound (weeks)	91.8 (88.1, 94.4)	91.8 (88.0, 94.4)
Gestational age of fetus at 1st ultrasound (days)	90.7 (86.1, 93.8)	90.6 (86.0, 93.8)
Height (cm)	87.6 (82.0, 91.5)	87.5 (81.9, 91.4)
Pre-pregnancy weight (kg)	55.8 (-9.19, 83.4)	55.3 (41.9, 66.4)
Final pregnancy weight (kg)	99.0 (98.2, 99.4)	99.0 (98.2, 99.4)
Early or pre-pregnancy body mass index (kg/m^2)	90.8 (86.4, 93.9)	90.7 (86.3, 93.8)
Gestational age of infant at delivery (weeks)	92.8 (86.2, 95.9)	92.8 (89.9, 94.9)
Infant birthweight (g)	99.9 (99.9, 99.9)	99.9 (99.9, 99.9)

Table A.11 Detailed data dictionary and coding for medical records data

Variables recoded/created	Levels	Definition/data source/coding
GDM diagnosed and screened	Yes	Medical record (usually AN1/2 or LD notes) indicates patient was diagnosed with GDM during this pregnancy.
	No * derived	If "GDM screening completed"!="Yes" and no diagnosis of GDM from medical record, then GDM =="No"
	Missing data derived	If not screened or screening status unable to be determined, then GDM diagnosis is set to missing (true denominator)
GDM diet-controlled	Yes	Note in the chart that this patient was diet-controlled GDM AND No medications (insulin or metformin) noted in prenatal records or LD notes
	No	Not screened for GDM by chart information OR GDM was medication controlled
GDM medication-controlled	Yes	Indication that this patient was taking medication for gestational diabetes during pregnancy (prenatal records, diabetes clinic referrals noted, other sources)
	No	Not screened for GDM by chart information OR GDM was diet-controlled
GBS screen completed (vaginal-rectal swab)	Yes	Chart reports at least 1 GBS test weeks OR a urine screening test with a positive GBS bacteriuria result OR chart indicates GBS positive
	No	Chart reports GBS screening declined OR No GBS test noted and late-onset prenatal care OR No GBS test noted and scheduled CS noted OR No GBS test noted AND Positive GBS bacteriuria in urine sample
	Missing or no data	Chart does not report GBS screening result or completion and no indication that screening was declined or not offered
GBS positive	Yes	Chart indicates GBS positive (usually on AN1-2 or in LD notes)
	No*	Derived from GBS Screening completed == "Yes" & NOT GBS positive
	Missing or no data	No indication of GBS screening completed and no indication of GBS positive status
Prenatal care provider type**	RM	Qualitative assessment by chart abstractor (EN) that the majority of prenatal care (>2 trimesters) was provided by RMs
	OB	Qualitative assessment that >2 trimesters or MRP for prenatal care after 20 weeks was an Obstetrician ** Since prenatal care visits were not always well documented in the chart, this is difficult to determine
	FP	Qualitative assessment that >2 trimesters of prenatal care was provided by a FP doctor who is not an OB. For some births it appears that family practice doctors transferred clients to an OB for delivery but did all prenatal care.
	Missing or no data	No prenatal care record or no provider noted or late onset of prenatal care and no clear indication of a MRP who provided prenatal care for this pregnancy.
Pre-pregnancy diabetes diagnosed	Yes	Usually from AN 1 – indication that this patient was diagnosed with diabetes pre-pregnancy, sometimes in other provider notes.

* Re. "Screening=NO" results for all screening tests: Additional coding in unscreened was: Unscreened – declined screening; Unscreened – not eligible for screening (i.e. delivery occurred before screening would be offered or pre-pregnancy diabetes diagnosis); Unscreened – late prenatal care or no prenatal care indicated in chart; Unscreened – scheduled Cesarean delivery (for GBS only)

** Re prenatal care provider from charts: low degree of confidence in this for everyone except RM clients – quite difficult to determine for FP/OB mixed care who to indicate as MRP for prenatal care. Also for South Community Birth Program with shared care model (FP/RM) - were indicated as RM but may have mixed model of care.

Table A.12 Detailed data dictionary and coding for MSP billing variables for antenatal health care professional type

Variables recoded/created	Levels	Definition/data source/coding
Health care professional type * general method from[288]	OB	Count of codes billed by OB (05) that are 14090, 14091, 04717 (** none of these are consult codes, all are 'routine prenatal')
		If > 2 billings by OB or FP for prenatal care and 3 or more OB prenatal visits and <3 FP visit
		** If unable to assign, then additional check of 100 billings (routine office visit) and if >=3 by OB then assign as OB
	FP	Count of codes billed by FP (00) that are 14090, 14091, 04717
		If > 2 billings by OB or FP for prenatal care and 3 or more GP prenatal and <2 OB prenatal
		** If unable to assign, then additional check of 100 billings (routine office visit) and if >=3 by FP then assign as FP
	RM	Sum of codes:
		36010 full =1; 36014 or 36016 partial 1st tri = 0.5 each
		36020 full =1; 36024 or 36026 partial 2nd tri = 0.5 each
		36030 full; 36034 or 36036 partial 3rd tri= 0.5 each
		If 2 or more full trimesters of RM care, regardless of whether there is also some OB or FP care, then classify as RM care primarily
		** if unable to assign to OB, RM or FP in first pass, then use >=1 trimesters of RM billings
	Other or <2 AN visits	< 2 trimesters of RM care OR <=2 prenatal billings by MDs OR billings by NP

Table A.13 Detailed definitions of billing fee codes used for prenatal care utilization

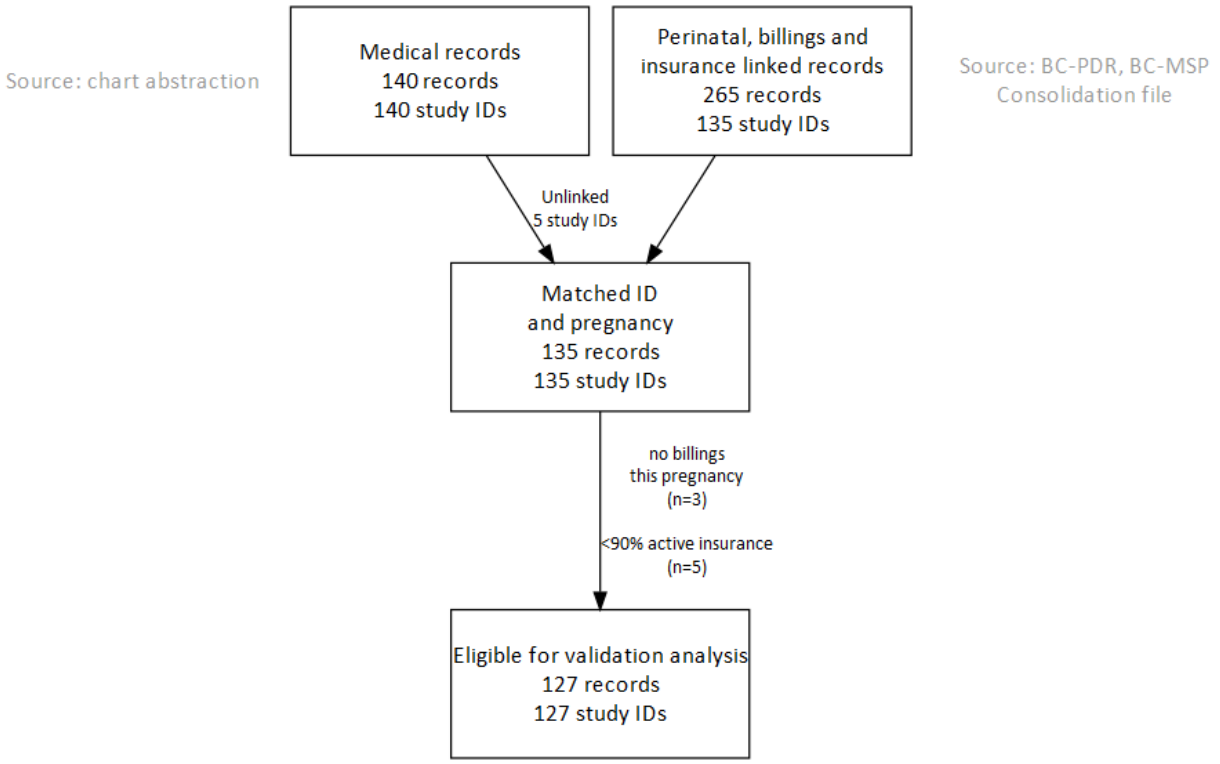
Code	Code description	Count in chart-linked data	For coding
14090	14090 PRENATAL VISIT- COMPLETE EXAMINATION	141	Prenatal care provider type
14091	14091 PRENATAL VISIT - SUBSEQUENT EXAMINATION	187	Prenatal care provider type
4717	4717 PRENATAL OFFICE VISIT -COMPLEX OBSTETRICAL PATIENT	23	Prenatal care provider type
36010	36010 MIDWIFE PHASE 1 (1ST TRIMESTER) - TOTAL CARE	73	Prenatal care provider type
36014	36014 MIDWIFE PHASE 1 (1ST TRIMESTER)-TRANS TO OTHR 40%	.	Prenatal care provider type
36016	36016 MIDWIFE PHASE 1 (1ST TRIMESTER)-TRANS FRM OTHR 60%	3	Prenatal care provider type
36020	36020 MIDWIFE PHASE 2 (2ND TRIMESTER) - TOTAL CARE	82	Prenatal care provider type
36021	36021 MIDWIFE PHASE 1 (1ST TRIMEST) 1ST VISIT IS IN PH 2	1	Prenatal care provider type
36024	36024 MIDWIFE PHASE 2 (2ND TRIMESTER)-TRANS TO OTHR 40%	.	Prenatal care provider type
36026	36026 MIDWIFE PHASE 2 (2ND TRIMESTER)-TRANS FRM OTHR 60%	5	Prenatal care provider type
36030	36030 MIDWIFE PHASE 3 (3RD TRIMESTER) - TOTAL CARE	87	Prenatal care provider type
36031	36031 MIDWIFE PHASE 3 (THIRD TRIMESTER) PHASE 3 SERVICES	.	Prenatal care provider type
36034	36034 MIDWIFE PHASE 3 (3ND TRIMESTER)-TRANS TO OTHR 40%	.	Prenatal care provider type
36036	36036 MIDWIFE PHASE 3 (3ND TRIMESTER)-TRANS FRM OTHR 60%	2	Prenatal care provider type
100	100 VISIT IN OFFICE (AGE 2 - 49)	235	Prenatal care provider type
101	101 IN OFFICE (AGE 2-49)-COMPLETE EXAMINATION	6	Prenatal care provider type
120	120 INDIVIDUAL COUNSELLING IN OFFICE (AGE 2-49)	53	Prenatal care provider type

Table A.14 Data dictionary for PDR variables used for validation (secondary variables)

Variables recoded/created	Levels	Definition/data source/coding
1st trimester ultrasound completed (m.ustri1)	Yes	IF PDR GA at 1st ultrasound <14 and NOT missing
	No	If PDR GA at 1st ultrasound >=14 weeks
	Missing or no data	If no data for PDR GA at 1st Ultrasound
GDM diagnosed (m.gdm)	Yes	If PDR GDM ID or Med = Positive
	No	All remaining
GDM medication-controlled (m.gdm.med)	Yes	If PDR GDM Med =Positive
	No	If Not DM diagnosed and NOT positive for GDM-med controlled
	Missing	DM positive or no data from PDR
GDM diet-controlled (m.gdm.diet)	Yes	If PDR GDM diet-controlled =Positive
	No	If Not DM diagnosed and NOT positive for GDM-diet controlled
	Missing	DM positive or no data from PDR
DM diagnosed (m.dm)	Yes	If PDR DM positive =yes
	No	All other
GBS screen completed (m.gbs.screen)	Yes	PDR GBS screening = Yes
	No	PDR GBS screening = No
	Missing or no data	PDR GBS screening = Unknown OR no data from PDR
GBS positive in PDR (m.gbs.diag)	Yes	GBS Positive in PDR
	No	Negative in PDR
	Missing	No data in PDR for GBS result
Prenatal care Midwife involved (m.midwifery.care)	RM	Midwife involved in care ** defined in PDR
	Other	No midwife involved

A.3 Figures

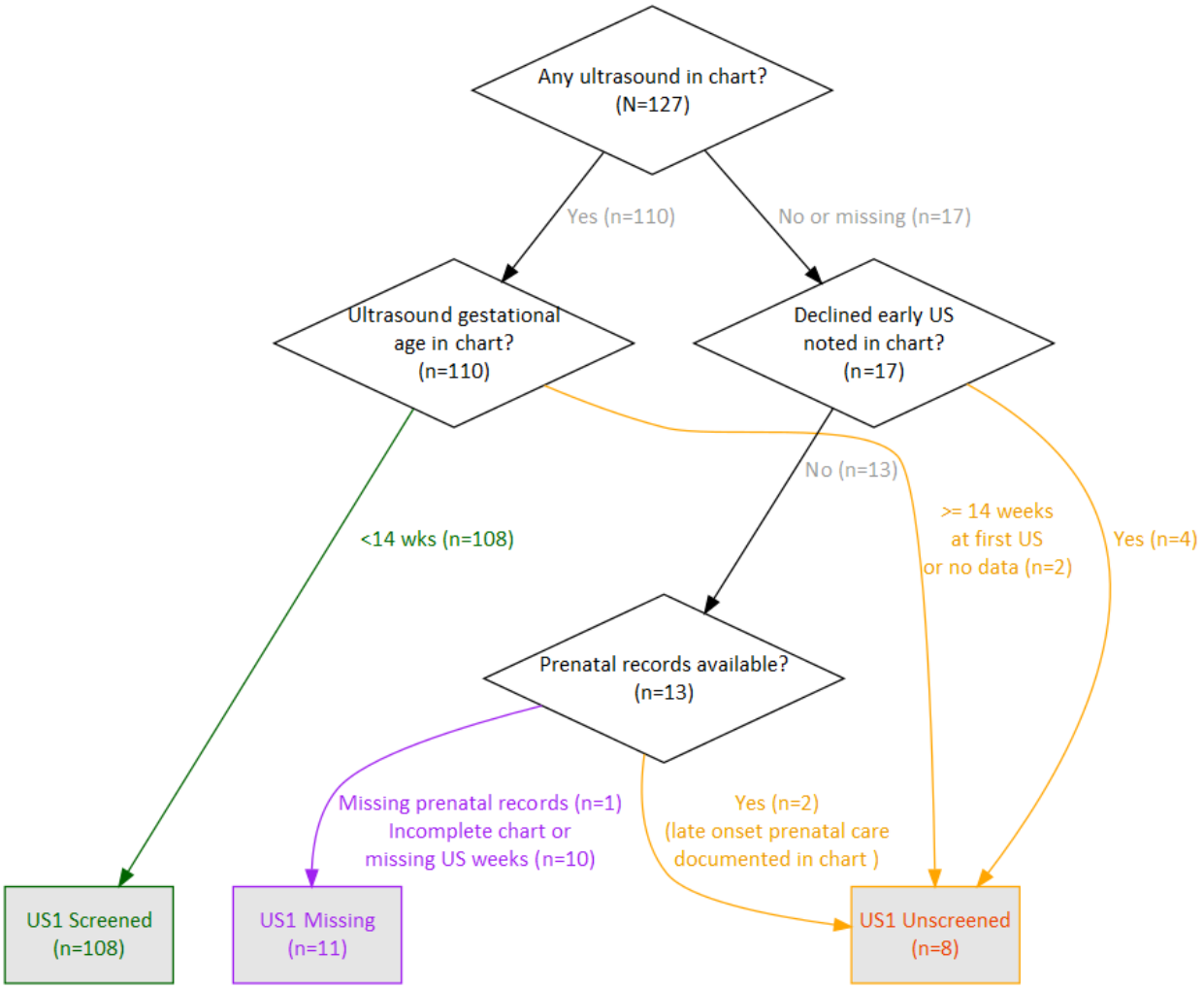
Figure A.1 Flowchart for linkage of chart-abstracted study data and administrative data



Abbreviations: BC-PDR=BC Perinatal Data Registry; BC-MSP=BC Medical Services Plan, ID=identifiers

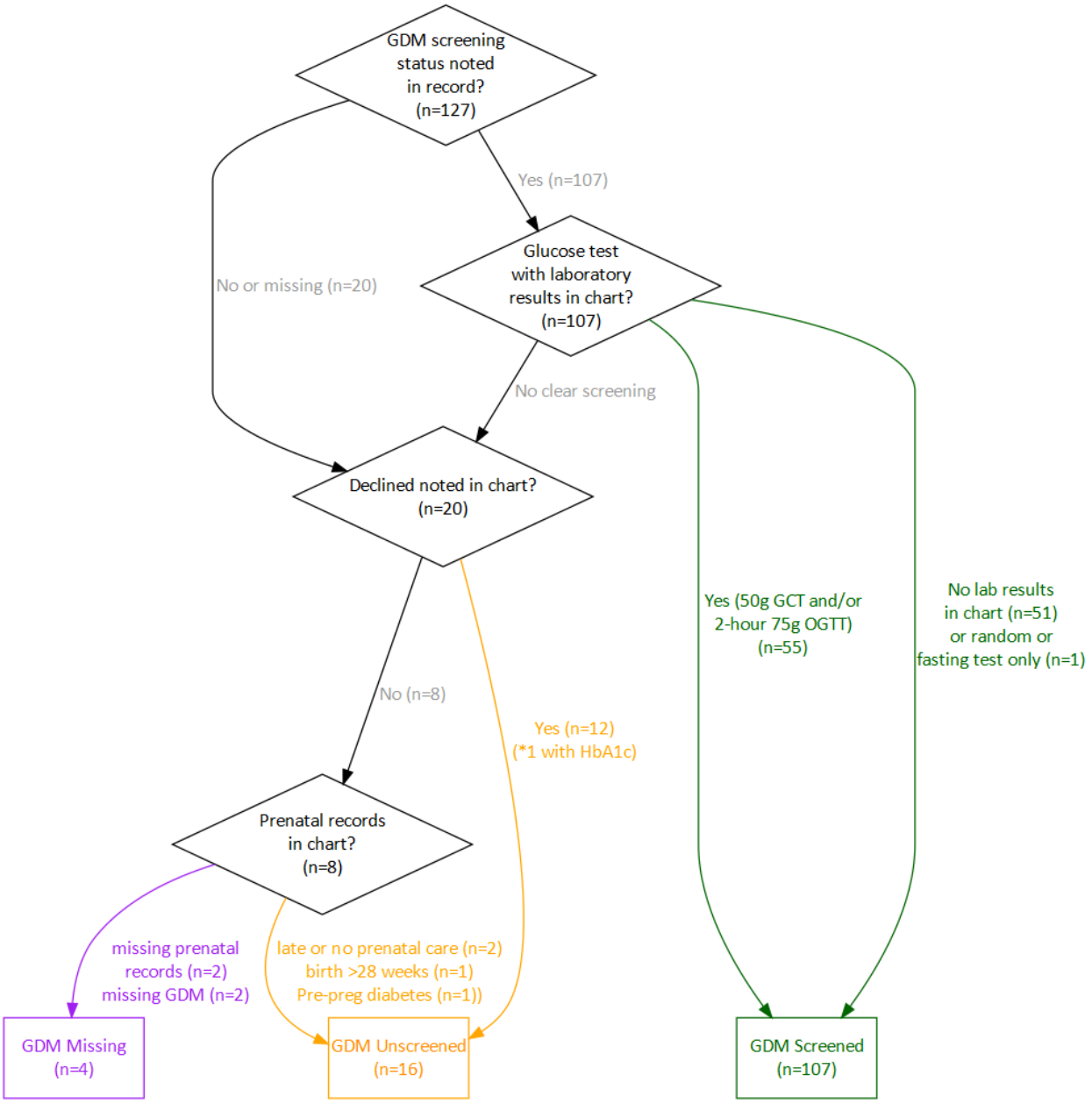
Population Data BC (Data Stewards) reported that the 5 unmatched IDs were due to "linkage uncertainty" because of inconsistencies between the two identifiers provided from medical records (personal health number and date of birth) and the administrative data sources. No additional linkage identifiers (i.e., name) were available because of privacy restrictions.

Figure A.2 Decision tree for 1st trimester ultrasound completion (screened, unscreened, missing) abstracted from medical records (n=127 for validation study)



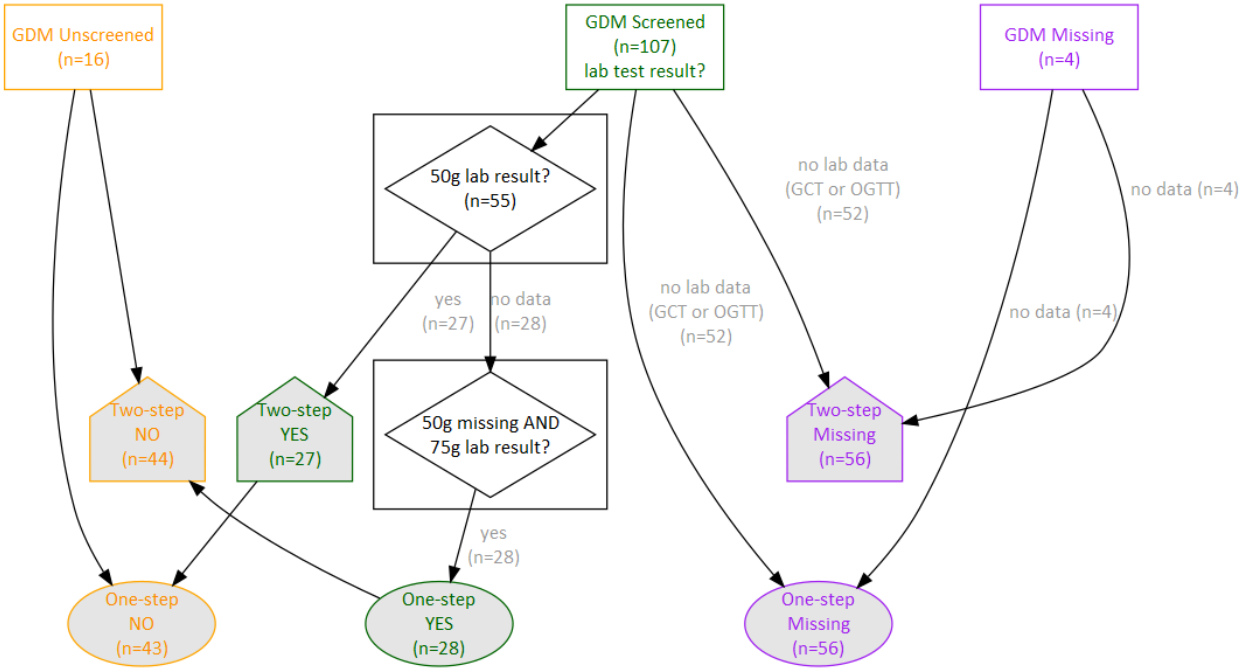
Abbreviations: US=ultrasound; US1=1st trimester ultrasound (defined as <14 weeks gestational age)

Figure A.3 Decision tree for gestational diabetes screen completion (screened, unscreened, missing) abstracted from medical records (n=127 linked for validation study)



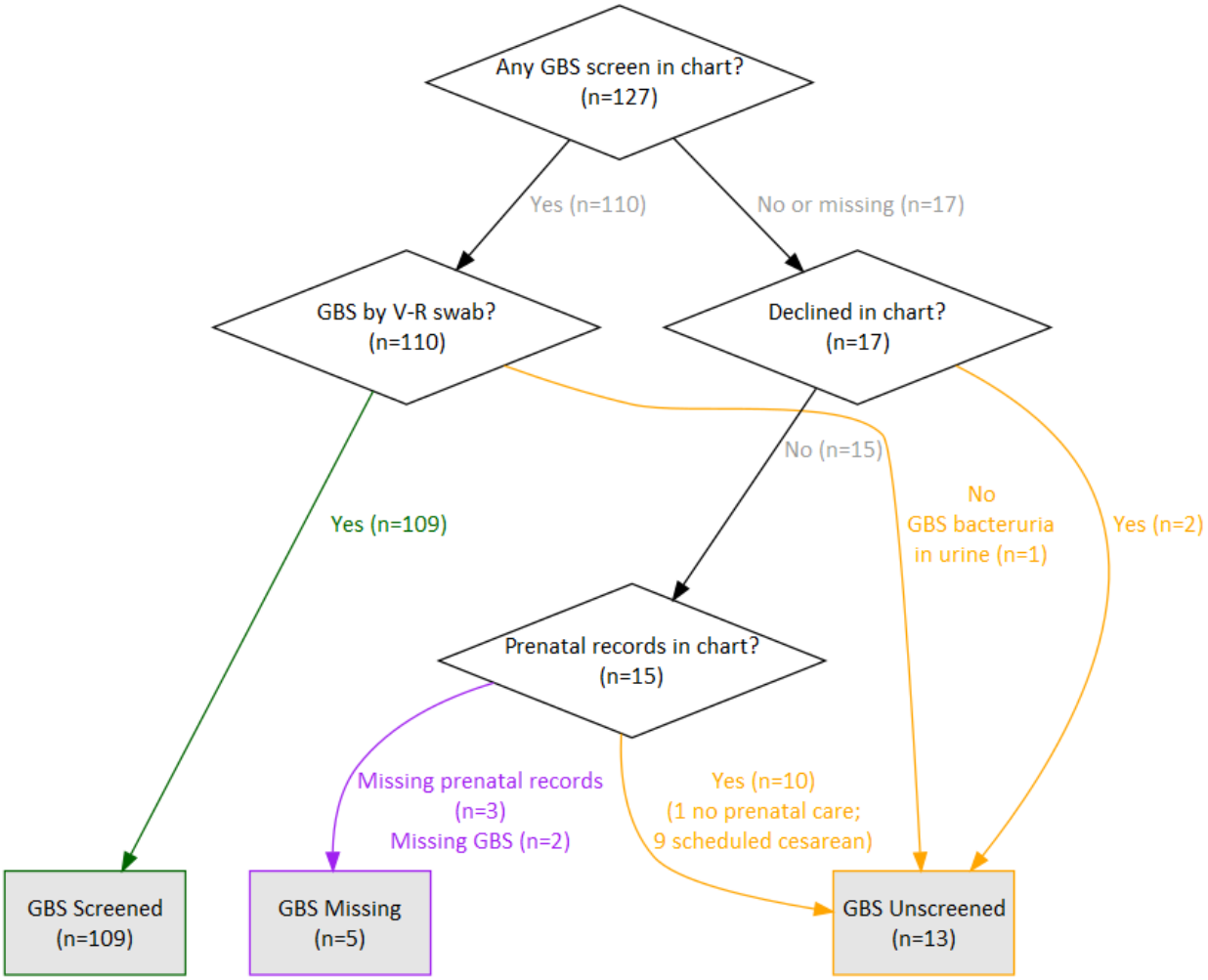
Abbreviations: GCT= glucose challenge test; OCTT=oral glucose tolerance test; GDM=gestational diabetes mellitus

Figure A.4 Decision tree for gestational diabetes screen methods (one-step or two-step) abstracted from medical records (n=127 linked for validation study)



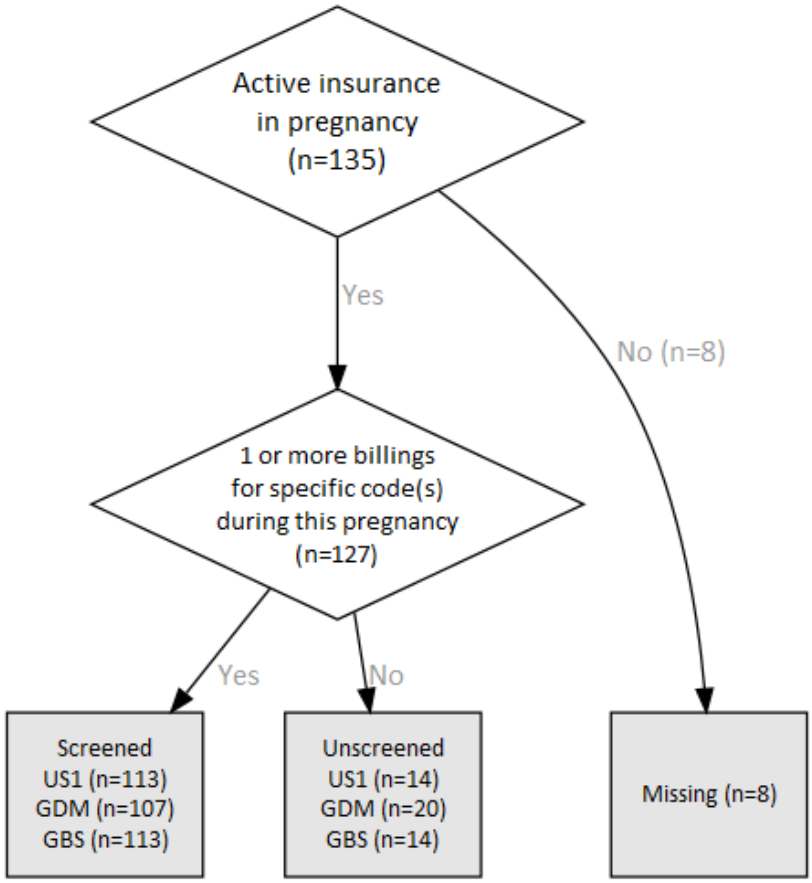
Abbreviations: GDM =gestational diabetes mellitus; OGTT =oral glucose tolerance test; GCT = 50g glucose challenge test

Figure A.5 Decision tree for Group B streptococcus test abstracted from medical records



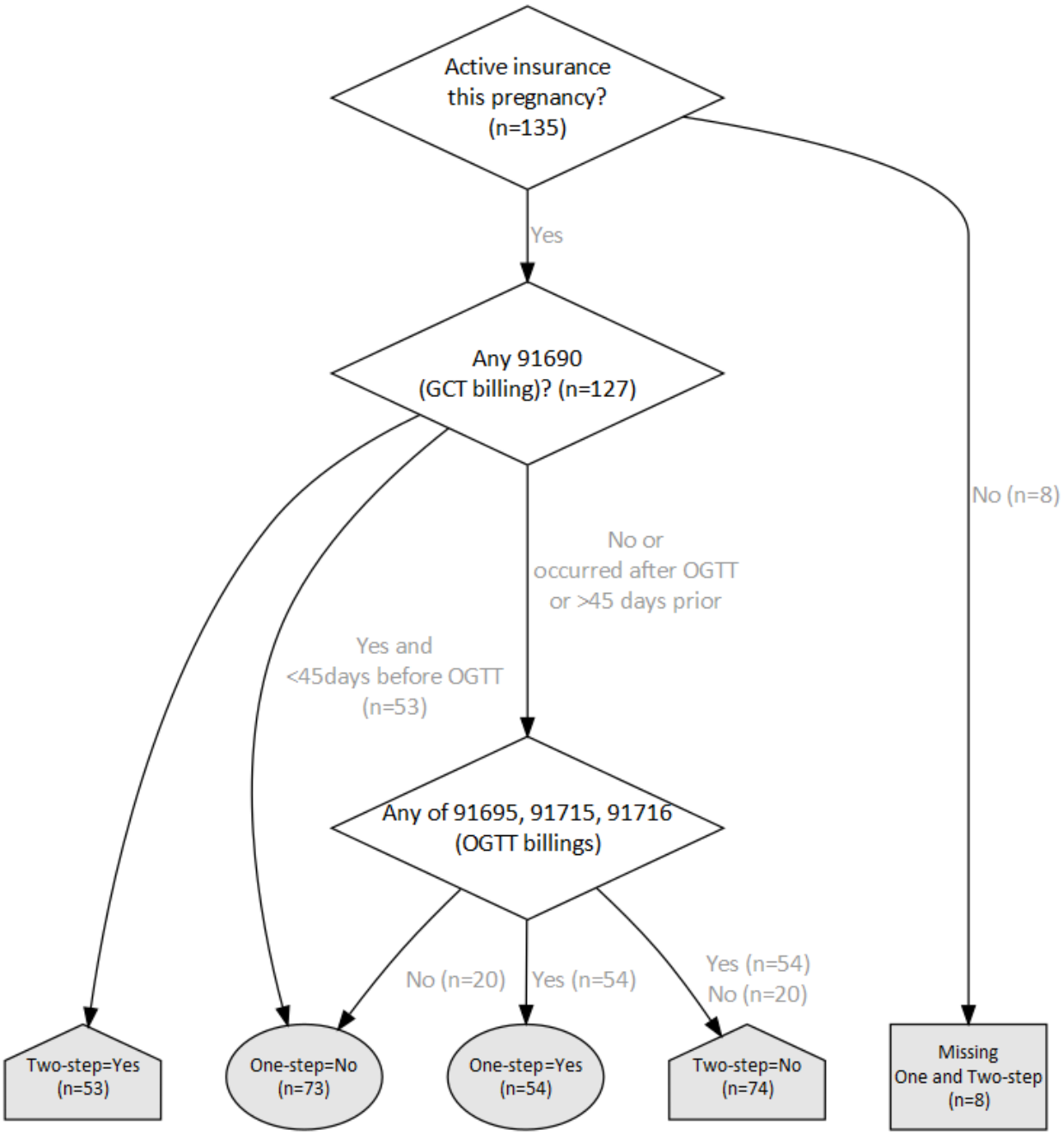
Abbreviations: GBS= Group B streptococcus; V-R = vaginal-rectal

Figure A.6 Decision tree for billings derived antenatal screening test results for 1st trimester ultrasound, GDM screening and GBS screening (screened v unscreened v missing) for n=135 records



Abbreviations: US1=1st trimester ultrasound, GDM=gestational diabetes mellitus, GBS = Group B streptococcus

Figure A.7 Decision tree for billings derived antenatal screening test results for gestational diabetes screening method (one-step or two-step) (n=135 records)



B. Descriptive study supplemental

B.1 Tables

Table B.1 Population demographics by gestational diabetes screening methods, BC, Canada, 2004-2019

