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Conclusions: Although these results provided no evidence indicating whether birth weight is more strongly related to early-onset than to later-onset breast cancer, our findings suggest an association between birth weight and breast cancer. The underlying biological mechanism relating to this phenomenon needs additional study.

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Xiaohui Xu, Ph.D.1, Amy B. Dailey, Ph.D.1, Mary Peoples-Sheps, Dr.P.H.1, Evelyn O. Talbott, Dr.P.H.2, Ning Li, Ph.D.1, and Jeffrey Roth, Ph.D.1

Abstract

Background: Birth weight has been identified as a birth-related factor associated with the risk of breast cancer. However, the evidence is inconsistent.

Methods: To investigate the association between birth weight and breast cancer, we conducted a meta-analysis of published studies between 1996 and 2008. Eighteen studies encompassing 16,424 breast cancer cases were included in the meta-analysis. Data were combined using a fixed-effect or random-effect model depending on the heterogeneity across studies.

Results: Women with their own birth weight >4000 g or 8.5 lb had a higher risk for developing breast cancer than those with birth weight <2500 g or 3000 g (OR = 1.20, 95% CI 1.08, 1.34). Findings were also consistent with a dose-response pattern effect. The summary effect estimate for breast cancer risk per 1 kg increase in birth weight was statistically significant (random effects OR = 1.07, 95% CI 1.02, 1.12).

Conclusions: Although these results provided no evidence indicating whether birth weight is more strongly related to early-onset than to later-onset breast cancer, our findings suggest an association between birth weight and breast cancer. The underlying biological mechanism relating to this phenomenon needs additional study.

Introduction

Breast cancer is the most commonly diagnosed malignant neoplasm among females in the United States, accounting for one of every three cancer diagnoses, with the highest incidence among women > age 50.1 In 2007, over 40,000 women died of breast cancer in the United States. Although the incidence of breast cancer has decreased slightly in recent years, an estimated 178,480 new invasive cases of breast cancer, including 62,030 new cases of in situ breast cancer, were expected to occur annually among women.1,2 Epidemiological, clinical, and genetic studies have identified a number of biological and social traits as risk factors of breast cancer. These factors include familial history of breast cancer, age, higher socioeconomic status, ionizing radiation, tallness in adult life, alcohol consumption, susceptibility genes of breast cancer 1 (BRCA1) and breast cancer 2 (BRCA2), and a variety of hormonal and metabolic factors.3 However, these well-established risk factors for female breast cancer do not sufficiently elucidate the incidence pattern of this cancer, and additional risk factors have to be considered to advance our understanding of breast carcinogenesis and suggest future intervention strategies.

Evidence has suggested that the prenatal period may be particularly relevant for the development of future adult breast cancer. Results from animal experiments and migrant population studies support the potential influence of prenatal life exposures on subsequent breast cancer development.4-7 Trichopoulos8 hypothesized that prenatal factors, such as elevated hormone concentrations in utero, may increase subsequent breast cancer risk. There are methodological and theoretical challenges that these studies face, however, including the long induction period between exposure and disease as well as lack of assurance about the critical time window of exposure. Several epidemiological studies have since linked birth weight as a marker of in utero environment with breast cancer risk. Some studies have reported high birth weight as a breast cancer risk factor,9-17 although other studies have not supported this relationship.18-24

Despite the relatively large number of studies, the evidence of an association between birth weight and breast cancer is inconclusive. Thus, combining data across these studies is
useful to determine the overall statistical pattern of evidence. Three previous meta-analyses have been conducted to evaluate the association between birth weight and breast cancer.\textsuperscript{25–27} However, these studies inadequately addressed the dose-response relationship between birth weight and breast cancer (i.e., risk of breast cancer per 1 kg increase in birth weight), and there are also concerns about heterogeneity across studies that were not accounted for. A pooled analysis of individual participant data was published in 2008,\textsuperscript{28} and although the results of this study are important, the pooled analysis method limited the number of studies that could be used to conduct a trend analysis based on continuous data. The World Cancer Research Fund (WCRF) report, launched in November 2007, examined breast cancer risk per 1 kg increase in birth weight but included only six cohort studies.\textsuperscript{29} In addition, although the meta-analysis conducted by Michels and Xue\textsuperscript{27} included analysis of potential effect modification by menopausal status, there were a few questions about the selection of studies, compatible birth weight category, and the analytical methods related to this analysis.

