Cost Analysis of Maternal Disease Associated With Suboptimal Breastfeeding

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OBJECTIVE: To estimate the U.S. maternal health burden from current breastfeeding rates both in terms of premature death as well as economic costs.

METHODS: Using literature on associations between lactation and maternal health, we modeled the health outcomes and costs expected for a U.S. cohort of 15-year-old females followed to age 70 years. In 2002, this cohort included 1.88 million individuals. Using Monte Carlo simulations, we compared the outcomes expected if 90% of mothers were able to breastfeed for at least 1 year after each birth with outcomes under the current 1-year breastfeeding rate of 23%. We modeled cases of breast cancer, premenopausal ovarian cancer, hypertension, type 2 diabetes mellitus, and myocardial infarction considering direct costs, indirect costs, and cost of premature death (before age 70 years) expressed in 2011 dollars.

RESULTS: If observed associations between breastfeeding duration and maternal health are causal, we estimate that current breastfeeding rates result in 4,981 excess cases of breast cancer, 53,847 cases of hypertension, and 13,946 cases of myocardial infarction compared with a cohort of 1.88 million U.S. women who optimally breastfed. Using a 3% discount rate, suboptimal breastfeeding incurs a total of $17.4 billion in cost to society resulting from premature death (95% confidence interval [CI] $4.38–24.68 billion), $733.7 million in direct costs (95% CI $612.9–859.7 million), and $126.1 million indirect morbidity costs (95% CI $99.00–153.22 million). We found a nonsignificant difference in number of deaths before age 70 years under current breastfeeding rates (4,396 additional premature deaths, 95% CI –810–7,918).

CONCLUSIONS: Suboptimal breastfeeding may increase U.S. maternal morbidity and health care costs. Thus, investigating whether the observed associations between suboptimal breastfeeding and adverse maternal health outcomes are causal should be a research priority.

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Major medical authorities recommend exclusive breastfeeding for a child's first 6 months of life, with continued breastfeeding after the introduction of complementary foods through at least the child's first year of life.[1,2] However, in the United States, although 75% of mother–neonate dyads initiate breastfeeding, only 23% breastfeed for 1 year or more.[3] Not breastfeeding is associated with an increased risk of adverse health outcomes for infants and children. Previous research has shown the adverse health effects associated with suboptimal breastfeeding cost the United States $14.2 billion annually (2011 dollars) in pediatric disease, including the costs of 911 child deaths.[4]

Breastfeeding is also associated with maternal health outcomes.[5] Shorter duration of lactation is associated with increased maternal breast cancer,[6] ovarian cancer,[7,8] hypertension,[9–11] type 2 diabetes mellitus,[9,12] and myocardial infarction (MI).[9,13] We estimate the burden of maternal disease that might be averted if more mothers

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were able to adhere to infant feeding recommendations, assuming a causal association between breastfeeding and maternal health.

MATERIALS AND METHODS

Based on prior research (Table 1), we simulated the health and health care costs for a cohort of 100,000 women who were aged 15 years in 2002. We modeled the cumulative life experience for this cohort through age 70 years. Each year, each simulated woman had a possibility of giving birth, after which she had a possibility of breastfeeding her child for 0–18 months; each year, each simulated woman also had a probability of developing one of the five health conditions of interest or of dying (Fig. 1).

We examined two sets of simulations with the suboptimal arm reflecting current levels of breastfeeding and the other reflecting optimal levels. We defined optimal levels as breastfeeding for at least 1 year after each birth, consistent with medical recommendations.[1,2] Current breastfeeding rates were taken from final monthly data from the National Immunization Survey (see Appendix 1, available online at http://links.lww.com/AOG/A398). The difference in outcomes for the two simulations represents the burden of suboptimal breastfeeding if observed associations between lactation and maternal health outcomes are causal. Assuming steady-state conditions, the discounted costs incurred by the cohort of women of a given age summed over their lifetime are equivalent to the cost incurred by women of all ages during the course of 1 year. Interventions to improve breastfeeding rates would occur around the time of pregnancy, whereas the costs of maternal health effects are

Table 1. Associations Between Lactation and Maternal Health Conditions Informing Model

