Matern Child Health J (2017) 21:825–835
DOI 10.1007/s10995-016-2176-9

Reassessing the Association between WIC and Birth Outcomes Using a Fetuses-at-Risk Approach

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Published online: 16 August 2016

Abstract *Objectives* Women with longer, healthier pregnancies have more time to enroll in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), biasing associations between WIC and birth outcomes. We examined the association between WIC and preterm birth (PTB), low birth weight (LBW), and perinatal death (PND) using a fetuses-at-risk approach to address this bias, termed gestational age bias. *Methods* We linked California Medi-Cal recipients with a singleton live birth or fetal death from the 2010 Birth Cohort to WIC participant data (n = 236,564). We implemented a fetuses-at-risk approach using survival analysis, which compared, in each week of gestation, women whose pregnancies reached the same length and who had the same opportunity to utilize WIC. In each gestational week, we assessed WIC enrollment and the number of food packages redeemed thus far and computed hazard ratios (HR) using survival models with time-varying exposures and effects. *Results* Adjusting for maternal socio-demographic and health characteristics, WIC enrollment was associated with a lower risk of PTB from week 29–36 ($HR_{29}=0.71$; $HR_{36}=0.52$); LBW from week 26–40 ($HR_{26}=0.77$; $HR_{40}=0.64$); and PND from week 29–43 ($HR_{29}=0.78$; $HR_{43}=0.69$) ($p<0.05$). The number of food packages redeemed was associated with a lower risk of PTB from week 27–36 ($HR_{27}=0.90$; $HR_{36}=0.84$); LBW from week 25–42 ($HR_{25}=0.93$; $HR_{42}=0.88$); and PND from week 27–46 ($HR_{27}=0.94$; $HR_{46}=0.91$) ($p<0.05$). *Conclusions for Practice* To our knowledge this is the first study to examine the association between WIC and birth outcomes using this approach. We found that beginning from about 29 weeks, WIC enrollment was associated with a reduced risk of PTB by 29–48%, LBW by 23–36%, and PND by 22–31%.

Keywords WIC · Birth outcomes · Gestational age bias · Survival analysis · Fetuses-at-risk

Electronic supplementary material The online version of this article (doi:10.1007/s10995-016-2176-9) contains supplementary material, which is available to authorized users.

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Significance

There has been more than four decades-worth of research evaluating WIC, yet gestational age bias has not been adequately addressed. Existing estimates likely overestimate (by not addressing gestational age bias) or underestimate (by controlling for gestational age at birth) the association between WIC and birth outcomes. We addressed gestational age bias using a fetuses-at-risk approach and found that WIC was associated with reduced risk of adverse birth outcomes. Because this bias pertains to any exposure that changes during pregnancy, this study may inform both evaluations of WIC and other perinatal outcomes studies.

Introduction

The Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) provides nutritious foods, referrals, breastfeeding support, and nutrition education to low-income pregnant and postpartum women, infants, and children under age five. The program has grown from serving 88,000 participants per month in 1974 to over 8.5 million in 2013 (Oliveira et al. 2002; United States Department of Agriculture 2013), yet few studies have evaluated the association between WIC and birth outcomes using recent, linked data. Although WIC has been associated with reductions in preterm birth (PTB), low birth weight (LBW), and infant mortality (Bitler and Currie 2005; Devaney and Schirm 1993; Kotelchuck et al. 1984; Kowaleski-Jones and Duncan 2002), most studies have been constrained by two biases—termed selection and gestational age bias (Joyce et al. 2008).

'Selection bias' refers to the possibility that WIC participants are more motivated and healthier than eligible non-participants, and would likely have better outcomes independent of WIC participation. This bias may be more accurately described as confounding in the epidemiologic literature. Although healthier women may indeed self-select into WIC, some studies have shown WIC participants are more likely to be multiparous, less educated, lower-income, obese, teens, and unmarried, suggesting that WIC is successfully reaching the population it is designed to serve (Bitler and Currie 2005). Nevertheless, the selection of healthier women into WIC is still a concern. Studies using administrative data often have a limited number of variables and may be unable to control for confounding factors, such as pre-existing medical conditions and poverty. Researchers have attempted to make WIC participants and eligible non-participants more comparable by restricting analyses to women with Medicaid, no prior live births, or first trimester prenatal care, or have examined level of participation among only women who enroll in WIC (Gueorguieva et al. 2009; Joyce et al. 2005).