This meta-analysis provides new information on the dose-response relationship between birth weight and breast cancer risk while also examining effect modification by menopausal status in detail. The primary aims of this meta-analysis were (1) to determine the overall risk for breast cancer of the highest birth weight (\( \geq 4000 \) g or \( \geq 8.5 \) lb) compared with the lowest birth weight (<2500 g or 3000 g), (2) to assess whether the association followed a dose-response pattern, and (3) to determine if the association could be discerned separately for women with breast cancer diagnosed at premenopausal or postmenopausal status.

Materials and Methods

Study identification

We performed a systematic literature search of PUBMED, EMBASE, and GOOGLE SCHOLAR Search Engine (scholar.google.com) through 2008 to identify epidemiological studies of the association between birth weight and breast cancer. We used the index terms birth weight, breast cancer, risk factors, and epidemiology in various combinations. A manual review of references from primary or review articles was performed to identify any additional relevant studies. The studies included in the meta-analysis were systematically selected based on the following criteria: (1) studies were peer-reviewed and published in English, (2) studies provided measures of odds ratios (OR) or relative risk (RR) (e.g., unadjusted or adjusted ORs) for breast cancer or the number of individuals (both cases and controls or both cases and person-years) in different birth weight strata as well as an indication of the uncertainty of the central estimate (e.g., 95\% confidence interval [CI]) corresponding to birth weight strata, and (3) studies with more comprehensive covariate adjustment, focused on breast cancer, or with compatible categorization of birth weight were preferred.

From a review of abstracts identified in the database search, 32 articles were selected for a full review after excluding review articles, studies of other risk factors, and commentary. We further excluded 14 studies of the total of 32 studies. Two studies did not provide adequate information for either dichotomous comparisons or trend analysis,\textsuperscript{21,30} 2 twins studies were excluded because we were concerned with differences between twins and general birth populations, particularly with regard to birth weight,\textsuperscript{31,32} and 10 other studies were excluded because their results were included in other detailed publications that provided more comprehensive results or adequate information.\textsuperscript{10,16,17,19,20,22,33–36} Thus, the present meta-analysis includes 18 unique studies: 11 case-control studies,\textsuperscript{9,13,18,23,37–43} and 7 cohort studies\textsuperscript{11,12,14,15,24,44,45} (Tables 1 and 2).

Data were extracted using standardized data extraction forms. For each study, extracted information included study country and year, study design, population characteristics (country and age), source of birth weight information, number of cases, sample size, unadjusted or adjusted ORs, and 95\% Cl in different birth weight strata. In addition, matching factors for cases and controls and factors for which statistical adjustment was performed were extracted.

Statistical analysis

Dichotomous comparisons. To obtain the association between high birth weight (i.e., \( \geq 4000 \) g or \( \geq 8.5 \) lb) and risk of breast cancer across studies, we used the lowest birth weight stratum as the reference group, a standard that most of the studies applied. A majority of the included studies used a birth weight cutoff of <2500 g or <5.5 lb as the lowest birth weight stratum. Only a few studies used a birth weight cutoff of <3000 g as the lowest birth weight stratum.\textsuperscript{12,14,37,45} For the statistical synthesis, the covariate adjusted ORs or RRs were used if they were provided. If not, we used the raw data to calculate the unadjusted OR or RR for the studies that used a reference other than the lowest birth weight stratum or that had no estimates for all age groups, if appropriate. To assess the effects of birth weight on early-onset and later-onset breast cancer, the dichotomous ORs or RRs were extracted separately for premenopausal and postmenopausal women if the data were available.

Trend analysis for unadjusted or adjusted strength of association. To obtain a uniform measure of the trend, the change in breast cancer risk per 1 kg increase in birth weight was extracted from each study when the information was provided. Otherwise, we used the method of corrected for covariance of log RR described by Greenland and Longnecker\textsuperscript{46} to quantify the change in risk per 1 kg increase in birth weight for studies that provided information for three or more birth weight strata. In this method, the regression coefficient and its CIs between the risk of breast cancer on the logit scale and the median of birth weight in each category were obtained. The ORs or RRs for the change in risk per 1 kg increase in birth weight were estimated by exponentiation of the regression coefficient.\textsuperscript{37,46}

