GYNECOLOGY

Predicting risk of pelvic floor disorders 12 and 20 years after delivery

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BACKGROUND: Little progress has been made in the prevention of pelvic floor disorders, despite their significant health and economic impact. The identification of women who are at risk remains a key element in targeting prevention and planning health resource allocation strategies. Although events around the time of childbirth are recognized clinically as important predictors, it is difficult to counsel women and to intervene around the time of childbirth because of an inability to convey a patient's risk accurately in the presence of multiple risk factors and the long time lapse, which is often decades, between obstetric events and the onset of pelvic floor disorders later in life. Prediction models and scoring systems have been used in other areas of medicine to identify patients who are at risk for chronic diseases. Models have been developed for use before delivery that predict short-term risk of pelvic floor disorders after childbirth, but no models that predict long-term risk exist.

OBJECTIVE: The purpose of this study was to use variables that are known before and during childbirth to develop and validate prognostic models that will estimate the risks of these disorders 12 and 20 years after delivery.

STUDY DESIGN: Obstetric variables were collected from 2 cohorts: (1) women who gave birth in the United Kingdom and New Zealand (n=3763) and (2) women from the Swedish Medical Birth Register (n=4991). Pelvic floor disorders were self-reported 12 years after childbirth in the United Kingdom/New Zealand cohort and 20 years after childbirth in the Swedish Register. The cohorts were split so that data during the first half of the cohort's time period were used to fit prediction models, and validation was performed from the second half (temporal validation). Because there is currently no consensus on how to best define pelvic floor disorders from a patient's perspective, we chose to fit the data for each model using multiple outcome definitions for prolapse, urinary incontinence, fecal incontinence, ≥1 pelvic floor disorder, and ≥2 pelvic floor disorders. Model accuracy was measured in the following manner: (1) by ranking an individual's risk among all subjects in the cohort (discrimination) with the

use of a concordance index and (2) by observing whether the predicted probability was too high or low (calibration) at a range of predicted probabilities with the use of visual plots.

RESULTS: Models were able to discriminate between women who experienced bothersome symptoms or received treatment at 12 and 20 years, respectively, for pelvic organ prolapse (concordance indices, 0.570, 0.627), urinary incontinence (concordance indices, 0.653, 0.689), fecal incontinence (concordance indices, 0.618, 0.676), ≥1 pelvic floor disorders (concordance indices, 0.639, 0.675), and ≥2 pelvic floor disorders (concordance indices, 0.635, 0.619). Route of delivery and family history of each pelvic floor disorder were strong predictors in most models. Urinary incontinence before and during the index pregnancy was a strong predictor for the development of all pelvic floor disorders in most models 12 years after delivery. The 12- and 20-year bothersome symptoms or treatment for prolapse models were accurate when predictions were provided for risk from 0% to approximately 15%. The 12- and 20-year primiparous model began to over predict when risk rates reached 20%. When we predicted bothersome symptoms or treatment for urinary incontinence, the 12-year models were accurate when predictions ranged from approximately 5—60%; the 20-year primiparous models were accurate from 5% and 80%. For bothersome symptoms or treatment for fecal incontinence, the 12- and 20-year models were accurate from 1—15% risk and began to over predict at rates at >15% and 20%, respectively.

CONCLUSION: Models may provide an opportunity before birth to identify women who are at low risk of the development of pelvic floor disorders and may provide institute prevention strategies such as pelvic floor muscle training, weight control, or elective cesarean section for women who are at higher risk. Models are provided at http://riskcalc.org/UR_CHOICE/.

Key words: fecal incontinence, machine learning, pelvic floor disorder, pelvic organ prolapse, prediction model, urinary incontinence

Pelvic floor disorders such as pelvic organ prolapse, urinary incontinence, and fecal incontinence constitute a huge global health problem that affects

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millions of women throughout the world. The prevalence of pelvic floor disorders has been reported to be 46%, and many women have >1.[1] Pelvic floor disorders can have a negative influence on a woman's well-being, quality of life, body image, and sexual function and prevent many women from participating in recreational and sporting activities.[1,2] The global costs of pelvic floor disorders to healthcare systems and society

are enormous.[1,3] Approximately, 1 of 5 women will undergo surgery for prolapse or urinary incontinence by age 85 years.[4,5] Current treatments, often surgical, carry risks and relatively high rates of recurrence.[6,7]

Little progress has been made in the prevention of pelvic floor disorders, despite their significant health and economic impact.[8] The identification of women who are at risk remains a key element in the targeting of prevention and planning health of resource

allocation strategies. The cause of pelvic floor disorders is known to be multifactorial; obstetric trauma during childbirth is 1 of the most important identifiable risk factors.[1] Numerous epidemiologic studies indicate an increased prevalence of pelvic floor disorders with increasing parity with the greatest increase in risk that is attributed to the birth of the first child.[1] Although events around the time of childbirth are recognized clinically as important predictors, many women undergo the labor and delivery process and do not experience long-term pelvic floor dysfunction. At present, it is difficult to counsel women and intervene around the time of childbirth because of an inability to convey a patient's risk accurately in the presence of multiple risk factors and the long-time lapse, often decades, between obstetric events and the onset of pelvic floor disorders later in life.

Prediction models and scoring systems have been used in other areas of medicine to identify patients who are at risk for chronic diseases.[9,10] Models have been developed for use before delivery that predict short-term risk of pelvic floor disorders after childbirth; however, no models that predict long-term risk exist.[11,12] The aims of this study were to construct and validate models that are capable of predicting the development of pelvic floor disorders 12 and 20 years after delivery with the use of data from 2 large independent international cohort studies.[13,14] Such models have potential to provide individual women more accurate predictions than the current standard of care that is given: (1) the paucity of existing tools, (2) the large amount of variability in the predicted rates of pelvic floor disorders that are provided by clinicians in practice, and (3) the increasing evidence that clinical prediction models consistently show superiority over expert clinicians because they avoid common cognitive biases.[15,16]

Methods

This study used methods set forth in the transparent reporting of a multivariable prediction model for individual prognosis or diagnosis: the TRIPOD statement.[17] The study population consisted of 2 longitudinal, prospective cohort studies. The Prolapse and Incontinence Long-term (ProLong) study aimed to determine whether delivery mode was predictive of pelvic floor disorders in 10,989 primiparous and multiparous women 12 years after the index birth.[14] The second cohort was the Swedish Pregnancy, Obesity and Pelvic Floor (SwePOP) study. The aim of SwePOP was to compare the prevalence of pelvic floor disorders in a cohort of 10,117 primiparous women identified from the Swedish Medical Birth Register 20 years after 1 delivery.[13,18] Both studies were designed to investigate delivery mode as a predictor of pelvic floor disorders and therefore captured key maternal, labor, and delivery variables that were known, at that time, to be potential risk factors of pelvic floor disorders. Study details have been published previously and are summarized in Figure 1.[14,18]