Gestational age bias occurs because women with longer, healthier pregnancies have more time to enroll in WIC during pregnancy. This has resulted in an overestimation of the protective association between WIC and adverse birth outcomes in studies which have assigned one exposure value for the entire pregnancy. Both dichotomous and continuous measures of WIC exposure are subject to this bias. Measures of 'any WIC' participation during pregnancy are particularly biased when PTB is the outcome because the exposure includes women who enroll after 36 weeks who are no longer at risk of PTB, yet studies continue to use this measure (Sonchak 2016). Measures of the number of days or weeks between the date of WIC enrollment and birth are biased because longer pregnancies are assigned a greater amount of time enrolled; and those expressed as a percentage of pregnancy enrolled are biased because the proportion of pregnancy not covered by WIC grows smaller the longer pregnancy lasts. Thus, it is difficult to disentangle whether WIC reduces adverse birth outcomes or whether better birth outcomes lead to higher WIC exposures.

To address gestational age bias, previous studies have stratified on gestational age at birth, adjusted for it as a covariate in models, or restricted their analysis to full-term births (Gueorguieva et al. 2009; Joyce et al. 2005; Sonchak 2016). This may address gestational age bias, but is not recommended (Wilcox et al. 2011), for three reasons. First, if gestational age at birth is a covariate, PTB cannot be examined as an outcome. Second, if gestational age at birth is an intermediate on the pathway between WIC and other outcomes, controlling for it will underestimate the total impact of WIC through all pathways (Schisterman et al. 2009). Third, adjusting for intermediates may also induce collider-stratification or selection bias (Greenland 2003). An example of this phenomenon is the birth weight paradox, whereby maternal smoking appeared protective of infant mortality among LBW infants (Hernandez-Diaz et al. 2006).

Thus, existing studies on the association between WIC and birth outcomes have likely overestimated the effect of WIC (by not controlling for gestational age at birth) or underestimated this effect (by controlling for gestational age at birth). It may be more appropriate to treat gestational age as the time-axis in a time-to-event analysis—known as a fetuses-at-risk approach—rather than a traditional covariate in logistic regression (Kramer et al. 2014). In an analysis that controls for gestational age at birth, unborn fetuses-at-risk of the outcome are excluded when calculating risk among births in a given week. With gestational age as the time-axis, the study population in a given week excludes births in previous weeks and includes live and stillbirths in that week, plus fetuses in utero. This type of analysis has been implemented in studies of birth outcomes using survival techniques (Mitchell et al. 2016; Platt et al. 2004). When used with time-varying exposures that assess WIC participation through each gestational week, survival analysis addresses gestational age bias by comparing, in each week of gestation, women whose pregnancies have reached the same length and who have had the same opportunity to utilize WIC. To our knowledge, no WIC evaluations have used these methods.

Objective

Examine the association between WIC and PTB, LBW, and perinatal death (PND) among women with Medi-Cal, California's Medicaid program, using a fetuses-at-risk approach, controlling for a number of variables obtained through data linkages.

Methods

Data Sources

Live births and infant and fetal deaths ≥20 weeks gestation from the 2010 California Birth Cohort File were linked with the 2010 Census, inpatient hospital discharge data, and WIC participant data. The California Committee for the Protection of Human Subjects determined this study exempt. The linkages between the birth file and each additional data source were conducted in three separate steps, described below.

Of 514,634 birth records, 99.3 % had a valid zip code and linked to the Census. Women who did not link to the Census were included in univariate but excluded from multivariate analyses.

Next, we linked birth records for women who delivered in California non-military hospitals (n = 494,879) to maternal hospital discharge records identified using published ICD-9 codes (Kuklina et al. 2008) plus additional codes for fetal deaths (n = 493,449). Over 97 % of records from the birth and hospital files linked (n = 482,931). Women who did not link to the hospital discharge data were included in univariate but excluded from multivariate analyses.

Finally, to determine WIC participation, we linked live births and fetal deaths in the birth file to WIC using previously published methods (Stopka et al. 2013). Although women with a fetal death were found in WIC, the linkage rate was calculated as the proportion of live births in WIC that linked to the Birth Cohort File because WIC serves women with miscarriages, abortions, and stillbirths <20 weeks gestation, which are not in the Birth Cohort File. Of 260,795 women with a prenatal WIC record who had a live birth in 2010, 259,188 (99.4 %) linked to the birth file.

From these linked data files, we limited our sample further. The birth file contained 237,577 California resident women with a live birth or fetal death who were eligible for WIC via Medi-Cal, California's Medicaid program. 1013 records were excluded because the obstetric estimate of gestational age or birth weight was missing, outside 20–42 weeks or 227–8165 grams, or because gestational age was implausible given birth weight (Alexander et al. 1996). This study included 236,564 California resident women with Medi-Cal and a singleton live birth or fetal death at or after 20 weeks gestation in 2010.

Outcomes

We examined PTB (<37 weeks), LBW (<2500 grams), and PND (fetal or infant deaths 20 through 46 weeks after the last menstrual period; 46 weeks was chosen because that was the last week a neonatal death occurred in our data, and is also consistent with the week used in a prior study) (Platt et al. 2004). Person-weeks of follow-up started at 20 completed weeks gestation because only pregnancies lasting at least 20 weeks are included in the Birth Cohort File. Depending on the outcome, follow-up stopped at the week of birth/fetal death or week 36, whichever came first (for PTB); week of birth/fetal death (for LBW); or the date of fetal/infant death or 46 weeks from last menstrual period, whichever came first (for PND).

