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Communication

The Camden Study—A Pregnancy Cohort Study of Pregnancy Complications and Birth Outcomes in Camden, New Jersey, USA

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Abstract: Background: Pregnancy is a unique stage of the life course characterized by trade-offs between the nutritional, immune, and metabolic needs of the mother and fetus. The Camden Study was originally initiated to examine nutritional status, growth, and birth outcomes in adolescent pregnancies and expanded to study dietary and molecular predictors of pregnancy complications and birth outcomes in young women. Methods: From 1985–2006, 4765 pregnant participants aged 12 years and older were recruited from Camden, NJ, one of the poorest cities in the US. The cohort reflects a population under-represented in perinatal cohort studies (45% Hispanic, 38% non-Hispanic Black, 17% White participants; 98% using Medicaid in pregnancy). Study visits, including questionnaires, dietary assessments, and biospecimen collection, occurred in early and late pregnancy as well as at delivery. Medical records were abstracted, and a subset of mothers and infants participated in a six-week postpartum visit. Results: Findings from the Camden Study have added to the understanding of adolescent and young adult maternal health and perinatal outcomes. These include associations of adolescent linear growth while pregnant with smaller neonatal birth size, low dietary zinc intake in early pregnancy with increased risk of delivery <33 gestational weeks, and higher circulating fatty acid levels with greater insulin resistance. More recent analyses have begun to unpack the biochemical pathways in pregnancy that may be shaped by race as an indicator of systemic racism. Conclusions: The Camden Study data and biorepositories are well-positioned to support future research aimed at better understanding perinatal health in under-represented women and infants. Linkages to subsequent health and administrative records and the potential for recontacting participants over 18–39 years after initial participation may provide key insights into the trajectories of maternal and child health across the life course.

Keywords: pregnancy; nutrition; gestational diabetes; perinatal epidemiology; maternal and child health; life course; postpartum

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1. Introduction

Pregnancy is a unique stage of the life course during which complications can have life-long impacts on maternal and fetal health [1]. Even in the absence of pre-existing health conditions, a poor physiological response to the fetus' dynamic nutritional, immune, and metabolic needs during gestation can increase the risk of perinatal complications such as preeclampsia/eclampsia, gestational diabetes (GDM), and preterm delivery [2,3]. In turn, these perinatal complications increase the risk of offspring developmental delay and chronic disease for both mother and offspring [4]. In the United States (US), the prevalence

of perinatal complications ranges depending on many factors. These include metabolic heterogeneity, body composition, lifestyle behaviors, as well as sociodemographic factors such as race/ethnicity that capture differences in societal and environmental influences, such as experiences of racism, poverty, social support, and education [5–7].

Maternal nutrition is a critical modifiable factor during pregnancy because it influences maternal metabolic adaptation to pregnancy, fetal development, and subsequently, long-term health outcomes for both mother and child [8–14]. In the US, women from racial/ethnic minority groups disproportionately experience barriers to accessing healthy diets and adhering to dietary recommendations [15–17]. Thus, poor diet quality or inadequate nutritional status may exacerbate disparities in perinatal outcomes.

The prevalence of perinatal complications, as well as their associated risk factors, are greater among women of color [18

individuals who are female at birth. In this article, we use the term 'women' throughout but acknowledge that not all individuals who experienced a pregnancy may self-identify as a woman) who received obstetric care between 1985–2006 at Cooper University Hospital, the Osborn Family Health Center, Our Lady of Lourdes Medical Center, and St. John the Baptist prenatal clinics, all located in Camden, NJ. At the time of recruitment, Camden was (and continues to be) one of the poorest cities in the United States [36]. Initial analyses focused on differences in growth and development between adolescents and adults that potentially affect pregnancy outcomes, and as such, initial study participants included primigravid and multigravida teenagers (<19 years) with a first pregnancy occurring prior to age 16, as well as older pregnant participants, aged 19–29 at first pregnancy. Subsequent analyses focused on the study of nutrition biomarkers and oxidative stress. Women with major non-obstetric health issues (e.g., non-insulin-dependent diabetes, chronic hypertension, seizure disorders, known drug or alcohol abuse issues, malignancies, leukemia, major psychiatric disorders, and lupus) at the time of recruitment were excluded. These exclusion criteria were selected to minimize ethical concerns, reduce confounding by non-obstetric, pre-existing health issues, and reduce the influence of specialized maternal-fetal-medicine care that is required in medically complex pregnancies.