Meta-analysis: Estimations of summary effects and heterogeneity evaluation. Each study contributed measures of ORs or RRs of breast cancer comparing highest birth weight to lowest birth weight for women of all ages, or separately by menopausal status, or ORs or rate ratios per 1 kg increase in birth weight (separately by menopausal status, if available). As a summary estimate, we used the general variance-based method, which provides an inverse variance weighted average of the study-specific estimates, to calculate the summary effect estimate for either the dichotomous ORs or RRs per 1 kg increase in birth weight. This summary effect estimate represents a weighted average estimate of the effect of birth weight on breast cancer across the studies.
Table 1. Characteristics of Studies Included in the Meta-Analysis

<table>
<thead>
<tr>
<th>Study/country</th>
<th>Year</th>
<th>Study design</th>
<th>Sources of cases and controls</th>
<th>Birth weight source</th>
<th>Case recruitment period</th>
<th>No. of cases</th>
<th>Sample size</th>
<th>Matching factors</th>
<th>Adjusting factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andersson/Sweden</td>
<td>2001</td>
<td>Cohort study</td>
<td>Cancer registry/ population-based cohort</td>
<td>Medical record</td>
<td>Born 1914, 1948, 1922, 1930</td>
<td>62</td>
<td>1,080</td>
<td>NA*</td>
<td>GA, BC, MP, BO, P, AM</td>
</tr>
<tr>
<td>Ekholm/Sweden</td>
<td>1997</td>
<td>Case-control</td>
<td>Cancer registry/ hospital control</td>
<td>Medical record</td>
<td>Born 1874-1961, Diagnosed 1958-1994</td>
<td>1,068</td>
<td>2,727</td>
<td>Hospital and date of birth</td>
<td>NA</td>
</tr>
<tr>
<td>Hilakivi-Clarke/Finland</td>
<td>2001</td>
<td>Cohort study</td>
<td>Hospital born birth cohort</td>
<td>Hospital record</td>
<td>Born 1924-1933</td>
<td>107</td>
<td>3,447</td>
<td>NA</td>
<td>GA, MP, AG, MG, P, MA, PA, R</td>
</tr>
<tr>
<td>Ekbom/Sweden</td>
<td>2004</td>
<td>Case-control</td>
<td>Hospital born birth cohort</td>
<td>Birth record</td>
<td>Born 1924-1950, age &gt;55 years, Born 1915-1929</td>
<td>89</td>
<td>327</td>
<td>Age</td>
<td>GA, MP, AM, H, BMI_14</td>
</tr>
<tr>
<td>Innes/USA9</td>
<td>1997</td>
<td>Case-control</td>
<td>Hospital born birth cohort</td>
<td>Birth record</td>
<td>Born 1924-1933</td>
<td>107</td>
<td>3,447</td>
<td>NA</td>
<td>GA, MP, AG, MG, P, MA, PA, R</td>
</tr>
<tr>
<td>Park/Poland</td>
<td>2006</td>
<td>Case-control</td>
<td>Hospital records and cancer registry/ population-based control</td>
<td>Interview</td>
<td>Diagnosed 2000-2003, age 20-74</td>
<td>2,386</td>
<td>4,888</td>
<td>Frequency match: age and residence</td>
<td>A, EDU, AM, MPS, AMP, AFB, CH, FHBC, MGS, BMI</td>
</tr>
<tr>
<td>Sanderson/USA</td>
<td>1996</td>
<td>Case-control</td>
<td>Cancer registry/ population control</td>
<td>Questionnaire</td>
<td>Diagnosed 1983-1990</td>
<td>1,147</td>
<td>2,546</td>
<td>Frequency match: age and residence</td>
<td>A, EDU, AM, MPS, AMP, AFB, CH, FHBC, MGS, BMI</td>
</tr>
<tr>
<td>dos Santos Silva/UK</td>
<td>2004</td>
<td>Cohort study</td>
<td>Cancer registry/ population-based cohort</td>
<td>Medical record</td>
<td>Born 1946</td>
<td>59</td>
<td>2,176</td>
<td>Frequency</td>
<td>A, EDU, AM, MPS, AMP, AFB, CH, FHBC, MGS, BMI</td>
</tr>
<tr>
<td>Barba/USA</td>
<td>2006</td>
<td>Case-control</td>
<td>Cancer registry/ population control</td>
<td>Self-reported</td>
<td>Diagnosed 1996-2001, age 35-80</td>
<td>845</td>
<td>2,883</td>
<td>Frequency-matched: age, race, and residency</td>
<td>A, EDU, AM, MPS, AMP, AFB, CH, FHBC, MGS, BMI</td>
</tr>
<tr>
<td>Hodgson/USA</td>
<td>2004</td>
<td>Case-control</td>
<td>Cancer registry/ population control</td>
<td>Birth record</td>
<td>Born 1949 or later, age 18-74</td>
<td>196</td>
<td>363</td>
<td>Frequency match: age and race</td>
<td>A, R, MA, BMI_A, SF, HB</td>
</tr>
<tr>
<td>Troisi/USA</td>
<td>2006</td>
<td>Cohort study</td>
<td>NCI DES cohort</td>
<td>Questionnaire and obstetrical charts</td>
<td>Diagnosed 1978-2001</td>
<td>97</td>
<td>118,985</td>
<td>Frequency match: age and race</td>
<td>A, GA</td>
</tr>
<tr>
<td>Vatten/Norway</td>
<td>2002</td>
<td>Case-control</td>
<td>Cancer registry/ population control</td>
<td>Birth record</td>
<td>Born 1990 and 1970, age 27-83</td>
<td>373</td>
<td>1,523</td>
<td>Year of birth, residency</td>
<td>AFB, P</td>
</tr>
<tr>
<td>Titus-Ernstoff</td>
<td>2002</td>
<td>Case-control</td>
<td>Cancer registry/licensed drivers and Medicare beneficiaries</td>
<td>Interview</td>
<td>Diagnosed 1992-1994</td>
<td>1,716</td>
<td>3,602</td>
<td>Frequency</td>
<td>A, Place</td>
</tr>
</tbody>
</table>