Characteristic	Full study N = 525,720	One-step screening[a] N = 135,427	Two-step[b] N = 364,698	Other glucose test[c] N = 25,595
Time period for guidelines on GDM screening				
Period 1 (Jun 1, 2004 – Sep 30, 2010) – Two-step	211,304 (40%)	4,208 (3.1%)	196,785 (54%)	10,311 (40%)
Period 2 (Oct 1, 2010 – Mar 31, 2013) – BC 2010 one-step	88,379 (17%)	39,972 (30%)	44,347 (12%)	4,060 (16%)
IADPSG				
Period 3 (Apr 1, 2013 – Jun 30, 2016) – DC 2013 guidelines	118,300 (23%)	50,606 (37%)	61,357 (17%)	6,337 (25%)
Period 4 (Jul 1, 2016 – May 31, 2019) – SOGC 2016 guidelines	107,737 (20%)	40,641 (30%)	62,209 (17%)	4,887 (19%)
Parity				
P0	249,629 (47%)	66,507 (49%)	174,316 (48%)	8,806 (34%)
P1-P3	268,359 (51%)	67,416 (50%)	185,344 (51%)	15,599 (61%)
P4 or more	7,714 (1.5%)	1,503 (1.1%)	5,022 (1.4%)	1,189 (4.6%)
Missing data	18	<5	16	<5
Age of birthing person/mother (years)				
less than 25	68,079 (13%)	10,731 (7.9%)	53,061 (15%)	4,287 (17%)
25-34	327,553 (62%)	84,661 (63%)	227,969 (63%)	14,923 (58%)
35+	130,088 (25%)	40,035 (30%)	83,668 (23%)	6,385 (25%)
Pre-pregnancy body mass index (kg/m^2)[54]				
Under or normal (<24.9)	249,414 (47%)	65,675 (48%)	171,439 (47%)	12,300 (48%)
Overweight (25.0-29.9)	85,229 (16%)	24,286 (18%)	57,282 (16%)	3,661 (14%)
Obese I (30.0-34.9)	33,772 (6.4%)	10,384 (7.7%)	21,758 (6.0%)	1,630 (6.4%)
Obese II & III (>=35.0)	21,206 (4.0%)	7,272 (5.4%)	12,620 (3.5%)	1,314 (5.1%)
Missing data	136,099 (26%)	27,810 (21%)	101,599 (28%)	6,690 (26%)
Region of birth of mother/birthing parent				
Canada or USA	352,453 (67%)	80,810 (60%)	250,936 (69%)	20,707 (82%)
Asia or Arabia	126,215 (24%)	41,743 (31%)	81,887 (23%)	2,585 (10%)
All other regions	45,137 (8.6%)	12,499 (9.3%)	30,545 (8.4%)	2,093 (8.2%)
Missing data	1,915	375	1,330	210
Antepartum medical or obstetric risk[d]				
No/low risk	484,334 (92%)	122,316 (90%)	338,885 (93%)	23,133 (90%)
Moderate/high risk	41,386 (7.9%)	13,111 (9.7%)	25,813 (7.1%)	2,462 (9.6%)
Previous history of gestational diabetes				
No	245,310 (47%)	65,254 (48%)	171,454 (47%)	8,602 (34%)
no prior pregnancy in data	263,667 (50%)	61,620 (46%)	186,765 (51%)	15,282 (60%)
Yes	16,743 (3.2%)	8,553 (6.3%)	6,479 (1.8%)	1,711 (6.7%)
Antenatal health care professional type[177]				
Family practice	366,353 (70%)	80,838 (60%)	273,406 (75%)	12,109 (47%)
Registered Midwife	78,118 (15%)	25,135 (19%)	42,393 (12%)	10,590 (41%)
Obstetrician	79,562 (15%)	29,248 (22%)	47,881 (13%)	2,433 (9.5%)
Missing or <2 antenatal visits	1,687 (0.3%)	206 (0.2%)	1,018 (0.3%)	463 (1.8%)
Planned home birth				
Planned hospital (all births)	513,278 (98%)	132,557 (98%)	358,425 (98%)	22,296 (87%)
Planned home (only available for RM care)	12,442 (2.4%)	2,870 (2.1%)	6,273 (1.7%)	3,299 (13%)
Adequacy of prenatal care usage index[188]				
Adequate Plus	65,600 (12%)	18,632 (14%)	44,172 (12%)	2,796 (11%)
Adequate	282,612 (54%)	75,117 (55%)	197,001 (54%)	10,494 (41%)
Intermediate	147,489 (28%)	35,742 (26%)	102,932 (28%)	8,815 (34%)
Inadequate	30,019 (5.7%)	5,936 (4.4%)	20,593 (5.6%)	3,490 (14%)
Region of residence of birthing person/mother[e]				
Metro Vancouver or Victoria	359,588 (68%)	113,020 (83%)	231,742 (64%)	14,826 (58%)
Northern region	39,799 (7.6%)	1,644 (1.2%)	35,410 (9.7%)	2,745 (11%)
Other southern areas (small towns and rural areas)	50,910 (9.7%)	7,588 (5.6%)	39,875 (11%)	3,447 (13%)
Other southern cities	75,423 (14%)	13,175 (9.7%)	57,671 (16%)	4,577 (18%)

Characteristic	Full study N = 525,720	One-step screening[a] N = 135,427	Two-step[b] N = 364,698	Other glucose test[c] N = 25,595
Rural or urban residence by local health area region				
Urban	509,204 (97%)	133,587 (99%)	351,197 (96%)	24,420 (95%)
Rural	16,516 (3.1%)	1,840 (1.4%)	13,501 (3.7%)	1,175 (4.6%)
Neighbourhood income per person				
lowest income quintile	111,692 (21%)	28,445 (21%)	77,383 (21%)	5,864 (23%)
mid-low income quintile	111,263 (21%)	29,107 (21%)	76,884 (21%)	5,272 (21%)
middle income quintile	107,022 (20%)	28,153 (21%)	73,798 (20%)	5,071 (20%)
mid-high income quintile	107,065 (20%)	28,351 (21%)	73,756 (20%)	4,958 (19%)
highest income quintile	81,950 (16%)	19,689 (15%)	58,252 (16%)	4,009 (16%)
missing or NA	6,728 (1.3%)	1,682 (1.2%)	4,625 (1.3%)	421 (1.6%)

a. One-step screening derived from laboratory billings as per Chapter 3; generally, if no screening test (91690) and/or 91695, 91715 or 91716 occurred > 45 days of 91690 (screening test)

b. Two-step screening derived from laboratory billings as per Chapter 3, if code 91690 was present

c. Other glucose tests derived from laboratory billings if neither one-step or two-step screening was identified and only codes 91745 (HbA1c) or 91707 or 91700 (Glucose quant or semi-quant) were present

d. Antepartum medical or obstetric risk defined using methods proposed by McRae et al. with the addition of a history of fetal complications from BC-PDR data (prior neonatal death, stillbirth or anomaly). Full definition includes: ICD-10-CA codes O991 O994 O99803/04/09 O101-4 O109 O266 O981 O984-9 O360 O361 and PDR: Antepartum anti-hypertensives prescribed, Prior NND/anomaly/Stillbirth or 2+ prior Cesarean

e. Regions derived as follows: Metro Vancouver or Victoria includes all local health areas within the greater Vancouver and Victoria metropolitan areas; Northern region includes all of the Northern health region; Other southern cities includes all cities with regional or tertiary hospitals located in the city; Rest of province = all other local health regions

Table B.2 Crude and adjusted Relative Risks (RR) for one-step gestational diabetes screening, BC, Canada, 2005-2019

Characteristic	One-step screening for gestational diabetes	
	Crude Relative Risks (RR)	Adjusted Relative Risks[a] (ARR)
GDM screening guidelines (BC 2010, DC 2013, SOGC 2016)		
Period 1	—[b]	—
Period 2	22.7 (22.0, 23.4)	22.2 (21.6, 22.9)
Period 3	21.5 (20.8, 22.2)	20.9 (20.3, 21.6)
Period 4	18.9 (18.4, 19.6)	18.2 (17.6, 18.8)
PDR data: Parity categorized		
P0	—	—
P1-P3	0.94 (0.93, 0.95)	0.93 (0.92, 0.94)
P4 or more	0.73 (0.69, 0.77)	0.80 (0.77, 0.83)
PDR data: Mothers age categorized		
less than 25	—	—
25-34	1.64 (1.61, 1.67)	1.13 (1.11, 1.14)
35+	1.95 (1.91, 1.99)	1.22 (1.20, 1.24)
Pre-pregnancy body mass index (kg/m2)		
Under or normal (<24.9)	—	—
Overweight (25.0-29.9)	1.08 (1.07, 1.10)	1.12 (1.11, 1.13)
Obese I (30.0-34.9)	1.17 (1.14, 1.19)	1.25 (1.23, 1.27)
Obese II & III (>=35.0)	1.30 (1.27, 1.33)	1.42 (1.39, 1.44)
missing	0.78 (0.77, 0.79)	0.97 (0.96, 0.98)
Region of birth of mother/birthing person		
Canada or USA	—	—
Asia or Arabia	1.44 (1.43, 1.46)	1.10 (1.09, 1.11)
All other regions	1.21 (1.19, 1.23)	1.02 (1, 1.03)
Antepartum risk		
No/low	—	—
Moderate/high	1.25 (1.23, 1.28)	1.07 (1.05, 1.08)
Antenatal health care professional type		
Family practice	—	—
Registered Midwife	1.46 (1.44, 1.48)	1 (0.99, 1.01)
Obstetrician	1.67 (1.64, 1.69)	1.25 (1.24, 1.26)
Missing	0.55 (0.48, 0.63)	0.70 (0.62, 0.79)
Planned home birth (full population)		
no	—	—
yes	0.89 (0.86, 0.93)	0.76 (0.74, 0.78)
APNCU index (MSP)		
Adequate Plus	—	—
Adequate	0.94 (0.92, 0.95)	0.95 (0.94, 0.96)
Intermediate	0.85 (0.84, 0.87)	0.91 (0.90, 0.93)
Inadequate	0.70 (0.68, 0.72)	0.83 (0.82, 0.85)
Region of residence of birthing person/mother		
Metro Vancouver or Victoria	—	—
Northern region	0.13 (0.13, 0.14)	0.15 (0.14, 0.16)
Other southern areas	0.47 (0.46, 0.49)	0.55 (0.54, 0.56)
Other southern cities	0.56 (0.55, 0.57)	0.60 (0.59, 0.61)
Rural or urban LHA		
Urban	—	—
Rural	0.42 (0.41, 0.44)	0.82 (0.79, 0.86)

a. Adjusted models include all covariates shown in the table; ARR = Adjusted Relative Risks;

b. Baseline (-) all values relative to baseline category

Table B.3 Gestational diabetes diagnosis and treatment type by screening methods in BC, Canada, 2011-2019 (after one-step was implemented)

Characteristic	One-step N = 131,219 % (95% CI[b])	Two-step N = 167,913 % (95% CI)	Other glucose test N = 15,284 % (95% CI)
Gestational diabetes diagnosis[a]	18% (17.8, 18.2)	8.8% (8.7, 9.0)	10.0% (9.5, 10.5)
Gestational diabetes diagnosis and treatment type			
No diabetes	82% (81.8, 82.2)	91% (91.0, 91.3)	90% (89.5, 90.5)
Diet-controlled	12% (12.2, 12.6)	6.4% (6.3, 6.6)	4.3% (4.0, 4.7)
Medication controlled	5.6% (5.5, 5.7)	2.4% (2.3, 2.4)	5.6% (5.3, 6.0)
GDM treatment type (Among those with a diagnosis)			
GDM diet-controlled	69% (68.3, 69.5)	73% (72.4, 73.8)	43% (40.9, 45.9)
GDM medication-controlled	31% (30.5, 31.7)	27% (26.2, 27.6)	57% (54.1, 59.1)

a. GDM diagnosis and treatment data obtained from BC-PDR data

b. CI = Confidence Interval

Table B.4 One-step gestational diabetes screening rates by region in subgroups, time periods and by year

Characteristic	Metro Vancouver and Victoria	Southern cities with Tertiary or Regional Hospitals	Southern small towns or rural areas	Northern region
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)
One-step GDM screening / Total in region	31.4% (31.3, 31.6)	17.5% (17.2, 17.7)	14.9% (14.6, 15.2)	4.1% (3.9, 4.3)
Screening guidelines (BC 2010, DC 2013, SOGC 2016)				
Period 1	2.1% (2.0, 2.1)	1.8% (1.6, 1.9)	1.8% (1.7, 2.0)	2.0% (1.8, 2.3)
Period 2	57.6% (57.2, 58.0)	22.6% (21.8, 23.3)	22.3% (21.4, 23.2)	3.2% (2.8, 3.7)
Period 3	51.1% (50.8, 51.4)	31.0% (30.3, 31.7)	28.5% (27.6, 29.3)	6.8% (6.3, 7.3)
Period 4	44.9% (44.6, 45.3)	29.8% (29.1, 30.5)	21.4% (20.7, 22.3)	6.2% (5.7, 6.8)
Parity				
P0	32.0% (31.7, 32.2)	18.2% (17.8, 18.6)	15.6% (15.2, 16.1)	3.9% (3.6, 4.2)
P1-P3	31.0% (30.8, 31.2)	16.9% (16.5, 17.3)	14.4% (14.0, 14.8)	4.3% (4.0, 4.6)
P4 or more	28.8% (27.4, 30.2)	12.9% (11.1, 15.0)	11.9% (10.0, 14.0)	4.6% (3.6, 5.9)
Missing	<5	<5	<5	<5
Age				
less than 25	23.1% (22.6, 23.5)	12.4% (11.9, 13.0)	10.8% (10.2, 11.5)	2.9% (2.6, 3.3)
25-34	31.2% (31.0, 31.4)	17.9% (17.6, 18.3)	15.0% (14.6, 15.4)	4.3% (4.1, 4.6)
35+	34.6% (34.3, 34.9)	21.1% (20.4, 21.8)	18.7% (18.0, 19.5)	5.9% (5.2, 6.6)
Pre-pregnancy body mass index (kg/m2)				
Under or normal (<24.9)	30.6% (30.4, 30.8)	16.5% (16.1, 16.9)	16.5% (16.0, 17.0)	3.4% (3.1, 3.8)
Overweight (25.0-29.9)	34.3% (34.0, 34.7)	19.7% (19.0, 20.4)	18.3% (17.5, 19.3)	4.4% (3.9, 4.9)
Obese I (30.0-34.9)	37.8% (37.1, 38.4)	23.3% (22.2, 24.4)	22.6% (21.2, 24.1)	5.7% (4.9, 6.5)
Obese II & III (>=35.0)	42.5% (41.7, 43.4)	29.4% (28.0, 30.8)	25.4% (23.6, 27.2)	8.7% (7.7, 9.9)
missing	27.9% (27.6, 28.2)	13.5% (13.1, 14.0)	9.5% (9.1, 9.9)	3.5% (3.2, 3.8)
Region of birthplace of birthing person/mother				
Canada or USA	30.2% (30.0, 30.4)	17.0% (16.7, 17.3)	14.2% (13.8, 14.5)	4.0% (3.8, 4.2)
Asia or Arabia	33.9% (33.6, 34.1)	25.7% (24.3, 27.1)	23.9% (22.4, 25.6)	7.5% (6.3, 8.9)
All other regions	30.5% (30.0, 30.9)	18.3% (17.1, 19.6)	18.0% (16.7, 19.5)	4.3% (3.4, 5.4)
Missing	312	40	19	<5
Antepartum risk (yes)	38.3% (37.7, 38.9)	23.1% (22.0, 24.2)	20.1% (18.8, 21.3)	6.4% (5.6, 7.3)
History of GDM in previous pregnancy				
no	31.9% (31.7, 32.1)	18.2% (17.8, 18.6)	15.6% (15.1, 16.1)	3.9% (3.6, 4.2)
no prior pregnancy in data	29.2% (28.9, 29.4)	15.9% (15.5, 16.3)	13.7% (13.3, 14.1)	3.7% (3.5, 4.0)
yes	54.1% (53.2, 54.9)	46.0% (43.3, 48.7)	35.0% (31.9, 38.3)	22.3% (19.4, 25.6)
Antenatal health care professional type				
Family practice	27.6% (27.4, 27.8)	16.1% (15.8, 16.4)	12.9% (12.6, 13.3)	3.6% (3.4, 3.8)
Registered Midwife	38.0% (37.6, 38.4)	20.8% (20.2, 21.5)	20.2% (19.4, 21.1)	11.4% (10.2, 12.7)
Obstetrician	40.2% (39.9, 40.6)	21.3% (20.3, 22.3)	24.0% (22.6, 25.3)	5.0% (4.2, 6.0)
Missing	16.9% (14.6, 19.5)	7.3% (4.2, 12.1)	8.6% (5.5, 13.0)	3.9% (2.1, 6.8)
Planned home birth	27.5% (26.5, 28.5)	17.1% (15.8, 18.5)	17.3% (15.6, 19.2)	6.5% (4.0, 10.3)
APNCU index (MSP)				
Adequate Plus	34.1% (33.7, 34.5)	20.3% (19.6, 21.1)	16.1% (15.2, 17.1)	5.8% (5.1, 6.6)
Adequate	31.9% (31.7, 32.1)	18.0% (17.6, 18.4)	15.3% (14.8, 15.7)	4.1% (3.8, 4.4)
Intermediate	30.2% (29.9, 30.5)	15.5% (15.0, 16.0)	14.5% (14.0, 15.1)	3.8% (3.4, 4.1)
Inadequate	26.6% (26.0, 27.3)	13.4% (12.3, 14.6)	12.0% (11.0, 13.1)	3.8% (3.3, 4.4)
LHA type				
Urban	31.4% (31.2, 31.6)	n.a.[a]	16.3% (15.9, 16.6)	4.2% (4.0, 4.4)
Rural	37.1% (34.9, 39.4)		9.7% (9.1, 10.3)	3.7% (3.1, 4.3)

Characteristic	Metro Vancouver and Victoria	Southern cities with Tertiary or Regional Hospitals	Southern small towns or rural areas	Northern region
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)
Neighbourhood income per person				
lowest income quintile	31.4% (31.0, 31.7)	17.1% (16.5, 17.6)	13.9% (13.2, 14.6)	4.0% (3.6, 4.4)
mid-low income quintile	31.5% (31.1, 31.8)	17.4% (16.8, 18.0)	13.8% (13.1, 14.4)	4.3% (3.8, 4.8)
middle income quintile	31.5% (31.2, 31.9)	17.4% (16.8, 18.0)	14.7% (14.0, 15.4)	4.4% (3.9, 4.9)
mid-high income quintile	32.0% (31.6, 32.3)	17.4% (16.8, 18.0)	14.3% (13.5, 15.0)	3.9% (3.5, 4.3)
highest income quintile	30.2% (29.8, 30.6)	18.4% (17.7, 19.0)	18.1% (17.4, 18.9)	4.3% (3.9, 4.7)
missing or NA	34.9% (33.4, 36.4)	16.0% (13.2, 19.2)	13.4% (11.6, 15.3)	3.5% (2.4, 5.0)
Year				
2005	1.9% (1.7, 2.1)	1.6% (1.3, 2.1)	2.3% (1.8, 2.9)	2.2% (1.7, 2.9)
2006	2.0% (1.8, 2.2)	1.9% (1.5, 2.4)	2.2% (1.7, 2.7)	2.3% (1.7, 3.0)
2007	2.0% (1.8, 2.2)	1.7% (1.4, 2.1)	1.8% (1.4, 2.3)	2.1% (1.6, 2.7)
2008	2.0% (1.8, 2.2)	1.8% (1.5, 2.3)	1.5% (1.1, 1.9)	2.7% (2.1, 3.4)
2009	2.0% (1.8, 2.1)	1.9% (1.5, 2.3)	1.4% (1.1, 1.9)	1.9% (1.4, 2.5)
2010	2.0% (1.9, 2.2)	1.8% (1.4, 2.2)	2.0% (1.6, 2.5)	1.4% (1.0, 1.9)
2011	30.5% (29.9, 31.0)	6.1% (5.5, 6.8)	6.3% (5.5, 7.1)	1.5% (1.1, 2.1)
2012	60.2% (59.6, 60.8)	23.1% (21.9, 24.3)	23.0% (21.6, 24.5)	3.4% (2.8, 4.2)
2013	65.9% (65.3, 66.5)	33.7% (32.4, 35.0)	33.2% (31.6, 34.8)	5.3% (4.4, 6.2)
2014	57.2% (56.6, 57.9)	32.6% (31.4, 34.0)	33.0% (31.4, 34.6)	9.2% (8.1, 10.3)
2015	46.6% (46.0, 47.3)	29.9% (28.7, 31.2)	26.6% (25.1, 28.2)	5.3% (4.5, 6.2)
2016	46.9% (46.3, 47.5)	30.4% (29.2, 31.7)	25.6% (24.1, 27.1)	5.6% (4.8, 6.5)
2017	46.0% (45.4, 46.6)	29.2% (28.0, 30.5)	22.4% (21.1, 23.8)	6.1% (5.2, 7.0)
2018	44.4% (43.8, 45.0)	29.8% (28.5, 31.0)	22.2% (20.9, 23.7)	6.3% (5.5, 7.3)
2019	44.6% (44.0, 45.3)	30.3% (29.0, 31.5)	19.8% (18.5, 21.2)	6.3% (5.4, 7.3)

a. By definition, the Southern cities group included 'urban' local health areas.

Table B.5 One-step gestational diabetes screening rates by year, BC, Canada, 2005-2019

Year	One-step GDM screening % (95% CI)
2005	1.9% (1.8, 2.1)
2006	2.0% (1.9, 2.2)
2007	1.9% (1.8, 2.1)
2008	2.0% (1.8, 2.1)
2009	1.9% (1.7, 2.0)
2010	1.9% (1.8, 2.1)
2011	22.4% (22.0, 22.8)
2012	47.0% (46.5, 47.5)
2013	53.9% (53.4, 54.5)
2014	47.9% (47.4, 48.4)
2015	39.3% (38.8, 39.8)
2016	39.4% (38.9, 39.9)
2017	38.6% (38.1, 39.1)
2018	37.3% (36.8, 37.8)
2019	37.5% (37.0, 38.0)

B.2 Figures

Figure B.1 Study population derivation and exclusions

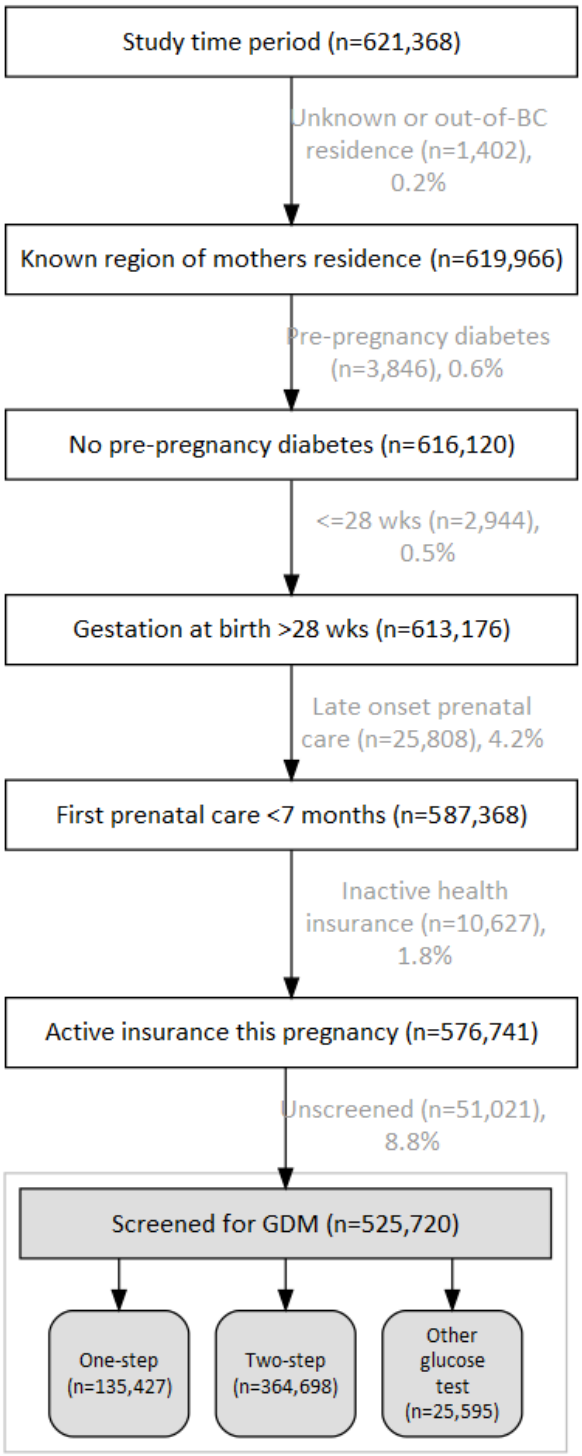


Figure B.2 Rates of GDM one-step screening by region and pre-pregnancy BMI

Figure B.3 Rates of GDM one-step screening by region and health care professional type

Figure B.4 Rates of GDM one-step screening by region and history of GDM

Figure B.5 Rates of GDM one-step screening by region and birth region of mother/birthing person

Figure B.6 Rates of GDM one-step screening by region and planned home birth

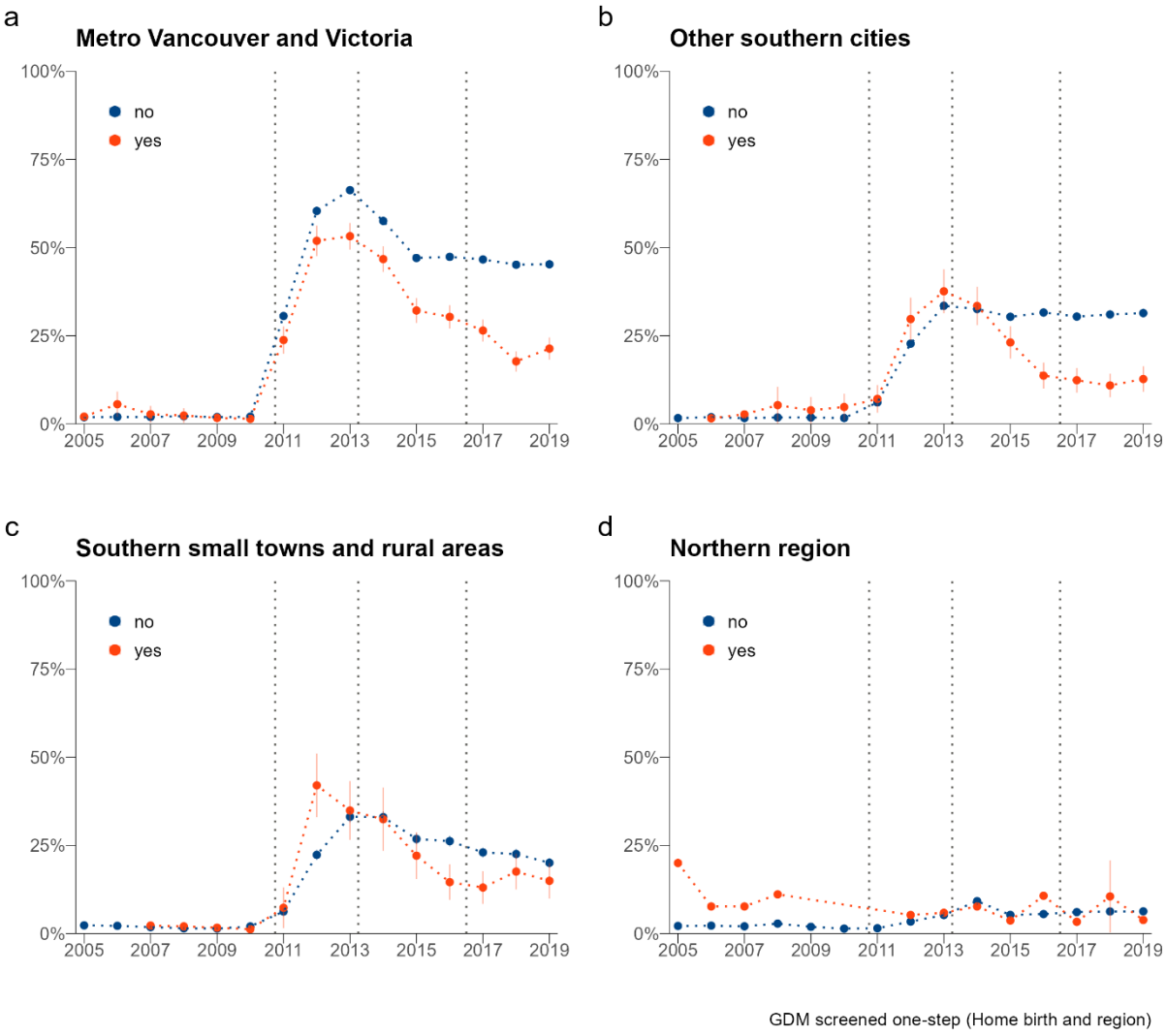


Figure B.7 Rates of GDM one-step screening by region and adequacy of prenatal care usage index

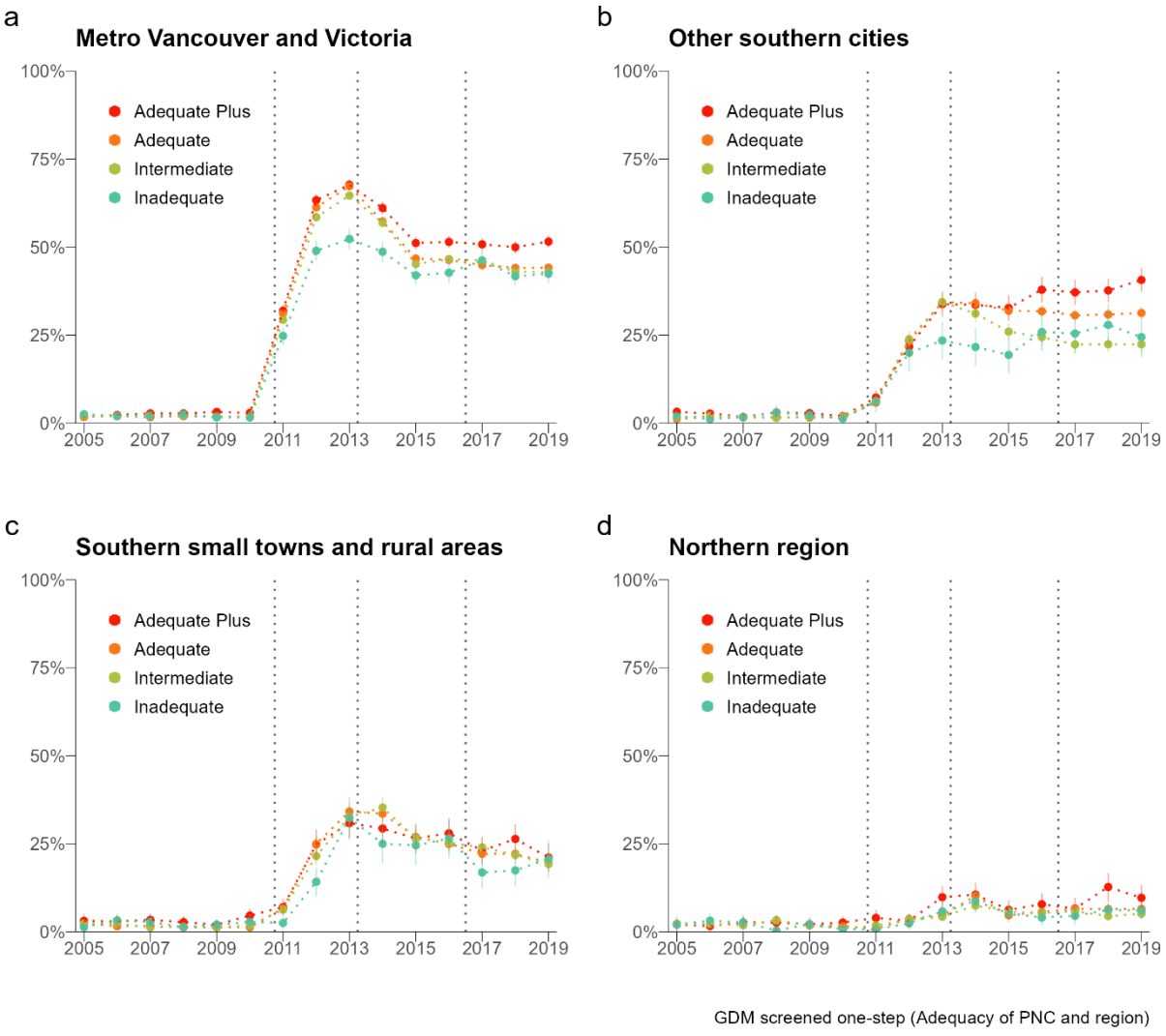


Figure B.8 Rates of GDM one-step screening by region and Health services delivery areas

Figure B.9 Gestational diabetes diagnoses rates by screening type

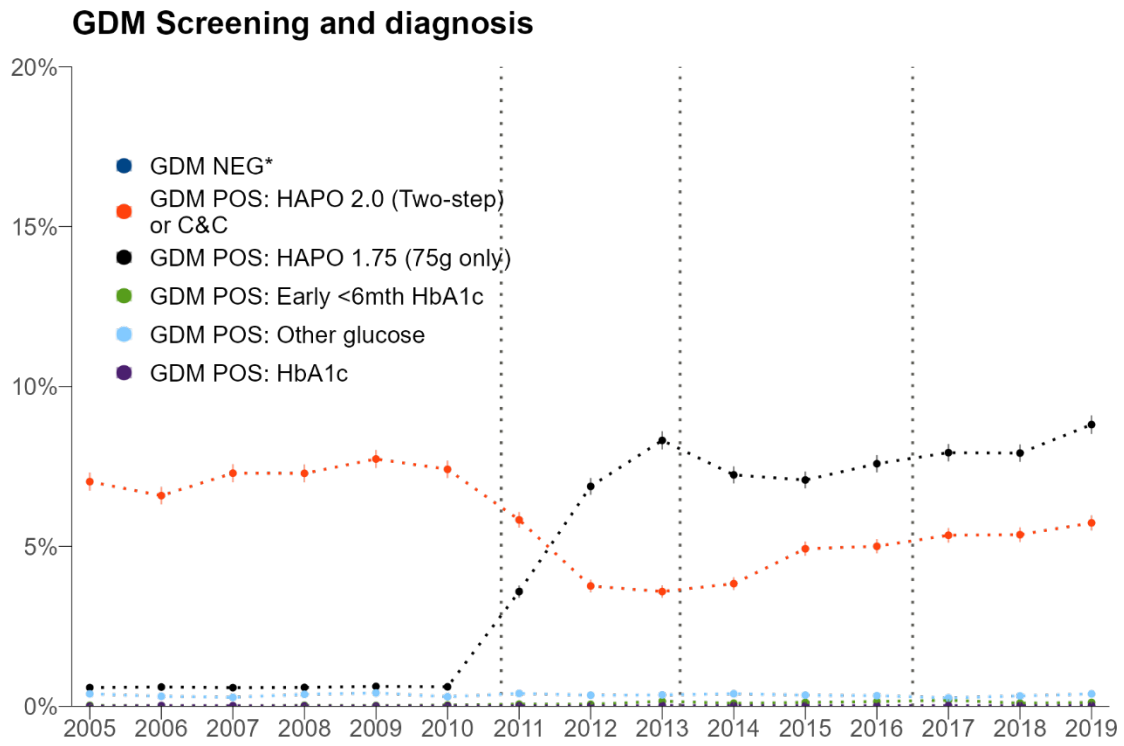


Figure B.10 Rates of one-step gestational diabetes screening in BC regions in 4 time periods by date of 1st glucose screening test for gestational diabetes by BC local health area