Condition	Source	Measure of Association	Effect on Maternal Risk of Condition	Measure of Lactation	Maximum Duration of Lactation With Effect on Condition in Model
Breast cancer	Collaborative Group, 2002[6]	Relative risk	4.3% (2.9–5.8%)	Per year lifetime	4 y lifetime
Premenopausal ovarian cancer	Table 2, Danforth et al, 2007[7]	Relative risk	0.66 (0.46–0.96)	18 or more mo lifetime	18 mo lifetime
			0.82 (0.54–1.24)	12–17 mo lifetime	
			0.76 (0.52–1.11)	7–11 mo lifetime	
			0.96 (0.76–1.21)	1–6 mo lifetime	
			1.0 (referent)	Never	
Type 2 diabetes mellitus	Table 5, Stuebe et al, 2005[12]	Hazard ratio	0.53 (0.40–0.70)	More than 23 mo lifetime	24 mo lifetime; risk reduction lasts 15 y after the woman's last birth
			0.76 (0.59–0.98)	From 11 to 23 mo	
			0.76 (0.58–0.99)	More than 6 to 11 mo lifetime	
			0.78 (0.57–1.06)	From 3 to 6 mo lifetime	
			1.03 (0.80–1.35)	Any lactation from 0 to 3 mo lifetime	
			1.0 (referent)	Never	
Hypertension	Table 3, Stuebe et al, 2011[18]	Hazard ratio	1.0 (referent)	12 or more mo per birth	12 mo per birth for up to four births
			1.07 (0.99–1.17)	9 to less than 12 mo per birth	
			1.09 (1.02–1.18)	6 to less than 9 mo per birth	
			1.19 (1.11–1.28)	More than 3 to less than 6 mo per birth	
			1.21 (1.12–1.30)	More than 0 to 3 mo per birth	
			1.22 (1.13–1.32)	Never	
MI	Table 3, Stuebe et al, 2009[13]	Hazard Ratio	0.66 (0.49–0.89)	More than 23 mo	24 mo lifetime risk reduction lasts 30 y after the woman's last birth
			0.89 (0.71–1.1)	More than 11 to 23 mo	
			0.96 (0.76–1.21)	More than 6 to 11 mo	
			0.98 (0.8–1.21)	More than 3 to 6 mo	
			0.94 (0.79–1.12)	More than 0 to 3 mo	
			1.0 (referent)	Never	

MI, myocardial infarction.

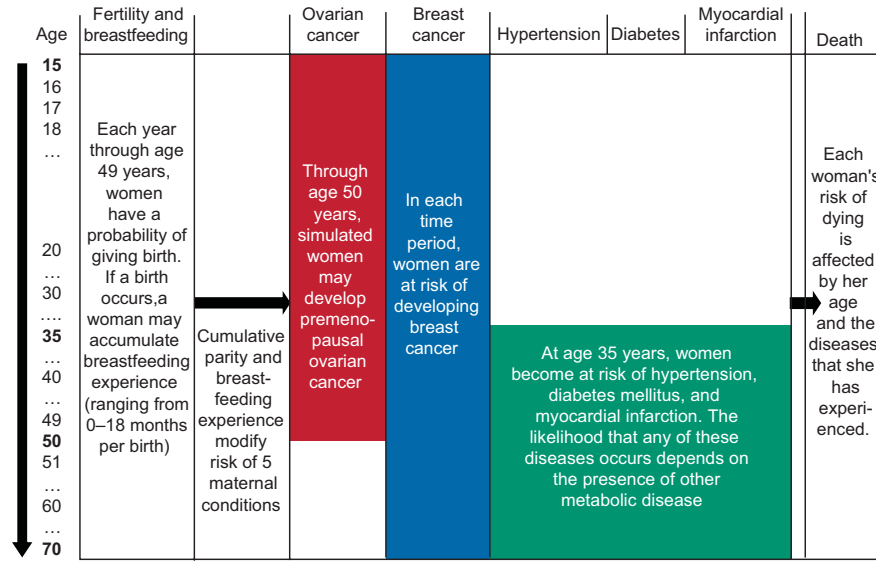

Fig. 1. Tracking the life experiences of a virtual woman in our model. Bold numbers indicate landmark ages.