* A, age; AC, alcohol consumption; AFB, age at first birth; AFM, age at first marriage; AM, age at menarche; AMP, age at menopause; AP, abruptio placenta; APG, age at peak growth; BC, birth cohort; BMI_A, adult BMI; BMI_14, BMI at 14 years; BO, birth order; BY, birth year; CH, children in the home; EDU, education; FHBC, family history of breast cancer; GA, gestational age; H, height; HB, history of biopsy; HBBD, history of breast benign disease; HF, history of fibroadenoma; IF, infertility; IN, income; L, lactation; MA, maternal age; MG, multifetal gestation; MGS, mammography screening; MP, maternal preeclampsia; MPS, menopausal status; MS, marital status; MSES, maternal socioeconomic status; MSK, maternal smoking; NA, not available; NJ, neonatal jaundice; O, occupation; OC, oral contraceptives; P, parity; PA, paternal age; PAC, physical activity; PCP, personal car possession; R, race; RY, reference year; SF, sampling fractions; SP, severe prematurity; TM, twin membership.
<table>
<thead>
<tr>
<th>Study/country</th>
<th>Year</th>
<th>Study design</th>
<th>Sources of cases and controls</th>
<th>Source of birth weight</th>
<th>Case recruitment period</th>
<th>No. of cases</th>
<th>Sample size</th>
<th>Reason for exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michels/USA</td>
<td>1996</td>
<td>Nested case-control</td>
<td>NHS cohort</td>
<td>Questionnaire</td>
<td>Born 1921–1945 and 1946–1965</td>
<td>582</td>
<td>2,151</td>
<td>Overlap with Michels/USA, 2006</td>
</tr>
<tr>
<td>Vatten/Norway</td>
<td>2005</td>
<td>Cohort study</td>
<td>Cancer registry/population-based cohort</td>
<td>Medical record</td>
<td>Born 1920–1958</td>
<td>312</td>
<td>16,016</td>
<td>Overlap with Vatten/Norway, 2002 and no adequate information for either &quot;dichotomous comparisons&quot; or &quot;trend analysis&quot;</td>
</tr>
<tr>
<td>Sanderson/USA</td>
<td>1998</td>
<td>Case-control</td>
<td>Cancer registry/population control</td>
<td>Questionnaire</td>
<td>Diagnosed 1983–1992, age under 45</td>
<td>510</td>
<td>436</td>
<td>Overlap with Sanderson/USA, 1996; part of data concerning breast cancer risk and only for premenopausal women</td>
</tr>
<tr>
<td>Ahlgren/Denmark</td>
<td>2003</td>
<td>Cohort study</td>
<td>Cancer registry/population-based cohort</td>
<td>School health records</td>
<td>Born 1930–1975</td>
<td>2340</td>
<td>3,266,070</td>
<td>Overlap with Ahlgren/Denmark, 2004</td>
</tr>
<tr>
<td>Ahlgren/Denmark</td>
<td>2007</td>
<td>Cohort study</td>
<td>Cancer registry/population-based cohort</td>
<td>School health records</td>
<td>Born 1930–1975</td>
<td>12,540</td>
<td>6,975,553</td>
<td>Overlap with Ahlgren/Denmark, 2004; no adequate information and evaluate other cancers including breast cancer</td>
</tr>
<tr>
<td>McCormack/Sweden</td>
<td>2005</td>
<td>Cohort study</td>
<td>Cancer registry/population-based cohort</td>
<td>Medical record</td>
<td>Born 1915–1929</td>
<td>2,685</td>
<td>11,529</td>