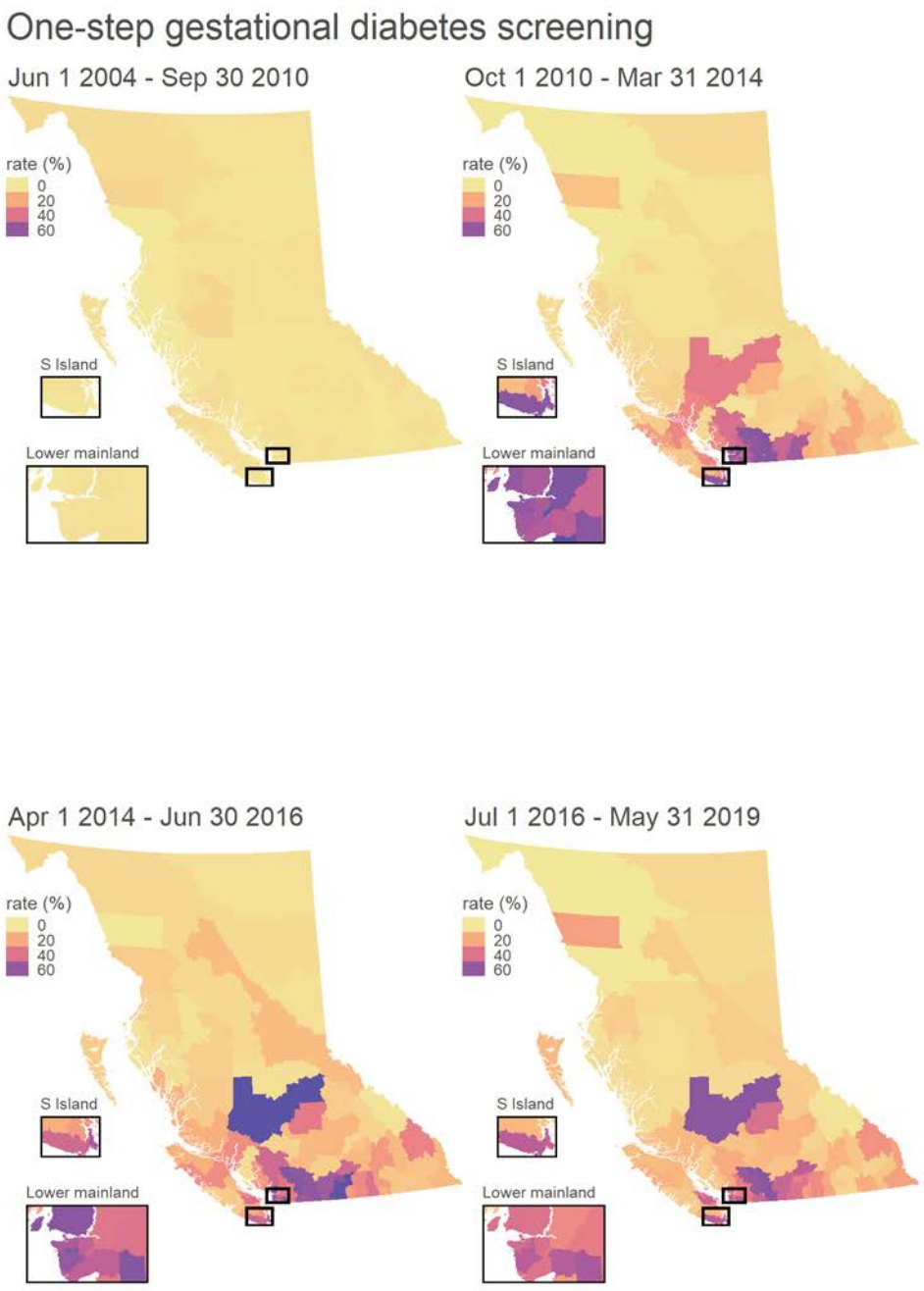
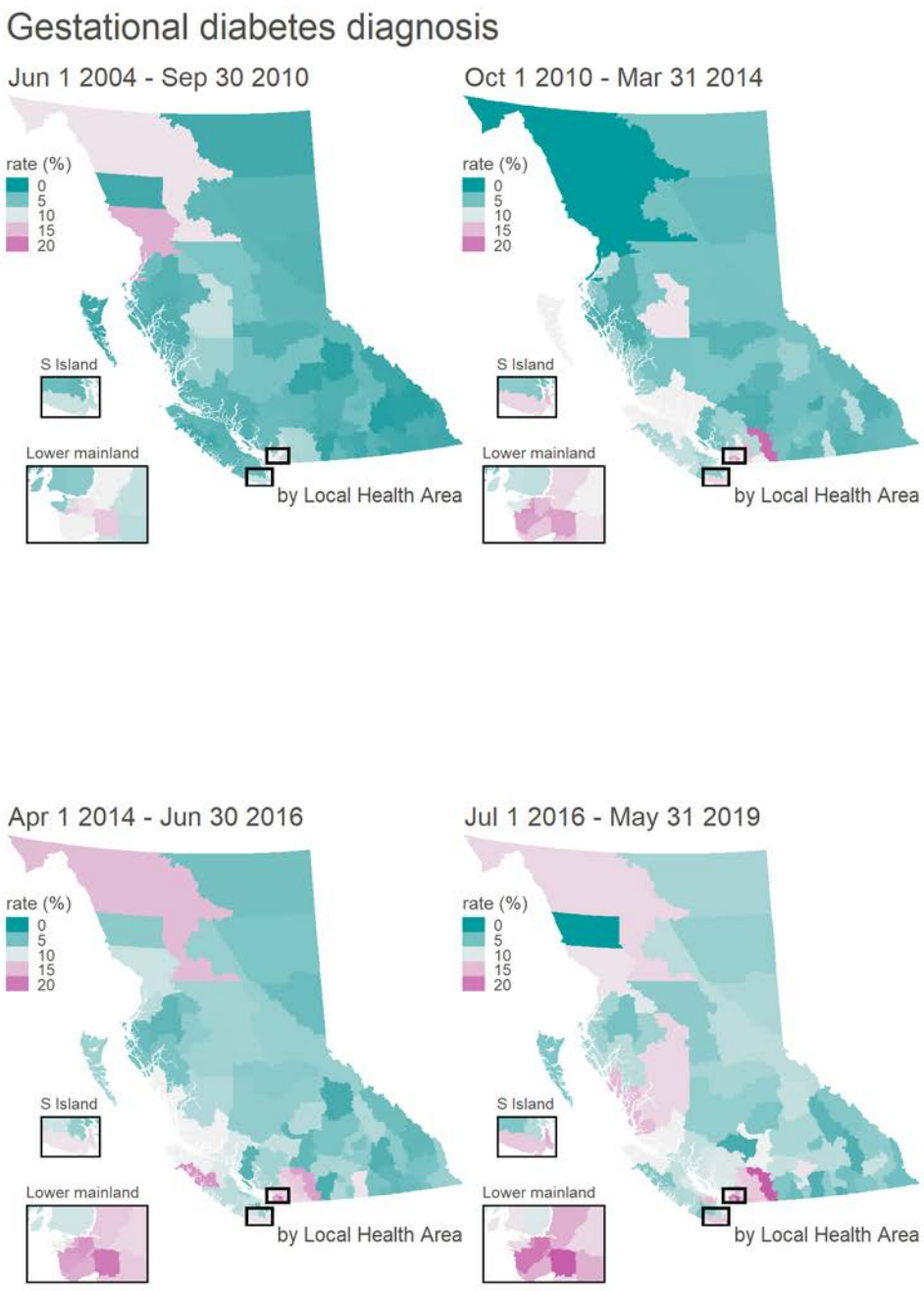


Figure B.11 Rates of gestational diabetes diagnoses in BC regions in 4 time periods by date of 1st glucose screening test for gestational diabetes



C. Gestational diabetes study supplemental

C.1 Methods

I conducted several sensitivity analyses to test if these results were sensitive to particular characteristics of our study population. In British Columbia, prior to October 2010,[105] the "two-step" method of screening included a 50g-GCT screening test, followed by a 3-hour, 100g OGTT diagnostic test using Carpenter-Coustan criteria. After October 2010, the "two-step" method continued to use a 50g-GCT but the diagnostic test used a 2-hour, 75g OGTT with the Diabetes Canada-2013 criteria[291]. These two screening approaches are similar, but not identical, and have different diagnostic prevalences. In the primary analysis, all two-step screening was treated as one screening method. In sensitivity analysis, we used an additional screening variable to control for the difference between the two-step methods (before October 2010, using C-C criteria and a 100g diagnostic OGTT compared to after October 2010 using the DC-2013 criteria). Overall results were unchanged and the additional variable was not statistically significant in the final models, thus we considered all two-step screening as one method for the main analysis.

I assessed the models using different years as the baseline (2006, 2009) and study end (2018) to determine if the findings were sensitive to the choice of baseline year. I also included health region as potential covariates in the "population characteristics" and also repeated the analyses in subgroups by health region to assess for potential confounding by region. We also considered additional covariates for pregnancy-associated complications: > 2 prior cesarean deliveries or prior macrosomia.

C.2 Tables

Table C.1 Model estimated risk of gestational diabetes in each study year (n=551,457)

	Model 1: Baseline		**Model 2: Add screen completion[a]**		**Model 3: Add screen method[b]**		**Model 4: Add population[c] factors**	
Estimated Year	RR[d]	CI[e]	RR	CI	RR	CI	RR	CI
2005	Baseline		Baseline		Baseline		Baseline	
2006	0.96	0.91 to 1.01	0.96	0.91 to 1.01	0.96	0.91 to 1.01	0.96	0.91 to 1.01
2007	1.04	0.99 to 1.10	1.04	0.98 to 1.09	1.04	0.98 to 1.09	1.04	0.98 to 1.09
2008	1.06	1.01 to 1.12	1.05	1.00 to 1.11	1.05	1.00 to 1.11	1.04	0.99 to 1.09
2009	1.12	1.06 to 1.17	1.10	1.04 to 1.16	1.10	1.04 to 1.16	1.09	1.03 to 1.14
2010	1.05	1.00 to 1.11	1.03	0.98 to 1.09	1.03	0.98 to 1.09	1.02	0.97 to 1.07
2011	1.27	1.21 to 1.34	1.25	1.19 to 1.31	0.98	0.93 to 1.03	1.02	0.97 to 1.07
2012	1.44	1.37 to 1.51	1.40	1.33 to 1.47	0.91	0.87 to 0.96	0.98	0.93 to 1.03
2013	1.60	1.52 to 1.67	1.55	1.47 to 1.62	0.97	0.92 to 1.02	1.04	0.99 to 1.09
2014	1.51	1.44 to 1.58	1.45	1.38 to 1.52	0.96	0.91 to 1.01	1.01	0.96 to 1.06
2015	1.66	1.58 to 1.74	1.58	1.51 to 1.66	1.10	1.05 to 1.16	1.13	1.07 to 1.18
2016	1.74	1.66 to 1.82	1.65	1.57 to 1.73	1.15	1.09 to 1.20	1.16	1.11 to 1.22
2017	1.85	1.77 to 1.94	1.74	1.66 to 1.82	1.22	1.17 to 1.28	1.19	1.13 to 1.24
2018	1.85	1.77 to 1.94	1.73	1.65 to 1.81	1.23	1.17 to 1.28	1.16	1.11 to 1.22
2019	2.04	1.94 to 2.13	1.89	1.81 to 1.98	1.34	1.28 to 1.40	1.25	1.19 to 1.31

a. Screen completion was modeled as any gestational diabetes screen v. unscreened/no data

b. Screen method was modeled as any two-step screening approach. In BC, until October 2010, two-step screening consisted of a 50g screening test followed by a 100g, 3-hour diagnostic test assessed using Carpenter-Coustan criteria.[150] After October 2010, two-step screening changed to a 50g screening test followed by a 75g, 2-hour test using the International Association of Diabetes and Pregnancy Study Groups (IADPSG) diagnostic criteria.[38,105]

c. Population factors included: parity (nulliparous v. multiparous), age at delivery of mother/birthing person (<25, 25-34, ≥35 years), pre-pregnancy body mass index (<24.5, 25-29.9, >30 kg/m^2 or missing data), pre-existing complications (any of pre-existing disease,[177] pre-existing hypertensive disorders, iso-immunization, prior stillbirth or neonatal death, >=2 prior Cesarean births), multifetal pregnancy, antenatal care by a Registered Midwife (v. any other), inadequate prenatal care[200] and mother's country of birth (all Asian or Arabian peninsula v. all others v. Canada/USA/missing).

d. Relative risk = RR

e. Confidence Intervals = CI, assessed using robust standard errors

Table C.2 Population characteristics by gestational diabetes diagnosis in BC, Canada from 2005 to 2019 (n=551,457)

Characteristic	Overall N = 551,457	No gestational diabetes diagnosed N = 495,175	Gestational diabetes diagnosed N = 56, 282
Nulliparous	254,588 (46%)	230,370 (47%)	24,218 (43%)
Pre-pregnancy body mass index (kg/m^2)			
<24.9	265,155 (48%)	244,370 (49%)	20,785 (37%)
25.0-29.9	87,533 (16%)	76,192 (15%)	11,341 (20%)
30.0-34.9	34,047 (6%)	28,060 (6%)	5,987 (11%)
>35.0	20,765 (4%)	15,970 (3%)	4,795 (9%)
Missing data	143,957 (26%)	130,583 (26%)	13,374 (24%)
Age of birthing person/mother (years)			
less than 25	73,118 (13%)	70,291 (14%)	2,827 (5%)
25-34	342,918 (62%)	310,705 (63%)	32,213 (57%)
35+	135,421 (25%)	114,179 (23%)	21,242 (38%)
Multifetal pregnancy (v singleton)	8,488 (2%)	7,247 (1%)	1,241 (2%)
Medical/obstetric complications (composite)[b]	39,945 (7%)	34,053 (7%)	5,892 (10%)
Mother's region of birth (infant birth certificate)			
All other regions	373,582 (68%)	346,355 (70%)	27,227 (49%)
Asia or Arabia	127,945 (23%)	103,821 (21%)	24,124 (43%)
Canada or USA (or missing (<0.5%))	47,701 (9%)	42,943 (9%)	4,758 (8%)
Registered Midwife (v other health care provider)	87,951 (16%)	82,120 (17%)	5,831 (10%)
Inadequate prenatal care (APNCU index)	35,524 (6%)	32,485 (7%)	3,039 (5%)
Neighbourhood income per person			
lowest income quintile	116,961 (21%)	103,426 (21%)	13,535 (24%)
mid-low income quintile	115,957 (21%)	102,396 (21%)	13,561 (24%)
middle income quintile	112,081 (20%)	100,630 (20%)	11,451 (20%)
mid-high income quintile	112,230 (20%)	101,960 (21%)	10,270 (18%)
highest income quintile	86,984 (16%)	80,149 (16%)	6,835 (12%)
missing	7,244 (1%)	6,614 (1%)	630 (1%)
Rural or urban local health area			
Urban	533,929 (97%)	478,568 (97%)	55,361 (98%)
Rural	17,528 (3%)	16,607 (3%)	921 (2%)
Year (July-June)			
2005	33,341 (6%)	30,940 (6%)	2,401 (4%)
2006	34,284 (6%)	31,918 (6%)	2,366 (4%)
2007	35,955 (7%)	33,256 (7%)	2,699 (5%)
2008	36,496 (7%)	33,704 (7%)	2,792 (5%)
2009	37,703 (7%)	34,674 (7%)	3,029 (5%)
2010	38,115 (7%)	35,224 (7%)	2,891 (5%)
2011	38,153 (7%)	34,653 (7%)	3,500 (6%)
2012	37,158 (7%)	33,316 (7%)	3,842 (7%)
2013	37,263 (7%)	32,978 (7%)	4,285 (8%)
2014	36,927 (7%)	32,917 (7%)	4,010 (7%)
2015	37,089 (7%)	32,668 (7%)	4,421 (8%)
2016	37,606 (7%)	32,895 (7%)	4,711 (8%)
2017	37,670 (7%)	32,639 (7%)	5,031 (9%)
2018	37,280 (7%)	32,313 (7%)	4,967 (9%)
2019	36,417 (7%)	31,080 (6%)	5,337 (9%)
Gestational diabetes screen completion (v. unscreened)	500,619 (91%)	445,255 (90%)	55,364 (98%)
Screening method			
Two-step	368,178 (67%)	336,723 (68%)	31,455 (56%)
One-step (IADPSG[38] criteria)	132,441 (24%)	108,532 (22%)	23,909 (42%)
Unscreened	50,838 (9%)	49,920 (10%)	918 (2%)
Prior history of GDM			

no	254,034 (46%)	229,879 (46%)	24,155 (43%)
no prior pregnancy in data	281,459 (51%)	258,152 (52%)	23,307 (41%)
yes	15,964 (3%)	7,144 (1%)	8,820 (16%)

a. Gestational diabetes defined from the gestational diabetes diagnosis variable in the BC-PDR (99.9% of cases)[176] with additional cases identified from the discharge summary of the delivery hospitalization data by ICD-10-CA codes (O24.8 – comparable to O24.4 in ICD-10-CM) (47, <0.1% additional cases)

b. Medical/obstetric complications composite[177] based ICD-10-CA codes in the discharge summary of the delivery hospitalization and the BC-PDR. Codes included pregnancy-complicating pre-existing diseases or conditions (O991, O994, O99803/04/09, O266, O981, O984 to 9, O360, O361), pre-existing hypertension (O100 to 4, O109) and from BC-PDR data: prior neonatal anomaly, stillbirth or neonatal death (direct coded variables)

Table C.3 Population characteristics by gestational diabetes diagnosis in BC, Canada from 2005 to 2019 comparing full available study years to excluded groups for different reasons compared to the included cohort

Characteristic	Full population	included	non-standard GDM screen	inactive insurance, out of BC or late PNC	DM or <29 wks
	N = 621,559	N = 551,457	N = 25,573	N = 37,908	N = 6,621
PDR: Nulliparous	287,690 (46%)	254,588 (46%)	8,606 (34%)	21,434 (57%)	3,062 (46%)
Missing	17	14	<5	<5	<5
Pre-pregnancy body mass index (kg/m2)					
<24.9	298,041 (48%)	265,155 (48%)	12,295 (48%)	18,670 (49%)	1,921 (29%)
25.0-29.9	96,799 (16%)	87,533 (16%)	3,666 (14%)	4,447 (12%)	1,153 (17%)
30.0-34.9	37,861 (6%)	34,047 (6%)	1,630 (6%)	1,478 (4%)	706 (11%)
>35.0	23,631 (4%)	20,765 (4%)	1,312 (5%)	804 (2%)	750 (11%)
Missing data	165,227 (27%)	143,957 (26%)	6,670 (26%)	12,509 (33%)	2,091 (32%)
Age of birthing person/mother (years)					
less than 25	87,129 (14%)	73,118 (13%)	4,277 (17%)	9,024 (24%)	710 (11%)
25-34	383,466 (62%)	342,918 (62%)	14,904 (58%)	21,982 (58%)	3,662 (55%)
35+	150,964 (24%)	135,421 (25%)	6,392 (25%)	6,902 (18%)	2,249 (34%)
Planned home birth	20,703 (3%)	15,976 (3%)	3,306 (13%)	1,396 (4%)	25 (0%)
Multifetal pregnancy (v singleton)	9,732 (2%)	8,488 (2%)	321 (1%)	507 (1%)	416 (6%)
Antepartum medical or obstetric risk	45,819 (7%)	39,945 (7%)	2,359 (9%)	2,365 (6%)	1,150 (17%)
Gestational age at delivery					
Median (IQR)	39 (38, 40)	39 (38, 40)	39 (38, 40)	39 (38, 40)	35 (26, 37)
Mean (SD)	38.57 (1.96)	38.64 (1.70)	38.55 (1.87)	38.80 (1.88)	31.71 (6.17)
Missing	<5	<5	<5	<5	<5
Region of birthplace of birthing person/mother					
Canada or USA	416,886 (67%)	373,582 (68%)	20,702 (82%)	18,786 (50%)	3,816 (68%)
Asia or Arabia	145,832 (24%)	127,945 (23%)	2,570 (10%)	13,945 (37%)	1,372 (24%)
All other regions	55,002 (9%)	47,701 (9%)	2,090 (8%)	4,752 (13%)	459 (8%)
Missing	3,839	2,229	211	425	974
Inadequate prenatal care (APNCU)	71,650 (12%)	35,524 (6%)	3,482 (14%)	31,783 (84%)	861 (13%)
Number of antenatal care visits					
Median (IQR)	9.0 (7.0, 11.0)	10.0 (8.0, 11.0)	9.0 (7.0, 12.0)	8.0 (5.0, 10.0)	7.0 (4.0, 10.0)
Mean (SD)	9.4 (3.2)	9.5 (3.1)	9.4 (3.6)	7.8 (3.8)	7.4 (3.8)
Missing	48,975	40,880	1,899	5,113	1,083
1st month of prenatal care visit					
Median (IQR)	2 (1, 3)	2 (1, 3)	2 (1, 3)	7 (5, 9)	2 (1, 3)
Mean (SD)	2.52 (1.63)	2.26 (1.10)	2.42 (1.26)	6.81 (2.67)	2.14 (1.21)
Missing	3,497	<5	<5	3,447	50
Percent of MSP coverage					
Median (IQR)	1.14 (1.12, 1.14)	1.14 (1.12, 1.14)	1.14 (1.12, 1.14)	0.71 (0.38, 1.12)	1.14 (1.14, 1.25)
Mean (SD)	1.11 (0.14)	1.14 (0.02)	1.14 (0.02)	0.69 (0.37)	1.18 (0.05)
Missing	216	<5	<5	216	<5
Total months of MSP					
Median (IQR)	10 (10, 11)	10 (10, 11)	10 (10, 11)	5 (3, 10)	9 (7, 10)
Mean (SD)	9.94 (1.51)	10.23 (0.61)	10.24 (0.61)	5.71 (3.43)	8.73 (1.44)
Missing	<5	<5	<5	<5	<5
Health region of residence					
Interior	89,059 (14%)	79,371 (14%)	3,603 (14%)	5,301 (14%)	784 (12%)
Fraser	246,036 (40%)	223,166 (40%)	7,177 (28%)	12,765 (34%)	2,928 (44%)
Vancouver Coastal	146,154 (24%)	128,719 (23%)	5,356 (21%)	10,725 (28%)	1,354 (20%)
Island	89,965 (14%)	77,566 (14%)	6,693 (26%)	4,697 (12%)	1,009 (15%)
Northern	48,889 (8%)	42,635 (8%)	2,744 (11%)	2,964 (8%)	546 (8%)
Unknown BC	1,075 (0%)	<5	<5	1,075 (3%)	<5

Out of province or out of country	203 (0%)	<5	<5	203 (1%)	<5
Unknown	178 (0%)	<5	<5	178 (0%)	<5
Other regional classification					
Metro Vancouver or Victoria	419,449 (67%)	375,266 (68%)	14,809 (58%)	24,738 (65%)	4,636 (70%)
Northern region	48,889 (8%)	42,635 (8%)	2,744 (11%)	2,964 (8%)	546 (8%)
Other southern areas	62,339 (10%)	54,503 (10%)	3,443 (13%)	3,833 (10%)	560 (8%)
Other southern cities	89,426 (14%)	79,053 (14%)	4,577 (18%)	4,917 (13%)	879 (13%)
Unknown or out of BC	1,456 (0%)	<5	<5	1,456 (4%)	<5
Neighbourhood income per person					
lowest income quintile	135,129 (22%)	116,961 (21%)	5,852 (23%)	10,680 (28%)	1,636 (25%)
mid-low income quintile	130,666 (21%)	115,957 (21%)	5,261 (21%)	7,984 (21%)	1,464 (22%)
middle income quintile	125,204 (20%)	112,081 (20%)	5,072 (20%)	6,712 (18%)	1,339 (20%)
mid-high income quintile	124,376 (20%)	112,230 (20%)	4,961 (19%)	5,957 (16%)	1,228 (19%)
highest income quintile	97,212 (16%)	86,984 (16%)	4,006 (16%)	5,371 (14%)	851 (13%)
missing or NA	8,972 (1%)	7,244 (1%)	421 (2%)	1,204 (3%)	103 (2%)
Region of residence					
Urban	599,751 (97%)	533,929 (97%)	24,398 (95%)	35,006 (96%)	6,418 (97%)
Rural	20,352 (3%)	17,528 (3%)	1,175 (5%)	1,446 (4%)	203 (3%)
Missing	1,456	<5	<5	1,456	<5
Labour type					
induced	136,613 (22%)	121,201 (22%)	4,813 (19%)	8,362 (22%)	2,237 (34%)
none	92,844 (15%)	83,003 (15%)	3,449 (13%)	4,499 (12%)	1,893 (29%)
spontaneous	392,094 (63%)	347,247 (63%)	17,310 (68%)	25,046 (66%)	2,491 (38%)
unknown	<5	<5	<5	<5	<5
Missing	8	6	<5	<5	<5
Mode of delivery					
Cesarean	200,160 (32%)	178,372 (32%)	6,808 (27%)	11,289 (30%)	3,691 (56%)
Vaginal	421,399 (68%)	373,085 (68%)	18,765 (73%)	26,619 (70%)	2,930 (44%)
Small for gestational age (SGA), <10th percentile	43,462 (7%)	37,380 (7%)	1,609 (6%)	3,875 (10%)	598 (9%)
Missing	567	278	19	26	244
Large for gestational age (LGA), >90th percentile	78,772 (13%)	69,725 (13%)	3,716 (15%)	3,482 (9%)	1,849 (29%)
Missing	567	278	19	26	244

Table C.4 Annual gestational diabetes counts and diagnoses (%) in excluded groups and full cohort

Year n (%)	All available births N=61,953 / 621,559	included N=56,282 / 551,457	insurance inactive N=3,118 / 37,908	DM or <28 wks N=209 / 6,621	non-standard GDM screen N=2,344 / 25,573
2005	2,686 (7.0%)	2,401 (7.2%)	154 (5.2%)	6 (2.0%)	125 (8.1%)
2006	2,657 (6.8%)	2,366 (6.9%)	164 (5.9%)	11 (3.2%)	116 (7.4%)
2007	2,963 (7.3%)	2,699 (7.5%)	158 (5.8%)	<5 (<1.0%)	102 (6.6%)
2008	3,131 (7.5%)	2,792 (7.7%)	190 (6.4%)	8 (2.0%)	141 (7.1%)
2009	3,356 (7.9%)	3,029 (8.0%)	161 (6.0%)	8 (2.0%)	158 (8.0%)
2010	3,180 (7.6%)	2,891 (7.6%)	156 (6.9%)	<5 (<0.5%)	131 (10.4%)
2011	3,838 (9.1%)	3,500 (9.2%)	155 (6.7%)	15 (3.6%)	168 (11.6%)
2012	4,235 (10.2%)	3,842 (10.3%)	233 (9.5%)	13 (2.8%)	147 (9.1%)
2013	4,723 (11.3%)	4,285 (11.5%)	230 (9.6%)	16 (3.2%)	192 (10.7%)
2014	4,423 (10.6%)	4,010 (10.9%)	218 (9.1%)	14 (2.8%)	181 (9.1%)
2015	4,859 (11.6%)	4,421 (11.9%)	240 (10.2%)	20 (4.2%)	178 (9.4%)
2016	5,180 (12.1%)	4,711 (12.5%)	276 (10.5%)	18 (3.7%)	175 (8.9%)
2017	5,494 (13.0%)	5,031 (13.4%)	259 (11.0%)	24 (4.6%)	180 (9.7%)
2018	5,391 (13.0%)	4,967 (13.3%)	236 (11.1%)	20 (3.9%)	168 (10.0%)
2019	5,837 (14.3%)	5,337 (14.7%)	288 (11.5%)	30 (6.0%)	182 (12.7%)

Table C.5 Annual gestational diabetes diagnoses in excluded groups and full cohort with 95% confidence intervals

Year n (%)	All available births N=61,953 / 621,559	included N=56,282 / 551,457	insurance inactive N=3,118 / 37,908	DM or <28 wks N=209 / 6,621	non-standard GDM screen N=2,344 / 25,573
2005	7.0% (6.8, 7.3)	7.2% (6.9, 7.5)	5.2% (4.5, 6.1)	2.0% (0.8, 4.5)	8.1% (6.8, 9.6)
2006	6.8% (6.6, 7.1)	6.9% (6.6, 7.2)	5.9% (5.1, 6.9)	3.2% (1.7, 5.8)	7.4% (6.2, 8.9)
2007	7.3% (7.0, 7.6)	7.5% (7.2, 7.8)	5.8% (4.9, 6.7)	1.0% (0.3, 2.8)	6.6% (5.5, 8.0)
2008	7.5% (7.2, 7.7)	7.7% (7.4, 7.9)	6.4% (5.6, 7.4)	2.0% (1.0, 4.1)	7.1% (6.0, 8.3)
2009	7.9% (7.6, 8.1)	8.0% (7.8, 8.3)	6.0% (5.2, 7.0)	2.0% (0.9, 4.1)	8.0% (6.9, 9.3)
2010	7.6% (7.3, 7.8)	7.6% (7.3, 7.9)	6.9% (5.9, 8.0)	0.5% (0.1, 1.8)	10.4% (8.8, 12.2)
2011	9.1% (8.8, 9.3)	9.2% (8.9, 9.5)	6.7% (5.7, 7.8)	3.6% (2.1, 6.0)	11.6% (10.0, 13.3)
2012	10.2% (9.9, 10.5)	10.3% (10.0, 10.7)	9.5% (8.4, 10.8)	2.8% (1.6, 4.9)	9.1% (7.7, 10.6)
2013	11.3% (11.0, 11.6)	11.5% (11.2, 11.8)	9.6% (8.5, 10.9)	3.2% (1.9, 5.3)	10.7% (9.3, 12.2)
2014	10.6% (10.3, 10.9)	10.9% (10.5, 11.2)	9.1% (8.0, 10.3)	2.8% (1.6, 4.8)	9.1% (7.9, 10.5)
2015	11.6% (11.3, 11.9)	11.9% (11.6, 12.3)	10.2% (9.0, 11.5)	4.2% (2.7, 6.5)	9.4% (8.1, 10.8)
2016	12.1% (11.8, 12.4)	12.5% (12.2, 12.9)	10.5% (9.4, 11.7)	3.7% (2.3, 6.0)	8.9% (7.7, 10.2)
2017	13.0% (12.6, 13.3)	13.4% (13.0, 13.7)	11.0% (9.8, 12.3)	4.6% (3.0, 6.8)	9.7% (8.4, 11.2)
2018	13.0% (12.6, 13.3)	13.3% (13.0, 13.7)	11.1% (9.8, 12.5)	3.9% (2.5, 6.1)	10.0% (8.7, 11.6)
2019	14.3% (13.9, 14.6)	14.7% (14.3, 15.0)	11.5% (10.3, 12.8)	6.0% (4.1, 8.5)	12.7% (11.0, 14.5)

Table C.6 Gestational diabetes counts and diagnoses, screening status in excluded groups and full cohort

Characteristic n (%)	Overall N = 621,559	included N = 551,457	non-standard GDM screen N = 25,573	inactive insurance, out of BC or late PNC N = 37,908	DM or <29 wks N = 6,621
Gestational diabetes diagnosis	61,953 (10.0%)	56,282 (10.2%)	2,344 (9.2%)	3,118 (8.2%)	209 (3.2%)
Gestational diabetes diagnosis combined with screening results					
Unscreened	64,597 (10.4%)	49,920 (9.1%)	0 (0.0%)	13,377 (35.3%)	1,300 (19.6%)
GDM NEG: Alt glucose	23,650 (3.8%)	<5	19,384 (75.8%)	1,886 (5.0%)	2,380 (35.9%)
GDM NEG: HbA1c	5,417 (0.9%)	<5	3,845 (15.0%)	309 (0.8%)	1,263 (19.1%)
GDM NEG: HAPO 2.0 (Two-step) or C&C	349,779 (56.3%)	333,803 (60.5%)	<5	15,043 (39.7%)	933 (14.1%)
GDM NEG: HAPO 1.75 (75g only)	116,163 (18.7%)	111,452 (20.2%)	<5	4,175 (11.0%)	536 (8.1%)
GDM POS: HAPO 2.0 (Two-step) or C&C	31,562 (5.1%)	30,199 (5.5%)	<5	1,302 (3.4%)	61 (0.9%)
GDM POS: HAPO 1.75 (75g only)	26,142 (4.2%)	25,165 (4.6%)	<5	895 (2.4%)	82 (1.2%)
GDM POS: Alt glucose	1,960 (0.3%)	<5	1,816 (7.1%)	114 (0.3%)	30 (0.5%)
GDM POS: HbA1c	574 (0.1%)	<5	528 (2.1%)	37 (0.1%)	9 (0.1%)
GDM POS: Unscreened	1,715 (0.3%)	918 (0.2%)	<5	770 (2.0%)	27 (0.4%)

Table C.7 Gestational diabetes counts and diagnoses, screening status in excluded groups and full cohort, rates with 95% CIs