Exposure

WIC-eligible non-participants who did not link to WIC were assigned no exposure to WIC during the entire pregnancy. For women who linked to WIC, we used dates of WIC food package redemptions to create time-varying exposures. Food packages are issued at local WIC offices and contain monthly checks to buy food at WIC-authorized stores. When a check is redeemed, the vendor submits information about the redemption to the state for reimbursement, which we obtained for this study. The average food package equates to about $45 a month. The standard prenatal package contains four checks for (1) fruits/vegetables, (2) dairy and beans, (3) dairy, grains and juice, and (4) dairy, cereal, and beans. Checks are valid for 31 days and can be used all at once or on different dates. If more checks were prescribed than redeemed, a partial package was counted (e.g., 1/4 checks = 0.25 packages).

Generally, women are issued their first food package when they enroll in WIC. We considered the date the first food package was valid the enrollment date. Two time-varying exposure variables were created for each gestational week starting at week 20: (1) enrolled in WIC from $week_4$ through $week_w$ (dichotomous); and (2) number of food packages redeemed from $week_4$ through $week_w$ (continuous). Exposure began 4 weeks from the last menstrual period because most women do not find out they are pregnant until their first missed period.

Prenatal packages contributed to the exposure for PTB and LBW. For PND, the exposure included prenatal packages until a live birth/fetal death. Following a live birth, maternal packages were counted until the infants received formula, after which infant packages were counted.

We compared the time-varying exposures described above with time-invariant exposures. Time-invariant exposures measured any WIC enrollment and the number of food packages redeemed from week 4 through the end of pregnancy (for PTB and LBW outcomes) or through the end of follow-up (for PND), which was the week of death or 46 weeks if the infant survived.

Covariates

Maternal race/ethnicity, age, education, parity, inter-pregnancy interval, prior pregnancy terminations, first trimester prenatal care initiation, and pre-pregnancy body mass index came from the Birth Cohort File. ICD-9 codes from the hospital discharge data identified cardiac (424–425, 648.5–648.6), renal (646.2), and lung disease (490–492, 494–519). Pre-existing asthma (493), hypertension (401, 642.0–642.2, 642.7, 642.9), diabetes (250.0–250.9, 648.0), and supervision of high-risk pregnancies due to prior poor birth outcomes (V23) were available from both the hospital and birth certificate data and defined using either source. The percentage of the population in poverty by residential zip code came from the Census. All of these time-fixed covariates were included in the adjusted models.

Analysis

Cox models assessed the association between time-varying WIC exposure and birth outcomes using gestational age as the time-axis in SAS 9.3 (Cary, NC). The time axis started at 20 weeks gestation because only pregnancies lasting at least 20 weeks are included in the Birth Cohort File. We tested for proportional hazards and found that the association between WIC and birth outcomes varied over time, violating this assumption. Therefore, restricted cubic splines were used to estimate time-dependent effects (Heinzl and Kaider 1997). This method separates the hazard function into periods that satisfy the proportional hazard assumption and creates separate models for each period, allowing associations between WIC and the outcomes to vary over time (Platt et al. 2004). Figures display both the adjusted hazard ratios (HR) allowed to vary over time and, for comparison, the HR from the proportional hazards model.

As in a traditional survival or time-to-event analysis, for the outcome of PND, the event was a fetal or infant death. For this outcome, the study population in a given week excludes infant and fetal deaths in previous weeks. Women with an infant or fetal death in that week are compared with women whose fetuses remain in utero and those whose infants were born and remain alive.

For the PTB and LBW outcomes, the event was a live birth or fetal death. For these outcomes, the study population in a given week excludes live births and fetal deaths in previous weeks. Women with a PTB in that week are compared with those whose fetuses remain in utero. Women with a live LBW birth in that week are compared with women whose fetuses remain in utero and those whose infant was born alive at a normal weight in that week. The models for PTB and LBW treated fetal deaths as competing risks, therefore fetal deaths in a given week are excluded from these comparisons (Strand et al. 2012).

With respect to the exposure, in each week the models compared women who had enrolled in WIC to those who had not enrolled in WIC at that point in time (dichotomous exposure). For the continuous exposure, we compared the number of food packages redeemed through that week. Thus, in a given gestational week, the HR is interpreted as the change in the risk of PTB (compared with remaining in utero), LBW (compared with remaining in utero or being born normal weight), or PND (compared with remaining in utero or alive) associated with WIC enrollment vs. no enrollment (dichotomous) or with a one unit-increase in the number of food packages (continuous).