<td>Duplication of data with McCormack/Sweden, 2003 on breast cancer and better controlling for confounding factors</td>
</tr>
<tr>
<td>Kaijser/Sweden</td>
<td>2003</td>
<td>Cohort study</td>
<td>Cancer registry/population-based cohort</td>
<td>Medical record</td>
<td>Born 1925–1949</td>
<td>39</td>
<td>1,483</td>
<td>No adequate information for either &quot;dichotomous comparisons&quot; or &quot;Trend analysis&quot;</td>
</tr>
<tr>
<td>Stavola/UK</td>
<td>2000</td>
<td>Cohort study</td>
<td>National survey of Health and Development</td>
<td>Birth records</td>
<td>Born March 3–9, 1946</td>
<td>37</td>
<td>2,221</td>
<td>Case-referent and different birth weight categories</td>
</tr>
<tr>
<td>Löf/Sweden</td>
<td>2007</td>
<td>Cohort study</td>
<td>National health registers/Women’s Lifestyle and Health study</td>
<td>Questionnaire</td>
<td>Diagnosed 1991–2003</td>
<td>657</td>
<td>38,566</td>
<td>No adequate information for either &quot;dichotomous comparisons&quot; or &quot;Trend analysis&quot;</td>
</tr>
<tr>
<td>Mogren/Sweden</td>
<td>1999</td>
<td>Cohort study</td>
<td>Cancer registry/population-based cohort</td>
<td>Birth registry</td>
<td>Born 1955–1990</td>
<td>57</td>
<td>Unavailable</td>
<td>Different birth weight categories and inadequate information</td>
</tr>
<tr>
<td>Hubinette/Sweden</td>
<td>2001</td>
<td>Case-control</td>
<td>Cancer registry/population-based female twins</td>
<td>Twin registry</td>
<td>Born 1886–1956</td>
<td>96</td>
<td>184</td>
<td>Different population (twins)</td>
</tr>
<tr>
<td>Kaijser/Sweden</td>
<td>2001</td>
<td>Case-control</td>
<td>Cancer registry/population-based opposite-sexed twins</td>
<td>Twin registry</td>
<td>Born 1926–1967</td>
<td>90</td>
<td>180</td>
<td>Different population (opposite-sexed twins)</td>
</tr>
</tbody>
</table>
For each fixed effects of ORs, we quantified the degree of heterogeneity in the measures across studies with a Q-statistic, which follows the chi-square distribution with degrees of freedom (df) equal to the number of included studies minus 1. In this study, if the p value of the Q-statistic was <0.1, we considered studies to exhibit significant statistical heterogeneity. In this case, a random-effects OR is reported. The random-effects OR is also a weighted average of study-specific ORs that considers heterogeneity and can be a reasonable summary effect estimate of the effect of birth weight on breast cancer when heterogeneity exists across studies. In addition, we also calculated the $I^2$-statistic, which is equal to the Q-statistic minus the df and then divided by the Q-statistic itself. Its CI was also calculated using the method described by Higgins and Thompson. The $I^2$-statistic is a quantitative measure of the degree of between-study heterogeneity. Smaller values of the $I^2$-statistic suggested lower between-study heterogeneity (0 in $I^2$-statistic suggests no heterogeneity, and larger values indicate increasing heterogeneity).