Characteristic n (%)	Overall N = 621,559	included N = 551,457	non-standard GDM screen N = 25,573	inactive insurance, out of BC or late PNC N = 37,908	DM or <29 wks N = 6,621
Gestational diabetes diagnosis	10.0% (9.9, 10.0)	10.2% (10.1, 10.3)	9.2% (8.8, 9.5)	8.2% (8.0, 8.5)	3.2% (2.8, 3.6)
Gestational diabetes diagnosis combined with screening results					
Unscreened	10.4% (10.3, 10.5)	9.1% (9.0, 9.1)	<5	35.3% (34.8, 35.8)	19.6% (18.7, 20.6)
GDM NEG: Alt glucose	3.8% (3.8, 3.9)	<5	75.8% (75.3, 76.3)	5.0% (4.8, 5.2)	35.9% (34.8, 37.1)
GDM NEG: HbA1c	0.9% (0.8, 0.9)	<5	15.0% (14.6, 15.5)	0.8% (0.7, 0.9)	19.1% (18.1, 20.0)
GDM NEG: HAPO 2.0 (Two-step) or C&C	56.3% (56.2, 56.4)	60.5% (60.4, 60.7)	0.0% (0.0, 0.0)	39.7% (39.2, 40.2)	14.1% (13.3, 15.0)
GDM NEG: HAPO 1.75 (75g only)	18.7% (18.6, 18.8)	20.2% (20.1, 20.3)	<5	11.0% (10.7, 11.3)	8.1% (7.5, 8.8)
GDM POS: HAPO 2.0 (Two-step) or C&C	5.1% (5.0, 5.1)	5.5% (5.4, 5.5)	<5	3.4% (3.3, 3.6)	0.9% (0.7, 1.2)
GDM POS: HAPO 1.75 (75g only)	4.2% (4.2, 4.3)	4.6% (4.5, 4.6)	<5	2.4% (2.2, 2.5)	1.2% (1.0, 1.5)
GDM POS: Alt glucose	0.3% (0.3, 0.3)	<5	7.1% (6.8, 7.4)	0.3% (0.2, 0.4)	0.5% (0.3, 0.7)
GDM POS: HbA1c	0.1% (0.1, 0.1)	<5	2.1% (1.9, 2.2)	0.1% (0.1, 0.1)	0.1% (0.1, 0.3)
GDM POS: Unscreened	0.3% (0.3, 0.3)	0.2% (0.2, 0.2)	<5	2.0% (1.9, 2.2)	0.4% (0.3, 0.6)

C.3 Figures

Figure C.1 Study population flow chart and exclusions

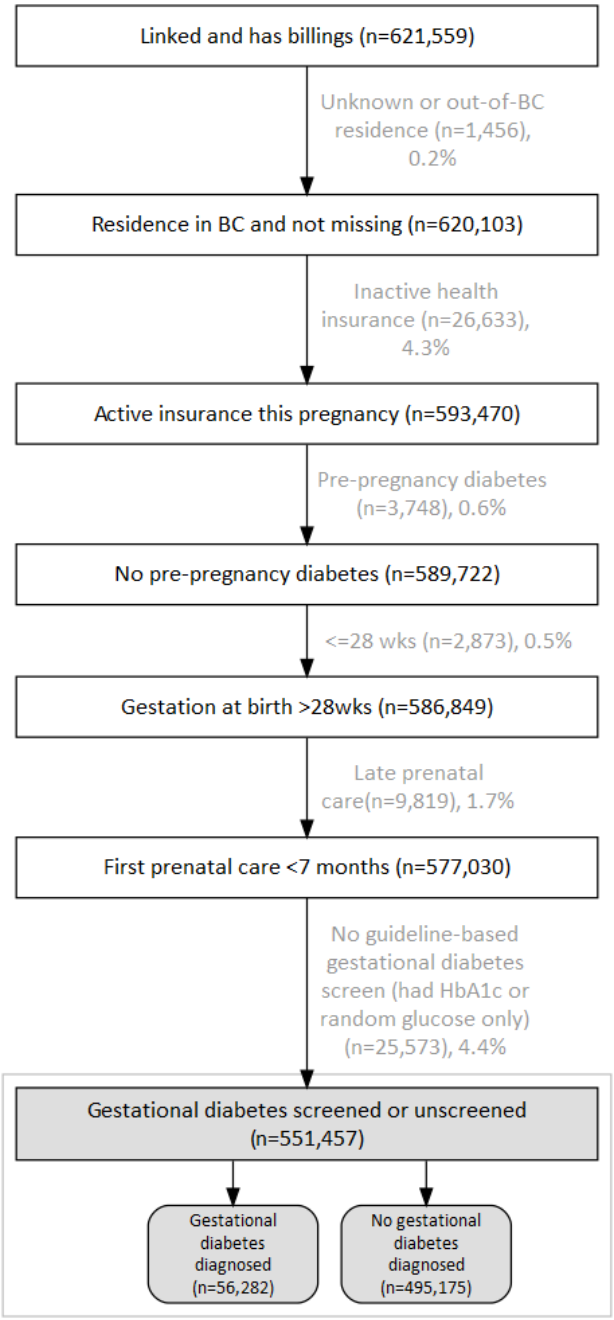


Figure C.2 Gestational diabetes screening and diagnosis rates with two-step by C-C and DC-2013 criteria

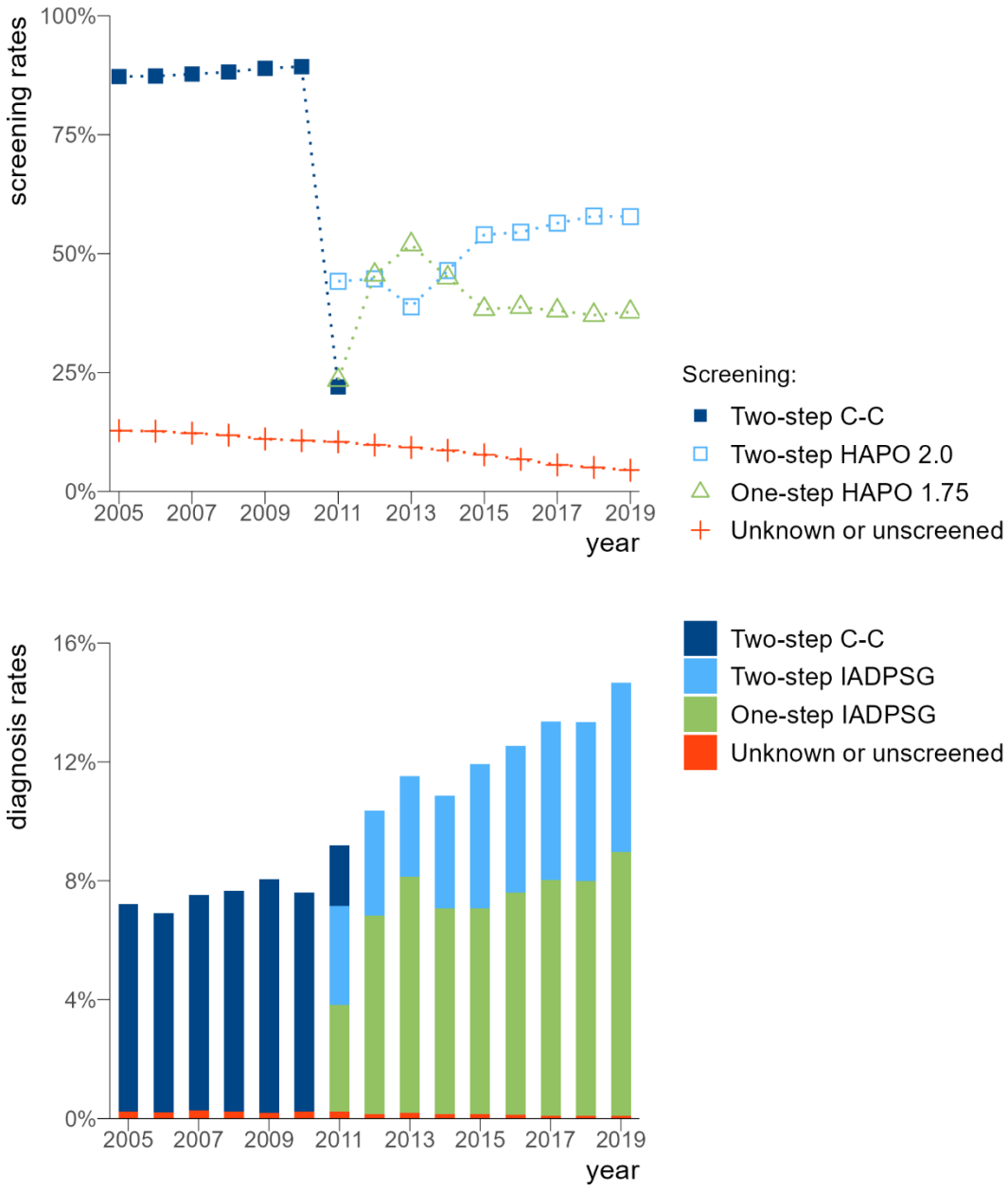


Figure C.3 Gestational diabetes rates modeled with addition of prior history of gestational diabetes (sensitivity analysis)

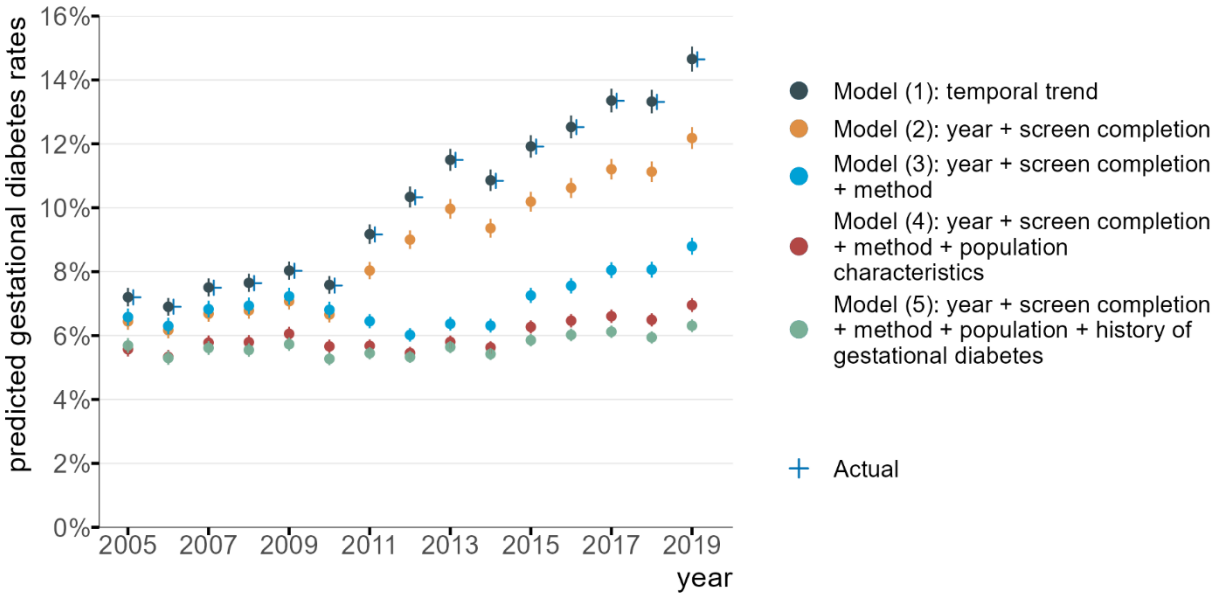


Figure C.4 Models with covariates added in reverse order

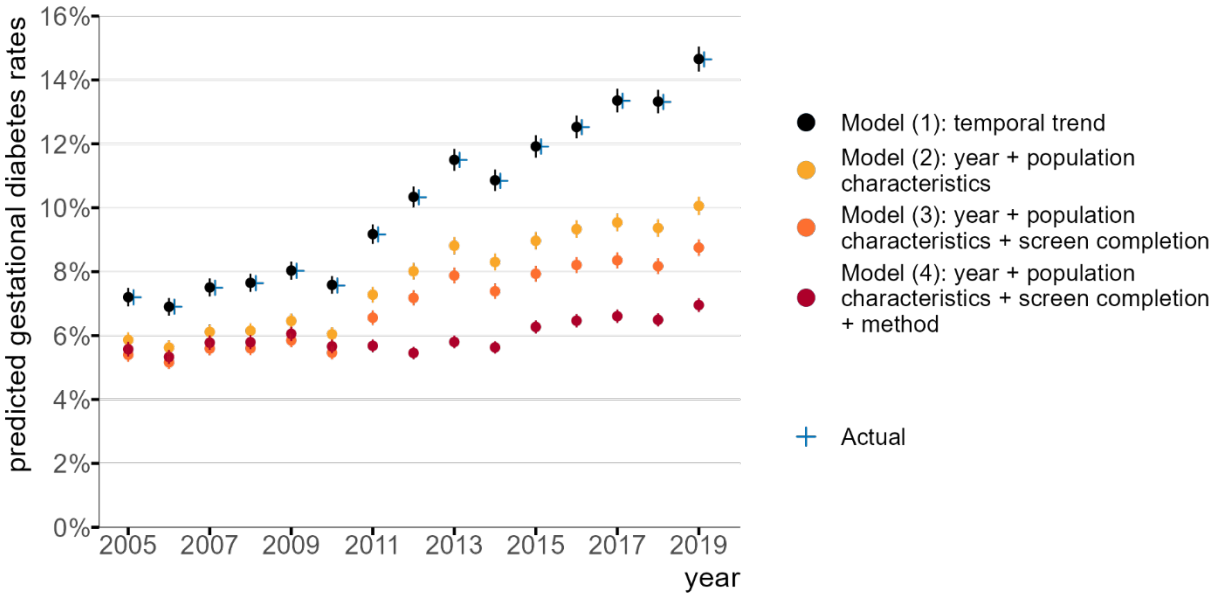
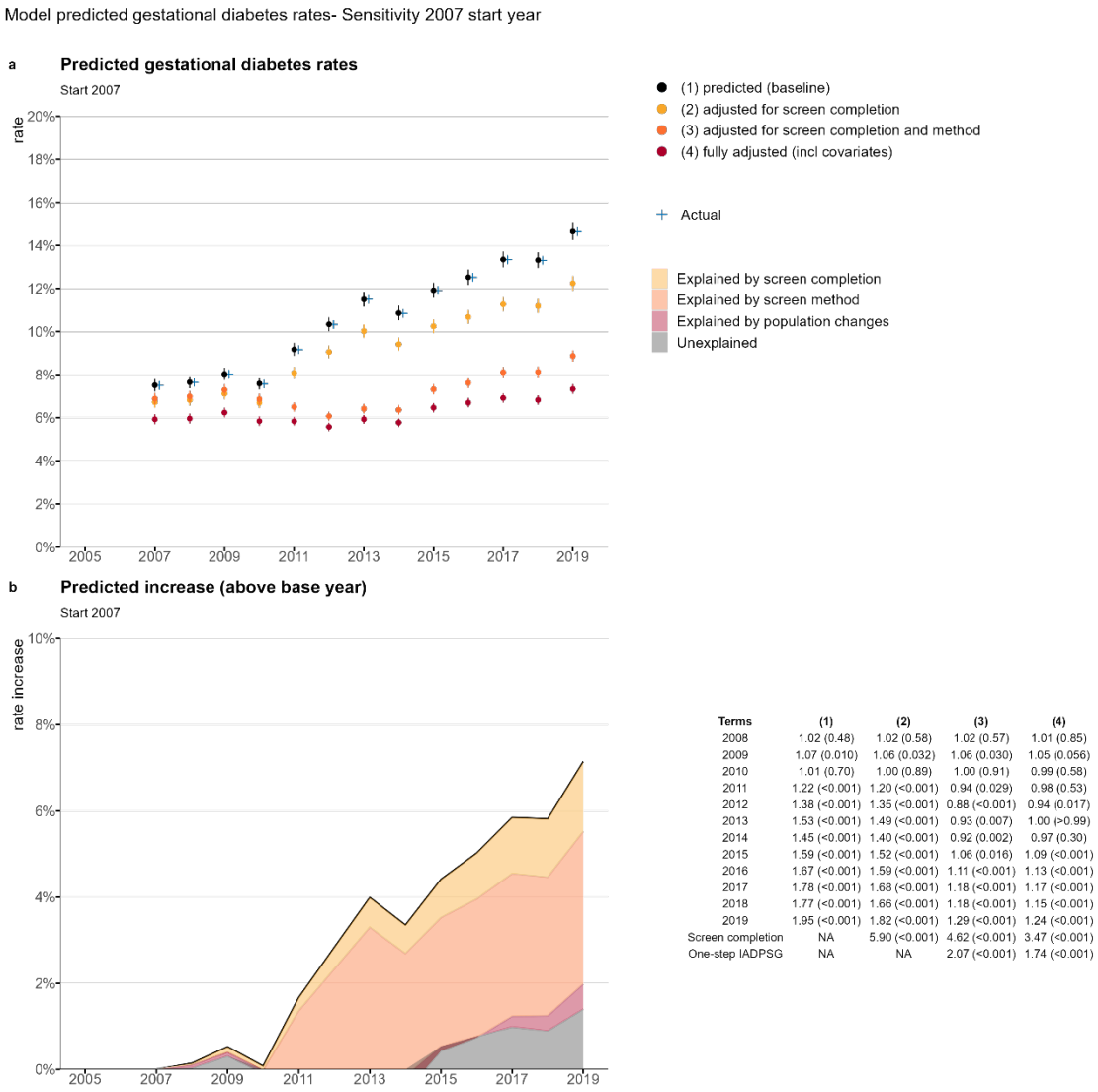
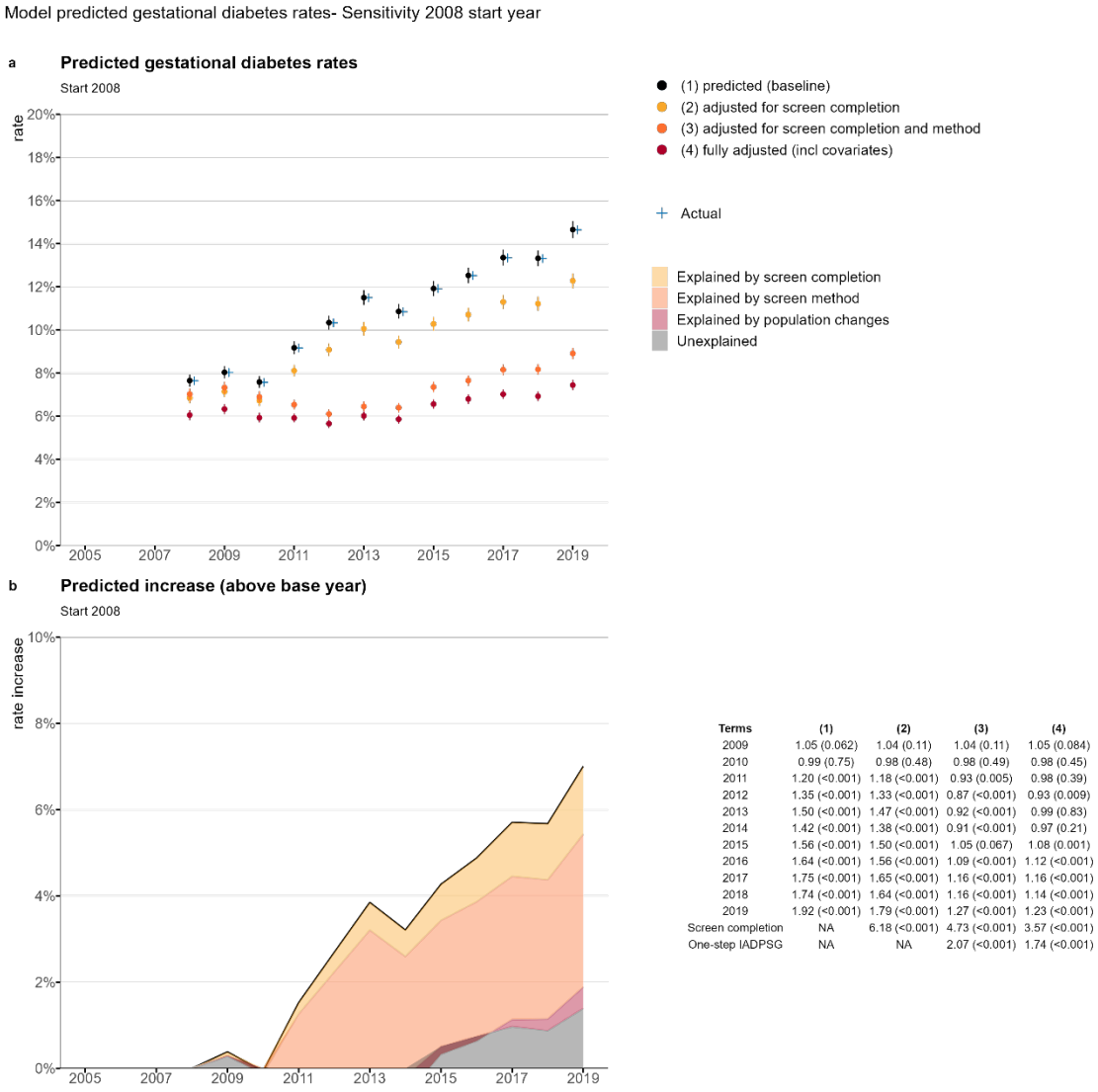


Figure C.5 Sensitivity analyses 2007 start year



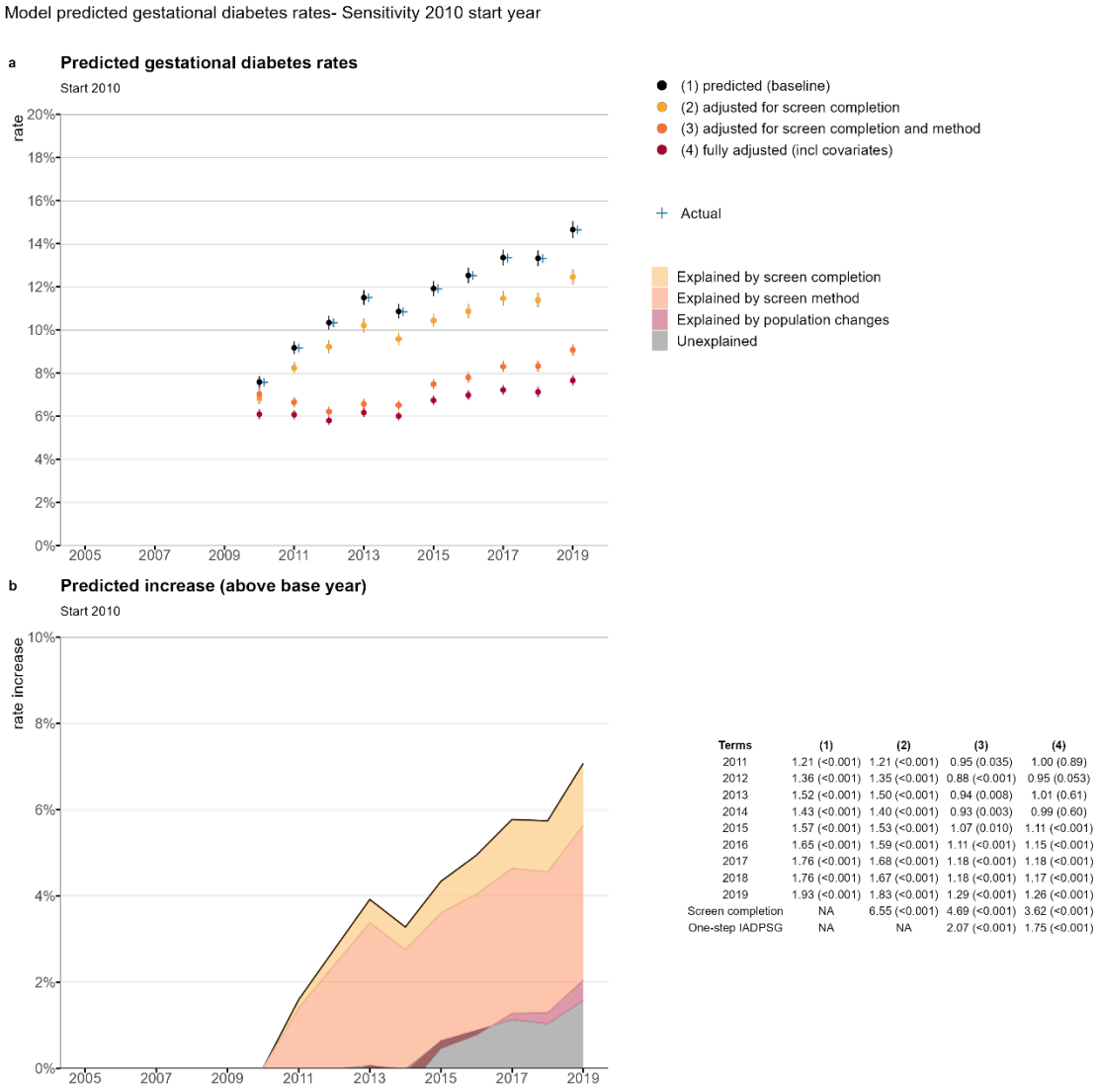
Terms	(1)	(2)	(3)	(4)
2008	1.02 (0.48)	1.02 (0.58)	1.02 (0.57)	1.01 (0.85)
2009	1.07 (0.010)	1.06 (0.032)	1.06 (0.030)	1.05 (0.056)
2010	1.01 (0.70)	1.00 (0.89)	1.00 (0.91)	0.99 (0.58)
2011	1.22 (<0.001)	1.20 (<0.001)	0.94 (0.029)	0.98 (0.53)
2012	1.38 (<0.001)	1.35 (<0.001)	0.88 (<0.001)	0.94 (0.017)
2013	1.53 (<0.001)	1.49 (<0.001)	0.93 (0.007)	1.00 (>0.99)
2014	1.45 (<0.001)	1.40 (<0.001)	0.92 (0.002)	0.97 (0.30)
2015	1.59 (<0.001)	1.52 (<0.001)	1.06 (0.016)	1.09 (<0.001)
2016	1.67 (<0.001)	1.59 (<0.001)	1.11 (<0.001)	1.13 (<0.001)
2017	1.78 (<0.001)	1.68 (<0.001)	1.18 (<0.001)	1.17 (<0.001)
2018	1.77 (<0.001)	1.66 (<0.001)	1.18 (<0.001)	1.15 (<0.001)
2019	1.95 (<0.001)	1.82 (<0.001)	1.29 (<0.001)	1.24 (<0.001)
Screen completion	NA	5.90 (<0.001)	4.62 (<0.001)	3.47 (<0.001)
One-step IADPSG	NA	NA	2.07 (<0.001)	1.74 (<0.001)

Figure C.6 Sensitivity analyses 2008 start year



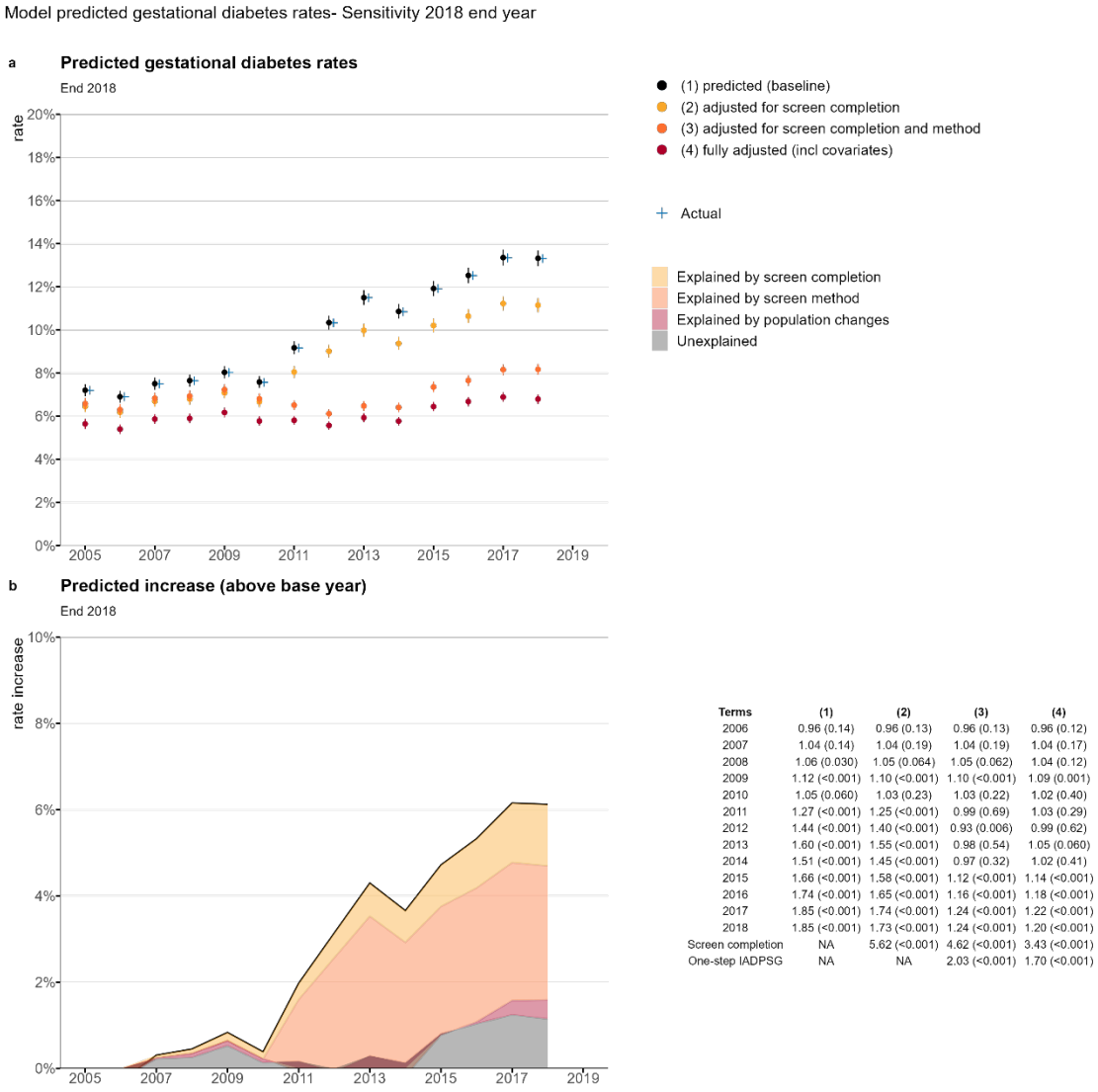
Terms	(1)	(2)	(3)	(4)
2009	1.05 (0.062)	1.04 (0.11)	1.04 (0.11)	1.05 (0.084)
2010	0.99 (0.75)	0.98 (0.48)	0.98 (0.49)	0.98 (0.45)
2011	1.20 (<0.001)	1.18 (<0.001)	0.93 (0.005)	0.98 (0.39)
2012	1.35 (<0.001)	1.33 (<0.001)	0.87 (<0.001)	0.93 (0.009)
2013	1.50 (<0.001)	1.47 (<0.001)	0.92 (<0.001)	0.99 (0.83)
2014	1.42 (<0.001)	1.38 (<0.001)	0.91 (<0.001)	0.97 (0.21)
2015	1.56 (<0.001)	1.50 (<0.001)	1.05 (0.067)	1.08 (0.001)
2016	1.64 (<0.001)	1.56 (<0.001)	1.09 (<0.001)	1.12 (<0.001)
2017	1.75 (<0.001)	1.65 (<0.001)	1.16 (<0.001)	1.16 (<0.001)
2018	1.74 (<0.001)	1.64 (<0.001)	1.16 (<0.001)	1.14 (<0.001)
2019	1.92 (<0.001)	1.79 (<0.001)	1.27 (<0.001)	1.23 (<0.001)
Screen completion	NA	6.18 (<0.001)	4.73 (<0.001)	3.57 (<0.001)
One-step IADPSG	NA	NA	2.07 (<0.001)	1.74 (<0.001)

Figure C.7 Sensitivity analyses 2010 start year



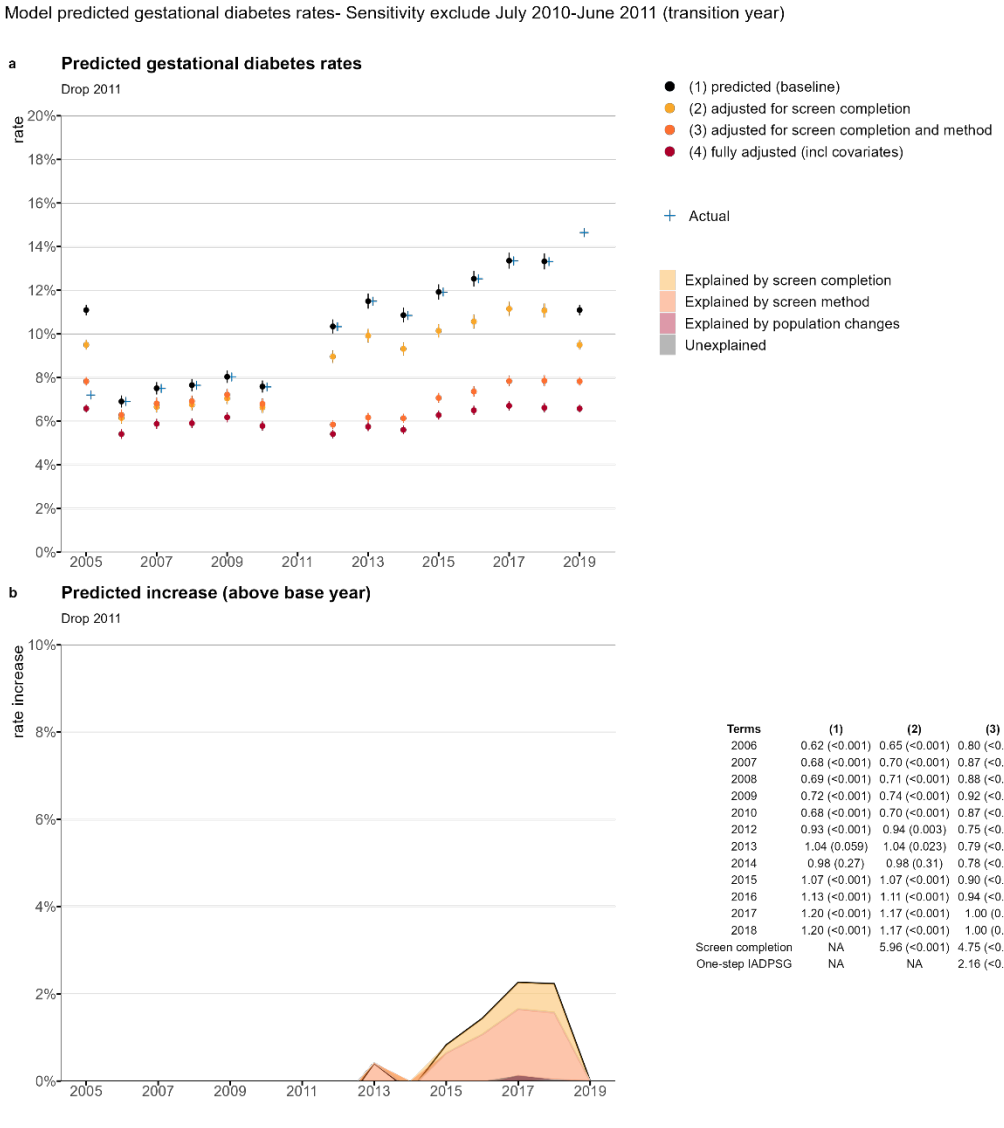
Terms	(1)	(2)	(3)	(4)
2011	1.21 (<0.001)	1.21 (<0.001)	0.95 (0.035)	1.00 (0.89)
2012	1.36 (<0.001)	1.35 (<0.001)	0.88 (<0.001)	0.95 (0.053)
2013	1.52 (<0.001)	1.50 (<0.001)	0.94 (0.008)	1.01 (0.61)
2014	1.43 (<0.001)	1.40 (<0.001)	0.93 (0.003)	0.99 (0.60)
2015	1.57 (<0.001)	1.53 (<0.001)	1.07 (0.010)	1.11 (<0.001)
2016	1.65 (<0.001)	1.59 (<0.001)	1.11 (<0.001)	1.15 (<0.001)
2017	1.76 (<0.001)	1.68 (<0.001)	1.18 (<0.001)	1.18 (<0.001)
2018	1.76 (<0.001)	1.67 (<0.001)	1.18 (<0.001)	1.17 (<0.001)
2019	1.93 (<0.001)	1.83 (<0.001)	1.29 (<0.001)	1.26 (<0.001)
Screen completion	NA	6.55 (<0.001)	4.69 (<0.001)	3.62 (<0.001)
One-step IADPSG	NA	NA	2.07 (<0.001)	1.75 (<0.001)