In the ProLong study, prolapse symptoms were measured with the use of the validated Pelvic Organ Prolapse Symptom Score.[19] Urinary and fecal incontinence questions were designed by the study team because, at the time of recruitment (1993/94), there were no suitable validated questionnaires on incontinence. Family history was measured with the use of a response of either "yes" or "no" to the following questions: "Have any of your blood relatives ever had a prolapse?" "If yes, how are they related to you (eg, mother, sister)?" In the SwePOP study, prolapse was defined with the use of the validated five-item questionnaire[20]; urinary incontinence was defined with the use of the Sandvik severity scale,[21] and fecal incontinence was defined with the use of the Wexner score.[22] Family history was measured with a response of either "yes" or "no" to each of the following questions: "Has your mother suffered from urinary leakage?" "Has your mother suffered from prolapse?" and "Has your mother suffered from leakage of flatus/gas or feces?" Each study received ethics committee approval at all centers. Written informed consent was obtained from participants in both studies.
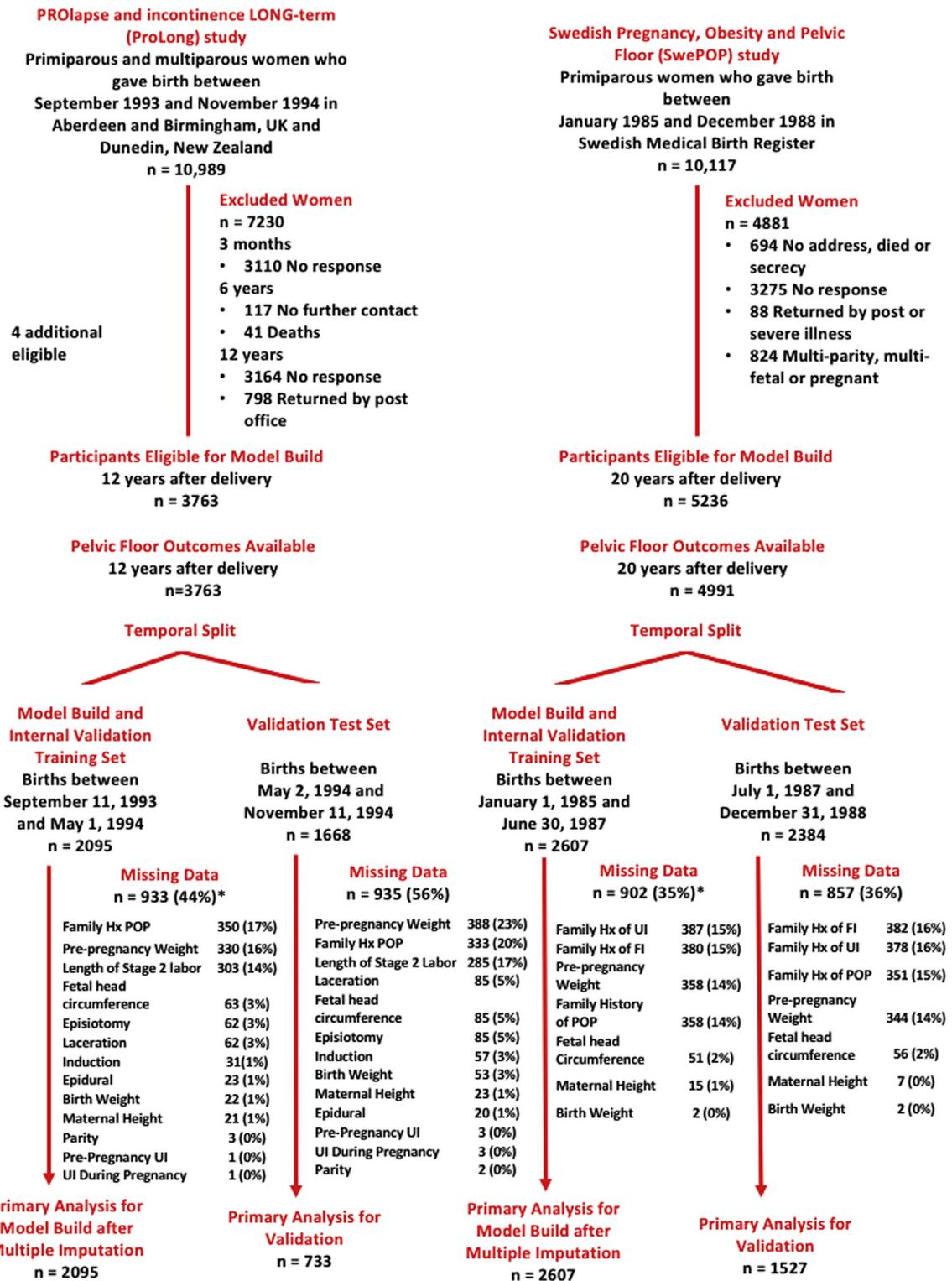
To allow for temporal validation, each cohort was split temporally so that women who gave birth in the first half of the cohort's time period were considered for the training dataset and used to build each model. For the ProLong dataset, data from primiparous and multiparous women who gave birth between September 11, 1993, and May 1, 1994, and who responded at 12 years (n=2095) were used to build models to predict 12-year outcomes for women who gave birth between May 2, 1994, and November 11, 1994 (n=1668). Similarly, in the SwePOP dataset, data from primiparous women who gave birth between January 1, 1985, and June 30, 1987 (n=2607) were used to build models to predict 20-year outcomes for women who gave birth between July 1, 1987, and December 31, 1988 (n=2384). For each training dataset, the multiple imputation with the use of chained equations method was used to calculate missing values for predictors.[23] Predictors for the test dataset and outcomes for all models were based on actual, not imputed values.

Because there is currently no consensus on how to best define pelvic floor disorders from a patient's perspective, we chose to fit the data for each model using multiple outcome definitions for prolapse, urinary incontinence, fecal incontinence, ≥1 pelvic floor disorders and ≥2 pelvic floor disorders. We developed models in the following 4 categories to predict (1) the presence of "any symptoms" regardless of severity, (2) the presence of bothersome symptoms, (3) treatment for the disorder, or (4) the combination of either bothersome symptoms or receiving treatment for each disorder (prolapse, urinary incontinence, fecal incontinence) and their combination (any pelvic floor disorder or ≥2 pelvic floor disorders; Table 1). Data are presented only for category 4, and all remaining outcomes are available in the supplemental results.

Multiple logistic regression models were fit to the training data that consisted of the full set of candidate predictors and each outcome. Harrell's "Model Approximation" process of backwards elimination was used to rank the variables in order of importance,

FIGURE 1
Participant flow diagram

PROlapse and incontinence LONG-term (ProLong) study
Primiparous and multiparous women who gave birth between September 1993 and November 1994 in Aberdeen and Birmingham, UK and Dunedin, New Zealand
n = 10,989

Swedish Pregnancy, Obesity and Pelvic Floor (SwePOP) study
Primiparous women who gave birth between January 1985 and December 1988 in Swedish Medical Birth Register
n = 10,117

Excluded Women
n = 7230
3 months
• 3110 No response
6 years
• 117 No further contact
• 41 Deaths
12 years
• 3164 No response
• 798 Returned by post office

4 additional eligible

Excluded Women
n = 4881
• 694 No address, died or secrecy
• 3275 No response
• 88 Returned by post or severe illness
• 824 Multi-parity, multi-fetal or pregnant

Participants Eligible for Model Build
12 years after delivery
n = 3763

Participants Eligible for Model Build
20 years after delivery
n = 5236

Pelvic Floor Outcomes Available
12 years after delivery
n=3763

Pelvic Floor Outcomes Available
20 years after delivery
n = 4991

Temporal Split

Temporal Split

Model Build and Internal Validation Training Set
Births between September 11, 1993 and May 1, 1994
n = 2095

Validation Test Set
Births between May 2, 1994 and November 11, 1994
n = 1668

Model Build and Internal Validation Training Set
Births between January 1, 1985 and June 30, 1987
n = 2607