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experienced in later life. The mean of the distribution of age at first birth in the United States is 25 years. Accordingly, we discounted all costs by the number of years difference between the age at which the cost is incurred and age 25 years.[14]

The first set of simulations describes maternal health outcomes with current rates of breastfeeding. This model simulates women from age 15 years through age 70 years using breastfeeding rates from the 2008 birth cohort from the Centers for Disease Control and Prevention.[15] Because the Centers for Disease Control and Prevention does not collect breastfeeding data beyond age 18 months, the maximum duration modeled in our analysis was 18 months for each birth. We used data from the National Center for Health Statistics to model birth rates and capped parity at six.[16]

A second simulation modeled the experiences of 100,000 hypothetical women who optimally breastfed. Given that some women cannot breastfeed, we assumed that 10% of simulated women would not breastfeed under optimal conditions. Of the remaining 90% of women, all were assumed to breastfeed at least 12 months, but the exact amount each woman breastfed ranged from 12 to 18 months and was determined using a formula that specified that 40% of women who breastfed (36% of all women) breastfeed for 18 months, whereas the remaining 54% of simulated women were randomly assigned across 12 months through 17 months.

To arrive at projected disease rates, deaths, and associated costs for the U.S. female population aged 15 years in 2002 (1.883 million[17]), we multiplied all results by a factor of 18.83. Because associations between breastfeeding and maternal health manifest over time, future costs were discounted at 3%. All simulations were performed in Java.

Because all relationships between lactation and health outcomes described in the literature are estimates, projections of future health outcomes must reflect that uncertainty. We therefore performed each simulation 2,000 times, drawing key parameters at random from triangular distributions covering the range of estimates available in the literature associating breastfeeding with maternal health outcomes, centered on the point estimate provided in the literature and a distribution width of four standard errors. Each simulation produced a data set that reflected a different combination of key estimates. We analyzed variability in our key outcomes across these data sets; these analyses represent a form of probabilistic sensitivity analyses.

We assumed that breastfeeding rates were correlated between pregnancies based on several sources of observational data[18,19] and used data from the Infant Feeding Practices Study II to model breastfeeding duration in a subsequent pregnancy contingent on duration of breastfeeding for the prior birth.[19]

Our analyses focused on five conditions that have been consistently associated with breastfeeding in observational studies that adjusted for parity as well as known or suspected confounders such as diet, physical activity, oral contraceptive use (in the case of cancer and hypertension),[6,7,18] and socioeconomic status (Table 1). For the purposes of our model, we assumed that these multivariate-adjusted associations reflect a causal relationship between breastfeeding and

maternal health. As women aged, their risk of experiencing each of the conditions depended on their breastfeeding experience to that point.

Associations between lifetime duration of lactation and invasive breast cancer (premenopausal or postmenopausal) were drawn from a meta-analysis of 47 epidemiologic studies.[6]

Lactation has been associated with reduced risk of ovarian cancer, and particularly premenopausal ovarian cancer.[7,8,20] We therefore modeled an association between breastfeeding and ovarian cancer until age 51 years, the average age of menopause.[21] Lactation is associated with lower maternal risk of hypertension.[9,18] We used estimates of this relationship from the Nurse's Health Study II,[18] which were adjusted for multiple potentially confounding covariates.

In multiple studies, lactation is associated with reduced maternal risk of type 2 diabetes mellitus.[12,22] Several studies have found differences in diabetes prevalence among postmenopausal women.[22,23] However, the only study to measure incident disease found that the association between breastfeeding and incident type 2 diabetes mellitus disappeared after 15 years after a woman's last birth.[12] Thus, we limited the effect of lactation on type 2 diabetes mellitus accordingly.

Data exist relating breastfeeding duration to coronary heart disease in general[9,24] and to MI in particular.[13] We used estimates of the association between lifetime lactation and incident MI from the Nurses' Health Study.[13] In accordance with this study, we limited the effect of lactation on MI to 30 years after a woman's last birth.