Figure C.8 Sensitivity analyses 2018 end year



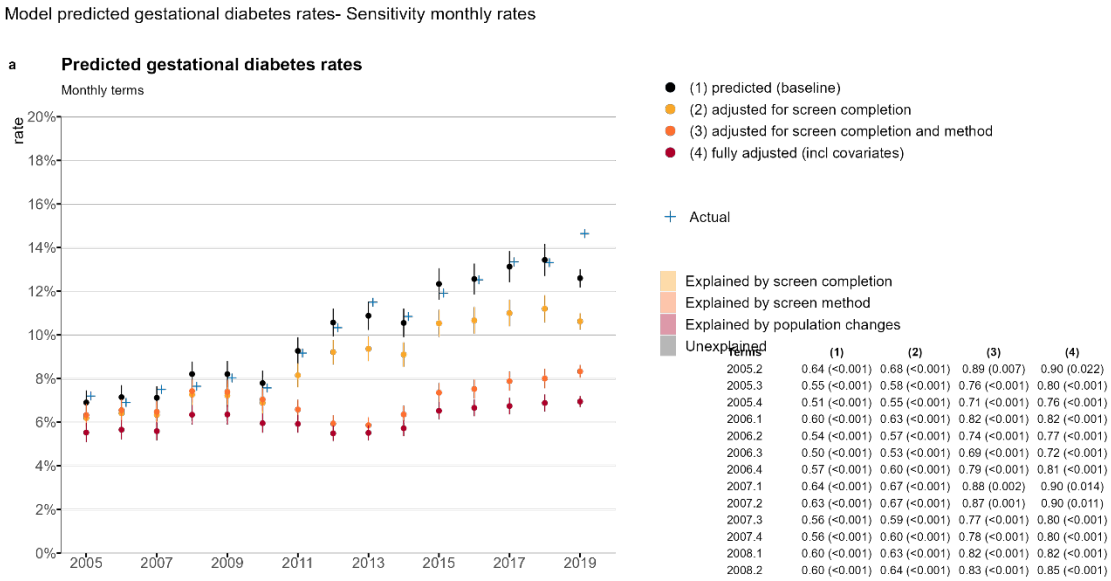
Terms	(1)	(2)	(3)	(4)
2006	0.96 (0.14)	0.96 (0.13)	0.96 (0.13)	0.96 (0.12)
2007	1.04 (0.14)	1.04 (0.19)	1.04 (0.19)	1.04 (0.17)
2008	1.06 (0.030)	1.05 (0.064)	1.05 (0.062)	1.04 (0.12)
2009	1.12 (<0.001)	1.10 (<0.001)	1.10 (<0.001)	1.09 (0.001)
2010	1.05 (0.060)	1.03 (0.23)	1.03 (0.22)	1.02 (0.40)
2011	1.27 (<0.001)	1.25 (<0.001)	0.99 (0.69)	1.03 (0.29)
2012	1.44 (<0.001)	1.40 (<0.001)	0.93 (0.006)	0.99 (0.62)
2013	1.60 (<0.001)	1.55 (<0.001)	0.98 (0.54)	1.05 (0.060)
2014	1.51 (<0.001)	1.45 (<0.001)	0.97 (0.32)	1.02 (0.41)
2015	1.66 (<0.001)	1.58 (<0.001)	1.12 (<0.001)	1.14 (<0.001)
2016	1.74 (<0.001)	1.65 (<0.001)	1.16 (<0.001)	1.18 (<0.001)
2017	1.85 (<0.001)	1.74 (<0.001)	1.24 (<0.001)	1.22 (<0.001)
2018	1.85 (<0.001)	1.73 (<0.001)	1.24 (<0.001)	1.20 (<0.001)
Screen completion	NA	5.62 (<0.001)	4.62 (<0.001)	3.43 (<0.001)
One-step IADPSG	NA	NA	2.03 (<0.001)	1.70 (<0.001)

Figure C.9 Sensitivity analyses exclude 2011 (transition year)



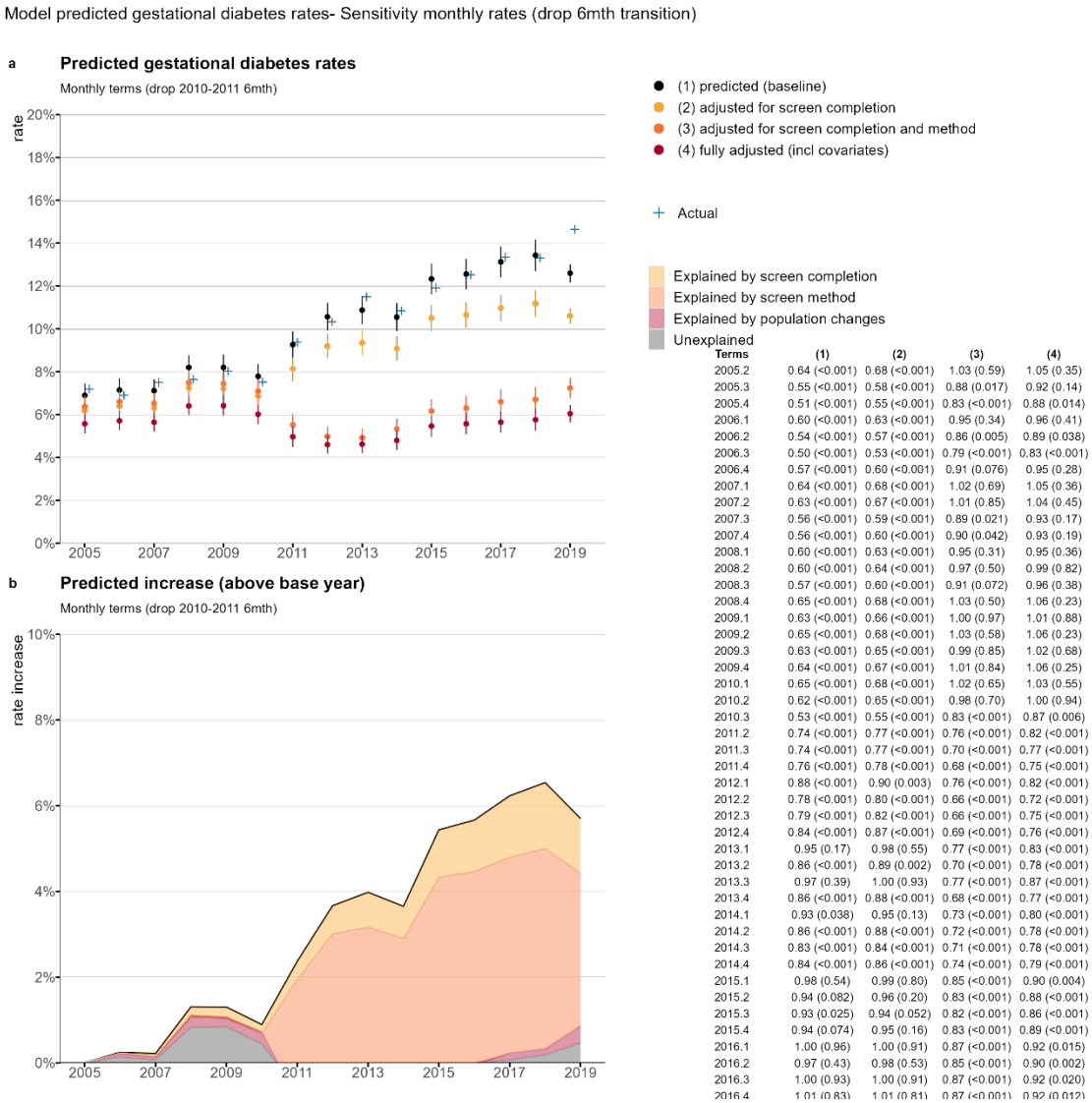
Terms	(1)	(2)	(3)	(4)
2006	0.62 (<0.001)	0.65 (<0.001)	0.80 (<0.001)	0.82 (<0.001)
2007	0.68 (<0.001)	0.70 (<0.001)	0.87 (<0.001)	0.89 (<0.001)
2008	0.69 (<0.001)	0.71 (<0.001)	0.88 (<0.001)	0.90 (<0.001)
2009	0.72 (<0.001)	0.74 (<0.001)	0.92 (<0.001)	0.94 (0.004)
2010	0.68 (<0.001)	0.70 (<0.001)	0.87 (<0.001)	0.88 (<0.001)
2012	0.93 (<0.001)	0.94 (0.003)	0.75 (<0.001)	0.82 (<0.001)
2013	1.04 (0.059)	1.04 (0.023)	0.79 (<0.001)	0.87 (<0.001)
2014	0.98 (0.27)	0.98 (0.31)	0.78 (<0.001)	0.85 (<0.001)
2015	1.07 (<0.001)	1.07 (<0.001)	0.90 (<0.001)	0.95 (0.013)
2016	1.13 (<0.001)	1.11 (<0.001)	0.94 (<0.001)	0.99 (0.50)
2017	1.20 (<0.001)	1.17 (<0.001)	1.00 (0.93)	1.02 (0.30)
2018	1.20 (<0.001)	1.17 (<0.001)	1.00 (0.83)	1.01 (0.77)
Screen completion	NA	5.96 (<0.001)	4.75 (<0.001)	3.57 (<0.001)
One-step IADPSG	NA	NA	2.16 (<0.001)	1.78 (<0.001)

Figure C.10 Sensitivity analyses use monthly rates instead of year



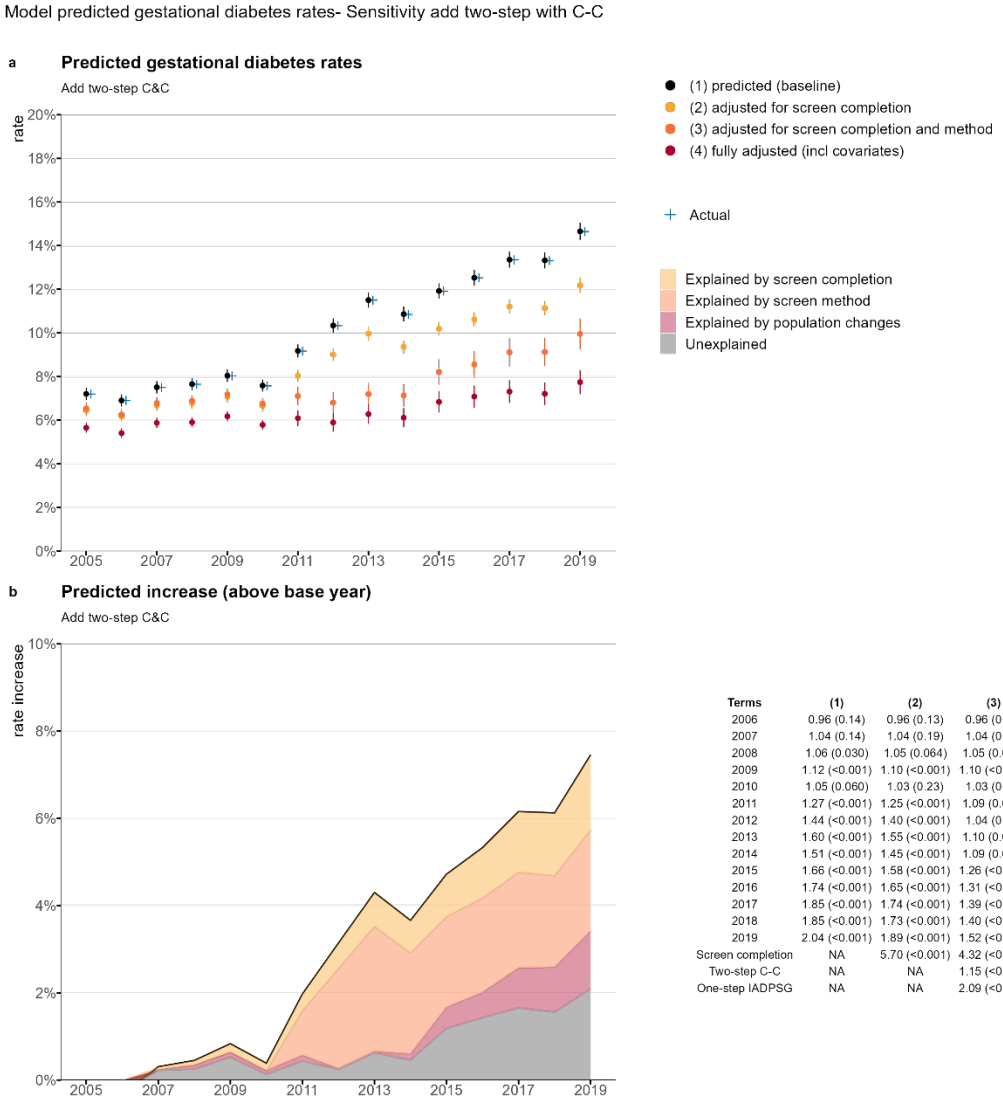
Terms	(1)	(2)	(3)	(4)
2005.2	0.64 (<0.001)	0.68 (<0.001)	0.89 (0.007)	0.90 (0.022)
2005.3	0.55 (<0.001)	0.58 (<0.001)	0.76 (<0.001)	0.80 (<0.001)
2005.4	0.51 (<0.001)	0.55 (<0.001)	0.71 (<0.001)	0.76 (<0.001)
2006.1	0.60 (<0.001)	0.63 (<0.001)	0.82 (<0.001)	0.82 (<0.001)
2006.2	0.54 (<0.001)	0.57 (<0.001)	0.74 (<0.001)	0.77 (<0.001)
2006.3	0.50 (<0.001)	0.53 (<0.001)	0.69 (<0.001)	0.72 (<0.001)
2006.4	0.57 (<0.001)	0.60 (<0.001)	0.79 (<0.001)	0.81 (<0.001)
2007.1	0.64 (<0.001)	0.67 (<0.001)	0.88 (0.002)	0.90 (0.014)
2007.2	0.63 (<0.001)	0.67 (<0.001)	0.87 (0.001)	0.90 (0.011)
2007.3	0.56 (<0.001)	0.59 (<0.001)	0.77 (<0.001)	0.80 (<0.001)
2007.4	0.56 (<0.001)	0.60 (<0.001)	0.78 (<0.001)	0.80 (<0.001)
2008.1	0.60 (<0.001)	0.63 (<0.001)	0.82 (<0.001)	0.82 (<0.001)
2008.2	0.60 (<0.001)	0.64 (<0.001)	0.83 (<0.001)	0.85 (<0.001)
2008.3	0.57 (<0.001)	0.60 (<0.001)	0.79 (<0.001)	0.82 (<0.001)
2008.4	0.65 (<0.001)	0.68 (<0.001)	0.89 (0.004)	0.91 (0.022)
2009.1	0.63 (<0.001)	0.66 (<0.001)	0.86 (<0.001)	0.87 (<0.001)
2009.2	0.65 (<0.001)	0.68 (<0.001)	0.89 (0.004)	0.91 (0.031)
2009.3	0.63 (<0.001)	0.65 (<0.001)	0.85 (<0.001)	0.88 (0.001)
2009.4	0.64 (<0.001)	0.67 (<0.001)	0.87 (<0.001)	0.91 (0.017)
2010.1	0.65 (<0.001)	0.68 (<0.001)	0.88 (0.002)	0.89 (0.003)
2010.2	0.62 (<0.001)	0.65 (<0.001)	0.85 (<0.001)	0.86 (<0.001)
2010.3	0.53 (<0.001)	0.55 (<0.001)	0.72 (<0.001)	0.75 (<0.001)
2010.4	0.61 (<0.001)	0.64 (<0.001)	0.83 (<0.001)	0.85 (<0.001)
2011.1	0.68 (<0.001)	0.70 (<0.001)	0.91 (0.020)	0.92 (0.037)
2011.2	0.74 (<0.001)	0.77 (<0.001)	0.79 (<0.001)	0.85 (<0.001)
2011.3	0.74 (<0.001)	0.77 (<0.001)	0.73 (<0.001)	0.80 (<0.001)
2011.4	0.76 (<0.001)	0.78 (<0.001)	0.70 (<0.001)	0.78 (<0.001)
2012.1	0.88 (<0.001)	0.90 (0.003)	0.79 (<0.001)	0.85 (<0.001)
2012.2	0.78 (<0.001)	0.80 (<0.001)	0.68 (<0.001)	0.75 (<0.001)
2012.3	0.79 (<0.001)	0.82 (<0.001)	0.68 (<0.001)	0.77 (<0.001)
2012.4	0.84 (<0.001)	0.87 (<0.001)	0.71 (<0.001)	0.79 (<0.001)
2013.1	0.95 (0.17)	0.98 (0.55)	0.80 (<0.001)	0.86 (<0.001)
2013.2	0.86 (<0.001)	0.89 (0.002)	0.73 (<0.001)	0.81 (<0.001)
2013.3	0.97 (0.39)	1.00 (0.93)	0.80 (<0.001)	0.91 (0.004)
2013.4	0.86 (<0.001)	0.88 (<0.001)	0.70 (<0.001)	0.79 (<0.001)
2014.1	0.93 (0.038)	0.95 (0.13)	0.76 (<0.001)	0.83 (<0.001)
2014.2	0.86 (<0.001)	0.88 (<0.001)	0.74 (<0.001)	0.81 (<0.001)
2014.3	0.83 (<0.001)	0.84 (<0.001)	0.74 (<0.001)	0.81 (<0.001)
2014.4	0.84 (<0.001)	0.86 (<0.001)	0.76 (<0.001)	0.82 (<0.001)
2015.1	0.98 (0.54)	0.99 (0.80)	0.88 (<0.001)	0.94 (0.068)
2015.2	0.94 (0.082)	0.96 (0.20)	0.86 (<0.001)	0.92 (0.012)
2015.3	0.93 (0.025)	0.94 (0.052)	0.85 (<0.001)	0.90 (0.001)
2015.4	0.94 (0.074)	0.95 (0.16)	0.86 (<0.001)	0.92 (0.017)
2016.1	1.00 (0.96)	1.00 (0.91)	0.91 (0.004)	0.95 (0.17)
2016.2	0.97 (0.43)	0.98 (0.53)	0.88 (<0.001)	0.93 (0.044)

Figure C.11 Sensitivity analyses use monthly rates excluding transition period where methods changed



Terms	(1)	(2)	(3)	(4)
2005.2	0.64 (<0.001)	0.68 (<0.001)	1.03 (0.59)	1.05 (0.35)
2005.3	0.55 (<0.001)	0.58 (<0.001)	0.88 (0.017)	0.92 (0.14)
2005.4	0.51 (<0.001)	0.55 (<0.001)	0.83 (<0.001)	0.88 (0.014)
2006.1	0.60 (<0.001)	0.63 (<0.001)	0.95 (0.34)	0.96 (0.41)
2006.2	0.54 (<0.001)	0.57 (<0.001)	0.86 (0.005)	0.89 (0.038)
2006.3	0.50 (<0.001)	0.53 (<0.001)	0.79 (<0.001)	0.83 (<0.001)
2006.4	0.57 (<0.001)	0.60 (<0.001)	0.91 (0.076)	0.95 (0.28)
2007.1	0.64 (<0.001)	0.68 (<0.001)	1.02 (0.69)	1.05 (0.36)
2007.2	0.63 (<0.001)	0.67 (<0.001)	1.01 (0.85)	1.04 (0.45)
2007.3	0.56 (<0.001)	0.59 (<0.001)	0.89 (0.021)	0.93 (0.17)
2007.4	0.56 (<0.001)	0.60 (<0.001)	0.90 (0.042)	0.93 (0.19)
2008.1	0.60 (<0.001)	0.63 (<0.001)	0.95 (0.31)	0.95 (0.36)
2008.2	0.60 (<0.001)	0.64 (<0.001)	0.97 (0.50)	0.99 (0.82)
2008.3	0.57 (<0.001)	0.60 (<0.001)	0.91 (0.072)	0.96 (0.38)
2008.4	0.65 (<0.001)	0.68 (<0.001)	1.03 (0.50)	1.06 (0.23)
2009.1	0.63 (<0.001)	0.66 (<0.001)	1.00 (0.97)	1.01 (0.88)
2009.2	0.65 (<0.001)	0.68 (<0.001)	1.03 (0.58)	1.06 (0.23)
2009.3	0.63 (<0.001)	0.65 (<0.001)	0.99 (0.85)	1.02 (0.68)
2009.4	0.64 (<0.001)	0.67 (<0.001)	1.01 (0.84)	1.06 (0.25)
2010.1	0.65 (<0.001)	0.68 (<0.001)	1.02 (0.65)	1.03 (0.55)
2010.2	0.62 (<0.001)	0.65 (<0.001)	0.98 (0.70)	1.00 (0.94)
2010.3	0.53 (<0.001)	0.55 (<0.001)	0.83 (<0.001)	0.87 (0.006)
2011.2	0.74 (<0.001)	0.77 (<0.001)	0.76 (<0.001)	0.82 (<0.001)
2011.3	0.74 (<0.001)	0.77 (<0.001)	0.70 (<0.001)	0.77 (<0.001)
2011.4	0.76 (<0.001)	0.78 (<0.001)	0.68 (<0.001)	0.75 (<0.001)
2012.1	0.88 (<0.001)	0.90 (0.003)	0.76 (<0.001)	0.82 (<0.001)
2012.2	0.78 (<0.001)	0.80 (<0.001)	0.66 (<0.001)	0.72 (<0.001)
2012.3	0.79 (<0.001)	0.82 (<0.001)	0.66 (<0.001)	0.75 (<0.001)
2012.4	0.84 (<0.001)	0.87 (<0.001)	0.69 (<0.001)	0.76 (<0.001)
2013.1	0.95 (0.17)	0.98 (0.55)	0.77 (<0.001)	0.83 (<0.001)
2013.2	0.86 (<0.001)	0.89 (0.002)	0.70 (<0.001)	0.78 (<0.001)
2013.3	0.97 (0.39)	1.00 (0.93)	0.77 (<0.001)	0.87 (<0.001)
2013.4	0.86 (<0.001)	0.88 (<0.001)	0.68 (<0.001)	0.77 (<0.001)
2014.1	0.93 (0.038)	0.95 (0.13)	0.73 (<0.001)	0.80 (<0.001)
2014.2	0.86 (<0.001)	0.88 (<0.001)	0.72 (<0.001)	0.78 (<0.001)
2014.3	0.83 (<0.001)	0.84 (<0.001)	0.71 (<0.001)	0.78 (<0.001)
2014.4	0.84 (<0.001)	0.86 (<0.001)	0.74 (<0.001)	0.79 (<0.001)
2015.1	0.98 (0.54)	0.99 (0.80)	0.85 (<0.001)	0.90 (0.004)
2015.2	0.94 (0.082)	0.96 (0.20)	0.83 (<0.001)	0.88 (<0.001)
2015.3	0.93 (0.025)	0.94 (0.052)	0.82 (<0.001)	0.86 (<0.001)
2015.4	0.94 (0.074)	0.95 (0.16)	0.83 (<0.001)	0.89 (<0.001)
2016.1	1.00 (0.96)	1.00 (0.91)	0.87 (<0.001)	0.92 (0.015)
2016.2	0.97 (0.43)	0.98 (0.53)	0.85 (<0.001)	0.90 (0.002)
2016.3	1.00 (0.93)	1.00 (0.91)	0.87 (<0.001)	0.92 (0.020)
2016.4	1.01 (0.83)	1.01 (0.81)	0.87 (<0.001)	0.92 (0.012)

Figure C.12 Sensitivity analyses use two variables for two-step screening to account for change in diagnostic criteria after IADPSG adopted in 2010 (change from C-C to DC-2013 for two-step)



Terms	(1)	(2)	(3)	(4)
2006	0.96 (0.14)	0.96 (0.13)	0.96 (0.13)	0.96 (0.12)
2007	1.04 (0.14)	1.04 (0.19)	1.04 (0.19)	1.04 (0.17)
2008	1.06 (0.030)	1.05 (0.064)	1.05 (0.062)	1.04 (0.12)
2009	1.12 (<0.001)	1.10 (<0.001)	1.10 (<0.001)	1.09 (0.001)
2010	1.05 (0.060)	1.03 (0.23)	1.03 (0.22)	1.02 (0.41)
2011	1.27 (<0.001)	1.25 (<0.001)	1.09 (0.028)	1.08 (0.051)
2012	1.44 (<0.001)	1.40 (<0.001)	1.04 (0.35)	1.04 (0.33)
2013	1.60 (<0.001)	1.55 (<0.001)	1.10 (0.026)	1.11 (0.015)
2014	1.51 (<0.001)	1.45 (<0.001)	1.09 (0.043)	1.08 (0.073)
2015	1.66 (<0.001)	1.58 (<0.001)	1.26 (<0.001)	1.21 (<0.001)
2016	1.74 (<0.001)	1.65 (<0.001)	1.31 (<0.001)	1.25 (<0.001)
2017	1.85 (<0.001)	1.74 (<0.001)	1.39 (<0.001)	1.29 (<0.001)
2018	1.85 (<0.001)	1.73 (<0.001)	1.40 (<0.001)	1.28 (<0.001)
2019	2.04 (<0.001)	1.89 (<0.001)	1.52 (<0.001)	1.37 (<0.001)
Screen completion	NA	5.70 (<0.001)	4.32 (<0.001)	3.34 (<0.001)
Two-step C-C	NA	NA	1.15 (<0.001)	1.07 (0.057)
One-step IADPSG	NA	NA	2.09 (<0.001)	1.74 (<0.001)

Figure C.13 Sensitivity analyses GDM screening rates in health regions over time

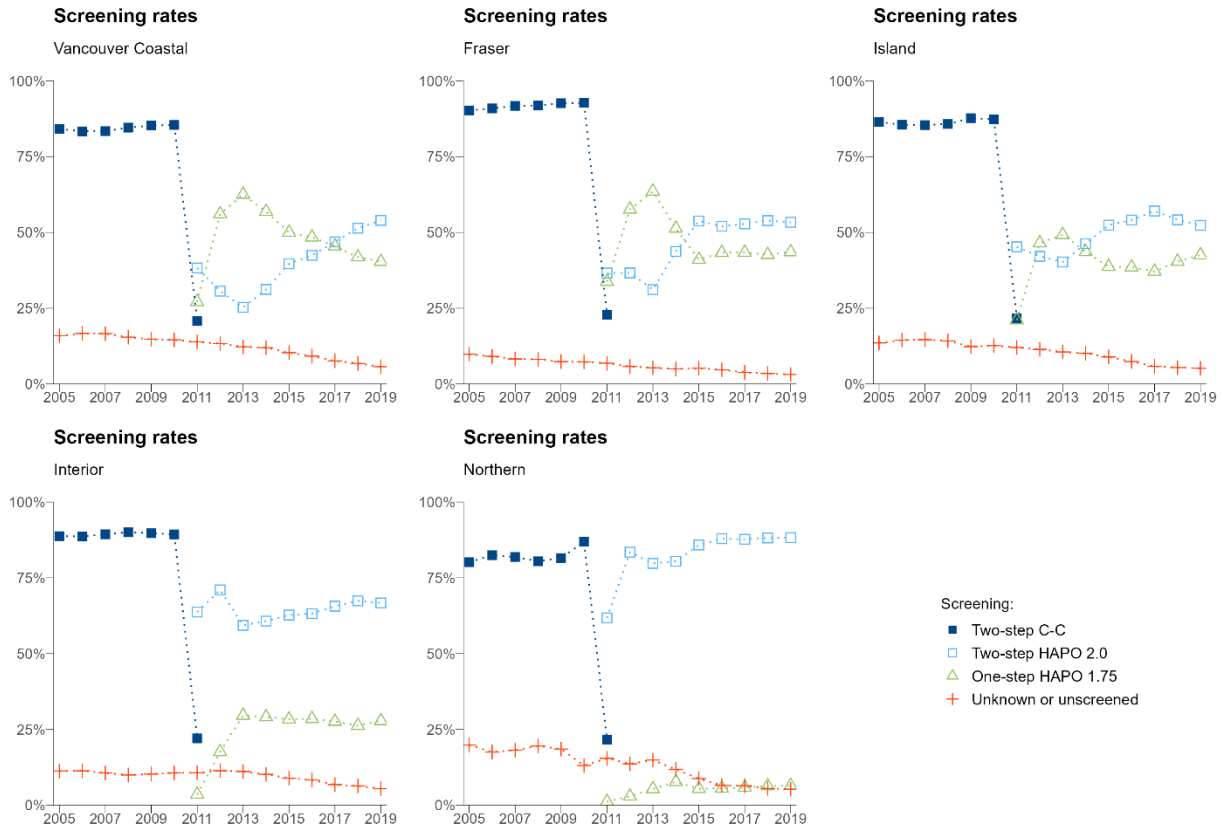


Figure C.14 Sensitivity analyses GDM diagnosis risk in health regions over time

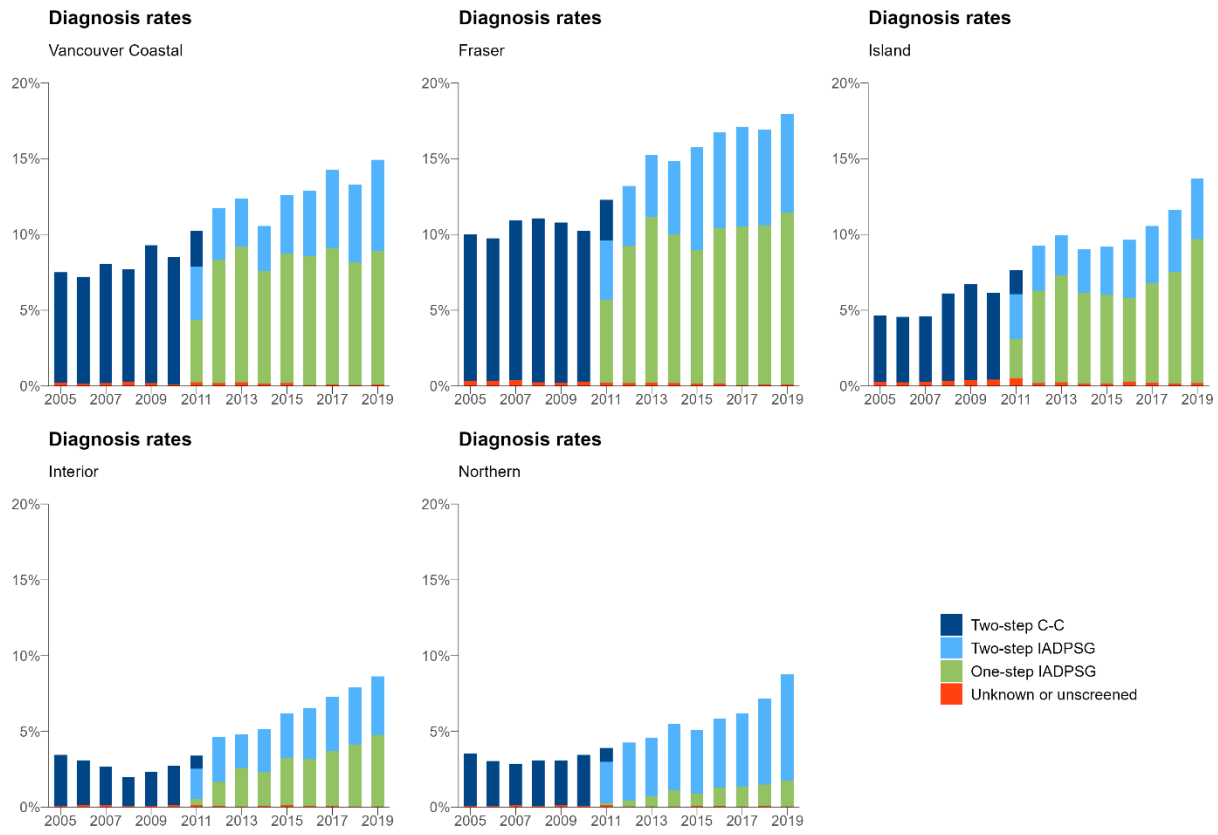


Figure C.15 Predicted risk of GDM diagnosis by year (modeled) in stratified analyses by health region

