**ORIGINAL ARTICLE**

**Association of lactation with maternal risk of type 2 diabetes: A systematic review and meta-analysis of observational studies**

Ana-Catarina Pinho-Gomes DPhil$^{1,2,3}$ | Georgia Morelli MSc$^3$ | Alexandra Jones PhD$^3$ | Mark Woodward PhD$^{2,3,4}$

$^1$King’s College London, London, UK
$^2$The George Institute for Global Health, Imperial College London, London, UK
$^3$The George Institute for Global Health, University of New South Wales, Sydney, New South Wales, Australia
$^4$Welch Center for Epidemiology, Prevention and Clinical Research, Johns Hopkins University, Baltimore, Maryland

**Correspondence**
Ana-Catarina Pinho-Gomes, DPhil, The George Institute for Global Health, Imperial College London, London, UK.
Email: cat.pinho-gomes@kcl.ac.uk

**Funding information**
ACPG is funded by the National Institute for Health Research, UK. The study funder was not involved in the design of the study; the collection, analysis and interpretation of data; writing the report; and did not impose any restrictions regarding the publication of the report.

**Abstract**

**Aim:** To investigate the association between lactation and maternal risk of type 2 diabetes, including a potential graded association according to lactation duration.

**Methods:** A systematic review and meta-analysis of observational studies that investigated the reported association between lactation (irrespective of duration, intensity or mode) and maternal risk of type 2 diabetes in the first months after birth in women with gestational diabetes were conducted.

**Results:** A total of 22 studies (17 cohort studies and five cross-sectional studies) were included in this systematic review, and 16 contributed to the meta-analysis. Studies that investigated the association of lactation with risk of type 2 diabetes in the first months after birth in women with gestational diabetes reported conflicting results. Studies with a longer follow-up showed a graded protective association for lactation and the risk of type 2 diabetes, with a potentially larger risk reduction in women with gestational diabetes than in those without gestational diabetes. Overall, ever versus never lactation was associated with a 27% lower risk of type 2 diabetes (RR 0.73, 95% CI [0.65, 0.83]). Each additional month of lactation was associated with a 1% lower risk of type 2 diabetes (RR 0.99, 95% CI [0.98, 0.99]). However, the overall quality of the studies was modest.

**Conclusions:** Lactation is associated with a significantly reduced risk of maternal type 2 diabetes over the life course, particularly in women with gestational diabetes. The protective effect seems to increase with longer duration of lactation. Further research is warranted to understand whether this association is modified by exposure to other risk factors.

**KEYWORDS**
dose response, meta-analysis, relationship, systematic review, type 2 diabetes

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**1 | INTRODUCTION**

The World Health Organization (WHO) and the United Nations International Children’s Emergency Fund (UNICEF) recommend exclusive breastfeeding for the first 6 months of life, followed by the introduction of complementary foods along with continued breastfeeding, up to at least the age of 2 years.$^1$ There is compelling evidence of the short- and long-term benefits of breastfeeding for children, such as protection against childhood conditions, particularly infections and obesity, as well as chronic conditions...
diseases, including type 2 diabetes and cardiovascular disease later in life.\textsuperscript{2-4} Comparably less attention has been given to the benefits of lactation (i.e. breastfeeding a child) for mothers, although previous studies have suggested that lifetime duration of lactation is associated with a reduced risk of breast and thyroid cancer, metabolic syndrome, atherosclerosis and hypertension.\textsuperscript{5-9} However, evidence of the effects of lactation on women’s risk of developing type 2 diabetes is conflicting, with some studies suggesting a protective effect, whilst others report no association.\textsuperscript{10-14} Almost all studies are limited by their inability to account for metabolic risk profiles before lactation, and previous history of gestational diabetes (GD), a strong risk factor for type 2 diabetes in women. Furthermore, previous meta-analyses have only included subsets of available studies and have not investigated the possibility of a graded association between duration of lactation and type 2 diabetes in women.\textsuperscript{15-17}

Therefore, the aims of this study were to investigate the effects of lactation on maternal risk of type 2 diabetes overall and according to previous history of GD, and to investigate the existence of a dose-response relationship between lactation and maternal risk of type 2 diabetes.