To account for potential overlap among hypertension, diabetes, and MI, we modeled transitions over time between comorbid disease states using a first-order Markov process. We calculated these transition probabilities using data from the longitudinal National Health and Nutrition Evaluation Survey, which assessed a cohort of women in 1987 and the same women again in 1992.[25] Several limitations of these data affect our model: 1) because this national survey lacks data on women before age 35 years, women in our model could not develop hypertension, type 2 diabetes mellitus, or MI before age 35 years; 2) because longitudinal survey data were only available for a 5-year interval, we assumed that transition probabilities were stable within the 5-year intervals and converted these probabilities from 5-year to 1-year intervals; 3) because the survey data were too few to provide stable estimates by year of age, we used transition probabilities for women in three age groups: aged 50 years and younger, 51–65 years, and 65 years and older.

Nulliparity and age at first birth predict breast cancer risk; we estimated the effect of these factors using the Breast Cancer Risk Assessment Tool.[26] For women younger than 35 years, we used data from Surveillance Epidemiology and End Results.[27] To model the relationship between parity and premenopausal ovarian cancer, we estimated from the literature that nulliparous women had twice the odds (95% confidence interval [CI] 1.4–3.3) of ovarian cancer compared with parous women.[28] To estimate associations between nulliparity and metabolic disease risk, we used data showing that nulliparous women have body mass indices[29] and body composition[30] similar to parous women who have breastfed at least 6 months. We therefore assigned nulliparous women the same risk of metabolic disease as women who breastfed for 6 or more months. Available data on type 2 diabetes mellitus, parity, and breastfeeding support this assumption.[23] Given the widespread use of effective contraception in the United States,[31] we assumed that duration of lactation did not affect likelihood of future birth.

To estimate mortality rates for women who developed breast or ovarian cancer, we used data from the yearly survival data from Surveillance Epidemiology and End Results.[27] We used age-specific mortality rates to account for the fact that premenopausal women tend to have less aggressive ovarian cancer and lower mortality rates.[28] For type 2 diabetes mellitus, hypertension, and MI, we used mortality rates from the National Health and Nutrition Examination Survey, although the 1992 survey data reflected all-cause deaths of the women assessed in 1987 and thus reflected the combination of all health conditions a woman had in 1987. All models assumed steady-state rates of disease and mortality.

We defined "premature death" as death at age 69 years or younger, because the median lifespan of a 20-year-old woman in the United States is 81.2 years.[32] We chose this age as a conservative measure of premature death, which reflects a loss of over 10 years from the average life expectancy of a woman in the United States. Simulated women could die from any cause; however, differences attributable to changes in rates of lactation reflect only mortality related to the five illnesses we model.

Published cost data were converted into 2011 dollars using the rate of medical inflation for direct costs and general inflation for indirect costs,[33] because medical inflation outpaces general inflation. Where no dollar year was specified in a source, we assumed the year before publication. We assumed that breastfeeding does not influence the costs of childbearing and discounted future costs by 3% per year, the social discount

rate, to the year when our hypothetical women were aged 25 years, the mean age of U.S. women at first birth.[14] We performed sensitivity analyses with discount rates of 0% and 5%. We subsequently briefly discuss the source and magnitude of each cost estimate; details are in Appendix 2, available online at http://links.lww.com/AOG/A399.

We calculated each death's cost using the value of a statistical life taken from the standard model using a revealed preference model to prevent a premature death (Table 2).[34] This measure is commonly used by government agencies and policymakers.[35,36] Although the Environmental Protection Agency's 2003 value of a statistical life at any age was $8.15 million,[35] other research has shown that the value of a statistical life varies over a lifetime with the highest value for those aged 35–44 years ($12.9 million)[34] and the lowest value for those over age 62 years ($2.81 million).[34,37,38] Although some authors include the cost of lost productivity resulting from premature death in the indirect costs, we did not count mortality-related costs in our estimates of indirect costs.