Validation Test Set
Births between July 1, 1987 and December 31, 1988
n = 2384

Missing Data
n = 933 (44%)*

Family Hx POP	350 (17%)
Pre-pregnancy Weight	330 (16%)
Length of Stage 2 labor	303 (14%)
Fetal head circumference	63 (3%)
Episiotomy	62 (3%)
Laceration	62 (3%)
Induction	31 (1%)
Epidural	23 (1%)
Birth Weight	22 (1%)
Maternal Height	21 (1%)
Parity	3 (0%)
Pre-Pregnancy UI	1 (0%)
UI During Pregnancy	1 (0%)

Missing Data
n = 935 (56%)

Pre-pregnancy Weight	388 (23%)
Family Hx POP	333 (20%)
Length of Stage 2 labor	285 (17%)
Laceration	85 (5%)
Fetal head circumference	85 (5%)
Episiotomy	85 (5%)
Induction	57 (3%)
Birth Weight	53 (3%)
Maternal Height	23 (1%)
Epidural	20 (1%)
Pre-Pregnancy UI	3 (0%)
UI During Pregnancy	3 (0%)
Parity	2 (0%)

Missing Data
n = 902 (35%)*

Family Hx of UI	387 (15%)
Family Hx of FI	380 (15%)
Pre-pregnancy Weight	358 (14%)
Family History of POP	358 (14%)
Fetal head Circumference	51 (2%)
Maternal Height	15 (1%)
Birth Weight	2 (0%)

Missing Data
n = 857 (36%)

Family Hx of FI	382 (16%)
Family Hx of UI	378 (16%)
Family Hx of POP	351 (15%)
Pre-pregnancy Weight	344 (14%)
Fetal head circumference	56 (2%)
Maternal Height	7 (0%)
Birth Weight	2 (0%)

Primary Analysis for Model Build after Multiple Imputation
n = 2095

Primary Analysis for Validation
n = 733

Primary Analysis for Model Build after Multiple Imputation
n = 2607

Primary Analysis for Validation
n = 1527

An *asterisk* denotes imputation was performed.

FI, fecal incontinence; *Hx*, history; *POP*, pelvic organ prolapse; *SwePOP*, Swedish pregnancy, obesity and pelvic floor; *UI*, urinary incontinence.

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TABLE 1
Overall rates of pelvic floor disorders with 95% confidence intervals 12 and 20 years after delivery

Variable	Parity	Any		Bothersome		Treatment		Bothersome or Treatment	
		N	% (95% confidence interval)	N	% (95% confidence interval)	N	% (95% confidence interval)	N	% (95% confidence interval)
Pelvic organ prolapse, yr[a]									
12	0	291	17 (15.1–18.7)	102	6 (4.8–7.0)	28	2 (1.2–2.6)	126	8 (7.0–9.8)
20	0	646	13 (12.1–14.0)	300	6 (5.4–6.7)	73	1.5 (1.2–1.9)	346	7 (6.6–8.1)
12	≥1	347	17 (15.4–18.7)	111	5 (4.5–6.4)	61	3 (2.6–4.3)	159	9 (7.6–10.3)
Urinary incontinence, yr[b]									
12	0	877	51 (48.5–53.3)	380	22 (20.2–24.2)	83	5 (3.9–6.0)	423	25 (23.2–27.4)
20	0	1895	38 (36.9–39.6)	822	17 (15.7–17.8)	163	3 (2.9–3.9)	902	19 (17.9–20.1)
12	≥1	1103	54 (52.0–56.4)	510	25 (23.5–27.3)	113	6 (4.7–6.8)	564	29 (26.8–30.8)
Fecal incontinence, yr[c]									
12	0	203	12 (10.3–13.4)	42	2 (1.7–3.2)	37	2 (1.5–2.9)	68	4 (3.2–5.1)
20	0	671	14 (12.6–14.5)	112	2 (1.8–2.7)	54	1 (0.8–1.4)	145	3 (2.5–3.5)
12	≥1	283	14 (12.5–15.5)	74	4 (2.8–4.5)	56	3 (2.1–3.6)	109	6 (4.5–6.6)
≥1 Pelvic floor disorders, yr									
12	0	1031	60 (57.7–62.3)	461	27 (25.0–29.2)	132	9 (7.6–10.6)	528	35 (32.4–37.2)
20	0	2322	47 (45.7–48.5)	1051	22 (20.3–22.7)	265	6 (5.1–6.5)	1163	25 (24.0–26.5)
12	≥1	1255	62 (59.7–63.9)	590	29 (27.4–31.4)	197	12 (10.1–13.1)	680	38 (35.8–40.3)
≥2 Pelvic floor disorders, yr									
12	0	298	17 (15.5–19.1)	60	3.5 (2.6–4.4)	15	1 (0.4–1.4)	74	4 (3.5–5.4)
20	0	743	15 (14.0–16.0)	167	3 (2.9–3.9)	25	0.5 (0.3–0.7)	185	4 (3.3–7.1)
12	≥1	406	20 (18.3–21.7)	97	5 (3.9–5.7)	31	1.5 (1.0–2.1)	120	6 (5.1–7.2)

[a] *Pelvic organ prolapse* was defined at 12 years with responses to the following question: "Do you have a feeling of something coming down from or in your vagina?" Responses were occasionally, sometimes, most of the time, or all of the time. *Bothersome pelvic organ prolapse* was defined with the following responses: sometimes, most of the time, or all of the time. At 20 years, pelvic organ prolapse was defined with responses to the following question: "Do you have a feeling of something bulging from your vagina?" Responses were infrequently, sometimes, or often. Bothersome pelvic organ prolapse was defined with responses of sometimes or often; [b] *Urinary incontinence* was defined at 12 years with responses to the following questions: "Do you ever lose urine when you don't mean to?" If yes, "in the last month how often has this happened, on average?" Responses for any urinary incontinence were <2 times per month, weekly, or ≥3 times a day; responses for *bothersome urinary incontinence* were weekly or ≥3 times a day. At 20 years, urinary incontinence was defined with the following questions: "Do you have involuntary leakage of urine?" If yes, "how often has this happened, on average?" Responses for any incontinence were <2 times per month, weekly, ≥3 times a day; responses for bothersome urinary incontinence were weekly or ≥3 times a day; [c] *Fecal incontinence* was defined at 12 years with responses to the following question: "Do you ever lose control of bowel motions (stool/feces) from your back passage in between visits to the toilet?" Responses for any fecal incontinence were occasionally, sometimes, most of the time, or all of the time. Responses for *bothersome fecal incontinence* were most of the time and all of the time. At 20 years, having fecal incontinence was defined as responses to the Wexner scale questions: "Do you have involuntary leakage of solid feces?" or "Do you have involuntary leakage of liquid feces?" Any fecal incontinence was defined with the following responses: less than once a month (rarely), once a month but less than once a week (sometimes), greater than once a week but less than once a day (usually), or once or more every day (always). Bothersome fecal incontinence was defined with responses to the following question: "Has involuntary leakage of liquid or solid feces influenced your feeling of frustration?" Responses of moderately or very much were considered bothersome, although responses of not at all or a little were not bothersome.

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starting from the full model with the use of a bootstrap bias-corrected concordance index as the stopping criteria to find the best parsimonious model.[24] Variables with individual probability values that were >.05 were left in the model if they offered information to improve the overall model accuracy. Removal was evaluated by the determination of which variable had the smallest effect on the R^2 and was stopped when the bootstrap concordance index had a change <.01. This process provided a parsimonious model for each outcome.