Publication bias. The funnel plot method was applied to determine if there was publication bias among the included studies. The funnel plot includes the log of the ORs as the x-axis and the standard error (SE) of the log of ORs as the y-axis. If the plot is asymmetrical, it is interpreted to imply that publication bias is present. This method provides a direct visual inspection.

Results

Description of studies

The 18 studies included in the meta-analysis were published between 1996 and 2008. The study populations included participants from the United States, Europe, and China, for a total of 16,424 women with breast cancer. The cases in these studies were primarily obtained from cancer registries, hospital records, or both. Birth weight was ascertained from birth records or interviews and questionnaires (Table 1).

Birth weight and breast cancer

Fifteen studies provided estimates of the association between risk of breast cancer and birth weight using dichotomous comparisons (highest vs. lowest). Among them, 8 studies presented the ORs or RRs for the effect of highest birth weight on breast cancer among all women, regardless of menopausal status. Figure 1 shows the forest plot for the study-specific ORs or RRs of these studies and the summary estimate across them. All 8 studies included in this meta-analysis suggested a positive association between highest birth weight and breast cancer risk, although the association was statistically significant in only 2 of the studies (summary fixed-effect OR 1.20, 95% CI 1.08, 1.34 for highest vs. lowest birth weight). There was little heterogeneity in effect estimates across the reviewed studies (Q-statistic = 4.52, $p$ for heterogeneity = 0.72, $I^2$-statistic = 0, 95% CI 0, 50%).

Figures 2 shows the forest plots of the association estimates of highest birth weight on premenopausal and postmenopausal breast cancer and the summary estimates across them. Altogether, 9 studies provided adequate information to ascertain the association between birth weight and premenopausal breast cancer risk (Fig. 2A). Because of the heterogeneity of the estimates (Q-statistic = 15.89, $p$ for heterogeneity<0.05, $I^2$-statistic = 50%, 95% CI 0, 76.5%), a random-effects summary OR was calculated. The random-effects summary OR

<table>
<thead>
<tr>
<th>Study (reference)</th>
<th>Odds ratio (fixed) 95%Cl</th>
<th>Weight%</th>
<th>Odds ratio (fixed) 95%Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andersson 2001 (45)</td>
<td>1.69</td>
<td>1.57 (0.68-3.66)</td>
<td></td>
</tr>
<tr>
<td>Ahlgren 2004 (15)</td>
<td>68.07</td>
<td>1.17 (1.02-1.33)</td>
<td></td>
</tr>
<tr>
<td>Barba 2006 (40)</td>
<td>6.01</td>
<td>1.09 (0.70-1.71)</td>
<td></td>
</tr>
<tr>
<td>Ekbom 1997 (23)</td>
<td>4.19</td>
<td>1.21 (0.71-2.07)</td>
<td></td>
</tr>
<tr>
<td>Hilakivi-clarke 2001(24)</td>
<td>1.24</td>
<td>1.90 (0.70-5.00)</td>
<td></td>
</tr>
<tr>
<td>Park 2006 (13)</td>
<td>9.59</td>
<td>1.54 (1.08-2.91)</td>
<td></td>
</tr>
<tr>
<td>Sanderson 1996 (39)</td>
<td>7.93</td>
<td>1.01 (0.68-1.48)</td>
<td></td>
</tr>
<tr>
<td>Silva 2004 (14)</td>
<td>1.29</td>
<td>1.57 (0.60-4.13)</td>
<td></td>
</tr>
<tr>
<td>Fixed effects (OR)</td>
<td>100</td>
<td>1.20 (1.08-1.34)</td>
<td></td>
</tr>
</tbody>
</table>

FIG. 1. Odds ratio with corresponding 95% confidence intervals for breast cancer in women of all ages with highest (>4000 g or 8.5 lb) vs. lowest (<2500 g or 3000 g) birth weight. The Q-statistic and $I^2$-statistic tests indicated no heterogeneity (Q-statistic = 4.52, $p$ for heterogeneity = 0.72, $I^2$-statistic = 0, 95% CI 0, 50%). The fixed-effects odds ratio is 1.20 (95% CI 1.08, 1.34).
was 1.37 (95% CI 0.98, 1.92) for the effect of highest birth weight (>4000 g or 8.5 lb) compared with the lowest birth weight (<2500 g, <5.5 lb, or <3000 g). Only 6 studies provided adequate information on postmenopausal breast cancer and birth weight to allow the dichotomous comparison (Fig. 2B). The heterogeneity in the association estimates from these 6 studies was also significant (Q-statistic = 12.0, p for heterogeneity < 0.05, I²-statistic = 58%, 95% CI 0, 83%). The random-effects OR was 1.13 (95% CI 0.85, 1.51).