We estimated direct health costs and the indirect costs of morbidity and premature mortality. For cancers, we partitioned direct costs into those for the year of diagnosis, each year after the year of diagnosis, and the year before death from that cancer. To obtain indirect costs for breast and ovarian cancer, we applied the ratio from the National Institutes of Health of indirect to direct costs of cancer of 0.229.[39]

We used National Cancer Institute data on the direct costs of invasive breast cancer, which ranged from $23,863 for year of diagnosis in women aged 65 years or older to $97,490 for the final year of life in women younger than 65 years[40] (see Appendix 3, available online at http://links.lww.com/AOG/A400). We used cost data from the National Cancer Institute on the direct costs of premenopausal ovarian cancer, which range from $102,147 for the year of diagnosis to $8,578 for years after the year of diagnosis and $154,658 for the final year of life.[40] All deaths resulting from premenopausal ovarian cancer were assumed to occur before age 65 years.

Table 2. Value of a Statistical Life by Age

Age (y)	Value in 2011 Dollars
18–24	$4,130,120
25–34	$11,802,210
35–44	$12,873,950
45–54	$10,416,790
55–62	$4,835,900
Older than 62	$2,810,050

Data from Aldy J, Viscusi W. Age differences in the value of statistical life: revealed preference evidence. Review of Environmental Economics and Policy 2007;1:241–60 and converted into 2011 dollars. There is a paucity of data for value of a statistical life beyond age 62 y. We developed a conservative estimate based on extrapolating Figure 6 in Aldy J, Viscusi W. Age variations in workers' value of statistical life. Cambridge (MA): National Bureau of Economic Research; 2003.

We considered the cost of hypertension alone plus the cost of hypertension as a risk factor for other cardiovascular disease,[41] subtracting out that portion resulting from coronary heart disease.[42,43] We used a direct annual cost of $998 and indirect annual morbidity cost of $98.

Microvascular disease resulting from diabetes (nephropathy, neuropathy, and retinopathy) accounts for 48% of total diabetes costs.[44] We used $3,557 for annual microvascular direct costs and $893 for microvascular indirect morbidity costs. We excluded costs for macrovascular disease to ensure that we did not double count the costs of MI.

Direct medical costs for acute MI are $13,426[42] with indirect morbidity costs of $1,506. After MI, annual ongoing costs for coronary heart disease vary between $1,599[41] and $5,782.[43] Yearly indirect cost estimates vary from $434[41] to $648.[43] To be conservative, we used the lowest cost estimates for subsequent coronary heart disease.

We used Stata 11 to analyze the 4,000 data sets generated by the simulations. We estimated the variability of differences in the population prevalence of maternal cancers, type 2 diabetes mellitus, hypertension, MI, and premature mortality when women breastfed at current compared with optimal rates and the proportion of current disease burden that this change would reflect. We also calculated the range of differences in direct and indirect costs. To avoid double-counting, the latter include lost wages resulting from morbidity only. The CIs reported in Table 3 represent the 2.5th and 97.5th percentiles for the distribution of the outcome of interest across the 2,000 data sets simulated under each rate of lactation. The disease-specific cost differences shown in Table 4 were calculated using the cost estimates provided in Appendix 2 (http://links.lww.com/AOG/A399).

The study was exempt from the Cambridge Health Alliance institutional review board because it does not involve human subjects.

RESULTS

Comparisons of estimated rates of maternal illness under current rates of breastfeeding and under optimal breastfeeding conditions are shown in Table 3. We found significant reductions in three maternal conditions (MI, hypertension, and breast cancer) could be

Table 3. Lifetime Incidence of Maternal Conditions at Current and Optimal Breastfeeding Lactation Rates, Monte Carlo Simulation Model

	Current Rates of Lactation, Cases/1,000 Women	Optimal Lactation, Cases/1,000 Women	Mean Difference With Change From Current to Optimal Lactation, Cases/1,000 Women (95% CI)	Excess Annual Cases of U.S. Maternal Disease Resulting From Suboptimal Lactation* (95% CI)
Breast cancer	61.0	58.3	2.6 (2.1–3.2)	4,981 (3,992–6,044)
Premenopausal ovarian cancer	0.581	0.566	0.02 (−0.01 to 0.05)	28.7 (−19 to 94)
Hypertension	515.7	487.1	28.6 (23.3–34.3)	53,847 (43,836–64,596)
Type 2 diabetes mellitus	67.3	65.0	2.4 (−0.42 to 4.3)	4,482 (−791 to 8,022)
MI	86.8	79.4	7.4 (3.4–11.2)	13,946 (6,318–21,090)
Death before age 70 y	66.1	63.8	2.3 (−0.4 to 4.2)	4,396 (−810 to 7,918)