To compare our results with prior studies of the association between WIC and birth outcomes, we computed odds ratios (ORs) from logistic regression models unadjusted and adjusted for gestational age at birth using time-fixed exposures.

Results

Participant Characteristics

This study includes 236,564 women with Medi-Cal who had a singleton live birth or fetal death during or after 20 weeks of gestation in 2010. Most of these women had a prenatal WIC redemption (87.7%). Among women who did redeem, 54.4% first redeemed in the first trimester, 34.5% in the second, and 11.1% in the third (Table 1). Among women who redeemed during pregnancy, the mean number of prenatal food packages redeemed was 5.1. Almost all women with a prenatal redemption (95.7%) and approximately one-third without (36.2%) redeemed postpartum.

Women with a prenatal redemption, compared with women without a prenatal redemption, were more likely to be foreign-born Hispanic (47.0 vs. 19.8%), teens (14.5 vs. 9.0%), have less than a high school education (44.5 vs. 25.7%), report pre-pregnancy obesity (25.5 vs. 19.9%), and live in a zip code with greater than 20% poverty (44.0 vs. 29.9%) (Table 1). Women without a prenatal redemption were more likely to have a prior pregnancy termination (17.9 vs. 16.1%), late/no prenatal care (7.8 vs. 3.5%), and a high-risk pregnancy due to a prior poor birth outcome (7.6 vs. 3.9%).

Table 1 Characteristics of women according to WIC redemptions during pregnancy, among California resident women with Medi-Cal who had a singleton live birth or fetal death in 2010

	Redeemed during pregnancy		Did not redeem during pregnancy	
	n	%	n	%
Total	207,395	87.7	29,169	12.3
WIC enrollment during pregnancy				
1st trimester (<14 weeks)	112,756	54.4	N/A	
2nd trimester (14–27 weeks)	71,613	34.5	N/A	
3rd trimester (>27 weeks)	23,026	11.1	N/A	
Number of prenatal food packages redeemed, mean (standard deviation)	5.1	(2.1)	N/A	
Enrolled postpartum (≤46 weeks after last menstrual period)	198,384	95.7	10,565	36.2
Race/ethnicity				
Asian/Pacific Islander	10,725	5.2	3021	10.6
Black	12,627	6.2	2499	8.7
Hispanic, US-born	58,755	28.6	7112	24.8
Hispanic, foreign-born	96,381	47.0	5672	19.8
White	22,883	11.2	9294	32.5
Other	3785	1.8	1044	3.6
Maternal age				
19 or younger	30,084	14.5	2621	9.0
20–24	64,012	30.9	8455	29.0
25–34	90,168	43.5	14,382	49.3
≥35	23,128	11.2	3702	12.7
Education				
<High school	89,265	44.5	7171	25.7
High school graduate	66,233	33.0	9610	34.4
Some college or college graduate	45,012	22.5	11,146	39.9
Last live birth				
<18 months before last menstrual period	36,693	17.8	5429	18.8
≥18 months before last menstrual period	94,177	45.8	12,985	45.0
No prior live births	74,877	36.4	10,472	36.3
Grand multiparous (≥5 prior live births)	13,894	6.7	2174	7.5
Prior pregnancy termination	33,413	16.1	5224	17.9
Prenatal care initiation				
1st trimester	159,733	78.7	19,471	68.8
2nd trimester	36,137	17.8	6624	23.4
3rd trimester/none	7143	3.5	2195	7.8
Pre-pregnancy body mass index				
Underweight	6897	3.6	1380	5.1
Healthy weight	81,806	42.2	13,280	49.4
Overweight	55,622	28.7	6862	25.5
Obese	49,381	25.5	5346	19.9
Poverty rate in zip code				
<10%	27,450	13.3	7788	26.9
10 to <20%	88,175	42.7	12,486	43.2
≥20%	90,940	44.0	8654	29.9
Pre-existing health conditions				
Asthma	5666	2.8	974	3.5
Cardiac disease	622	0.3	133	0.5

Table 1 (continued)

	Redeemed during pregnancy		Did not redeem during pregnancy	
	n	%	n	%
Total	207,395	87.7	29,169	12.3
Hypertension	3655	1.8	647	2.3
Diabetes	2669	1.3	253	0.9
Renal disease	294	0.1	46	0.2
Lung disease	346	0.2	72	0.3
High risk pregnancy due to prior poor birth outcome	7892	3.9	2148	7.6

Descriptive Results

The prevalence of adverse birth outcomes was lower among women who enrolled in WIC late in pregnancy (Table 2), demonstrating that women whose pregnancies lasted longer (and consequently had better outcomes) had more time to enroll in WIC. The prevalence of PTB (13.9 %) and LBW (10.8 %) was highest among women who only enrolled in WIC postpartum because women with a PTB or LBW had less time to enroll during the (shorter) pregnancy. If they delivered before they had the opportunity to enroll in WIC, they could only enroll postpartum. Similarly, the rate of PND was highest among women who did not enroll in WIC during the study period (23.0 per 1000 live births and fetal deaths). The fetal or infant death may have occurred before these women had the opportunity to enroll in WIC.