The Institutional Review Board at Rutgers University gave ethical approval for this work. All participants signed written informed consent prior to engaging in any study activities. Data were accessed to create tables for this analysis on 4 August 2023.

2.2. Overview of Camden Study Activities

Study activities varied modestly across waves of recruitment and typically included one in-person visit in early / mid pregnancy (visit 1) followed by a subsequent visit in late pregnancy (visit 2), birth biospecimen collection, and a single in-person, postnatal visit at 4–6 weeks postpartum and up to 6 months postpartum in ~600 participants. Biospecimens (e.g., serum, urine, and saliva) were collected from participants and stored in the Camden Study biorepository. An overview of collected measures and biospecimens / biomarkers can be found in Tables 1 and 2.

Table 1. Measures collected in the Camden Study.

Domain	Key Measures	Timepoint(s)	
		Prenatal	Postpartum
Maternal interviews	Sociodemographic characteristics	X	X
	Reproductive and general medical history	X	X
	Medications	X	
	Smoking, alcohol, and drug use	X	X
	Infections	X	X
	Breastfeeding		X
Maternal dietary intake	Total caloric intake	X	X
	Macro- and micronutrient intake	X	X
	Fatty acid intake	X	
	Glycemic index	X	
Maternal anthropometric measures	Pre-pregnancy weight (recalled)	X	
	Height, weight	X	X
	Skinfold thickness	X	X
	Growth by knee height	X	X
	Blood pressure	X	X
	Gestational weight gain	X	
Bone mass and density *	Dual-energy X-ray densitometry (DEXA) scan	X	X
	Bone ultrasound	X	X

Table 2. *Cont.*

Bio-Specimen	Biomarkers Measured to Date	Assay Type	Timepoint(s)			
			Pregnancy		Birth	Postpartum
			Early/mid	Late		
Maternal whole blood	Lead	Spectrophotometry	X	X	X	X
Maternal urine	Creatinine	Enzyematic assays				
	8-OHdG	GCMS	X			
	8-iso-$PGF_{2\alpha}$	Spectrophotometry	X			
Maternal saliva			X	X		
Cord blood serum	IGF-1	RIA			X	
	Osteocalcin	RIA			X	
Cord blood plasma	α-Tocopherol (and isomers)	HPLC			X	

Abbreviations: sICAM-1—Soluble Intercellular Adhesion Molecule-1; SVCAM-1—Soluble Vascular Adhesion Molecule 1; ELISA—Enzyme-Linked Immunosorbent Assay; RIA—Radioimmunoassay; hsCRP—High-Sensitivity C-Reactive Protein; IGF-1—Insulin-Like Growth Factor 1; TC—Total Cholesterol; HDL-C—High-Density Lipoprotein Cholesterol; LDL-C—Low-Density Lipoprotein Cholesterol; TG—Triglycerides; apoA1—Apolipoprotein AI; apoB—Apolipoprotein B; IRMA—Immunoradiometric Assays; TSH—Thyroid Stimulating Hormone; HPLC—High-Performance Liquid Chromatography; PCR—Polymerase Chain Reaction; GCMS—Gas Chromatography–Mass Spectrometry; 8-OHdG—8-Hydroxy-2^{0}-Deoxyguanosine; 8-iso-PGF2α—8-Iso-Prostaglandin F2α.

2.3. Questionnaires

At visits 1 and 2, trained study staff conducted structured interviews to collect data on sociodemographic and lifestyle factors. These interviews included items on race/ethnicity, education, occupation, insurance status, household composition, lifestyle (e.g., cigarette smoking, alcohol and drug use), reproductive and medical history, and family health history.