CI, confidence interval; MI, myocardial infarction.
* Assuming 1.883 million 15-year-old U.S. women per year (data from U.S. Census, 2005).[17]

achieved with changes in population rates of breastfeeding. If observed associations between lactation and maternal health are causal, our model found that optimal breastfeeding would prevent 8.5% (95% CI 3.9–12.7%) of maternal MI, 5.5% (95% CI 4.6–6.6%) of maternal hypertension, and 4.3% (95% CI 3.5–5.3%) of the breast cancers expected under current rates of lactation. This would represent savings in

Table 4. Potential Cost Burden at Current Breastfeeding Rates, in 2011 Million Dollars, by Discount Rate

	At 0% Discount Rate (95% CI)	At 3% Discount Rate (95% CI)	At 5% Discount Rate (95% CI)
Disease-specific costs			
Breast cancer			
Direct cost	$253.43 ($199.49–312.34)	$104.77 ($82.62–129.11)	$61.43 ($48.32–76.20)
Indirect cost	$58.03 ($45.71–71.51)	$23.99 ($18.92–29.56)	$14.07 ($11.08–17.45)
Premenopausal ovarian cancer			
Direct cost	$5.31 ($5.00–18.36)	$3.04($2.73–10.67)	$2.18 ($2.10–7.93)
Indirect cost	$1.22 (−$1.14 to $4.21)	$0.70 (−$62 to $2.44)	$0.50 (−$0.48 to $1.81)
Hypertension			
Direct cost	$823.59 ($670.65–984.18)	$336.15 ($274.32–400.87)	$194.68 ($158.47–232.09)
Indirect cost	$80.87 ($65.84–96.70)	$33.01 ($26.94–39.37)	$19.12 ($15.57–22.79)
Type 2 diabetes mellitus			
Direct cost	$276.02 (−$5.48 to $478.00)	$113.08 ($1.12–196.96)	$65.26 ($1.56–114.04)
Indirect cost	$66.97 (−$1.33 to $115.97)	$27.43 ($0.28–47.80)	$15.83 ($0.38–27.66)
MI			
Direct cost	$430.30 ($220.08–629.70)	$176.69 ($90.74–257.71)	$102.18 ($52.68–148.50)
Indirect cost	$104.91 ($56.49–150.41)	$40.99 ($21.88–58.82)	$22.92 ($12.22–32.84)
All-cause costs			
Total direct cost	$1,788.65 ($1,495.14–2,091.49)	$733.72 ($612.64–859.67)	$425.72 ($354.43–499.37)
Total indirect cost	$312.00 ($243.96–378.56)	$126.12 ($99.00–153.22)	$72.44 ($856.78–87.97)
Premature death (all cause)	$42,461.14 ($17,243.56–58,547.80)	$17,405.60 ($4,375.09–24,676.64)	$9,986.41 ($1,22.31–14,505.70)
Total	$44,561.79 ($19,021.46–60,942.50)	$18,265.44 ($5,136.52–25,625.45)	$10,484.58 ($1,636.08–15,052.66)

CI, confidence interval; MI, myocardial infarction.

direct medical costs of $733.72 (95% CI $612.94–859.67) million and indirect medical costs of $126.12 (95% CI $99.00–153.22) million using a discount rate of 3%. The potential cost savings with optimal lactation under other discount rates are shown in Table 4.

Premature deaths that might be prevented by changes in rates of lactation are estimated to be 4,396 (95% CI –810 to 7,918). At a 3% discount rate, the cost to society of these premature deaths totals $17.41 (95% CI $4.38–24.68) billion. When alternative discount rates are considered, these society costs are shown in Table 4.