Regression Models

WIC Enrollment

Figure 1 compares HRs from Cox proportional and non-proportional hazards models using time-varying exposures with ORs from logistic regression models using time-fixed exposures, unadjusted and adjusted for gestational age at birth. PTB could not be examined as an outcome when adjusting for gestational age at birth.

For each outcome, the ORs from logistic regression models of time-fixed exposures unadjusted for gestational age at birth were lower than the HRs from Cox proportional hazards models, suggesting that the protective association between WIC and adverse birth outcomes is overestimated if gestational age bias is not addressed.

Table 2 Adverse birth outcomes according to timing of WIC enrollment, among California resident women with Medi-Cal who had a singleton live birth or fetal death in 2010

	Total live births	Total fetal deaths	Adverse birth outcomes					
			Preterm birth (PTB)		Low birth weight (LBW)		Perinatal death (PND)	
			n	%[a]	n	%[a]	n	Rate[b]
Total	235,531	1033	16,529	7.0	13,008	5.5	1952	8.3
WIC enrollment								
1st trimester (<14 weeks)	112,348	408	8089	7.2	6046	5.4	864	7.7
2nd trimester (14–27 weeks)	68,363	285	4520	6.6	3708	5.4	512	7.5
3rd trimester (27 weeks–birth)	25,932	59	1175	4.5	1068	4.1	104	4.0
Postpartum (birth–46 weeks after last menstrual period)	10,548	17	1467	13.9	1141	10.8	44	4.2
Did not enroll during the study period	18,340	264	1278	7.0	1045	5.7	428	23.0