Model accuracy was measured (1) by ranking an individual's risk among all subjects in the cohort (discrimination) with the use of a concordance index and (2) by observing whether the predicted probability was too high or low (calibration) at a range of predicted

TABLE 2
Discrimination of risk with the use of concordance indices for models to predict pelvic floor disorders 12[a] and 20[b] years after delivery

Outcome	Year	Model build		Temporal validation Concordance index
		Concordance index	95% Confidence interval	
Pelvic organ prolapse				
Any	12	0.623	0.591–0.653	0.598
	20	0.680	0.648–0.712	0.619
Bothersome	12	0.660	0.612–0.706	0.598
	20	0.736	0.695–0.779	0.606
Treatment	12	0.734	0.667–0.804	0.560
	20	0.809	0.739–0.870	0.751
Bothersome or treatment	12	0.644	0.603–0.683	0.570
	20	0.751	0.714–0.791	0.627
Urinary incontinence				
Any	12	0.672	0.650–0.696	0.641
	20	0.714	0.692–0.734	0.695
Bothersome	12	0.702	0.677–0.730	0.640
	20	0.691	0.665–0.717	0.684
Treatment	12	0.651	0.602–0.702	0.712
	20	0.685	0.625–0.745	0.634
Bothersome or treatment	12	0.704	0.679–0.731	0.653
	20	0.698	0.673–0.724	0.689
Fecal incontinence				
Any	12	0.605	0.570–0.636	0.586
	20	0.648	0.619–0.677	0.624
Bothersome	12	0.640	0.569–0.710	0.638
	20	0.720	0.658–0.788	0.658
Treatment	12	0.687	0.620–0.750	0.542
	20	0.674	0.571–0.759	0.642
Bothersome or treatment	12	0.670	0.616–0.721	0.618
	20	0.701	0.644–0.759	0.676
≥ 1 Pelvic floor disorder				
Any	12	0.664	0.643–0.688	0.650
	20	0.700	0.681–0.719	0.685
Bothersome	12	0.686	0.663–0.713	0.643
	20	0.693	0.668–0.717	0.667
Treatment	12	0.670	0.628–0.710	0.649
	20	0.656	0.614–0.698	0.623
Bothersome or treatment	12	0.687	0.661–0.711	0.639
	20	0.698	0.674–0.722	0.675

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(continued)

TABLE 2
Discrimination of risk with the use of concordance indices for models to predict pelvic floor disorders 12[a] and 20[b] years after delivery (continued)

| Outcome | Year | Model build | | Temporal validation |
		Concordance index	95% Confidence interval	Concordance index
≥2 Pelvic floor disorders				
Any	12	0.648	0.618–0.677	0.581
	20	0.702	0.673–0.729	0.676
Bothersome	12	0.730	0.680–0.781	0.661
	20	0.760	0.707–0.808	0.621
Treatment	12	0.738	0.650–0.831	0.711
	20	0.600	0.507–0.744	0.513
Bothersome or treatment	12	0.706	0.644–0.751	0.635
	20	0.753	0.705–0.802	0.619

[a] Year 12 includes data from the Prolapse and Incontinence Long-Term Study dataset; [b] year 20 includes data from Swedish Pregnancy, Obesity and Pelvic Floor Study dataset.

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probabilities with the use of visual plots. Once the models were built and before temporal validation was performed, all concordance indices were validated internally with the use of 1000 bootstrap samples to adjust for overfitting biases on the initial build, and 95% confidence intervals were calculated. Calibration curves along with distributions of predicted probabilities of those with and without each outcome were generated to observe visually how close model predictions were to actual predictions.

Temporal validation requires a prognostic model to produce accurate predictions when it is tested in cohorts from different time periods. It is a prospective form of validation that is recommended when an independent validation data set with similar obstetric populations and long-term outcomes is not available.[17] Models were developed with the use of antepartum variables, previous delivery variables, and delivery mode. We specifically investigated whether events that occurred at the time of delivery (eg, episiotomy, perineal laceration) significantly improved the accuracy of prediction by comparing the difference in accuracy with the use of a bootstrap method from their respective receiver-operating characteristic curve.

All models were combined into a single integrated web-based calculator so that a complete set of predictors can be entered; outcomes for all pelvic floor disorders are presented. All analyses were performed using *R* version 3.2.3 (2015-12-10).

Results

Baseline characteristics and outcomes were available in 3763 participants in the ProLong study 12 years after their index birth and 4991 of the participants in the SwePOP study 20 years after their first and only birth. The overall rates of pelvic floor disorders with 95% confidence intervals 12 and 20 years after delivery are described in Table 1. The descriptive statistics of candidate predictors among each study cohort are provided in the Supplemental Table.
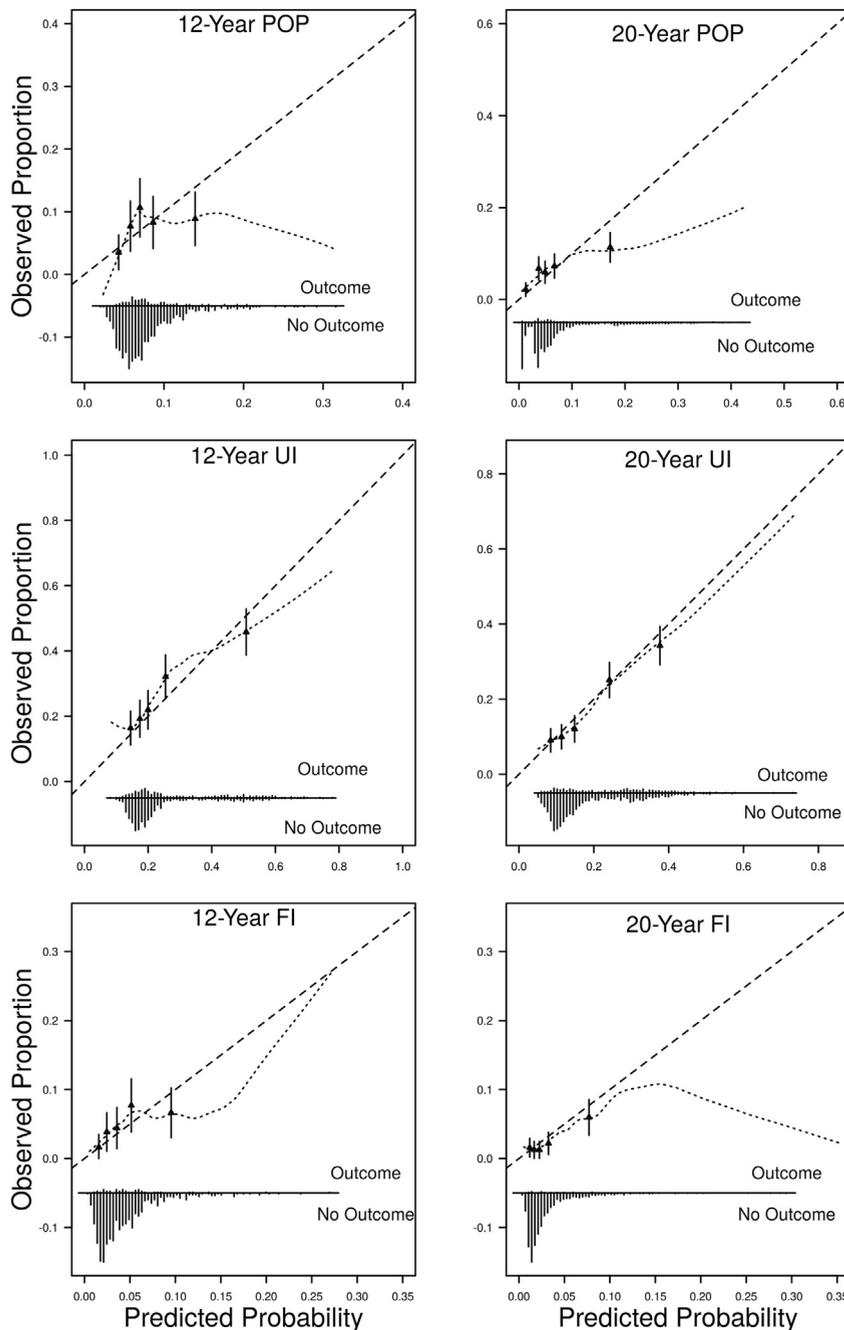
Model discrimination