DISCUSSION

Our Monte Carlo simulations indicate that if observed associations between lactation and maternal health are causal, optimal breastfeeding[1,2] could significantly reduce rates of breast cancer, hypertension, and MI for U.S. women. Our model found that approximately 4,000 premature maternal deaths could be prevented by optimal breastfeeding, although CIs for this estimate crossed zero. Of note, our point estimate for premature death exceeds the annual number of U.S. deaths from cervical cancer (3,909), asthma (3,361), or influenza (3,055).[45] If a randomized control trial were to demonstrate similar effects to those reported in the observational literature, the "number needed to treat" with optimal breastfeeding to prevent a case of maternal hypertension would be 35, to prevent a maternal MI would be 135, and to prevent a case of breast cancer would be 385.

Previous work has shown that suboptimal breastfeeding is associated with annual pediatric costs of $14.2 billion[4] (or $3,430 per live birth). Our current work builds on these pediatric costs by estimating that the United States annually incurs an additional $18.3 billion in potentially preventable maternal health costs, attributable largely to the high value placed on life lost before the age of 70 years. However, the CIs around this estimate are wide with a lower bound of $5.1 billion.

Of note, our models may underestimate the true maternal costs of suboptimal breastfeeding; we modeled the effects of lactation on only five maternal health conditions despite data linking lactation with other maternal health outcomes.[46] In addition, women in our model could not develop type 2 diabetes mellitus, hypertension, or MI before age 35 years, although these conditions are becoming increasingly prevalent among young adults.[47] Although some studies have found an association between lactation and rates of postmenopausal diabetes[22,23] and cardiovascular disease,[10] we conservatively limited the duration of lactation's effect on both diabetes and MI. Limitations in the underlying studies prevent us from modeling the effect of extended lactation on some maternal conditions (eg, ovarian cancer). Finally, all cost inputs were purposely conservative. It is worth noting that the largest cost–effect in our simulation involves the association between hypertension and breastfeeding. Our source data on this relationship[18] considers the potential effect of unobserved confounding and argues that such confounding is unlikely to explain the adjusted association between breastfeeding and hypertension.

Because of the uncertainty in the underlying research literature, our estimates have broad CIs. The variability in our model results reflects the imprecision of the studies that underlie our model. Although the CIs cross zero for incidence of type 2 diabetes mellitus, premenopausal ovarian cancer, and premature deaths, the associated costs are statistically significant because of the nonlinear nature of these relationships. Key cost figures are sensitive to the choice of discount rates because many health outcomes are observed far into the future; however, under a range of discount rates, our models indicate that investment in policies to support lactation could produce significant cost savings.

Our models assume casual relationships between lactation and maternal health outcomes. Although the observational studies that underlie our models all adjusted for multiple confounders, including known risk factors for the disease outcomes of interest, risk factors for early breastfeeding cessation such as preterm birth, preeclampsia, and obesity are also risk factors for metabolic disease in later life. Our use of observational data reflects the existing literature on lactation and maternal health; apart from a single randomized trial examining the effect of exclusive lactation duration on maternal weight loss,[48] there are no published studies of maternal health outcomes in randomized trials of breastfeeding.

Future studies should capture and report each month of lactation rather than grouping duration responses into multimonth ranges or bins, because finer grained data would strengthen models of breastfeeding's effect on health outcomes. In addition, studies are needed on the effects of lactation on the disease course of women who develop each of the conditions we considered. Data are also needed on the costs of infant feeding. Because we were unable to find adequate data on the time costs of preparing and feeding an infant formula compared with breastfeeding, these costs are not considered in our models. However, we recognize that infant feeding practices have quantifiable time costs in terms of both maternal employment and income. More broadly, updated longitudinal studies of

the natural history of hypertension, diabetes, and cardiovascular disease are needed, because the data from the National Health and Nutrition Examination Survey that we used in our model are somewhat dated.

In conclusion, our models suggest that if associations between lactation and maternal health outcomes are causal, suboptimal breastfeeding currently results in substantial morbidity, mortality, and health costs for U.S. women. The magnitude of these costs warrants definitive study of whether lactation plays a causal role in determining maternal health and should inform national policies and programs to enable more women to reach their personal breastfeeding goals.

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