[a]Prevalence of PTB/LBW among live births

[b]Rate of PND per 1000 live births and fetal deaths

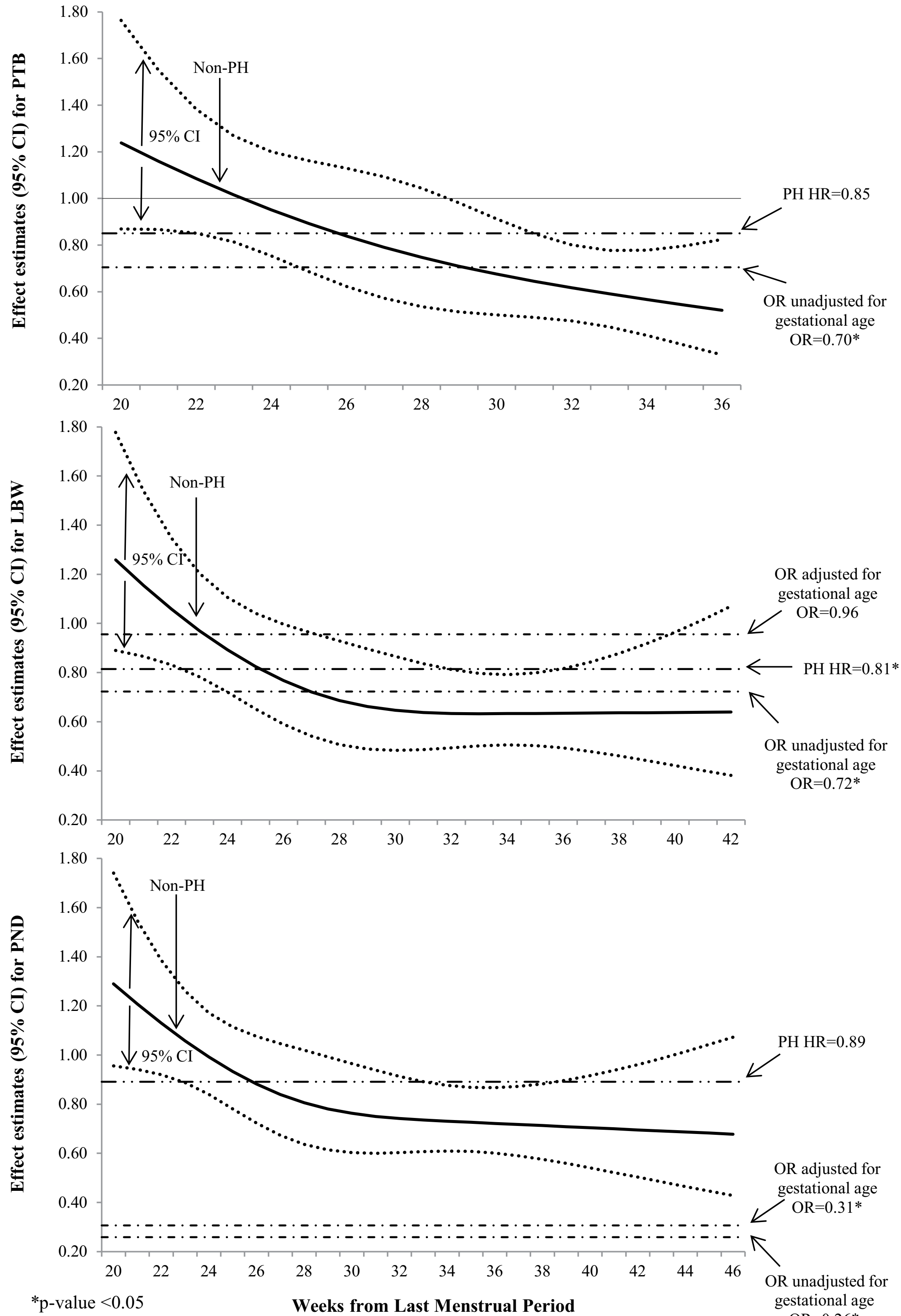

Fig. 1 Adjusted hazard ratios for the association between WIC enrollment (dichotomous exposure) and *PTB* preterm birth, *LBW* low birth weight, and *PND* perinatal death from Cox *PH* proportional hazard models and non-PH models that allowed the hazard ratio to vary over time, compared with *OR* odds ratios from logistic regression models

For LBW, adjusting for gestational age at birth brought the OR (0.96; 95% CI 0.88–1.03) above the HR (0.81; 95% CI 0.69–0.97) from the Cox proportional hazards model, suggesting that adjusting for gestational age at birth underestimates the association between WIC and LBW. Unlike LBW, the OR (0.31; 95% CI = 0.26–0.37) adjusted for gestational age at birth still overestimated the protective association between WIC and PND when compared with the HR (0.89; 95% CI 0.78–1.02).

Allowing the associations between WIC and the outcomes to vary over time in the survival models, WIC enrollment was associated with a lower risk of PTB from week 29 (HR 0.71; 95% CI 0.51–0.98) through week 36 (HR 0.52; 95% CI 0.33–0.82), of LBW from week 26 (HR 0.77; 95% CI 0.59–0.997) through week 40 (HR 0.64; 95% CI 0.42–0.96), and of PND from week 29 (HR 0.78; 95% CI 0.61–0.99) through week 43 (HR 0.69; 95% CI 0.48–0.99).

WIC Utilization

We also found a protective association between the number of food packages redeemed and each outcome (Fig. 2): PTB from week 27 (HR 0.90; 95% CI 0.83–0.99) through week 36 (HR 0.84; 95% CI 0.77–0.93); LBW from week 25 (HR 0.93; 95% CI 0.87–0.99) through week 42 (HR 0.88; 95% CI 0.80–0.96); and PND from week 27 (HR 0.94; 95% CI 0.90–0.99) through week 46 (HR 0.91; 95% CI 0.85–0.97).

Supplemental Analyses

The results described above, which were adjusted for maternal socio-demographic and health characteristics, were similar to unadjusted results. We also restricted analyses to WIC participants, women with first trimester prenatal care, and women without prior live births, and found these results (see Supplementary Material) were similar to those described above.

Discussion

Both WIC enrollment and greater utilization of WIC food packages were associated with reductions in PTB, LBW and PND and associations varied by week of gestation. Beginning from about 29 weeks, WIC enrollment was associated with a reduced risk of PTB by 29–48%, LBW by 23–36%, and PND by 22–31%. A one-unit increase in the number of food packages redeemed was associated with a reduced risk of PTB by 10–16%, LBW by 7–12%, and PND by 6–9%. WIC was not associated with improved birth outcomes in early gestational weeks. These early births may have causes that are less amenable to intervention, such as birth defects (Broussard et al. 2012), or it may have been too early for WIC to have an impact.

Prematurity's contribution to infant mortality makes PTB an important area of focus for research and prevention activities, as it accounts for up to 75% of perinatal deaths annually in the United States (Ananth and Vintzileos 2006). Nevertheless, some WIC evaluations have not examined PTB, reasoning that nutritional supplementation and counseling are unlikely to prevent PTB and studies demonstrating otherwise have been influenced by gestational age bias (Joyce et al. 2005). Although clinical trials examining the impact of specific nutrients on PTB have indeed yielded mixed results (Villar et al. 2003), several physiological pathways exist whereby nutrition could affect premature labor (Lu and Lu 2007). Clinical interventions of a single nutrient also do not account for all the mechanisms that explain how 'WIC works'. In addition to providing checks for food, WIC may contribute to better birth outcomes by reducing stress about accessing food, referring women to earlier PNC, and providing education that may reduce risk behaviors, like smoking (Yunzal-Butler et al. 2010). WIC has also been associated with healthier dietary choices after the new food package was implemented in 2009, which emphasized fruits and vegetables, whole grains, and low/non-fat dairy (Whaley et al. 2012).