Forty separate models were developed from the 2 cohorts that included 20 models that predict outcomes in primiparous and multiparous women 12 years after delivery and 20 models that predict outcomes in primiparous women 20 years after delivery. All 40 final models included predictors known or estimated before delivery along with actual route of delivery. Each model's discriminatory ability is shown in Table 2. Models were able to discriminate between women who experienced bothersome symptoms or received treatment at 12 and 20 years, respectively, for pelvic organ prolapse (concordance indices, 0.570, 0.627), urinary incontinence (concordance indices, 0.653, 0.689), fecal incontinence (concordance indices, 0.618, 0.676), ≥1 pelvic floor disorders (concordance indices, 0.639, 0.675) and ≥2 pelvic floor disorders (concordance indices, 0.635, 0.619).

Model calibration

Calibration curves for the models from the 2 cohorts that predicted bothersome pelvic floor disorders or the need for treatment at 12 and 20 years are shown in Figure 2. The majority of models predicted probabilities close to actual probabilities throughout a range of clinically useful predictions but began to over-predict at higher probabilities. The 12- and 20-year bothersome symptom or treatment for prolapse models was accurate when predictions for risk were provided from 0% to approximately 15% (average risk, 7-10%; Table 1).

The 12- and 20-year primiparous model began to over-predict when risk rates reached 20%. When bothersome symptoms or treatment for urinary incontinence are predicted, the 12-year models were accurate when predictions ranged from approximately 5–60% (average risk, 23-31%; Table 1), and the 20-year primiparous models were accurate from 5–80% (average risk, 18-20%; Table 1). For bothersome symptoms or treatment for fecal incontinence, the 12-

FIGURE 2
Calibration curves

Calibration curves models that, before delivery, predict bothersome pelvic floor disorder or the need for treatment for a pelvic floor disorder 12 and 20 years after delivery. The *horizontal axis* is the predicted probability provided by the model; the *vertical axis* is the actual probability of the outcome. The plots were inspected for predicted probabilities to remain close to actual probabilities (the *45-degree line*) within the range of probabilities at which point patient or clinical decisions are made. When the *dotted line* is under the dashed 45-degree line, the model provides predictions that are higher than actual probabilities (over-prediction); if the *dotted line* is over the dashed 45-degree line, the model provides predictions that are lower than actual probabilities (under-prediction).

FI, fecal incontinence; *POP*, pelvic organ prolapse; *UI*, urinary incontinence.

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and 20-year models were accurate from 1–15% risk (average risk, 3-7%; Table 1). The bothersome symptoms or treatment for fecal incontinence models began to over-predict at rates above 15% and 20% for the 12- and 20-year model, respectively. A complete set of calibration curves for models that predicted all outcomes at 12 and 20 years are available in Supplemental Figure 1. An online calculator (http://riskcalc.org/UR_CHOICE/) is available for clinical use, and 2 examples of predictions for a hypothetical average and high-risk patient are displayed (Supplemental Figure 2).

Model variables
The relative influence of each predictor for models predicting the combination of bothersome symptoms or receiving treatment for each disorder is summarized in Figure 3. Route of index delivery, number of previous births, and family history of each pelvic floor disorder were the most influential elements in most models. Any urinary incontinence before pregnancy was an influential predictor for women experiencing bothersome prolapse or having treatment for prolapse, urinary incontinence, and fecal incontinence 12 years after delivery. In primiparous women at 20 years, having a vaginal delivery was associated significantly with increasing a woman's 20-year risk of the development of bothersome symptoms or treatment for prolapse and urinary incontinence. The strength of association among the predictors for all models is provided in Supplemental Figure 3.

Comment
Most women undergo childbirth without experiencing bothersome pelvic floor disorders or requiring treatment for pelvic floor disorders throughout their lifespan. More recently, women are seeking more evidence-based informed decision-making before labor that will reassure them that the birthing process will not be detrimental to their long-term health.

Informing a woman of her risks of pelvic floor disorders along with other risks of childbirth is in accordance with the judgment of the 2015 United Kingdom Supreme Court case and

FIGURE 3
Odds ratios

Odds ratios for predictors in the models that predict bothersome pelvic organ prolapse, urinary or fecal incontinence, or the need for treatment for these conditions 12 and 20 years after delivery. Each *box* indicates the odd ratio of each variable that was included in the model; the *horizontal line* indicates the 95% confidence interval. If the horizontal line and box are *green* then the variable was significant at a level of .05. An *arrow* indicates that the line or the odd ratio extend off of the plot.

C, cesarean; *FI*, fecal incontinence; *POP*, pelvic organ prolapse; *UI*, urinary incontinence.

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supports a woman's autonomy and her right to informed choice regarding her care in pregnancy and childbirth.[25] A major barrier to effective prevention of pelvic floor disorders is the inability to identify "at risk" women to target prevention programs. Childbirth is among the most important and consistent risk factor for pelvic floor disorders; however, in most women, clinically relevant symptoms and treatment occur decades later in life.[26] The models that are presented, although not perfect, predict better than chance and are able to discriminate between those women with and without pelvic floor disorders 51—75% of the time. Traditionally, when estimates of risk are provided to women during pregnancy, they are based on a clinician's knowledge and experience by quoting overall average population risk to all women or by heuristically assigning individuals into crude categories

such as low- or high-risk groups. Even when high-level evidence exists, estimates typically are provided without accurately accounting for the specifics of a woman's unique characteristics, such as her age, parity, comorbidities, and family history.

The development and implementation of accurate clinical tools that go beyond clinical judgment and predict an individual woman's future risk of the development of pelvic floor disorders will be an essential component of any primary prevention strategy and will help reassure most mothers when serious pelvic floor damage is not predicted strongly.

We developed models for multiple definitions of each pelvic floor disorder outcome, combined into a single, easy-to-use, on-line calculator. The models allow calculation of risk that includes past delivery characteristics and planned

route of delivery (vaginal vs cesarean). The role of elective cesarean delivery in the prevention of pelvic floor disorders remains controversial and, given the potential maternal and fetal risks, is unlikely to be an effective prevention strategy for most women.[26,27] It has been estimated, for instance, that approximately 9 cesarean deliveries would be necessary to prevent urinary incontinence in 1 primiparous woman of average risk.[18] However, a strategy of offering cesarean delivery to women who are at substantially higher than average risk for pelvic floor disorders may be a more appropriate and effective prevention strategy. At what risk threshold that occurs currently is unknown however and must be balanced against the risks of cesarean delivery and, in many cases, multiple repeat cesarean deliveries, especially because maximum protection may occur when all deliveries are by

cesarean section.[14,26] After delivery, the models are intended for women who may be considering other secondary prevention strategies. Prevention strategies such as pelvic floor muscle training and weight loss programs offer promise but have not been studied adequately long term or many years after delivery.[28] Compliance with long-term prevention programs is a significant challenge and may be improved by informing women about their individual risk of the development of the disorders.[29]