### Trend analysis

We conducted a separate meta-analysis to determine if there is a log-linear effect of birth weight on breast cancer risk. This analysis included 16 studies, which met the inclusion criteria for the trend analysis, that is, the effect estimates of breast cancer risk associated with a 1 kg increase in birth weight being presented or estimated using the Greenland and Longnecker method, and provided 19 effect estimates. Figure 3 shows a forest plot of these study-specific effect estimates and the summary estimate across them. Among the 19 effect estimates, a positive association was found in 13 studies, although the association was statistically significant in only 5 of the studies. A negative association was observed in 6 other studies in addition to 1 with a statistically significantly negative association (Fig. 3). There was an overall statistically significant association between breast cancer and each 1 kg increase in birth weight (random-effects OR 1.07, 95% CI 1.02, 1.12). The effect estimates were heterogeneous across studies (Q-statistic = 30.02, p for heterogeneity < 0.05, I²-statistic = 40%, 95% CI 0, 65%). The high heterogeneity among the studies seemed to be a result of the effect among African Americans in the study by Hodgson et al. The overall heterogeneity became nonsignificant (Q-statistic = 24.9, p for heterogeneity > 0.10, I²-statistic = 30%, 95% CI 0, 62%) after excluding the study. However, the exclusion did not substantially change the summary effect estimate (fixed-effects OR = 1.08, 95% CI 1.02, 1.13).

### Publication bias

Visual inspection of the funnel plots does not suggest substantial publication bias suggested in this meta-analysis (data not shown).
**Discussion**

This meta-analysis of 18 epidemiological studies showed a significant, albeit modest in magnitude, summary effect of breast cancer risk with high birth weight (>4000 g or 8.5 lb) compared with the lowest category of birth weight (<2500 g or 3000 g) among women of all ages. Our results (OR = 1.37, 95% CI 0.98, 1.92 for premenopausal women; OR = 1.13, 95% CI 0.85, 1.51 for postmenopausal women) differed from the estimates from the meta-analysis conducted by Michels and Xue in 200627 (OR = 1.25, 95% CI 1.14, 1.38 for premenopausal women; OR = 1.04, 95% CI 0.91, 1.19 for postmenopausal women), with our estimates higher and approaching significance for premenopausal women. The alternative analytic strategy employed in the study and inclusion of additional studies are the likely reasons behind these differences. In terms of methodological differences, we employed a random-effects model rather than a fixed-effects model to provide a summary estimate accounting for the heterogeneity across the studies. We also used more consistent and clear definitions of highest (birth weight >4000 g) and referent (birth weight <2500 g or <3000 g) categories in our analysis. In addition, we have an alternative approach to Michels and Xue27 for combining effect estimates based on categorical birth weight together with the effect estimates based on continuous birth weight to generate a single summary estimate. In our analysis, we analyzed both the categorical and continuous measurement, but we did them separately. In addition to these methodological differences, we included 3 publications from 200611,13,40 that have become available since the publication of Michels and Xue.27

The findings from this meta-analysis demonstrated a clear dose-response relation between birth weight and breast cancer risk after accounting for the heterogeneity across the studies. These results indicated that breast cancer risk increased approximately 7% per 1 kg increase in birth weight. Our results were consistent with the findings of the WCRF report,29 which indicated that breast cancer risk increased 8% per 1 kg increase in birth weight (based on 6 cohort studies). Another pool analysis14 indicated that breast cancer risk increased 6% per 1 SD (0.5 kg) increase in birth weight; our estimate is slightly lower but comparable. Our study adds...
additional information that pooled analyses might be unable to quantify. We were able to include additional studies that measured birth weight only in categorical variables by using the Greenland and Longnecker method\(^{46}\) to estimate the dose-response relationship. In our meta-analysis, although the effect estimate among premenopausal women is larger in magnitude than the effect among postmenopausal women, the association was not statistically significant. Even with the inclusion of additional studies that provided adequate information for stratification by menopausal status and applying the Greenland and Longnecker methods for estimating dose-response relationships incorporating categorical measures, our findings remain consistent with the earlier meta-analyses.