To our knowledge this is the first study to examine the association between WIC and birth outcomes treating gestational age as the time-axis in survival models of time-varying exposures. Together, survival analysis and time-varying exposures addressed gestational age bias. Survival models address this bias by comparing, in each week of gestation, women whose pregnancies had reached the same length and who had the same opportunity to utilize WIC. Women with longer pregnancies (who had more opportunity to enroll and better outcomes) were not compared with women with shorter pregnancies (who had less opportunity and worse outcomes).

Time-varying exposures classified time before enrollment as unexposed, thus avoiding one form of immortal time bias. Although, to our knowledge, this concept has not appeared in the WIC literature, it is related to gestational age bias. The outcome could not have occurred before WIC enrollment because the participant 'survived' (i.e. no PTB, LBW, or PND) to enroll later—hence, the period between eligibility and enrollment is termed 'immortal'. Excluding or misclassifying immortal time as exposed overestimates WIC's impact (Beyersmann et al. 2008). We were, however, unable to address another form of immortal time bias related to the issue of left truncation, which results from the exclusion of pregnancies lasting less than 20 weeks gestation (Schisterman et al. 2013). Unfortunately, early losses of pregnancy are not captured in vital statistics data. The

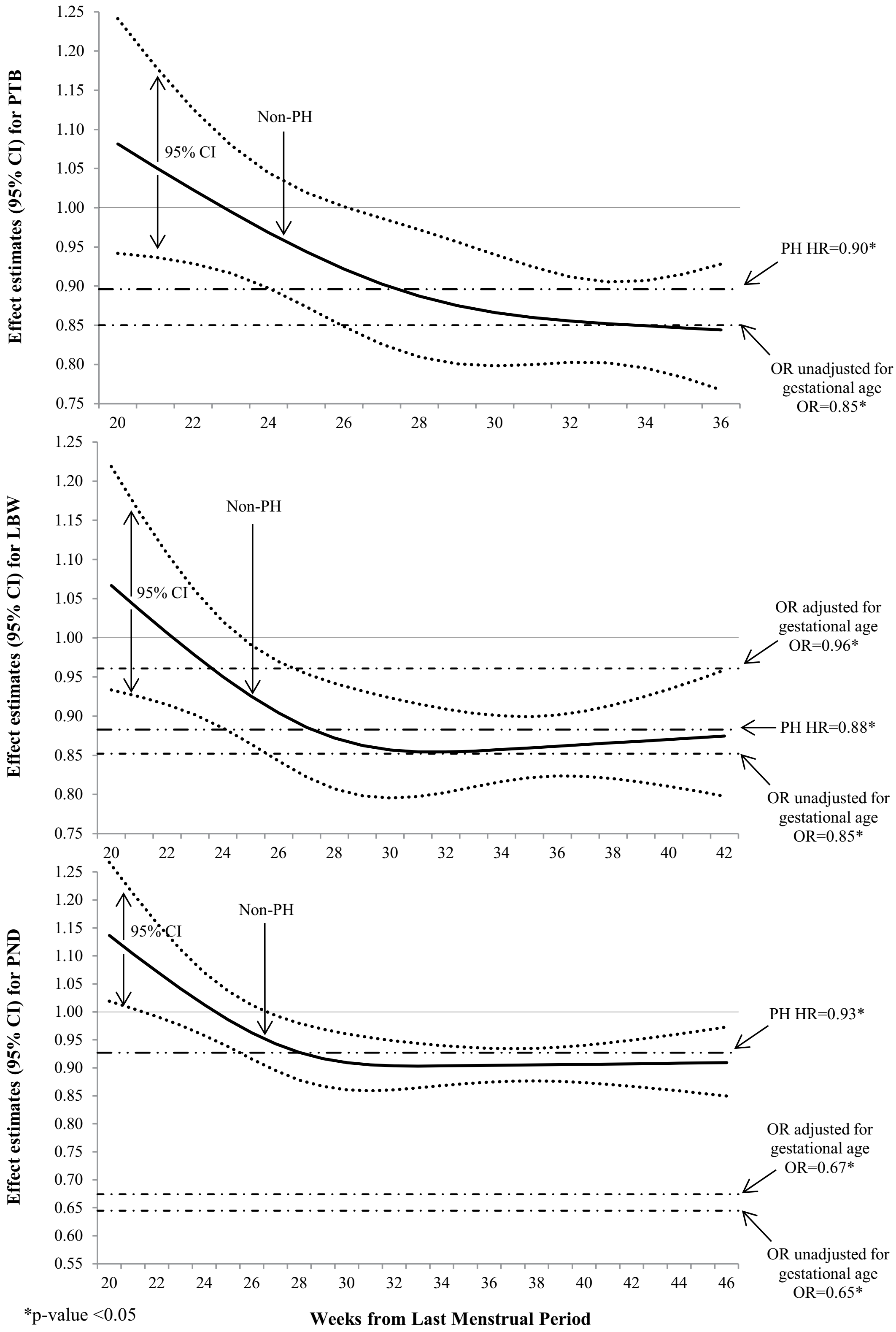

Fig. 2 Adjusted hazard ratios for the association between the number of WIC food packages redeemed (continuous exposure) and *PTB* preterm birth, *LBW* low birth weight, and *PND* perinatal death from Cox *PH* proportional hazard models and non-PH models that allowed the hazard ratio to vary over time, compared with *OR* odds ratios from logistic regression models

exclusion of these records may result in selection bias because the cohort under study is not representative of all conceptions.