2METHODS

2.1Study design

A systematic review and meta-analysis of observational studies was conducted according to the Meta-analyses Of Observational Studies in Epidemiology (MOOSE) statement and the Cochrane Collaboration.\textsuperscript{18,19} The protocol was registered with the PROSPERO database of systematic reviews (CRD42020221183).

2.2Literature search

The bibliographic databases Medline (via PubMed) and Embase (via Ovid) were searched, from inception to February 2021, with MESH terms for lactation and breastfeeding and for type 2 diabetes (the search criteria are provided in the supporting information). No restrictions were applied to type of study or language. This was complemented with hand-searching of reference lists of eligible studies and related systematic reviews.

2.3Inclusion and exclusion criteria

Cohort, case control or cross-sectional studies that investigated the effects of lactation on risk of type 2 diabetes were included, irrespective of the duration and intensity (e.g. exclusive, predominant or intermittent) of lactation. No restriction on the number of participants or duration of follow-up was applied. Studies that only reported outcomes for offspring, that compared the effects of different strategies to increase lactation, that only measured the effects of other perinatal exposures, or that only reported maternal outcomes other than type 2 diabetes, were excluded.

2.4Definition of exposure

The exposure to lactation was measured according to the definitions adopted by the included studies, which included average lactation per child and cumulative lifetime lactation and lactation for the index pregnancy (for studies that followed up women after an index pregnancy).

2.5Definition of outcome

Type 2 diabetes was defined according to the included studies. Prospective studies measured incidence of type 2 diabetes according to international guidelines based on oral glucose tolerance tests. Retrospective and cross-sectional studies used a combination of self-reported diagnoses, fasting plasma glucose testing or linked medical records.

2.6Study selection

Two investigators (ACPG and GM) independently screened titles and abstracts for all eligible studies according to the inclusion and exclusion criteria. Full-text articles were retrieved and reviewed in duplicate, with disagreements resolved by a third reviewer (AJ). EndNote X8 software was used to manage references and record screening and selection operations. Details of the study selection are documented in Figure S1.

2.7Data extraction

Data extraction was performed by one reviewer (ACPG) using a structured form. Data were collected for study and population characteristics, including demographics, history of GD, lactation mode and duration and risk of type 2 diabetes.

2.8Risk of bias and quality assessment

The methodological quality of eligible studies was assessed using the Newcastle-Ottawa Scale for non-randomized studies.\textsuperscript{20} Studies were given stars depending on specific criteria in three fields: selection, comparability and outcomes.
2.9 | Data analysis

The association between lactation and maternal risk of type 2 diabetes was explored in two complementary analyses: (a) ever versus never lactation and (b) according to duration of lactation. All studies that reported adjusted risk estimates were included in the first meta-analysis,\(^{14,21–31}\) and those that reported effect sizes for intervals of duration of lactation were included in the second meta-analysis.\(^{12,24,29,31–34}\) Three studies contributed to both analyses.\(^{26,29,31}\)

Reported hazard ratios for type 2 diabetes with 95% confidence intervals (CIs), with adjustment for confounders, were extracted for cohort studies, when available. Reported risk or odds ratios and 95% CIs, with adjustment for confounders, were extracted if hazard ratios were not available for cohort studies. Reported odds ratios, with adjustment for confounders, with 95% CIs were extracted for cross-sectional studies. When numbers of cases but not adjusted effect sizes were reported, studies were excluded from the meta-analysis. Unadjusted effect sizes were not calculated for studies that only reported the number of cases in exposed versus unexposed individuals because of the high risk of confounding in observational studies. Those studies were only included in the qualitative synthesis.\(^{10–12,35,36}\) All studies were adjusted at least for age and body mass index (BMI) in multivariable models, with most adjusting for additional variables, such as ethnicity, education, smoking and parity. Whenever results for more than one model were reported, we selected the model with the highest number of covariates. The specific covariates used in multivariable models for each study are provided in Table S2.

Inverse variance weighted random effects meta-analyses, based on restricted maximum likelihood estimators (REML), were performed. Pooled estimates were reported as relative risks (RRs) with 95% CIs and are presented using forest plots. Heterogeneity was quantified using the I\(^2\) statistic and was tested using Cochran’s Q test.