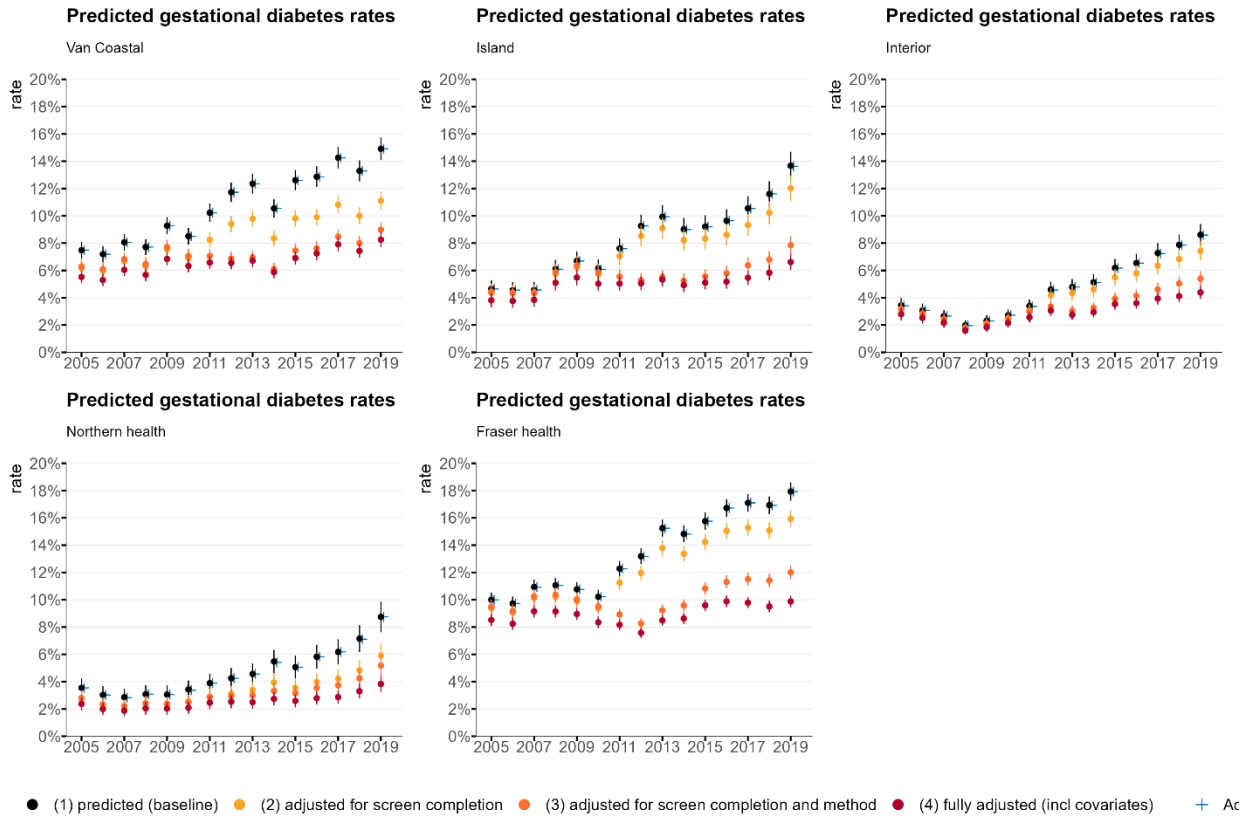
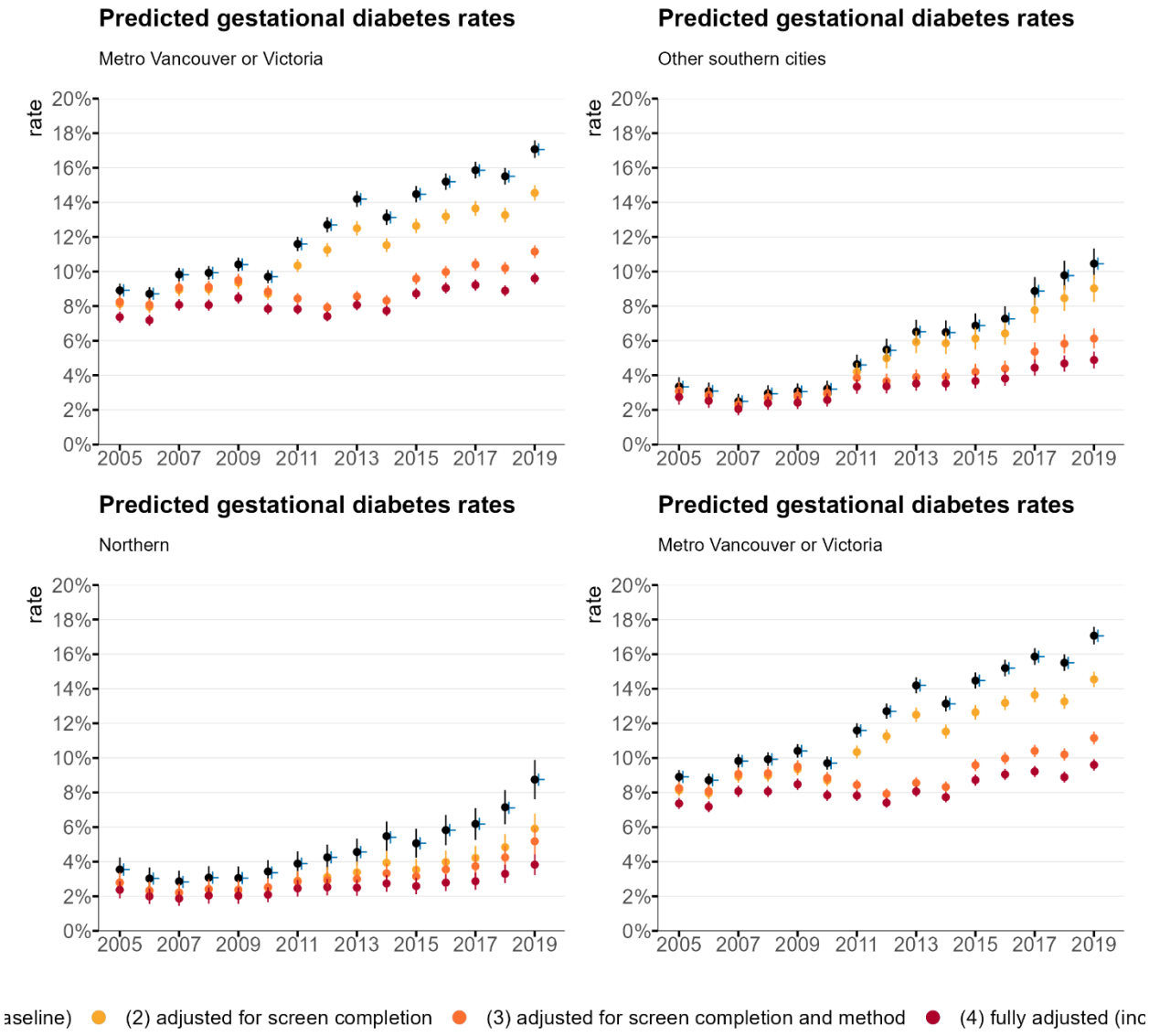


Figure C.16 Predicted risk of GDM diagnosis by year (modeled) in stratified analyses by alternate region classification



D. Covid-19 Pandemic, weight gain and infant birthweight supplemental

D.1 Methods

Covariate selection and DAG

Interrupted time series studies are only vulnerable to confounding by factors with contemporaneous changes around the intervention time point – and not **caused** by the intervention. For example, if other factors associated with weight gain changed: 1) at the time point of the intervention and 2) due to some other cause (not the pandemic).

To identify possible confounders for the association between the onset of the COVID-19 pandemic and pregnancy weight gain, pregnancy weight gain z-score and infant birthweight z-score, I reviewed existing literature [236–238] and then used a directed-acyclic graph (DAG) approach.[292,293] After constructing a causal diagram (Figure D.2), and identifying confounders which could be modeled using available data, I plotted time-series for annual rates and yearly means across the study period. If I noted a discontinuity at the intervention time-point *and* there was no plausible association between that factor and the intervention (pandemic countermeasures), this justified inclusion in the model. The DAG represents the relationship between the COVID-19 pandemic and pandemic-associated countermeasures, on pregnancy weight gain and infant birthweight. The primary exposure is noted in yellow, the primary outcome in blue.

Because most potential covariates (i.e. height, pre-pregnancy weight, history of GDM in previous pregnancy, antepartum risk status, health care professional type) occurred temporally prior to the pandemic onset, they are not potential confounders. Those on the causal pathway between the exposure and outcome should *not* be adjusted for in models to determine causal effects of the pandemic on weight gain/infant birthweight**.** Covariates without representative data sources in the OB COAP registry are indicated in white. I assessed the following covariates in time series: socio-economic factors (Medicaid insurance payor, a rural residence indicator, distressed community index), race/ethnicity, age, parity, antenatal health care professional type (midwife v. family practice v obstetrician) and pre- or early-pregnancy body mass index (BMI) (in kg/m^2). None demonstrated a discontinuity at the time point of interest (the COVID-19 intervention time point (March 23, 2020) noted by the vertical blue line).

Conception week v Delivery week

In order to model seasonal trends in pregnancy weight gain, comparable pregnancies were grouped together by duration of exposure to the seasonal effect (modeled as calendar month). As an initial approach, I grouped pregnancies by week of delivery and later analyses used the week of conception (calculated using the delivery week and subtracting gestational age at delivery (in weeks)). Monthly mean outcome data using the two methods (conception week or delivery week) (Figure D.3) were generally similar. Overall model fit was improved using the conception week seasonal term, although overall conclusions were unchanged. Final models used conception week as this more accurately controls for exposure over the course of the complete pregnancy.[243]

Modeling seasonality

I considered several statistical approaches to model seasonality in the interrupted time series models. These included: a single sine term, a series of Fourier terms (sine and cosine pairs, 2, 4 and 8 terms), indicator variables for month, restricted cubic splines and restricted periodic cubic splines (using R library peRiodiCS in R).[294] The most appropriate method was selected based on lowest Akaike's Information Criterion (AIC) using generalized linear models (without random effects) and visualization of the fitted plots. For splines, I tested different numbers of knots (between 4 and 20 knots); 2 knots/year (for seasonal extremes (winter/summer)) and +2 for endpoints was the most reasonable fit (4 knots).[241,294,295] Restricted cubic splines, however, did not provide a reasonable fit to the data after examining fitted plots; so this method was rejected. Model testing used fixed effects only, random effects for hospital site were added to the final models.

Model specification(s)

$$Outcome_{ij}\,(T) = \beta_0 + \upsilon_{0j} + (\beta_1 + \upsilon_{1j}) \times Time_{ij} + \beta_2 \times Pandemic\ onset_i + \beta_3 \times PostpandemicTime_i + \beta_4 \times covariates + \beta_5 \times seasonality_i + \varepsilon_{ti}$$

Where:

Outcome = Outcome for pregnant person *i* or infant *i* at hospital *j*

Model 1 Outcome = Pregnancy weight gain (kg)

Model 2 Outcome = Gestational weight gain z-score

Model 3 Outcome = Infant birthweight z-score

Time= time in weeks from study start to delivery for pregnant person *i* or birth for infant *i*

Pandemic onset = Level shift indicator for intervention time point (0 for time before Feb 23, 1 for time after March 23)

Post-pandemic Time = Time in weeks from March 23 at which delivery or birth occurred (for post-intervention time trend)

Seasonality = sine ((2*pi/52.1429)*ConceptionWeek)

υ_{0j} and υ_{1j} are random effect terms (intercept and slope) for hospital j

$\varepsilon_{ti} \sim N(0, \sigma_2)$

D.2 Sensitivity analyses

I conducted a number of sensitivity analyses to examine potential sources of bias in the primary analysis presented in Chapter 5. For all sensitivity analyses, I modeled the interrupted time series (ITS) and compared results to the primary models (Chapter 5). Results are summarized in this section (Table D.3).

Methods

First, I assessed whether the findings were impacted by COVID-19 disease status. A variable for any COVID-19 diagnosis was created by searching in three open text fields ("Other Pregnancy Complications", "Other Pregnancy Diagnoses" or in "Other Pre-pregnancy Diagnoses") in the OB COAP data registry. Trained abstractors had been instructed to use these fields to indicate COVID-19 cases as there was no specific variable in the dataset at this time. This method identified 341 cases, with a COVID-19 positive rate of (2%%) from April to December of 2020.

An analysis of COVID-19 prevalence in Washington state (March 1 – June 30, 2020) reported an infection rate of 1.4% among pregnant women.[296] Time trends also demonstrates a substantial increase in COVID-positive (~4-5%) by the last two months of 2020 which aligns with data on infection in the region.[297] After exclusions (valid weight gain and infant birthweight), 230 pregnancies and 340 infants from COVID-19 positive mothers remained. All ITS models (for all three outcomes) were repeated excluding these cases.

Second, I considered the impact of known repeated pregnancies to the same individual during the study years. While this data registry did have a unique patient identifier, this had many limitations. Importantly, this identifier had not been validated, nor previously used for research. Within the limitations of this identifier, to conduct the sensitivity analysis, I randomly created a subset with only 1 birth per person and repeated all ITS models using this subset. Prior to any exclusions, only 22% of available pregnancies had more than 1 birth in the dataset which is much lower than the rate of multiparity (>50%).

Third, I examined whether the results for the z-score based analyses were reproducible using a different reference standard. Thus, I calculated pregnancy weight gain z-scores using the INTERGROWTH 21 gestational weight gain[228] standard and infant birthweight z-scores with the INTERGROWTH 21 fetal

growth birthweight standards [298] by infant sex and gestational age. Notably, the INTERGROWTH standard was only available for normal pre-pregnancy body mass index (BMI) (between 18.5 to 24.9kg/m2) thus this standard was only applied to a subgroup with normal BMI.

Next, I conducted two more sensitivity analyses for only the infant birthweight z-score cohort. First, to investigate possible uncontrolled confounding by parity in the infant z-score analyses, I 1) calculated infant z-scores using parity-adjusted [225] reference charts and 2) included parity as a covariate in the ITS models. Second, to consider whether the findings for the infants were biased because a larger sample (n=104,936) was used for this cohort compared to the weight gain cohort (n=77,411) which was restricted to pregnancies with valid weight gain data, I restricted to a subset of infants with valid birthweight data (n=77,344) matched to pregnancies in the weight gain cohort.

Results

Overall, the primary study findings (modest impact of the COVID-19 pandemic towards increasing pregnancy weight gain, no change for infant birthweight) were unchanged (Table D.3, Table D.4, Table D.5, Table D.6) using sensitivity analyses. A few results were of interest and are summarized briefly.

Excluding COVID-19 cases shifted the effect estimates for both pregnancy weight gain and pregnancy z-score further away from the null (Table D.4, Table D.5). Non-significant findings remained unchanged. Because of concerns with the reliability the COVID-19 case ascertainment, I did not exclude these from the main analysis; however, this suggests that including the COVID-positive cases is likely to have no impact, or to have biased findings towards the null.

Using the Intergrowth 21 standard for infant birthweight (Table D.6) resulted in a mean z-score (0.38) substantially higher than with the reference chart used for the primary analysis (0.1) confirming that the INTERGROWTH 21 standard is not well calibrated to a US reference population[299].

Using the cohort where infants were matched to mothers in the weight gain (Table D.6), mean z-scores were slightly increased (0.11) compared to the full cohort (0.09). This suggests this cohort may represent a slightly different population with higher mean infant birthweights. Given the exclusions for valid weight gain required a pre- or initial- pregnancy weight that was taken <14 weeks of pregnancy, this would bias the sample towards individuals with earlier prenatal care; likely a higher socio-economic/income group. In other words, people with incomplete or late prenatal care who are at increased risk for prematurity and small for gestational age would be excluded. Thus, a slight increase in infant birthweight is understandable when restricting to those infants of mothers meeting pregnancy weight gain criteria.

D.3 Conditional quantile regression

As a sensitivity analysis in the main manuscript, I reported the upper extremes (90^{th} percentile) of weight gain and z-score (Table D.7). However, I also examined the overall distribution of weight gain outcomes using a conditional quantile approach (Table D.7, Figure D.4).

Using conditional quantile regression modeled each percentile (0.05 to 0.95) using the ITS models. I included only the fixed effects from the mean regression models, because the quantile regression analytic library (R library quantreg) did not support random effect terms. Since the random effects terms had only negligible impacts on the effect estimates in the primary analyses, limiting to fixed effects only was reasonable.

This approach demonstrated a generally non-significant pandemic shift in weight gain and z-score for the lower percentiles of weight gain (Figure D.4). Statistically significant pandemic-related impacts on pregnancy weight gain and z-scores were noted above the 60^{th} percentile of weight gain. An increased level change, relative to the population mean (shaded blue line in the graphs) were noted for the distribution above the 90^{th} percentile of weight gain (Table D.7). Quantile regressions revealed no differences when compared to the mean regression results for the infant birthweight z-scores.

D.4 A re-analysis of the COVID-19 pandemic study using excess or inadequate pregnancy weight gain according to the Institute of Medicine criteria

Background

In Chapter 6, I found a modest increase in the population mean pregnancy weight gain and body-mass index adjusted z-scores after the onset of the COVID-19 pandemic. While total pregnancy weight gain is a more direct measure, weight gain in pregnancy is often assessed clinically using the Institute of Medicine's (IOM) categories for weight gain by pregestational BMI.[54] Also based on the IOM criteria, either "excess" or "inadequate" weight gain in pregnancy[56,57,300] are commonly used in research as an explanatory variable or as an outcome. While some have suggested these guidelines should be further revised to reflect current population norms, especially higher rates of obesity[55], the IOM guidelines remain the most commonly used clinical standards for weight gain in pregnancy.

The aim of this analysis was to assess whether there was an impact of the COVID-19 pandemic onset on either excess or inadequate weight gain as measured using these commonly referenced clinical criteria. This is one way to explore whether the findings of the mean regression analysis in Chapter 6 are sensitive to an alternate definition of weight gain.

Methods

The current (2009) IOM recommended ranges for weight gain in pregnancy are: underweight women (BMI < 18.5 kg/m^2) 12.5—18.0 kg, normal weight women (BMI 18.5—24.9 kg/m^2) 11.5—16.0 kg, overweight women (BMI 25.0—29.9) 7.0—11.5 kg, and obese women (BMI > 30.0 kg/m^2) 5-9 kg. Using the pregnancy weight gain variable and pre-pregnancy body mass index from the cohort in Chapter 4, I defined categorical variables for "excess weight gain" (v. recommended weight gain) and for "inadequate weight gain" (v. recommended weight gain), applying the IOM weight gain criteria within categories by pregestational body mass index. Using a modified Poisson regression approach for binomial outcomes,[190] I ran interrupted time series models similar to those in Chapter 4 but including weeks of gestation on delivery was included in the models because the IOM weight gain criteria is generally applied to term pregnancies. I restricted to a term cohort (>=37 weeks) without control for weeks on delivery. Models were adjusted for seasonality using the same approach as the generalized linear mixed regression models (single sine term using week of conception) and for hospital site (random slope and intercept).

Results

A majority of pregnant people experienced inadequate weight gain (42%) compared to the recommended weight gain (32%) (Table D.11). Using the ITS approach, there was an increase in the risk of ‘excess weight gain’ (relative risk) 1.055, (0.99, 1.121) associated with the pandemic time point. This represented an increase from 41% of pregnancies in 2019, to 43% of pregnancies after the pandemic who experienced ‘excess weight gain’. There was no predicted change in ‘inadequate weight gain’ associated with the pandemic time point (Table D.12). Results were similar when restricted to term deliveries. Similar to the findings for mean pregnancy weight gain, there was a modest increase in the risk of “excess weight gain” among pregnant individuals in this cohort after the onset of the COVID-19 pandemic.

D.5 **Tables**

Table D.1 Model estimates from interrupted time series analyses of the effect of the COVID-19 pandemic onset in a Washington State cohort (January 1, 2016 to December 28, 2020) (Primary analyses)

Model terms	**Estimate (95%CI)**	**p-value**
Pregnancy weight gain (kg)		
(Intercept)	-10.09 (-11.22, -9.070)	<0.001
Sine week using conception time	0.156 (0.093, 0.218)	<0.001
Gestational age at delivery (weeks)	0.582 (0.557, 0.607)	<0.001
Baseline time trend (kg/year)	-0.122, (-0.21, -0.03)	0.025
Level change at COVID-19 onset	0.486 (0.251, 0.730)	<0.001
Trend change at COVID-19 onset (kg/year)	-0.254, (-0.75, 0.25)	0.3
Pregnancy weight gain z-score		
(Intercept)	-0.070 (-0.143, 0.012)	0.12
Sine week using conception time	0.033 (0.022, 0.045)	<0.001
Baseline time trend (/year)	-0.016, (-0.03, 0.00)	0.085
Level change at COVID-19 onset	0.080 (0.031, 0.125)	<0.001
Trend change at COVID-19 onset (/year)	-0.015, (-0.11, 0.08)	0.7
Infant birthweight z-score		
(Intercept)	0.119 (0.072, 0.167)	<0.001
Sine week using conception time	-0.001 (-0.009, 0.008)	0.8
Baseline time trend (/year)	0.001, (-0.01, 0.01)	0.8
Level change at COVID-19 onset	-0.004 (-0.039, 0.034)	0.8
Trend change at COVID-19 onset (/week)	-0.013, (-0.09, 0.06)	0.7

Table D.2 Demographics and characteristics of excluded cases for a study of the effect of the COVID-19 pandemic onset in a Washington State cohort (January 1, 2016 to December 28, 2020)

	All excluded cases N=28034		**Complete case cohort (pregnancies) N=77411**	
	Pre-pandemic	**COVID-19 pandemic**	**Pre-pandemic**	**COVID-19 pandemic**
	N=24144 (86%)	***N=3890 (14%)***	***N=65214 (84%)***	***N=12197 (16%)***
Nulliparous	9232 (38.2)	1559 (40.1)	26631 (40.8)	5256 (43.1)
Race and ethnicity of birthing person:				
Non-Hispanic White	11755 (48.7)	1625 (41.8)	34515 (52.9)	5967 (48.9)
Non-Hispanic Black	1667 (6.9)	245 (6.3)	2670 (4.1)	512 (4.2)
Hispanic or Latinx	4406 (18.2)	669 (17.2)	10713 (16.4)	2046 (16.8)
Asian or Pacific Islander	3999 (16.6)	517 (13.3)	13060 (20.0)	2548 (20.9)
Native American or Native Alaskan	556 (2.3)	96 (2.5)	696 (1.1)	103 (0.8)
Other or mixed race	1169 (4.8)	176 (4.5)	1963 (3.0)	372 (3.0)
Missing	592 (2.5)	562 (14.4)	1597 (2.4)	649 (5.3)
Rural zip code:				
Yes	2076 (8.6)	374 (9.6)	5310 (8.1)	920 (7.5)
Missing	815 (3.4)	130 (3.3)	1649 (2.5)	351 (2.9)
Insurance payer:				
Medicaid*	11624 (48.1)	1849 (47.5)	19537 (30.0)	3351 (27.5)
Missing	168 (0.7)	23 (0.6)	2313 (3.5)	66 (0.5)
Distressed Communities Index:				
Prosperous	7704 (31.9)	1115 (28.7)	29543 (45.3)	5576 (45.7)
Comfortable	6293 (26.1)	1081 (27.8)	16137 (24.7)	3040 (24.9)
Mid-tier	3117 (12.9)	584 (15.0)	5931 (9.1)	1155 (9.5)
At risk	4924 (20.4)	795 (20.4)	10097 (15.5)	1765 (14.5)
Distressed	1611 (6.7)	236 (6.1)	2839 (4.4)	534 (4.4)
Missing	495 (2.1)	79 (2.0)	667 (1.0)	127 (1.0)
Age of birthing person (year)	29.4 (5.9)	29.7 (6.1)	30.4 (5.4)	30.8 (5.4)
Height of birthing person (cm)	162.7 (7.4)	162.6 (7.2)	163.1 (7.2)	163.0 (7.1)
Gestational age at delivery (weeks)	38.4 (2.4)	38.3 (2.3)	38.8 (1.7)	38.7 (1.7)
Pregnancy weight gain (kg) **only cases with non-missing weight gain data (N=21,560)*	18,554 / 21,560 (86%)	3006 / 21,560 (14%)		
Median (IQR)	6.8 (2.7 – 11)	7.1 (2.5 – 11.7)	12.3 (8.6 – 15.9)	12.3 (8.6 – 16.3)

Note: Excluded cases over both time periods had a higher proportion of younger age, multiparas, Medicaid, Black, Latinx and Missing race data and lower DCI quintiles. We surmised that the excluded weight group represented a high proportion of people with late prenatal care (as the weight measurement was in the second trimester). However, the proportion of the population with missing or invalid data is stable across the time periods therefore these underlying differences would not impact our overall findings across the pandemic time period, because these characteristics were not subject to differential bias by the pandemic.

Table D.3 Summary of sensitivity analyses results Covid-19 study

Sensitivity	**Total pregnancy weight gain (kg)**	**Weight gain z-score**	**Infant z-score**
Exclude COVID positive[a]	No change	No change	No change
1 birth/ID	No change	No change	No change
Intergrowth21 Standards	n/a	No change	No change (higher mean z-score)
Parity (2 methods)	n/a	n/a	No change
Matched infants to mothers	n/a	n/a	No change (higher mean z-score)

a. COVID-positive cases identified from open text fields in either: "Other Pregnancy Complications", "Other Pregnancy Diagnoses" or in "Other Pre-pregnancy Diagnoses". I used text-searching to identify all pregnancies with "covid" (case independent) and NOT ("investigation", "pui" or "unsure") in any of these open text fields.

Table D.4 Complete model terms for pregnancy weight gain models (kg) with sensitivity anlayses

Total pregnancy weight gain (kg) **Model terms**	**Estimate (95%CI)**	**p-value**
Primary analysis		
(Intercept)	-10.09 (-11.22, -9.070)	<0.001
Time trend, weekly	-0.002 (-0.004, -0.001)	0.025
Level change	0.486 (0.251, 0.730)	<0.001
Trend change	-0.005 (-0.014, 0.004)	0.3
Gestational age at delivery (weeks)	0.582 (0.557, 0.607)	<0.001
Sine week using conception	0.156 (0.093, 0.218)	<0.001
Sensitivity analyses:		
Subset excluding COVID-19 Positive pregnancies		
(Intercept)	-10.07 (-11.14, -9.001)	<0.001
Time trend, weekly	-0.002 (-0.004, -0.001)	0.024
Level change	0.506 (0.266, 0.747)	<0.001
Trend change	-0.005 (-0.015, 0.004)	0.3
Gestational age at delivery (weeks)	0.581 (0.556, 0.606)	<0.001
Sine week using conception	0.154 (0.092, 0.216)	<0.001
Subset to: 1 birth/patient identifier (random)		
(Intercept)	-10.32 (-11.44, -9.199)	<0.001
Time trend, weekly	-0.002 (-0.003, 0.000)	0.11
Level change	0.506 (0.252, 0.761)	<0.001
Trend change	-0.007 (-0.018, 0.003)	0.2
Gestational age at delivery (weeks)	0.586 (0.560, 0.612)	<0.001
Sine week using conception	0.159 (0.094, 0.224)	<0.001

Table D.5 Complete model terms for pregnancy weight gain z-score models with sensitivity analyses

Pregnancy weight gain z-score Model terms	**Estimate (95% CI)**	**p-value**
Primary analysis: using Santos' reference, adjusted for BMI and Gestational age		
(Intercept)	-0.070 (-0.143, 0.012)	0.12
Time trend, weekly	0.033 (0.022, 0.045)	<0.001
Level change	0.080 (0.031, 0.125)	<0.001
Trend change	0.000 (-0.001, 0.000)	0.085
Sine week using conception	0.000 (-0.002, 0.002)	0.7
Sensitivity analyses:		
INTERGROWTH 21 standard		
(Intercept)	0.097 (0.030, 0.164)	0.018
Time trend, weekly	0.000 (-0.001, 0.000)	0.003
Level change	0.075 (0.009, 0.142)	0.026
Trend change	0.001 (-0.001, 0.004)	0.4
Sine week using conception	0.049 (0.032, 0.066)	<0.001
Excluding COVID-19 Positive pregnancies		
(Intercept)	-0.071 (-0.136, -0.005)	0.053
Time trend, weekly	0.000 (-0.001, 0.000)	0.084
Level change	0.083 (0.038, 0.127)	<0.001
Trend change	0.000 (-0.002, 0.001)	0.7
Sine week using conception	0.033 (0.022, 0.044)	<0.001
Restriction to 1 birth/patient identifier		
(Intercept)	-0.078 (-0.149, -0.007)	0.052
Time trend, weekly	0.000 (-0.001, 0.000)	0.3
Level change	0.078 (0.031, 0.125)	0.001
Trend change	-0.001 (-0.002, 0.001)	0.6
Sine week using conception	0.034 (0.022, 0.046)	<0.001

Table D.6 Complete model terms for all infant birthweight z-score models with sensitivity analyses

Infant birthweight z-score Model terms	**Estimate (95% CI)**	**p-value**
Primary analysis: Aris' standards, adjusted for infant sex and gestational age		
(Intercept)	0.119 (0.072, 0.167)	<0.001
Time trend, weekly	-0.001 (-0.009, 0.008)	0.8
Level change	-0.004 (-0.039, 0.034)	0.8
Trend change	0.000 (0.000, 0.000)	0.8
Sine week using conception	0.000 (-0.002, 0.001)	0.7
Sensitivity analyses:		
INTERGROWTH 21		
(Intercept)	0.421 (0.367, 0.474)	<0.001
Time trend, weekly	0.000 (0.000, 0.000)	>0.9
Level change	0.004 (-0.031, 0.038)	0.8
Trend change	0.000 (-0.002, 0.001)	0.6
Sine week using conception	-0.001 (-0.010, 0.008)	0.8
Parity-adjusted z-score per Aris' reference		
(Intercept)	0.135 (0.087, 0.184)	<0.001
Time trend, weekly	0.000 (0.000, 0.000)	0.4
Level change	-0.003 (-0.039, 0.033)	0.9
Trend change	0.000 (-0.002, 0.001)	0.7
Sine week using conception	-0.001 (-0.010, 0.009)	0.9
Modeled adjustment for parity		
(Intercept)	0.238 (0.190, 0.285)	<0.001
Time trend, weekly	0.000 (0.000, 0.000)	0.4
Level change	-0.003 (-0.039, 0.032)	0.8
Trend change	0.000 (-0.002, 0.001)	0.8
Parity (nulliparous v. multiparous)	-0.324 (-0.336, -0.311)	<0.001
Sine week using conception	-0.001 (-0.010, 0.008)	0.9
Matched infants to pregnancies from weight gain cohort		
(Intercept)	0.144 (0.091, 0.198)	<0.001
Time trend, weekly	0.000 (0.000, 0.000)	>0.9
Level change	-0.008 (-0.050, 0.033)	0.7
Trend change	0.000 (-0.002, 0.001)	0.6
Sine week using conception	-0.005 (-0.016, 0.005)	0.3
Excluding COVID-19 Positive		
(Intercept)	0.119 (0.063, 0.176)	0.004
Time trend, weekly	0.000 (0.000, 0.000)	0.9
Level change	-0.007 (-0.043, 0.029)	0.7
Trend change	0.000 (-0.002, 0.001)	>0.9
Sine week using conception	-0.001 (-0.010, 0.008)	0.9
Restriction to 1 birth/patient identifier		
(Intercept)	0.119 (0.063, 0.176)	0.004
Time trend, weekly	0.000 (0.000, 0.000)	0.9
Level change	-0.007 (-0.043, 0.029)	0.7

Infant birthweight z-score Model terms	Estimate (95% CI)	p-value
Trend change	0.000 (-0.002, 0.001)	>0.9
Sine week using conception	-0.001 (-0.010, 0.008)	0.9

Table D.7 Quantile regression for 90th percentiles using an interrupted time series analyses of the effect of the COVID-19 pandemic onset in a Washington State cohort

Model terms	Quantile regression (90th percentile) Estimate 95% CI	Mean regression* (*fixed effects only) Estimate 95% CI
Pregnancy weight gain (kg)		
Level change	1.20 (0.75, 1.65)	0.47 (0.23, 0.71)
Trend change	-0.72 (-1.72, 0.27)	-0.16 (-0.66, 0.35)
Pregnancy weight gain z-score		
Level change	0.20 (0.12, 0.28)	0.079 (0.03, 0.12)
Trend change	-0.11 (-0.28, 0.06)	0.008 (-0.09, 0.10)
Infant birthweight z-score		
Level change	-0.041 (-0.10, 0.02)	-0.003 (-0.04, 0.03)
Trend change	0.073 (-0.06, 0.20)	-0.009 (-0.08, 0.07)

Table D.8 Quantile regression and mean regression results stratified by pregestational BMI (body mass index) categories for a study of the effect of the COVID-19 pandemic onset in a Washington State cohort (January 1, 2016 to December 28, 2020)

Model terms – pregestational BMI subgroups	90th percentile estimate (95%CI) [a]	p-value	Mean estimate (95%CI) [b]	p-value
Pregestational BMI ≤ 25 kg/m² (Normal or underweight)				
pregnancy weight gain (kg)				
Level change	1.20 (0.63, 1.76)	<0.001	0.42, (0.13, 0.71)	0.005
Trend change (/year)	-0.53 (-1.69, 0.62)	0.367	0.14, (-0.48, 0.75)	0.7
pregnancy weight gain z-score				
Level change	0.23 (0.10, 0.35)	<0.001	0.083, (0.02, 0.15)	0.016
Trend change (/year)	-0.11 (-0.35, 0.14)	0.393	0.053, (-0.09, 0.19)	0.5
Infant birthweight z-score				
Level change	0.015 (-0.07, 0.10)	0.737	0.031, (-0.02, 0.09)	0.3
Trend change (/year)	-0.016 (-0.20, 0.17)	0.862	-0.079, (-0.19, 0.04)	0.2
Pregestational BMI 25-<30 kg/m² (Overweight)				
pregnancy weight gain (kg)				
Level change	0.99 (0.14, 1.84)	0.023	0.43, (-0.02, 0.87)	0.061
Trend change (/year)	-0.75 (-2.66, 1.16)	0.441	-0.18, (-1.12, 0.76)	0.7
pregnancy weight gain z-score				
Level change	0.18 (0.04, 0.32)	0.013	0.072, (-0.01, 0.15)	0.089
Trend change (/year)	-0.17 (-0.49, 0.15)	0.291	-0.039, (-0.21, 0.14)	0.7
Infant birthweight z-score				
Level change	-0.028 (-0.13, 0.07)	0.588	-0.066, (-0.14, 0.00)	0.061
Trend change (/year)	0.11 (-0.11, 0.33)	0.314	0.16, (0.01, 0.30)	0.035
Pregestational BMI ≥ 30 kg/m² (Obese I, II, III)				
pregnancy weight gain (kg)				
Level change	1.03 (0.05, 2.00)	0.039	0.49, (-0.03, 1.01)	0.065
Trend change (/year)	-0.40 (-2.19, 1.39)	0.663	-0.76, (-1.83, 0.32)	0.2
pregnancy weight gain z-score				
Level change	0.20 (0.07, 0.34)	0.003	0.070, (-0.01, 0.15)	0.094
Trend change (/year)	-0.10 (-0.38, 0.19)	0.503	-0.075, (-0.25, 0.09)	0.4
Infant birthweight z-score				
Level change	-0.019 (-0.11, 0.07)	0.674	0.013, (-0.06, 0.08)	0.7
Trend change (/year)	0.050 (-0.16, 0.26)	0.635	-0.056, (-0.20, 0.09)	0.4

a. Quantile regression models were run using library quantreg in R and assess the changes in the outcomes across the distribution of the outcome variable. Quantile regression models were restricted to fixed effects only and did not include hospital-level random effects; however, difference between mean models with and without random effects was minimal. Other percentiles (<90th) were not significantly different than the mean regression.

b. Full models as described in Supplementary Methods and previous Supplementary Table 2.