The major strengths of this analysis are the application of predictive analytics to 2 large well-described cohorts of women that collected common maternal and obstetric variables and similarly defined pelvic floor disorder outcomes 12 and 20 years after delivery. Although not racially diverse, together these cohorts do provide important geographic and cultural diversity, which are important for conditions that affect quality of life. However, there are important differences in the 2 cohorts. The ProLong dataset includes primiparous and multiparous women and reports outcomes at 12 years after delivery; the SwePOP study included only primiparous women and reported outcomes at 20 years after delivery. Because of these differences, we chose not to develop our prediction models in 1 cohort and then externally validate them in the other, as is commonly done. Instead, we performed temporal validation in each separate cohort, which is a stronger approach than the more commonly performed random splitting of a dataset into a development and validation cohort.[17]

An important limitation of our models is that they are not perfect. In spite of this, they advance our current abilities to predict an individual's risk of the development of pelvic floor disorders many years after childbirth better than providing highly variable, average event rates. The models in this analysis provide similar discrimination to other predictive models that currently are used in clinical practice the concordance indices of which generally range from 0.6—0.8 that include widely used models such as the National Cancer Institute Gail model for the prediction of breast cancer risk

(concordance index, 0.59) and the Framingham Cardiovascular Risk Model (concordance index, 0.72).[9,30] Although the models developed in this analysis were well-calibrated at clinical decision-making thresholds, some models provide higher than actual probabilities when rates of actual outcomes are high and when there were fewer outcome events available.

In summary, the models provide individualized prediction of risk of the development of pelvic floor disorders 12 and 20 years after delivery with the use of maternal and obstetric variables that are available before childbirth. These models should help identify women who are at high risk in whom prevention strategies such as pelvic floor muscle training and weight control or elective cesarean section might be targeted. Ideally, external validation of the models should be conducted when and if other large cohorts with similar follow-up information become available. ∎

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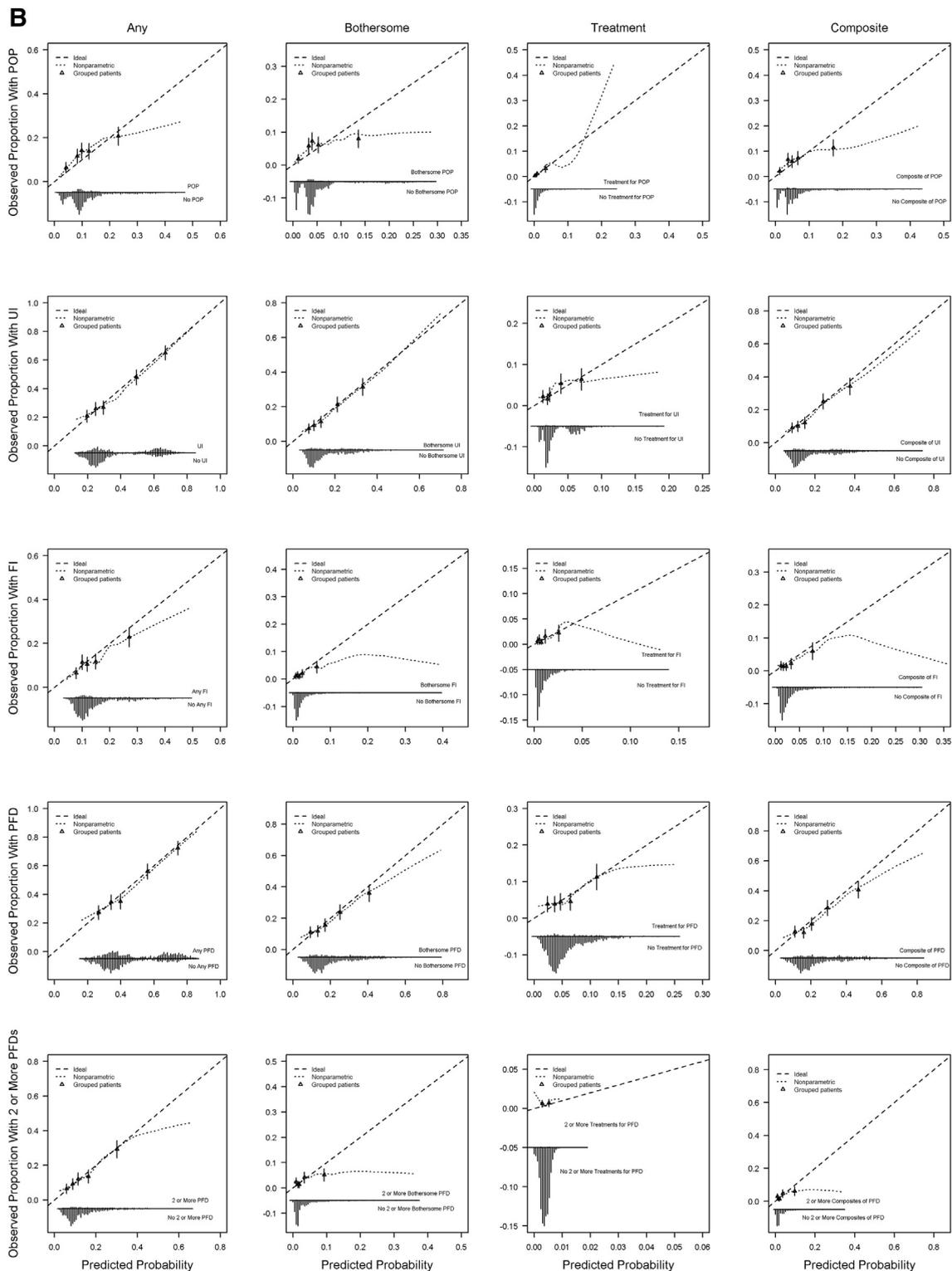Corresponding author: J. Eric Jelovsek, MD, MMEd. eric.jelovsek@duke.edu

SUPPLEMENTAL FIGURE 1
Calibration curves

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Calibration curves that predict pelvic floor disorders at **A,** 12 and **B,** 20 years after delivery for all models

FI, fecal incontinence; *PFD*, pelvic floor disorder; *POP*, pelvic organ prolapse; *UI*, urinary incontinence.

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SUPPLEMENTAL FIGURE 2
Example of the UR-CHOICE online calculator

A

Outcomes	Route of Delivery	Any	Bothersome	Treatment	Bothersome or Treatment	Average Risk of Bothersome or Treatment
Pelvic Organ Prolapse	Vaginal	10%	3%	1%	4%	9%
	C-Section	3%	1%	<0.5%	1%	3%
Urinary Incontinence	Vaginal	30%	14%	2%	15%	20%
	C-Section	20%	10%	1%	10%	15%
Fecal Incontinence	Vaginal	14%	3%	1%*	2%	3%
	C-Section	10%	1%	2%*	2%	3%
Any Pelvic Floor Disorder	Vaginal	40%	18%	4%	20%	27%
	C-Section	26%	10%	2%	12%	18%
Two or More Pelvic Floor Disorders	Vaginal	13%	2%	<0.5%	2%	4%
	C-Section	6%	1%	<0.5%	1%	2%