For the dose–response meta-analysis, the mean point of the interval for which the hazard ratio was available in each study was used (e.g. for 3 to 6 months, 4.5 months was used). The linearity of the association, on the log scale, was verified by drawing a bubble plot (Figure S2). Next, a dose–response meta-analysis was conducted accounting for the clustering of subjects within each study. This was achieved using a one-stage random effects model, which took into account study-specific deviations from the population average dose–response coefficients.\(^{37}\) This model used weighted least squares regression with cluster robust error variances. The regression line with respective 95% CI was plotted to illustrate the fitted dose–response association.

Subgroup analyses were performed by type of study (cohort vs. cross-sectional), duration of follow-up (under vs. over 1 year), and history of GD.

For the ever versus never meta-analysis, sensitivity analyses were conducted to explore the impact of including the study that compared lactation for under versus over 12 months, and excluding studies with a sample size of less than 500 participants.\(^{21–23,25,30}\) For the dose–response meta-analysis, sensitivity analyses were conducted (a) for studies that considered total lifetime duration versus average duration per child or duration for the index pregnancy, (b) excluding cross-sectional studies, and (c) for studies that included only women with a history of GD (i.e. excluding studies that included women without GD).

Publication bias was investigated using funnel plots and Egger’s tests. All P values were calculated from two-tailed tests. Analyses were performed using STATA version 16.\(^{38}\)

3 | RESULTS

A total of 22 studies were eligible for inclusion in this systematic review, but only 16 of them contributed to the meta-analysis, as the remaining did not provide adjusted risk estimates.\(^{10–12,35,36}\) One of the studies contributed with data for two different cohorts of women, and hence in reality there were 17 studies.\(^{34}\) The characteristics of the included studies are summarized in Table 1. There were 17 cohort studies (11 prospective and six retrospective studies) and five cross-sectional studies, of which two were baseline assessments of cohort studies, and three were based on national surveys. The studies were conducted in populations from North America, Europe, Asia and Australia, including multiethnic populations with a variable representation of ethnic minorities. Ten studies were restricted to patients with a diagnosis of GD, whilst the remaining 12 included a mix of patients with and without GD, of which six stated the proportion of women with GD. Duration of lactation was classified differently across studies as (a) total lifetime duration of lactation;\(^{12,24,26,32,34}\) (b) average duration of lactation per child;\(^{24,26,28,37}\) (c) total duration for a single pregnancy in studies that followed up women after a specific pregnancy;\(^{10,12,21,22,25,27,29–31,35}\) and (d) lactation at hospital discharge.\(^{14,23}\) Follow-up varied from 4 to 12 weeks for studies that evaluated the short-term association between lactation and type 2 diabetes after birth, and up to 25 years.

The overall quality of the studies was modest (Table S1), with the main caveat being that lactation was self-reported and often many years after birth. There were some good quality cohort studies with large sample sizes and a low risk of bias.\(^{13,31,32}\) However, there were also several small studies with a high risk of selection or information bias.\(^{10–12,23,25,27}\)

Overall, studies that investigated the association between lactation and the risk of type 2 diabetes in the first months after birth in women with GD reported conflicting results. Some studies suggested that lactation had a positive impact on glucose metabolism,\(^{27,35}\) while others reported that lactation had no effect on glucose tolerance.\(^{10–12,22}\) Studies with a longer follow-up showed a protective association between lactation and the RR of type 2 diabetes, with a stronger association in women with GD than in those without GD.\(^{13,31–33}\) The extent of the benefit seemed to increase in parallel with duration of lactation and to be independent of well-established risk factors for type 2 diabetes, such as obesity, ethnicity, diet, exercise, weight gain and antecedent metabolic risk profiles.\(^{24,28,34}\)