Table D.9 Model estimates from sensitivity analyses for increasing exposure to the pandemic by excluding births from February 23, 2020 to April 27, 2020 (9 weeks) and from February 23, 2020 to June 8, 2020 (15 weeks) from interrupted time series analyses of the effect of the COVID-19 pandemic onset in a Washington State cohort

April 27, 2020 pandemic onset models	**Estimate (95%CI)**	**p-value**
Pregnancy weight gain (kg) n=75915		
Level change at COVID-19 onset	0.562, (0.30, 0.82)	<0.001
Trend change at COVID-19 onset (kg/year)	-0.456, (-1.06, 0.15)	0.14
Pregnancy weight gain z-score n=75915		
Level change at COVID-19 onset	0.095, (0.05, 0.14)	<0.001
Trend change at COVID-19 onset (kg/year)	-0.016, (-0.03, 0.00)	0.086
Infant birthweight z-score n=102953		
Level change at COVID-19 onset	-0.010, (-0.05, 0.03)	0.6
Trend change at COVID-19 onset (kg/year)	-0.002, (-0.09, 0.09)	>0.9
June 8, 2020 pandemic onset models		
Pregnancy weight gain (kg) n=74025		
Level change at COVID-19 onset	0.549, (0.26, 0.84)	<0.001
Trend change at COVID-19 onset (kg/year)	-0.560, (-1.36, 0.24)	0.2
Pregnancy weight gain z-score n=74025		
Level change at COVID-19 onset	0.099, (0.05, 0.15)	<0.001
Trend change at COVID-19 onset (kg/year)	-0.078, (-0.23, 0.07)	0.3
Infant birthweight z-score n=100544		
Level change at COVID-19 onset	-0.017, (-0.06, 0.03)	0.5
Trend change at COVID-19 onset (kg/year)	0.014, (-0.11, 0.14)	0.8

Table D.10 Baseline weight and other characteristics stratified by pregestational BMI categories

Characteristic n (%) or Mean (SD)	**Pre pandemic**			**Post pandemic**		
	BMI <25 N = 30,128	**BMI 25.0-29.9** N = 17,794	**BMI ≥30.0** N = 17,292	**BMI <25** N = 5,454	**BMI 25.0-29.9** N = 3,288	**BMI ≥30.0** N = 3,455
Nulliparous	13,970 (46.4%)	6,879 (38.7%)	5,782 (33.4%)	2,721 (49.9%)	1,338 (40.7%)	1,197 (34.6%)
Medicaid Payor	6,629 (23.0%)	5,355 (31.2%)	7,553 (44.7%)	1,047 (19.3%)	882 (27.0%)	1,422 (41.4%)
Continuous						
Age of birthing person (year)	30.6 (5.3)	30.6 (5.4)	30.1 (5.6)	30.9 (5.3)	31.0 (5.3)	30.4 (5.6)
BMI in early pregnancy (kg/m^2)	21.9 (1.9)	27.2 (1.4)	36.0 (5.4)	22.0 (1.9)	27.2 (1.4)	36.1 (5.5)
Height of birthing person (cm)	163.5 (7.0)	162.8 (7.2)	162.7 (7.6)	163.4 (6.9)	162.7 (7.2)	162.7 (7.3)
Pregnancy weight gain (kg)	13.8 (5.0)	12.6 (5.9)	9.3 (6.9)	14.0 (5.2)	12.8 (6.3)	9.4 (7.3)
weight gain z-score	-0.1 (1.1)	-0.2 (1.1)	0.0 (1.1)	-0.1 (1.2)	-0.2 (1.2)	0.0 (1.2)
Gestational age at delivery (weeks)	38.9 (1.6)	38.8 (1.7)	38.6 (1.9)	38.9 (1.5)	38.7 (1.7)	38.5 (1.9)
Infant birthweight (g)	3,317.0 (504.0)	3,390.0 (541.0)	3,432.3 (583.0)	3,313.9 (492.4)	3,372.2 (528.3)	3,400.0 (592.6)

Table D.11 Institute of Medicine (2009) pregnancy weight gain classifications and pregestational BMI

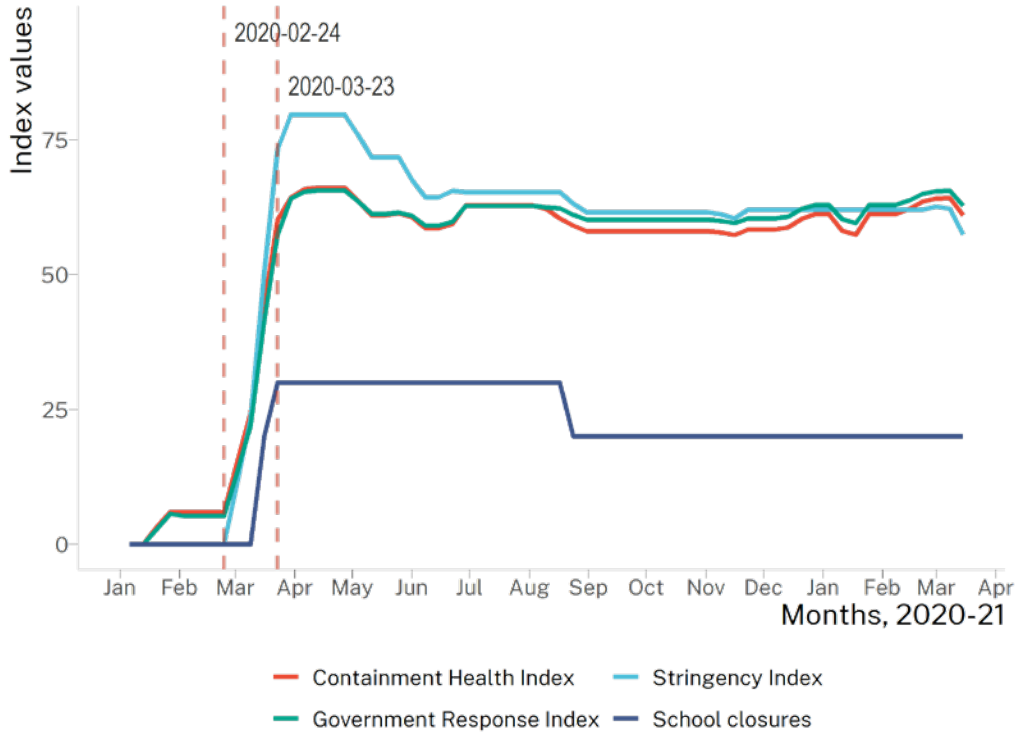
	Pre pandemic (N=65214)	COVID-19 pandemic time period (N=12197)	All (N=77411)
Total pregnancy weight gain by IOM standards for BMI			
Excess weight gain	26966 (41.4%)	5265 (43.2%)	32231 (41.6%)
Inadequate weight gain	17081 (26.2%)	3180 (26.1%)	20261 (26.2%)
Recommended weight gain	21167 (32.5%)	3752 (30.8%)	24919 (32.2%)
Pre- or Early- pregnancy body mass index (kg/m²)			
Underweight	1544 (2.4%)	272 (2.2%)	1816 (2.3%)
Normal	28584 (43.8%)	5182 (42.5%)	33766 (43.6%)
Overweight	17794 (27.3%)	3288 (27.0%)	21082 (27.2%)
Obese I	9362 (14.4%)	1809 (14.8%)	11171 (14.4%)
Obese II	4595 (7.0%)	935 (7.7%)	5530 (7.1%)
Obese III	3335 (5.1%)	711 (5.8%)	4046 (5.2%)

Table D.12 Full ITS model results for IOM excess or inadequate weight gain

Model terms	Estimate (95%CI)	p-value
Excess weight gain (full cohort)		
(Intercept)	0.016, (0.012, 0.021)	<0.001
Time trend, weekly	1.000, (1.000, 1.000)	0.8
Level change	1.055, (0.99, 1.121)	0.079
Trend change	1.000, (0.997, 1.002)	0.9
Gestational age at delivery (weeks)	1.089, (1.081, 1.097)	<0.001
Sine week using conception	1.026, (1.009, 1.042)	0.002
Inadequate weight gain (full cohort)		
(Intercept)	12.08, (9.413, 15.49)	<0.001
Time trend, weekly	1.000, (1.000, 1.000)	0.3
Level change	0.97, (0.895, 1.045)	0.4
Trend change	1.000, (0.997, 1.003)	0.9
Gestational age at delivery (weeks)	0.905, (0.899, 0.910)	<0.001
Sine week using conception	0.97, (0.95, 0.99)	0.003
Excess weight gain (>=37 weeks GA only)		
(Intercept)	0.440, (0.413, 0.469)	<0.001
Time trend, weekly	1.000, (1.000, 1.000)	0.6
Level change	1.065, (1.002, 1.133)	0.044
Trend change	1.000, (0.997, 1.002)	0.8
Sine week using conception	1.028, (1.011, 1.045)	<0.001
Inadequate weight gain (>=37 weeks GA only)		
(Intercept)	0.240, (0.224, 0.257)	<0.001
Time trend, weekly	1.000, (1.000, 1.001)	0.089
Level change	0.97, (0.891, 1.051)	0.4
Trend change	0.999, (0.996, 1.003)	0.7
Sine week using conception	0.97, (0.946, 0.99)	0.001

D.6 Figures

Figure D.1 COVID-19 policy indices (Containment Health Index, Stringency Index and Government Response Index) for Washington State, U.S. in 2020 using data from the Oxford COVID-19 Government Response Tracker



Source[205]

Figure D.2 Directed acyclic graph for COVID-19 pandemic and pregnancy weight gain or infant birthweight

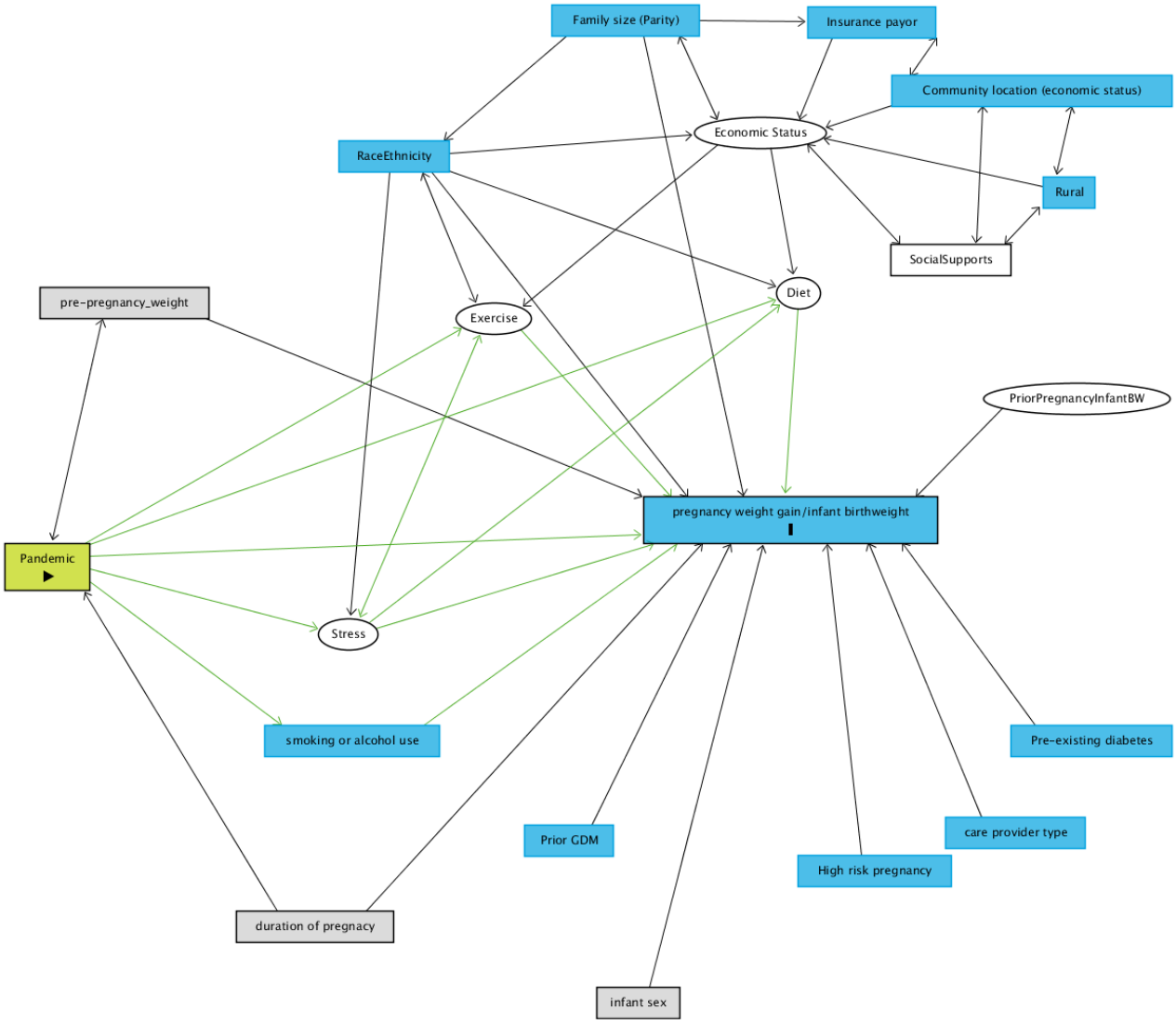


Figure D.3 Seasonal trends year-by-year comparing conception and delivery month

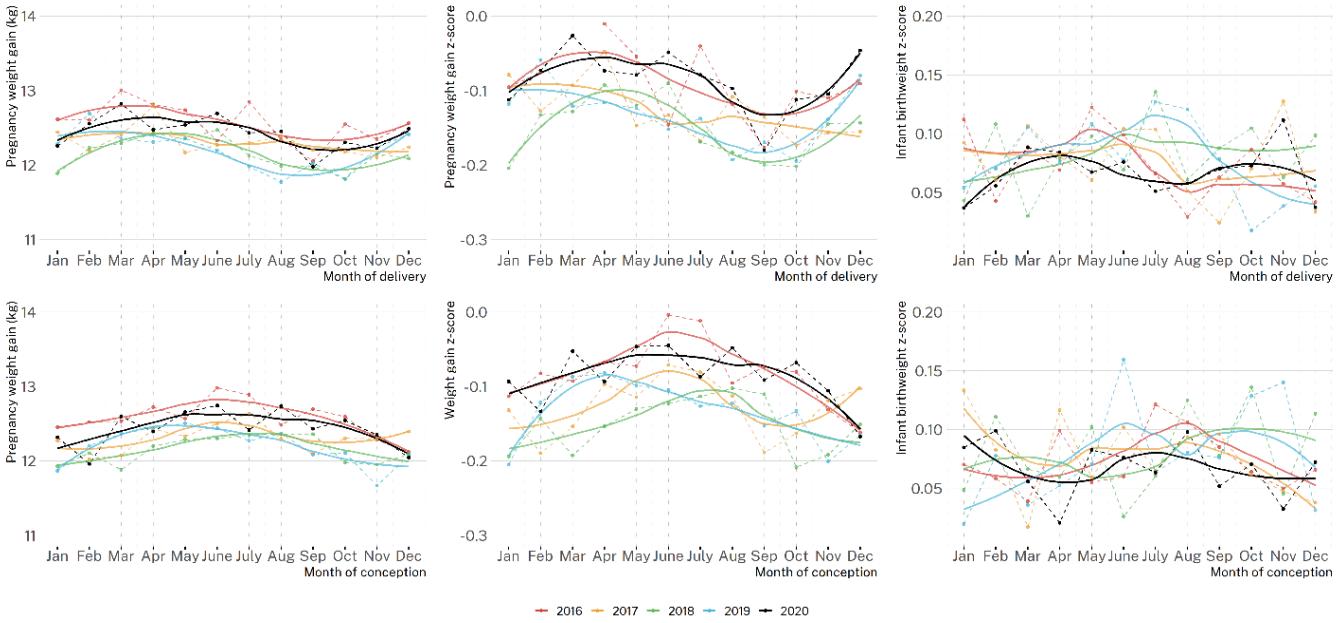
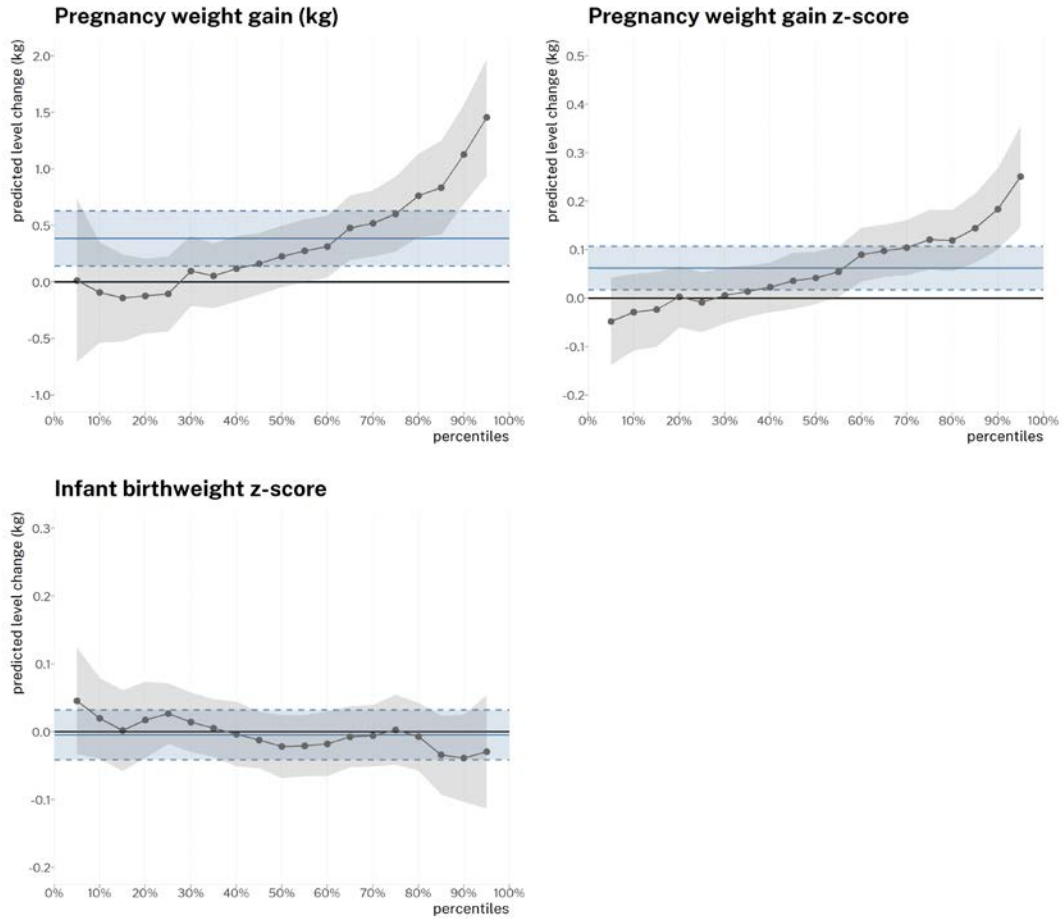
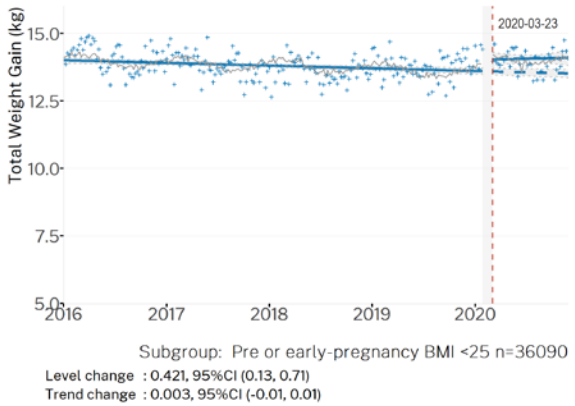


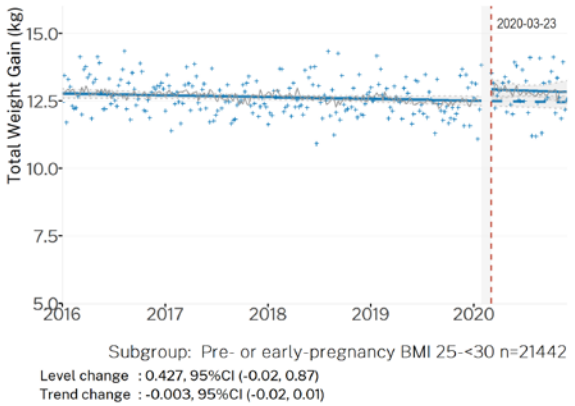
Figure D.4 Quantile regression modeled level change parameters across percentiles of pregnancy weight gain (model adjusted for gestational age at delivery and seasonality) and z-score (adjusted for seasonality)



Blue lines represent the mean regression (level change) parameter and dashed lines represent the 95% CIs. Shaded grey area represents 95% CI for the quantile regression model estimates.

Figure D.5 Subgroup analyses of pregnancy weight gain (kg) by pregestational BMI adjusted using an interrupted time series for a Washington State cohort (January 1, 2016 to December 28, 2020)





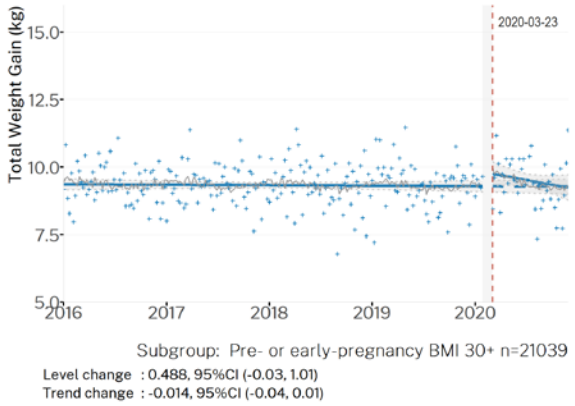


Figure D.6 Subgroup analyses of pregnancy weight gain z-score by Distressed Communities Index using an interrupted time series for a Washington State cohort

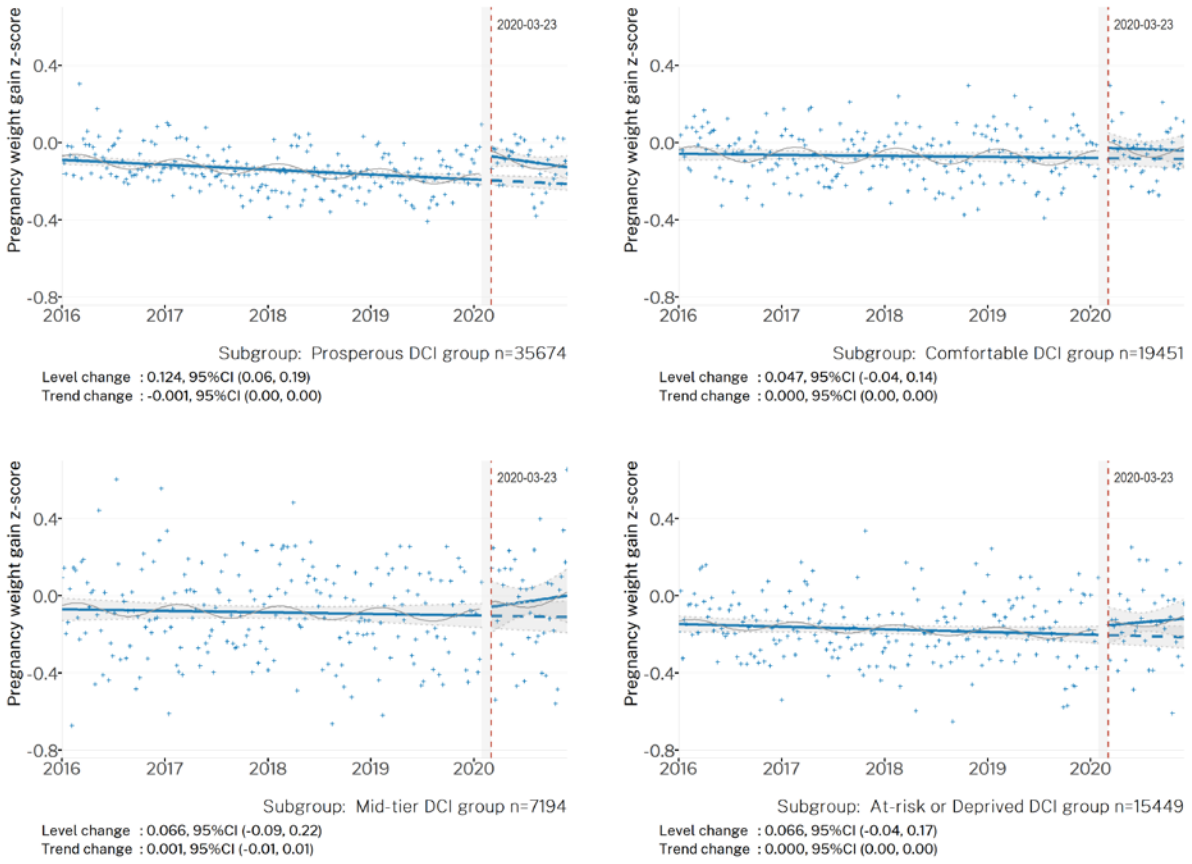


Figure D.7 Subgroup analyses of weight gain z-score by Race/ethnicity using an interrupted time series for a Washington State cohort

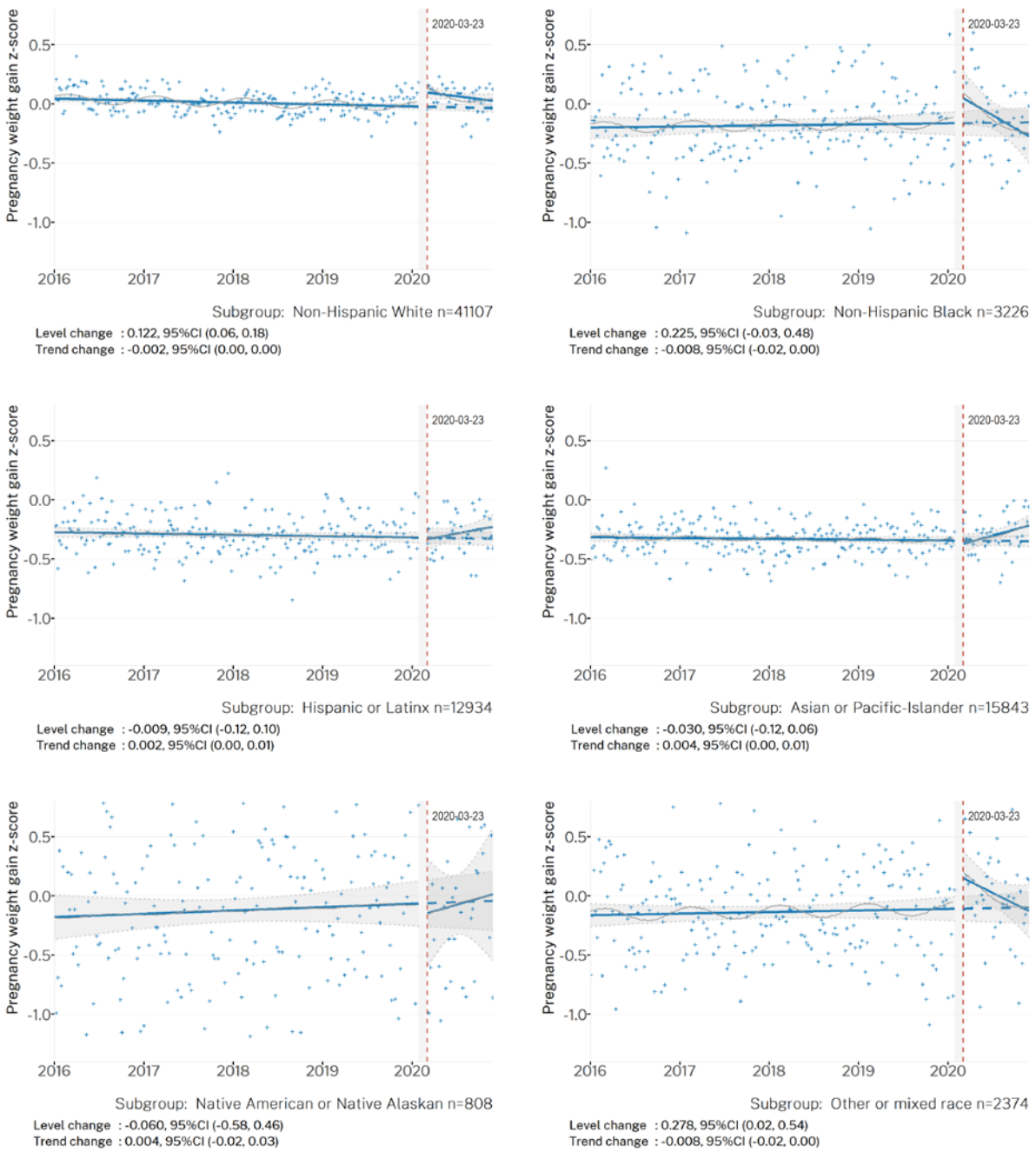
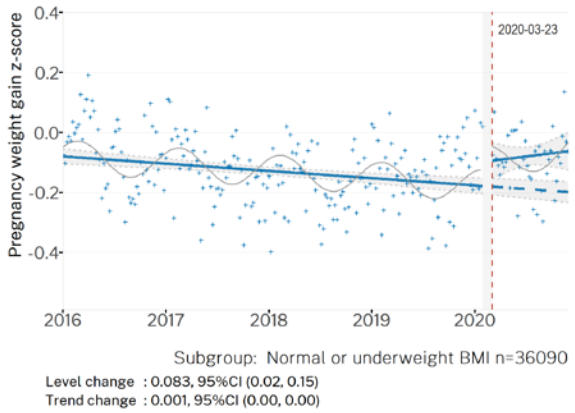
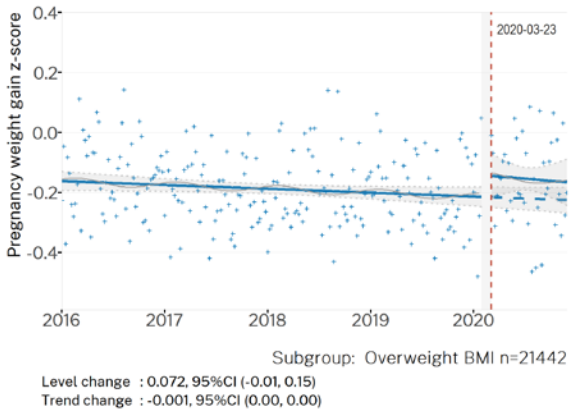


Figure D.8 Subgroup analyses of pregnancy weight gain z-score by pregestational BMI using an interrupted time series for a Washington State cohort





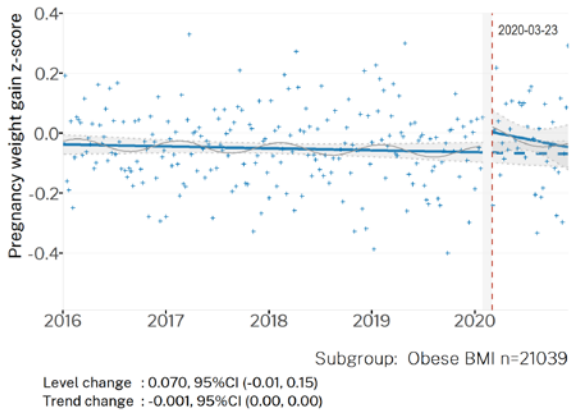


Figure D.9 Subgroup analyses of pregnancy weight gain z-score by insurance payor using an interrupted time series for a Washington State cohort

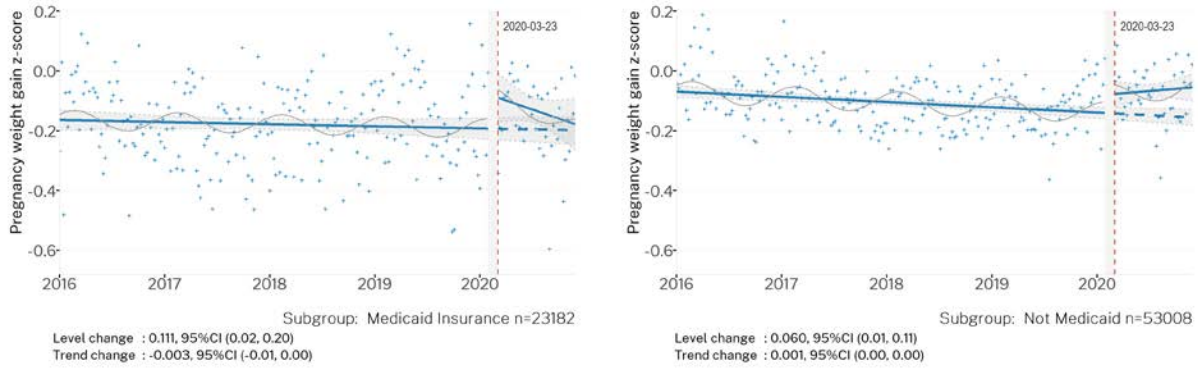


Figure D.10 Subgroup analyses of pregnancy weight gain z-score by Parity using an interrupted time series for a Washington State cohort