Birth weight as a proxy indicator of intrauterine environment has been linked with several hormone-related cancers, including testicular cancer,\(^{54–56}\) prostate cancer,\(^{57–59}\) and breast cancer, and other types of cancers, such as childhood leukemia.\(^{60–62}\) Although the underlying biological mechanisms that link high birth weight to a higher risk of breast cancer are still ambiguous, the findings from recent animal studies and epidemiological studies might provide clues to elucidate the association. We know that estrogen plays a major role in the etiology of breast cancer.\(^{63,64}\) Hence, hormonal exposures in early life might have a particularly significant influence on the subsequent breast cancer risk in adult life because the fetus is particularly susceptible to transient hormonal exposure and the change in the hormonal environment of the fetus alters the development of target organs by exerting lifelong effects.\(^{65,66}\)

In animal experiments, exposure to estrogens during fetal or early postnatal development can increase mammary tumorigenesis by changing both proliferation and differentiation of the mammary gland.\(^{67}\) Several epidemiological studies found that dizygotic twins who were exposed to more estrogens \textit{in utero} because of two placentas have a higher risk of breast cancer than singleton births.\(^{68–70}\) Pregnancy estrogen levels have been reported positively associated with birth weight.\(^{71–73}\) Therefore, high birth weight, like twinning, might be a proxy variable of early life exposure to high levels of pregnancy estrogens, as Trichopoulos proposed.\(^{8}\)

Another potential mechanism is that women with high birth weight may merely have a higher number of mammary gland cells at risk for transformation and, thus, have an increased subsequent breast cancer risk.\(^{74}\) Findings from the study by Cerhan et al.\(^{75}\) that birth weight was positively associated with mammographic breast density and dense area among women support the hypothesis because mammographic density is strongly correlated with mammary gland mass, which is also potentially associated with the mammary cells at risk for transformation.\(^{74}\) However, the specific biological mechanisms remain poorly understood. An important next step is to investigate more thoroughly plausible biological pathways that may explain the relationship between birth weight and breast cancer risk.

Some potential limitations of the meta-analysis should be considered. Publication bias is always a serious concern for meta-analyses; however, visual inspection of the funnel plots did not provide any obvious evidence of publication bias across studies. Many included studies also investigated additional intrauterine environmental factors associated with breast cancer, which could increase the chance of inclusion of studies with a nonsignificant association between birth weight and breast cancer and, consequently, reduce the potential publication bias. Bias within studies, such as information bias or selection bias, could also have influenced the validity of this meta-analysis study. In 7 of the studies we included, birth weight information was obtained from interviews or questionnaires. Recall bias might be a major problem among these studies. However, 1 study indicated that the birth information directly reported from the mother is as precise as the information from medical records.\(^{76}\) Therefore, the influence of recall bias in these studies could be negligible. Misclassification of cases might stem from the method of ascertaining the outcome through cancer registries as the result of possible incomplete reporting,\(^{77–79}\) errors in the registry,\(^{80–82}\) mismatched cases,\(^{83}\) residential mobility, and subsequent losses to follow-up. Although the potential impact of this problem is difficult to evaluate, there is no reason to believe that the misclassification is differential with regard to the breast cancer outcome among different birth weight categories. Finally, the inconsistent findings across the included studies might result from the differences in sample sizes, study populations, measurement cutoff points of birth weight, or other study design characteristics, such as inclusion of different potential confounding variables.

Overall, the results of this study supported the hypothesis that birth weight plays an important role in determining breast cancer risk in adult life. In particular, our findings indicated that breast cancer risk increased approximately 7% per 1 kg increase in birth weight. These results underscore the importance of conducting additional studies to clarify the underlying biological mechanisms that may further our understanding of the relationship between birth weight and breast cancer. This meta-analysis did not reveal effect modification by menopausal status, and additional studies are warranted because of the limited number of studies that stratified by this factor. In addition, more studies with improved research methods and analytic approaches are warranted to address the question of whether birth weight is more strongly associated with early-onset than with later-onset breast cancer.

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**Disclosure statement**

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**References**