2.4. Dietary Assessments

A registered dietitian collected data on maternal diet (including the use of prenatal vitamins and other dietary supplements) through 24 h recalls administered at visits 1 and 2. These data were processed using the Campbell Master Nutrient Data Base at the Campbell Institute of Research and Technology. The nutrient intake database was updated from the United States Department of Agriculture Nutrient Database for Standard Reference and the Survey Nutrient Database for Continuing Survey of Food Intakes by Individuals, as well as data from the scientific literature [37,38]. Detailed descriptions of the dietary assessments, as well as the reliability of the Camden Study's dietary recall data, have been published elsewhere [39]. To complement the 24 h recalls, at prenatal visits, data were collected on pre-conception vitamin and supplement use, nausea and hyperemesis, pica, food allergies, hunger, eating habits, and fasting/dieting behaviors.

2.5. Maternal Anthropometric Measures

densitometry (DEXA) (Lunar Corp., Madison, WI, USA; DPX-L, analysis software version 1.3y) within 2 days of delivery [42].

In addition, at both visits, arm circumference, waist circumference, hip circumference, and thigh girth were measured by trained examiners using a standard measuring tape. To quantify adiposity, a series of skinfold thickness measurements were collected at multiple sites, including subscapular, suprailiac, biceps, triceps, suprapatellar, thigh, calf, and ankle using standard protocols [43]. All skinfold thickness measurements were taken in duplicate and averaged. Upper arm muscle area and upper arm fat area were subsequently calculated using a standard equation [44]. Based on anthropometric measures, changes in height, weight, BMI (kg/m^2), upper arm muscle area (cm^2), upper arm fat area (cm^2), and skinfold thicknesses were calculated. Finally, diastolic and systolic blood pressure were measured at both visits.

2.6. Medical Record Review

After delivery, trained study personnel abstracted data from the prenatal medical record, delivery record, delivery logbooks and infant medical records. Data of interest included outcomes of all prior pregnancies, medication use, infections, fetal biometry (as determined by ultrasound), detailed data on labor and delivery for the index pregnancy, and any maternal or infant health issues. Gestational age at delivery was determined based on the last menstrual period (LMP) with confirmation or modification based on an early pregnancy ultrasound. In the case of size-for-dates discrepancies or if the LMP was uncertain, dating based on the early pregnancy ultrasound was used. Per convention, small-for-gestational age was defined as birth weight below the 10th percentile and large-for-gestational age was defined as birth weight above the 90th percentile-for-gestational age, adjusted for maternal parity, race/ethnicity and fetal sex [45]. Low birth weight was defined as birth weight <2500 g, macrosomia was defined as birth weight >4000 g, and preterm delivery was defined as delivery <37 weeks gestation.

2.7. Prenatal and Birth Biospecimen Collection

At each study visit, biospecimens were collected, as described briefly below.

Maternal blood was collected by venipuncture with a time of sample, time of last meal, and fasting status (12+ hours since last meal) recorded. Blood samples were processed, and resulting aliquots of serum, whole blood, and plasma were stored at –80 °C pending analysis. Numerous analyses based on maternal blood samples have been conducted (Table 2), and additional aliquots remain in the biorepository for future analysis. In addition, urine and saliva were collected in each trimester. Urinalysis was conducted in clinical laboratories to test for medical conditions (e.g., proteinuria, kidney stones) as well as microbes and viral infections (e.g., yeast, bacterial vaginosis, enterococcus faecalis, proteus mirabilis), after which samples were frozen at −80 °C for future analyses. At delivery, a cord blood specimen was obtained from a subset of participants and processed with aliquots of serum, plasma, and whole blood stored in the Camden Study repository for future analysis.

2.8. Postnatal Visits

Participants completed postpartum study visits approximately 4–6 weeks after delivery and up to 6 months postpartum (n = ~600 participants). These visits again included interviews with study staff. Participants reported on the extent and frequency of lactation, use of formula and juice/sweetened beverages for infants, use of WIC, and any maternal supplementation (e.g., vitamins, iron, bone meal). Participants again underwent extensive anthropometry and provided biospecimens as described above.