B

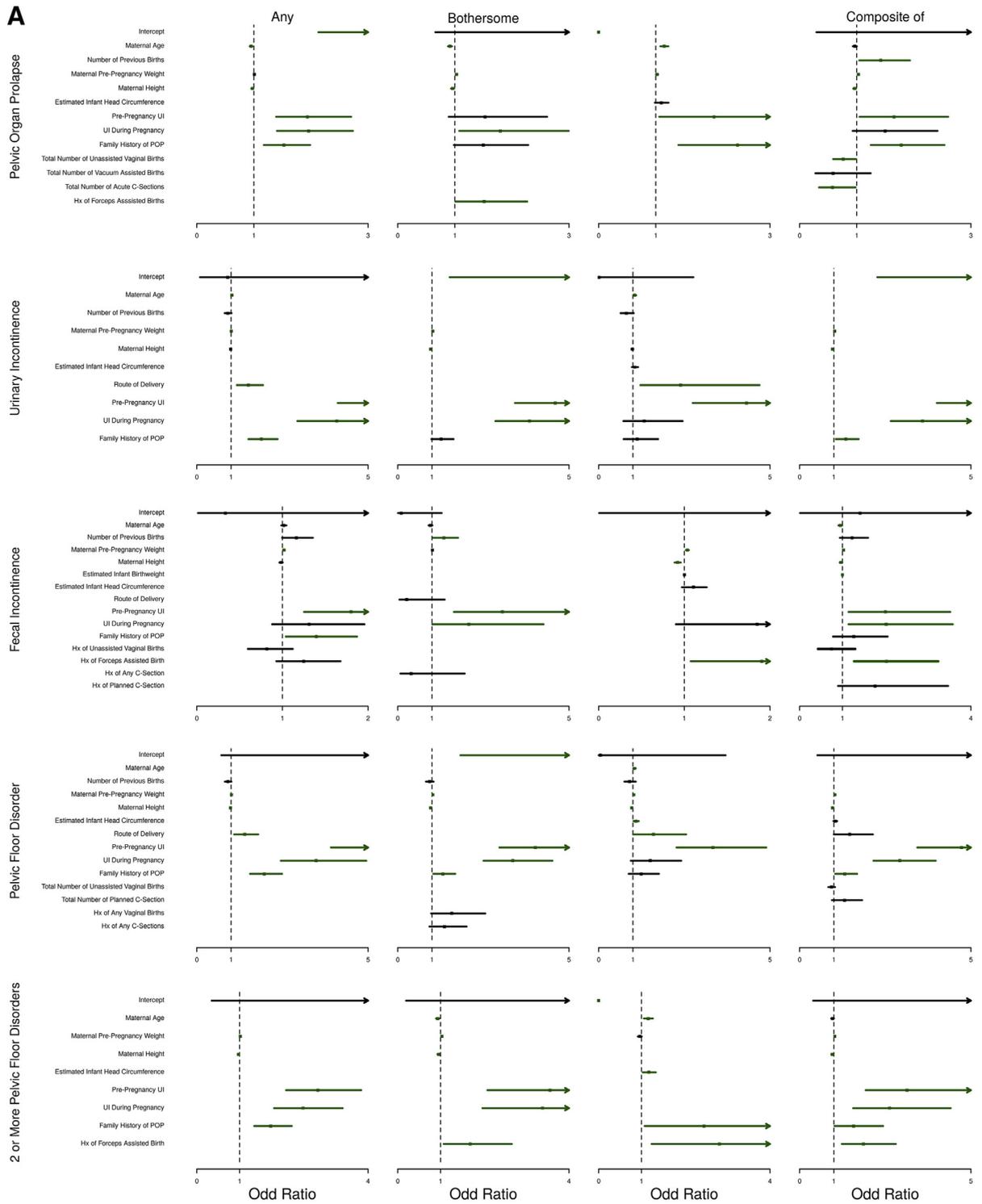| Outcomes	Route of Delivery	Any	Bothersome	Treatment	Bothersome or Treatment	Average Risk of Bothersome or Treatment
Pelvic Organ Prolapse	Vaginal	29%	>10%	3%	20%	9%
	C-Section	12%	5%	<0.5%	5%	3%
Urinary Incontinence	Vaginal	68%	33%	7%	>30%	20%
	C-Section	55%	25%	3%	27%	15%
Fecal Incontinence	Vaginal	14%	3%	1%*	4%	3%
	C-Section	10%	1%	2%*	4%	3%
Any Pelvic Floor Disorder	Vaginal	72%	>40%	10%	48%	27%
	C-Section	57%	28%	6%	33%	18%
Two or More Pelvic Floor Disorders	Vaginal	32%	>10%	<0.5%	>10%	4%
	C-Section	17%	5%	<0.5%	6%	2%

Online calculator for models that predict pelvic floor disorders 20 years after delivery. The patient is a 28-year-old primigravid woman who weighs 150 pounds, whose height is 5 feet 4 inches, whose estimated infant weight is 7 pounds 2 ounces with a head circumference of 35 cm, and who has no history of urinary incontinence before or during pregnancy. **A,** The average-risk patient has no family history of pelvic organ prolapse or urinary or fecal incontinence; **B,** the high-risk patient has a positive family history of pelvic organ prolapse and urinary incontinence as well as urinary incontinence during her pregnancy.

C, cesarean.

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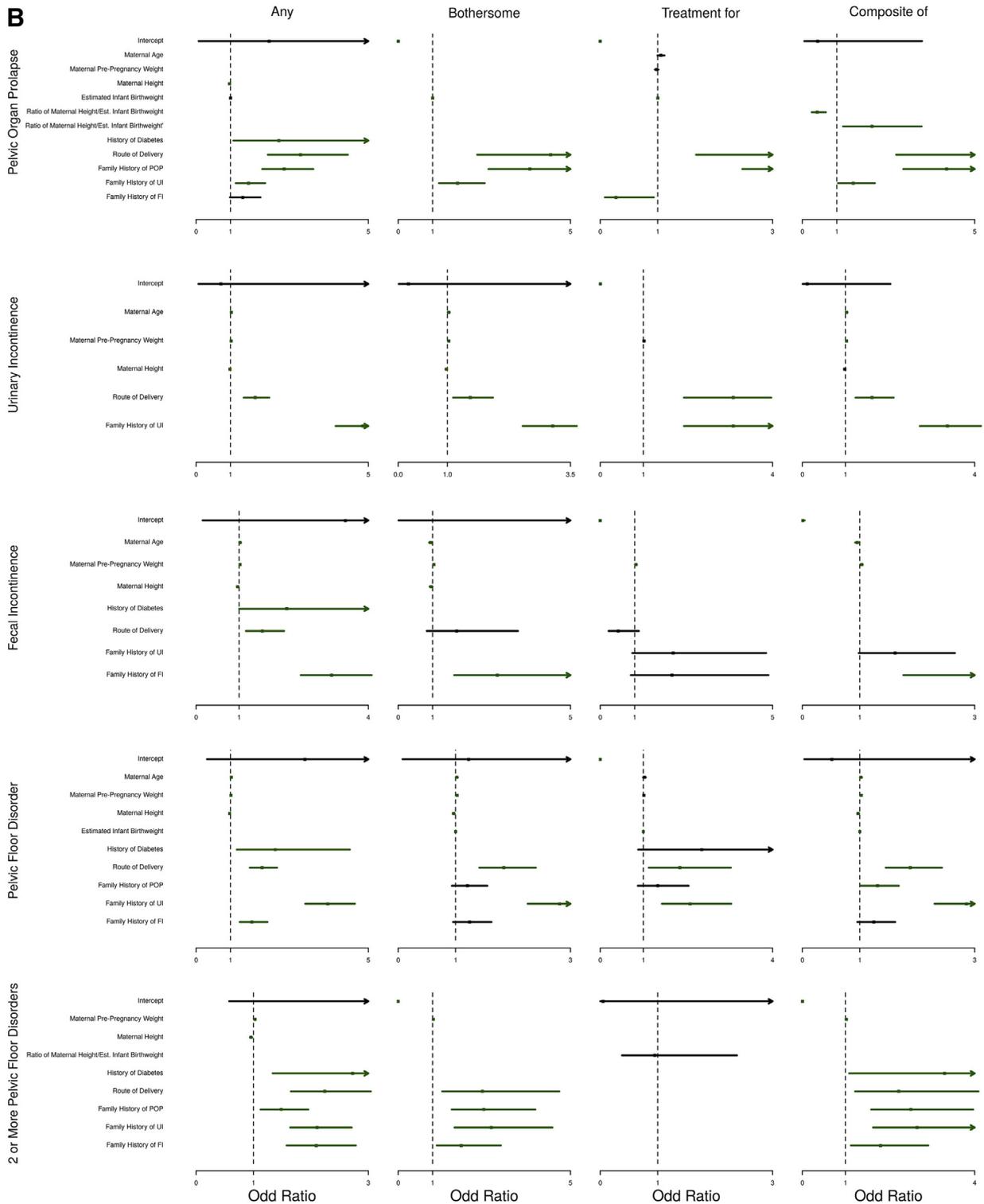
SUPPLEMENTAL FIGURE 3
Odds ratios