We compared our novel methods to methods previously used in the WIC and birth outcomes literature. While studies that adjust for gestational age at birth may be too conservative, studies that do not address gestational age bias may overestimate the protective association between WIC and birth outcomes. Adjusting for gestational age did underestimate the protective association between WIC and LBW, but resulted in an overestimate for PND, thus not fully addressing gestational age bias. This is because after birth, women whose infants survived through the end of follow-up (who had more time to enroll in and utilize WIC postpartum) were still compared with women who had an infant death (who had less opportunity).

We also used a new measure of WIC exposure, the number of food packages redeemed. This measure expands on previous study definitions, which have primarily measured any WIC exposure during pregnancy. Redemption of food packages may more accurately reflect utilization of WIC services than any WIC enrollment, as some women enroll but never participate. However, the number of food packages redeemed does not account for the amount or types of food consumed, whether all items on a check were purchased, or whether women received other services, such as education, nutritional counseling, or referrals. One limitation of this study is that we did not have data on these other aspects of WIC.

Women who enroll in WIC earlier may be different from those who enroll later or not at all. To address this confounding, we adjusted for a number of additional covariates including pre-existing health conditions and poverty through data linkages. However, adjusted results were similar to crude results. Restricting our analysis to women with Medi-Cal may have reduced confounding. Other studies have also restricted to more similar subgroups, such as first-time mothers or women who enrolled in prenatal care in the first trimester, in order to reduce confounding (Gueorguieva et al. 2009; Joyce et al. 2005). When we restricted our results to these groups, we still found that WIC was associated with reduced risk of adverse outcomes.

Additionally, confounding was likely operating in competing directions. WIC participants were more likely to be teens, less educated, and live in zip codes with greater poverty, as other studies have shown (Bitler and Currie 2005). However, non-participants had other risk factors, such as late prenatal care and prior poor birth outcomes, suggesting there may be a selection of women into WIC who are healthier in some aspects (Besharov and Germanis 2000). We may have also lacked data on potential confounders, such as past WIC enrollment; other time-varying exposures that occurred in parallel to WIC, including prenatal care past the first trimester and enrollment in other health programs such as CalFresh (i.e., California's food stamp program) and the Black Infant Health Program; as well as other health conditions and behaviors, such as mental health and substance use disorders during pregnancy. Lastly, administrative data are not collected for research purposes, which may have affected the quality of variables.

Conclusions for Practice

The United States Department of Agriculture has called for expanded linkages between WIC and other sources to strengthen evidence-based program planning and evaluation (Bell 2004). Linking birth certificate data with WIC allowed us to gain information on timing of WIC enrollment and use a fetuses-at-risk approach to address gestational age bias. These results from California suggest that after addressing gestational age bias, enrolling in WIC and utilizing food packages were associated with improved birth outcomes. Because gestational age bias pertains to any exposure that changes during pregnancy, this study may inform both evaluations of WIC and other perinatal outcomes studies.

Acknowledgments This work was supported by funds from the California Title V Maternal and Child Health Services Block Grant; and the California Special Supplemental Nutritional Program for Women, Infants and Children (WIC).

Authors' Contributions This work began while Dr. Fingar was employed at the Maternal, Child and Adolescent Health Program, Department of Public Health, Sacramento, CA. Dr. Fingar designed the study and directed its implementation, analyzed the data, conducted the literature review, and drafted and revised the manuscript. This work began while Dr. Lob was employed at the Maternal, Child and Adolescent Health Program, Department of Public Health, Sacramento, CA. Dr. Lob participated in the analysis of data, development of methods, literature review, and drafted and revised the manuscript. Dr. Dove participated in the analysis of data, development of methods, and drafted and revised the manuscript. Dr. Gradziel participated in the acquisition and interpretation of data and drafted and revised the manuscript. Dr. Curtis contributed to the conception and design of the study; oversaw the acquisition, analysis, and interpretation of data; and drafted and revised the manuscript.

Compliance with Ethical Standards

Conflicts of Interest There may be the appearance of a conflict of interest as this project was comprised of staff funded by California Title V Maternal and Child Health Services Block Grant and Special Supplemental Nutritional Program for Women, Infants and Children funds.

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