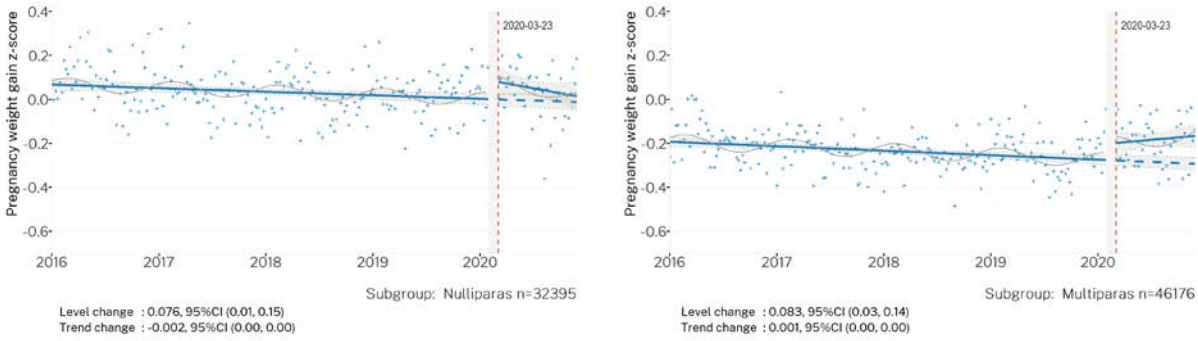


Figure D.11 Subgroup analyses of infant birthweight z-score by Distressed Communities Index using an interrupted time series for a Washington State cohort

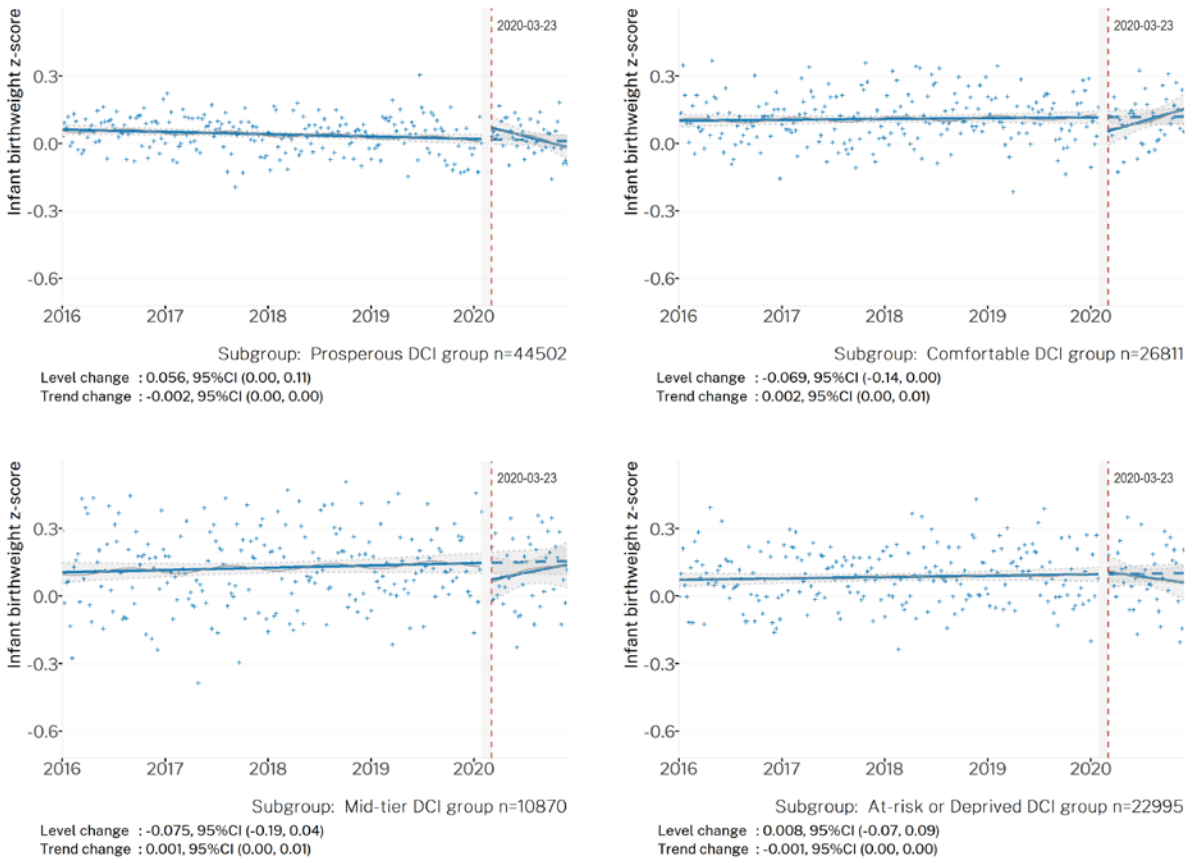


Figure D.12 Subgroup analyses of infant birthweight z-score by Race/ethnicity using an interrupted time series for a Washington State cohort

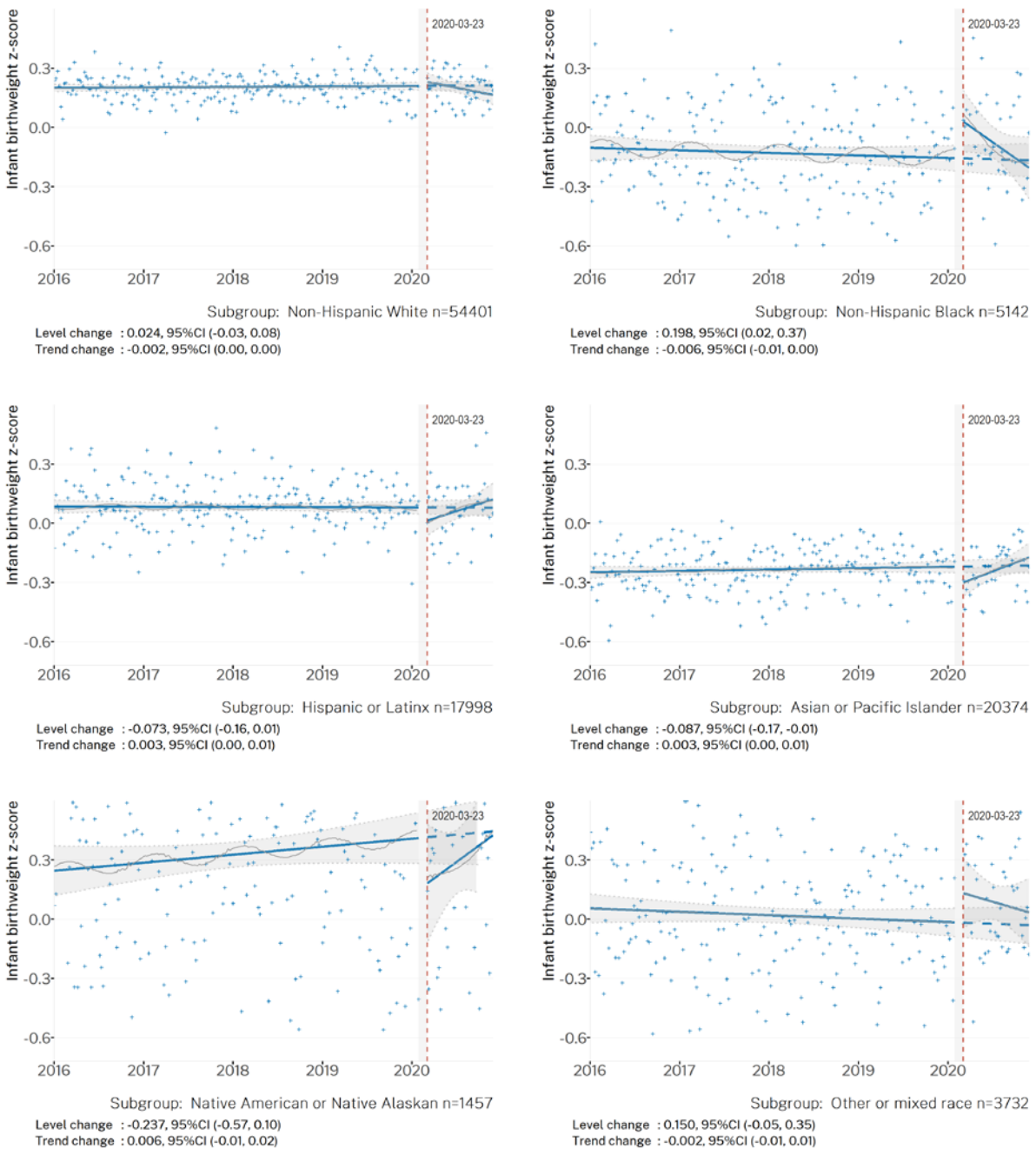


Figure D.13 Subgroup analyses of infant birthweight z-score by Race/ethnicity and parity adjusted using an interrupted time series for a Washington State cohort

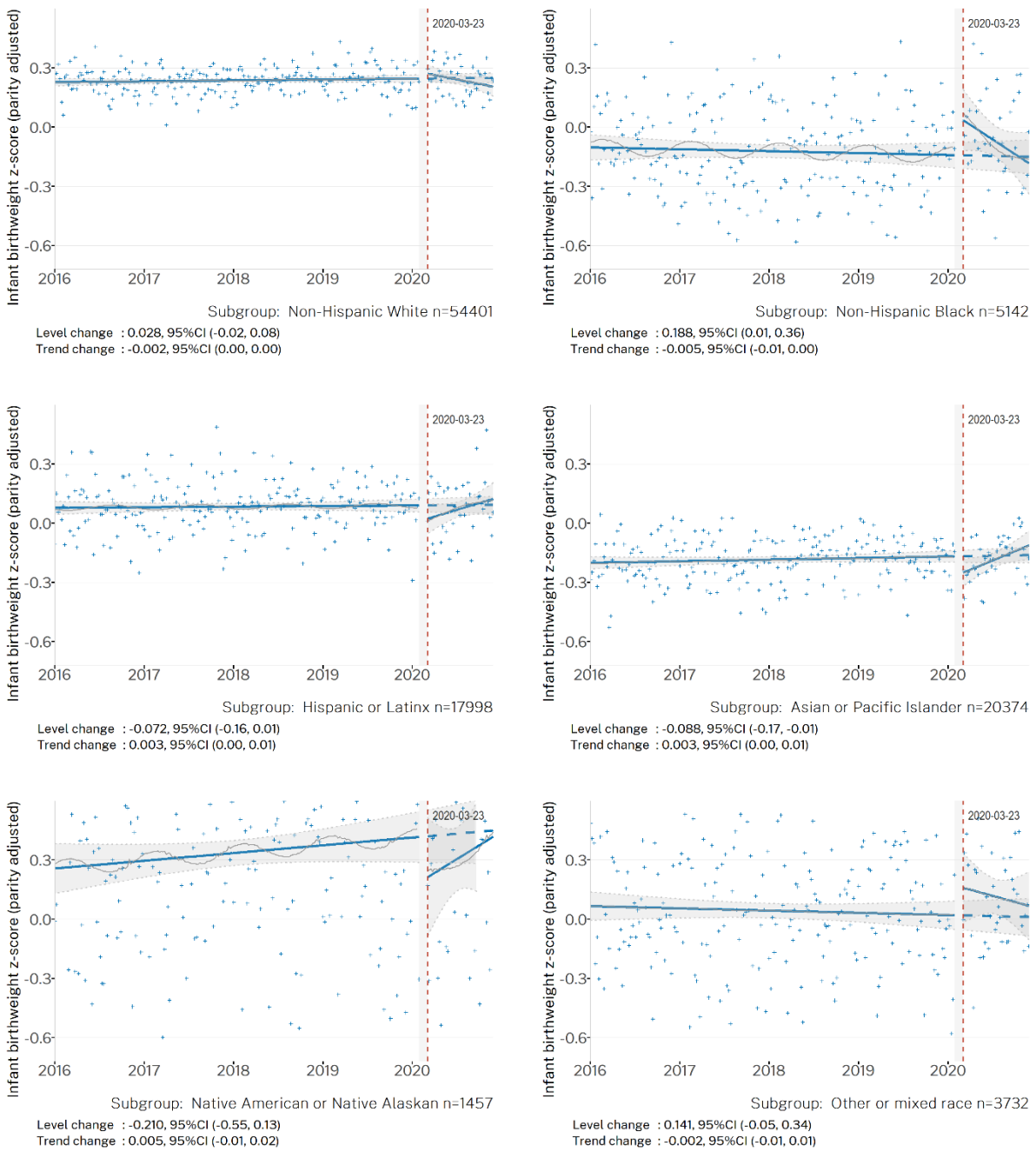


Figure D.14 Subgroup analyses of infant birthweight z-score by insurance payor using an interrupted time series for a Washington State cohort

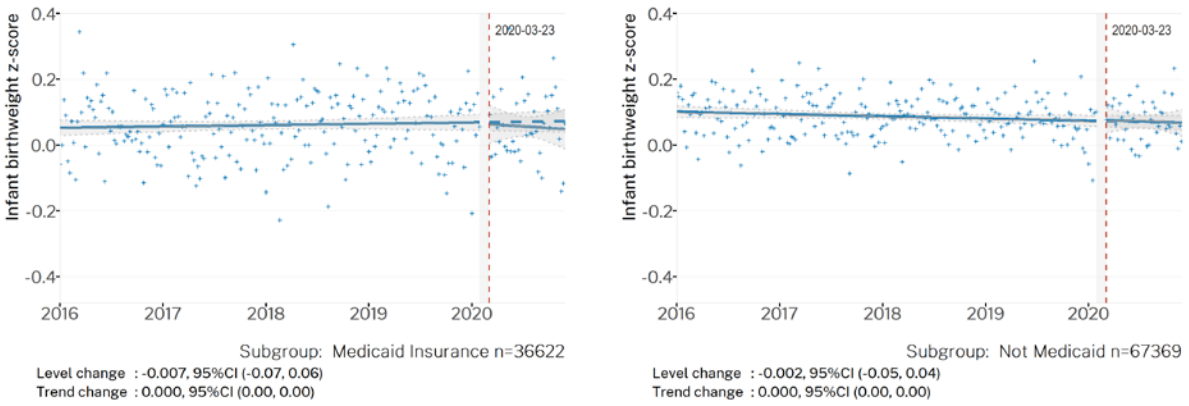


Figure D.15 Subgroup analyses of infant birthweight z-score by parity using an interrupted time series for a Washington State cohort

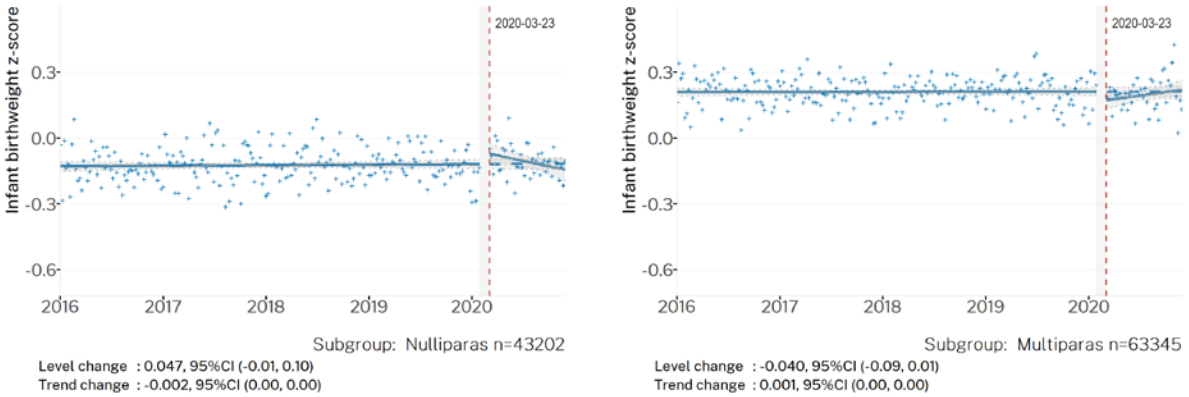
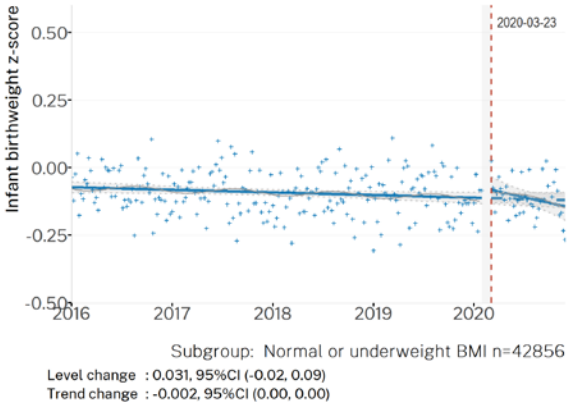
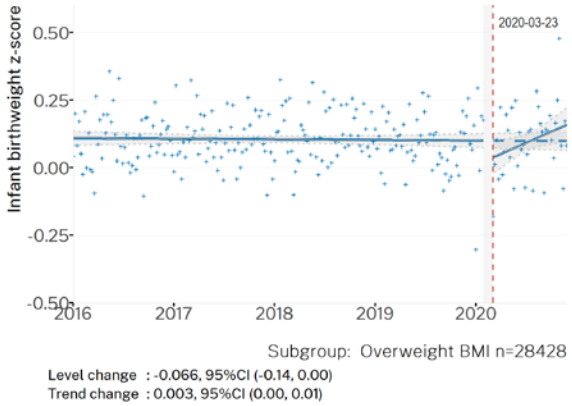


Figure D.16 Subgroup analyses of infant birthweight z-score by pregestational BMI using an interrupted time series for a Washington State cohort





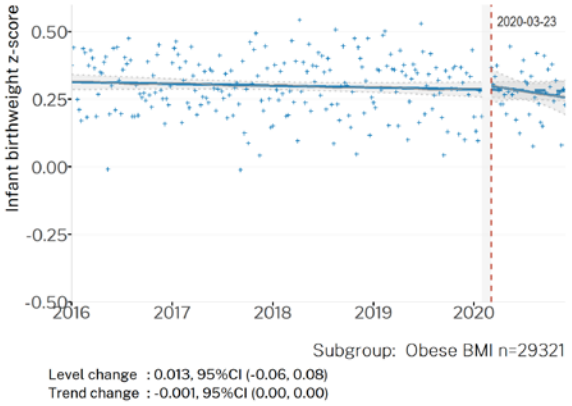


Figure D.17 Comparison of primary analyses and Intergrowth 21 standards for weight gain and infant birthweight z-scores

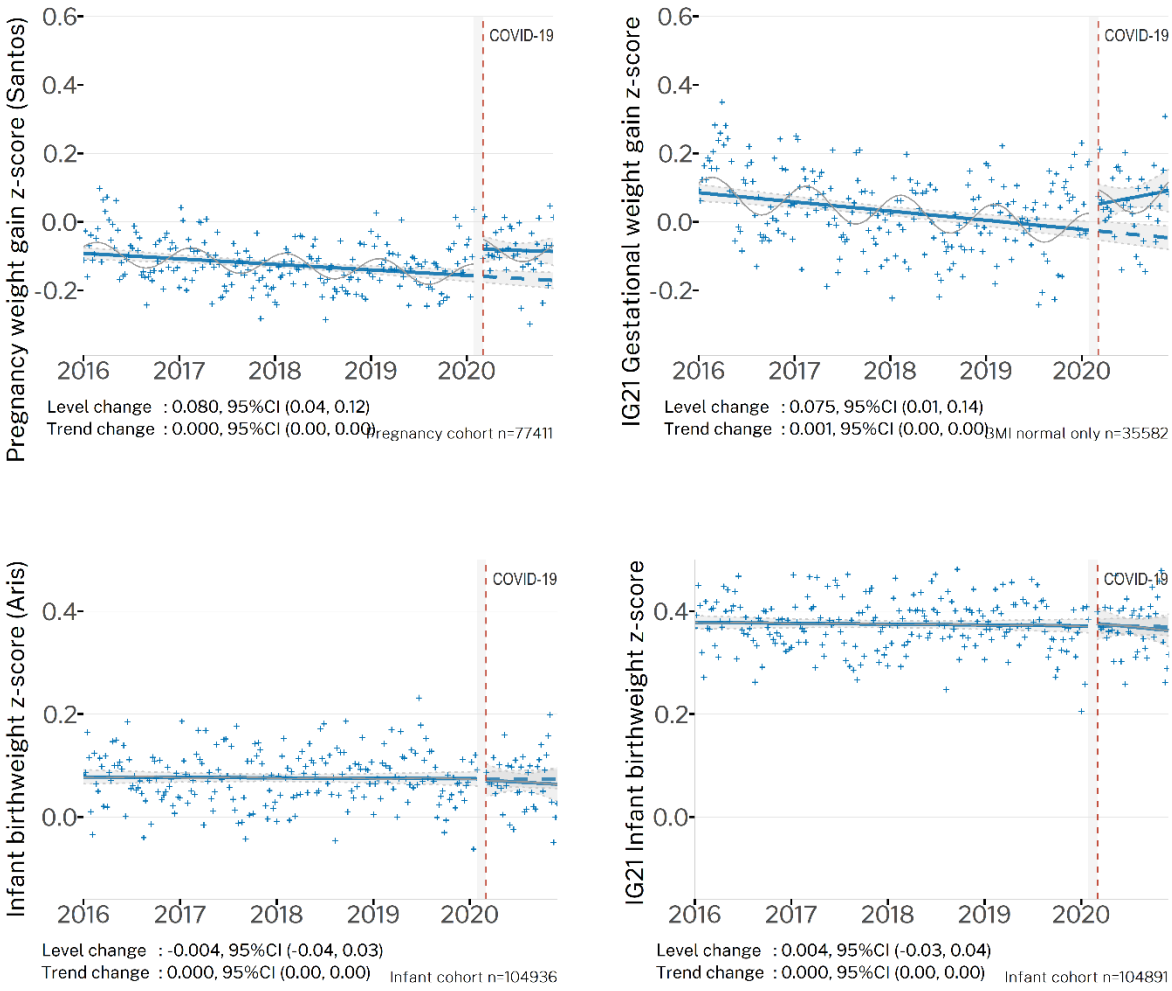


Figure D.18 Infant birthweight z-scores for primary cohort (infants) compared to a matched group with valid pregnancy weight gain

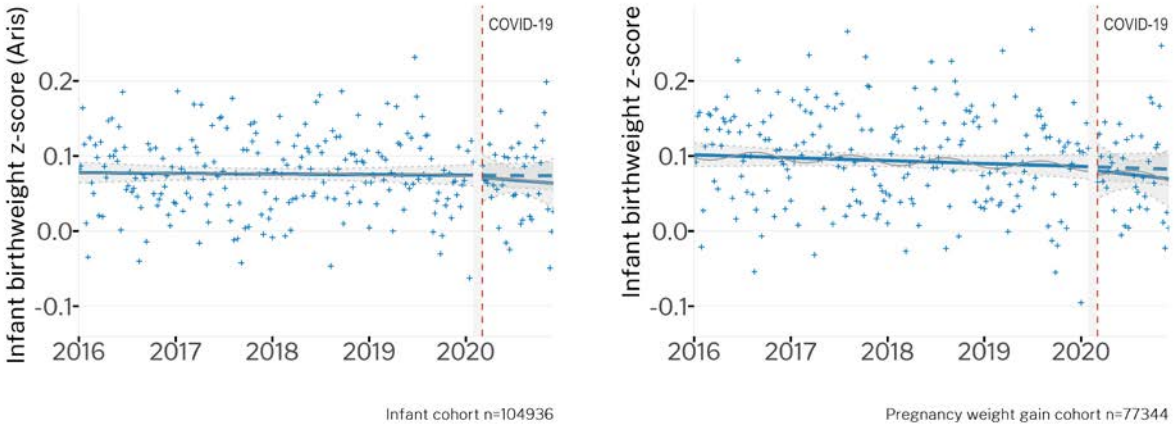


Figure D.19 Parity-adjusted infant z-scores compared to primary outcome

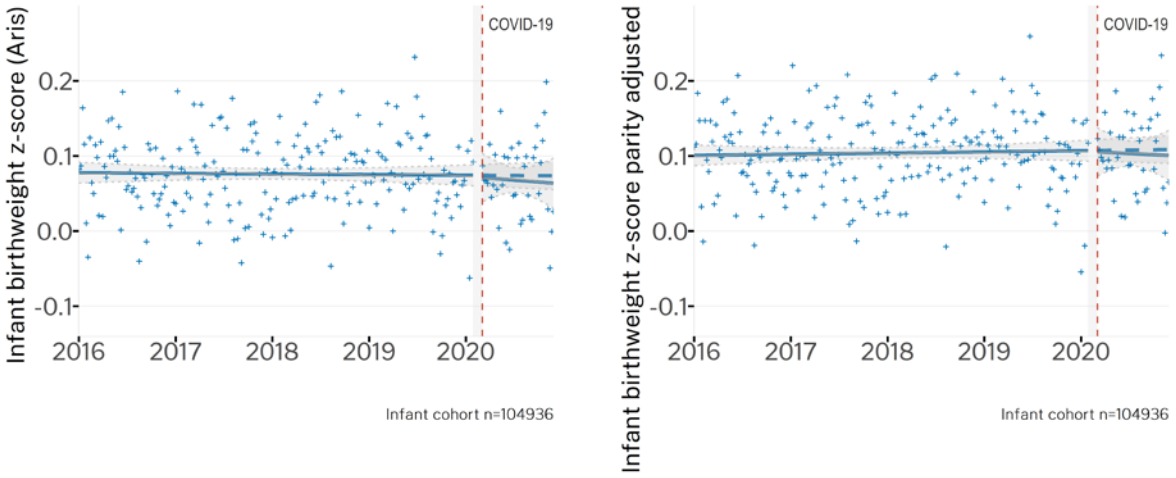


Figure D.20 Rate of monthly Covid-19 Positive pregnancies in complete dataset

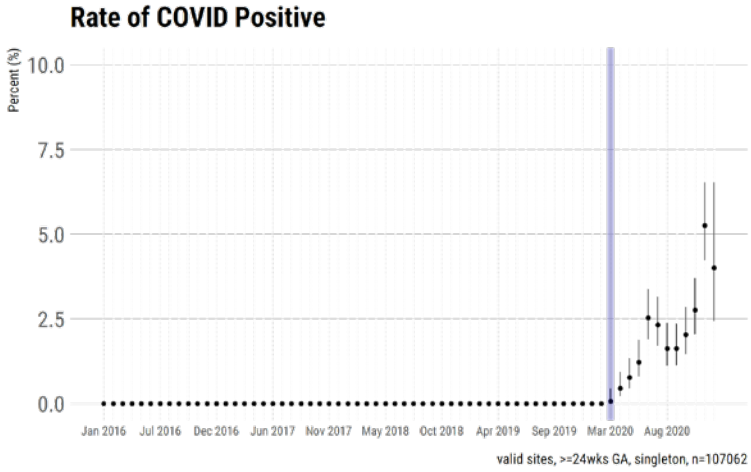


Figure D.21 Interrupted time series plots excluding any known Covid-19 Positive cases

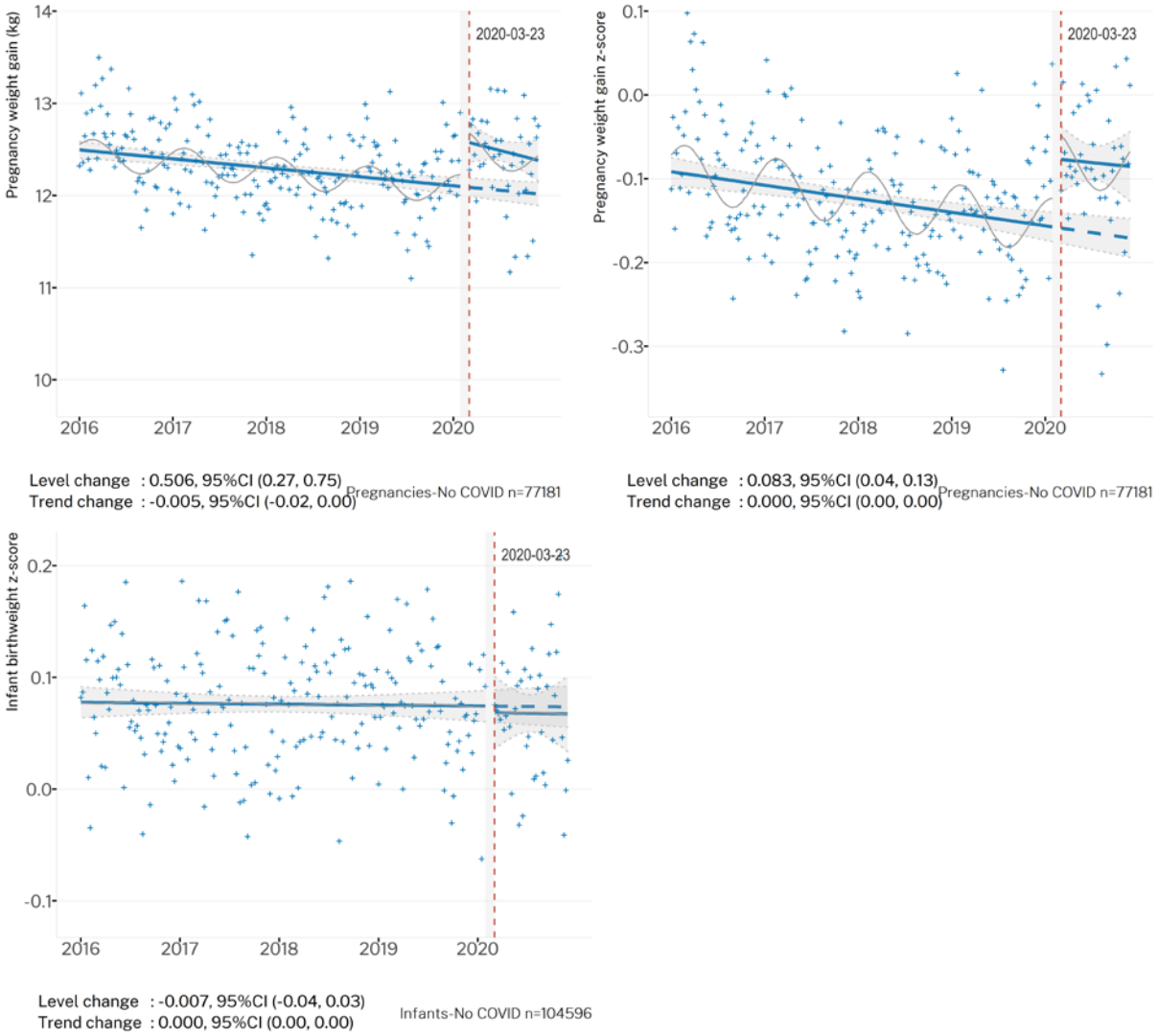
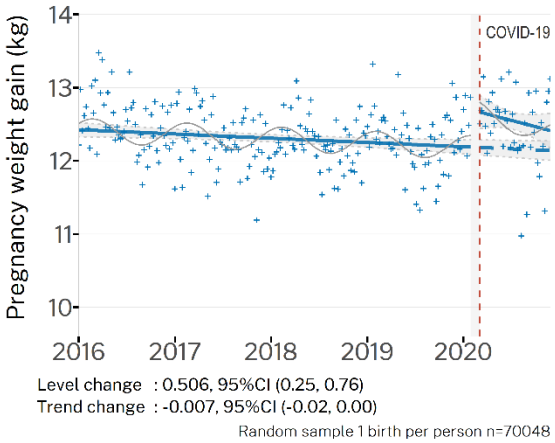
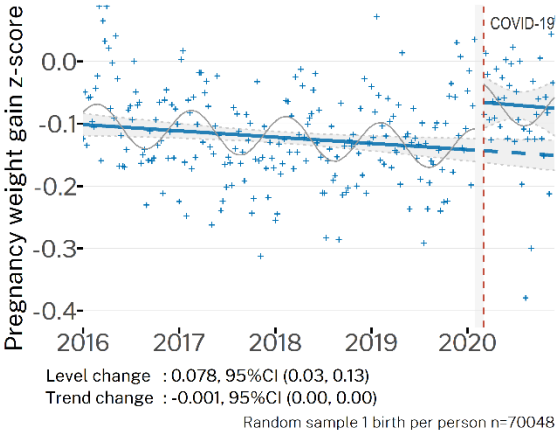


Figure D.22 Interrupted time series for random sampled 1 birth per person for repeated pregnancies





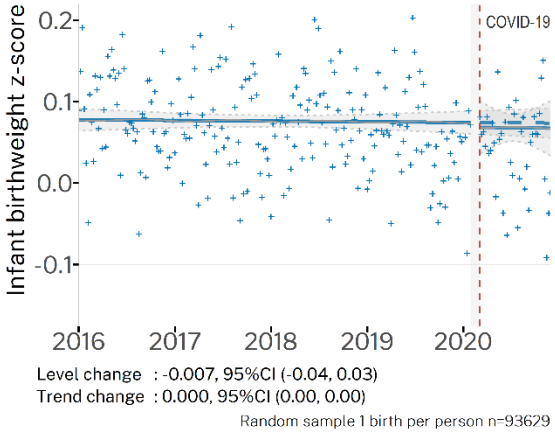
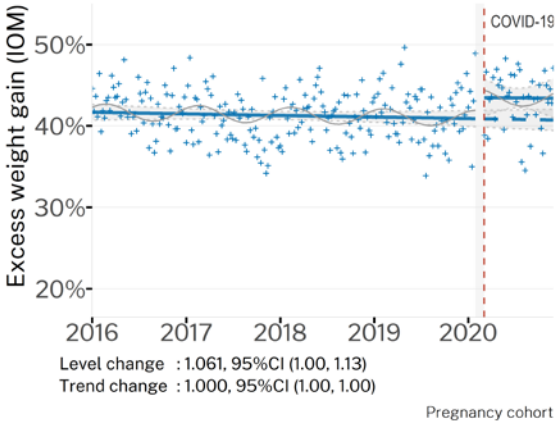


Figure D.23 Excess and Inadequate weight gain using IOM criteria (full cohort, adjusted for weeks): Interrupted time series plots



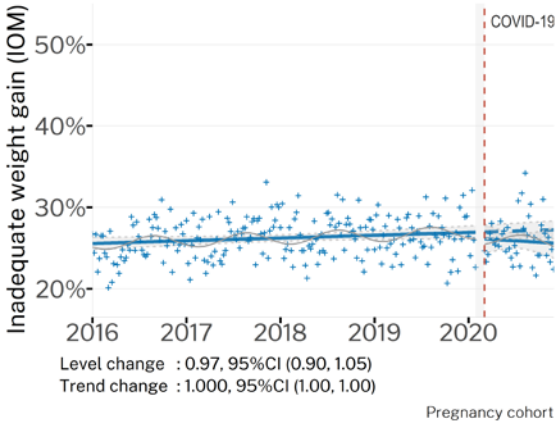


Figure D.24 Excess and Inadequate weight gain using IOM criteria (>=37wks GA only): Interrupted time series plots