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(continued)

Odds ratio of each variable included in predelivery models that predict pelvic floor disorders **A,** 12 and **B,** 20 years after delivery. Each *box* indicates the odd ratio of each variable that was included in the model; the *horizontal line* indicates the 95% confidence interval. If the horizontal line and box are *green*, then the variable was significant at a level of .05. An *arrow* indicates that the line or the odd ratio extends off of the plot.

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Candidate predictors of pelvic floor disorders in the Swedish pregnancy, obesity and pelvic floor study and the prolapse and incontinence long-term study

Variables	Prolapse and Incontinence Long-Term Study (N=3763)	Swedish Pregnancy, Obesity and Pelvic Floor Study (N=4991)
Maternal age at delivery[a]	29 (26, 32)	29 (25, 34)
Missing[b]	0	0
Maternal prepregnancy weight, kg[a]	60 (54, 67)	62 (56, 70)
Missing[b]	718 (19)	702 (14)
Maternal height, cm[a]	163 (159, 168)	167 (163, 170)
Missing[b]	44 (1)	22 (0)
No. of previous births[a]	1 (0, 1)	NA
Missing[b]	5 (0)	
0[b]	1723 (46)	
1[b]	1389 (37)	
2[b]	453 (12)	
3[b]	144 (4)	
≥4[b]	49 (1)	
Route of delivery (index birth)[b]		
Vaginal unassisted	2556 (68)	3061 (61)
Vacuum	193 (5)	726 (15)
Forceps	401 (11)	22 (0)
Cesarean		
Elective	271 (7)	764 (15)
Acute	342 (9)	418 (8)
No. of past unassisted vaginal deliveries[a]	1 (0, 2)	NA
Missing[b]	10 (1)	
0[b]	1067 (28)	
1[b]	1404 (37)	
2[b]	891 (24)	
3[b]	269 (7)	
≥4[b]	122 (3)	
No. of past forceps assisted deliveries[a]	0	NA
Missing[b]	10 (1)	
0[b]	2868 (76)	
1[b]	835 (22)	
2[b]	44 (1)	
3[b]	6 (0)	
No. of past vacuum assisted deliveries[a]	0	NA

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SUPPLEMENTAL TABLE
Candidate predictors of pelvic floor disorders in the Swedish pregnancy, obesity and pelvic floor study and the prolapse and incontinence long-term study (continued)

Variables	Prolapse and Incontinence Long-Term Study (N=3763)	Swedish Pregnancy, Obesity and Pelvic Floor Study (N=4991)
Missing[b]	10 (1)	
0[b]	3515 (93)	
1[b]	236 (6)	
2[b]	2 (0)	
No. of past planned cesarean deliveries[a]	0	NA
Missing[b]	10 (0)	
0[b]	3370 (90)	
1[b]	316 (8)	
2[b]	58 (2)	
≥3[b]	9 (0)	
No. of past acute cesarean deliveries[a]	0	NA
Missing[b]	10 (0)	
0[b]	3277 (87)	
1[b]	436 (12)	
2 & 3[b]	40 (1)	
No. of any past vaginal deliveries[a]	1 (1, 2)	NA
Missing[b]	10 (1)	
0[b]	478 (13)	
1[b]	1583 (42)	
2[b]	1169 (31)	
3[b]	365 (10)	
≥4[b]	158 (4)	
No. of any past cesarean deliveries[a]	0	NA
Missing[b]	10 (1)	
0[b]	2999 (80)	
1[b]	570 (15)	
2[b]	149 (4)	
≥3[b]	35 (1)	
Family history of pelvic organ prolapse		
Yes[b]	615 (16)	676 (14)
No[b]	2465 (66)	3606 (72)
Missing[b]	683 (18)	709 (14)

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SUPPLEMENTAL TABLE
Candidate predictors of pelvic floor disorders in the Swedish pregnancy, obesity and pelvic floor study and the prolapse and incontinence long-term study (continued)

Variables	Prolapse and Incontinence Long-Term Study (N=3763)	Swedish Pregnancy, Obesity and Pelvic Floor Study (N=4991)
Family history of urinary incontinence	NA	
Yes[b]		1374 (28)
No[b]		2852 (57)
Missing[b]		765 (15)
Family history of fecal incontinence	NA	
Yes[b]		629 (13)
No[b]		3600 (72)
Missing[b]		762 (15)
Prepregnancy urinary incontinence		NA
Yes[b]	382 (10)	
No[b]	3377 (90)	
Missing[b]	4 (0)	
Urinary incontinence during pregnancy		NA
Yes[b]	386 (10)	
No[b]	3373 (90)	
Missing[b]	4 (0)	
Infant birthweight, g[a]	3435 (3080, 3760)	3520 (3160, 3960)
Missing[b]	75 (2)	4 (0)
Infant head circumference (cm)	34.7 (34, 35.7)	35 (34, 36)
Missing[b]	148 (4)	107 (2)
Twins		NA
Yes[b]	81 (2)	
No[b]	3682 (98)	
Missing[b]	0	
Induction performed		NA
Yes[b]	646 (17)	
No[b]	3029 (80)	
Missing[b]	88 (2)	
Epidural used during labor		
Yes[b]	1196 (32)	1499 (30)
No[b]	2524 (67)	3492 (70)
Missing[b]	43 (1)	0 (0)
Episiotomy performed		

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SUPPLEMENTAL TABLE
Candidate predictors of pelvic floor disorders in the Swedish pregnancy, obesity and pelvic floor study and the prolapse and incontinence long-term study (continued)

Variables	Prolapse and Incontinence Long-Term Study (N=3763)	Swedish Pregnancy, Obesity and Pelvic Floor Study (N=4991)
Yes[b]	819 (22)	510 (10)
No[b]	2797 (74)	4481 (90)
Missing[b]	147 (4)	0 (0)
2nd-, 3rd-, or 4th-Degree perineal laceration occurred		
Yes[b]	1430 (38)	174 (3)
No[b]	2186 (58)	4817 (97)
Missing[b]	147 (4)	0 (0)
Time in second stage, min[a]	28 (8, 85)	NA
Missing[b]	588 (16)	

NA, Not available.

[a] Data are given as median (interquartile range); [b] Data are given as No. (%). Variables are relative to the index delivery.

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