2.9. Statistical Analyses

In the Camden Study, bivariate associations of maternal characteristics with perinatal outcomes were tested using t-tests and ANOVAs for continuous variables and Pearson

chi-squared tests for categorical variables. Unadjusted and adjusted multivariable logistic regression models were used to estimate associations with categorical outcomes such as preterm delivery (<37 gestational weeks) or GDM. Linear regression models were used when outcomes were treated as a continuous variable, such as birth weight. Covariate selection was based on a priori knowledge of confounders as well as bivariate associations. Each specific research question had a tailored covariates selection. Often, covariates included maternal age, pre-pregnancy BMI, smoking status, or race/ethnicity. Details of each analysis are included in Supplementary Table S1.

3. Results and Discussion of Findings

From 1985–2006, 4765 pregnant participants aged 12 years and older were recruited. The cohort reflects a population highly under-represented in perinatal cohort studies, with 45% Hispanic, 38% non-Hispanic Black, 17% White participants, and 98% using Medicaid in pregnancy. Baseline characteristics of the cohort are shown in Table 3. Below we summarize published Camden Study results across several key areas of focus.

Table 3. Descriptive statistics of mother-child dyads from the Camden Study (n = 4765).

in the postpartum period at caloric intakes comparable with pregnant older controls [50]. In addition, mothers who gained upper arm fat late in pregnancy or continued to accrue fat in the postpartum period had the largest gestational weight gains, had infants who were smaller at birth and retained the most weight postpartum [44]. Pregnant adolescents who were growing had infants with lower birth weights compared to infants of nongrowing adolescents and those of older pregnant controls [40]. In testing potential mechanisms for

utilized a two-step approach to diagnosing GDM, with a glucose threshold of >130 mg/dl following a 50 g glucose challenge. As expected, higher glucose levels in the 50 g glucose challenge test were positively associated with fetal growth, with significant linear trends

3.5. Racial/Ethnic Disparities in Biomarkers in Pregnancy

Exposure to systematic and structural racism imparts undue physiological chronic

Camden County was and continues to be one of the most polluted areas in N.J. and the U.S., with 13 designated Superfund sites [86,87]. These particular characteristics make the Camden Study pregnancy cohort a unique population for studying environmental exposures and pregnancy/birth outcomes, which have received little attention in this cohort to date. While we acknowledge that the quality of long-term banked specimens may not be universally appropriate for all types of analyses, research has demonstrated the feasibility of conducting analyses on samples preserved at −80 °C for extended periods [88]. Finally, the strategic linkage of the Camden Study to various resources, including medical records through the Camden Cooperative and administrative datasets, as well as the potential for recontact of participants 20–30 years after initial participation, may provide key insights into trajectories of maternal and child health across the life course.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/nu16244372/s1.

Author Contributions: X.C. jointly designed and led the study. E.S.B. and Z.R.-N. now provide leadership on the study. E.S.B., Z.R.-N. and S.S. led manuscript development with intellectual content and writing for subsections provided by all coauthors (A.A.-S., E.C.F., S.R., M.H., K.A.). All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: This study was approved by the Institutional Review Board at Rutgers University (ID# Pro2022002143; date: 15 June 2021). The Camden Study was conducted in accordance with the Declaration of Helsinki.

Informed Consent Statement: Informed written consent was obtained from each participant after an explanation of the nature and purpose of the study.

Data Availability Statement: Data are available upon reasonable request. Collaborations with the research team are welcome. Available data are listed in Tables 1 and 2. Researchers interested in collaboration are invited to contact the Principal Investigators (EB, ZRN). Data access requests will be assessed by the Executive Committee of the Camden Study. Researchers interested in possible collaborations utilizing data and/or biospecimens from the "Camden Study" should contact the Principal Investigators (EB, ZRN). Interested collaborators will be requested to produce a concept proposal for their analysis, which the Camden Study Executive Committee will review. Following approval of the concept proposal, an analysis plan and proof of IRB approval must be submitted by collaborators to the Executive Committee before data/samples can be received. Collaboration requests will be deliberated on an ongoing basis.

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