Meta-analysis of studies that compared ever with never lactation\(^{14,21–31}\) suggested that lactation was associated with a 27% lower risk of type 2 diabetes (RR 0.73, 95% CI [0.65, 0.83]) (Figure 1).
| First author, year, study | Type of study | Country | Number of participants | Follow-up duration (median) | Population characteristics | Age | % GD | Lactation definition | Type 2 diabetes definition and evaluation | Key findings |
|--------------------------|--------------|---------|------------------------|-----------------------------|---------------------------|-----|------|-------------------|-----------------------------------------|-------------|
| Stuebe 2005, NHS I 24    | Prospective cohort | United States | 83 585 | 16 y | Women in the Nurses’ Health Study (NHS), which was initiated in 1976 and enrolled 121 700 women aged 30–55 y at baseline | 52 y at baseline | NA | Self-reported lactation, including duration at baseline questionnaire. | Self-reported T2D assessed on biennial questionnaires and confirmed by supplemental questionnaire | Duration of lactation was inversely associated with risk of T2D in young and middle-aged women, independent of other T2D risk factors, including BMI, diet, exercise and smoking status. This association appeared to wane with time since last birth |
| Stuebe 2005, NHS II 24   | Retrospective cohort | United States | 73 418 | 12 y | Women in the Nurses’ Health Study II (NHS II), which began in 1989, enrolling 116 671 women aged 25–42 y | 35 y at baseline | 5 | Self-reported lactation, including duration at baseline questionnaire. | Self-reported T2D assessed on biennial questionnaires and confirmed by supplemental questionnaire | Duration of lactation was inversely associated with risk of T2D in young and middle-aged women, independent of other T2D risk factors, including BMI, diet, exercise and smoking status. This association appeared to wane with time since last birth |
| Liu 2010 24              | Retrospective cohort or cross-sectional | Australia | 53 726 | NA | Women recruited into the Australian 45 and up cohort study | NA | NA | Self-reported lactation, including duration at baseline questionnaire. | Self-reported T2D assessed using baseline questionnaire | Compared with nulliparous women, childbearing women who do not breastfeed have about a 50% increased risk of T2D in later life. Lactation significantly reduces this excess risk, and the benefits increase with longer duration of lactation |
| Schwarz 2010, RRISK 28   | Retrospective cohort or cross-sectional | United States | 2233 | NA | Women in the Reproductive Risk Factors for Incontinence Study at Kaiser (RRISK) study, which enrolled multiethnic women aged 40–78 y. | 55 y at baseline | NA | Self-reported lactation, including duration in interview. | Self-reported physician diagnosed T2D, antidiabetic medication in interview, laboratory values for fasting plasma glucose or HbA1c. | Parous women have an increased risk of T2D compared with nulliparous women. This risk can be significantly reduced by lactation, independently of physical activity and BMI in later life |

(Continues)
| First author, year, study | Type of study | Country | Number of participants | Follow-up duration (median) | Population characteristics | Age | % GD | Lactation definition | Type 2 diabetes definition and evaluation | Key findings |
|---------------------------|---------------|---------|------------------------|-----------------------------|-----------------------------|-----|------|---------------------|----------------------------------------|-------------|
| O'Reilly 2011<sup>27</sup> | Prospective cohort | Ireland | 520 | 12 wk | Women with and without GD in the Atlantic diabetes in pregnancy (Atlantic DIP) partnership | 33 y at delivery | 58 | Self-reported lactation at 12 wk postpartum for index pregnancy | or inclusion in diabetes registry | T2D diagnosed by OGTT at 12 wk postpartum | Lactation may improve glucose metabolism postpartum |
| Ziegler 2012<sup>30</sup> | Prospective cohort | Germany | 204 | 19 y | Women with GD participating in the prospective German GD study | 31 y at delivery | 100 | Self-reported lactation, including duration for index pregnancy (no other pregnancies were considered) | T2D diagnosed by means of OGTT at 2 and 9 mo; 2, 5, 8, 11, 15 and 19 y after pregnancy; or clinical diagnosis of T2D | Lactation did not affect T2D development among islet autoantibody-positive women. Among islet autoantibody-negative women, lactation was associated with a marked delay in T2D development compared with women who did not breastfeed. Duration of lactation was inversely associated with postpartum T2D risk and diabetes-free survival. Effects were sustained over time. |
| Zhang 2015<sup>29</sup> | Cross-sectional | China | 9128 | NA | Parous women (aged 40–81 y) recruited from the population of four urban communities in Beijing, who had had only one lifetime birth | 55 y at baseline | NA | Self-reported lactation, including duration (only one lifetime birth) | Self-reported physician diagnosed T2D or fasting plasma glucose level on blood test; diagnosis confirmed by linked medical records | Parous women who breastfeed have a lower risk of T2D in later life than those who do not breastfeed, with larger benefits for longer duration of lactation |
| Moon 2015<sup>25</sup> | Prospective cohort | South Korea | 418 | 4 y | Women with GD in four hospitals in Korea | 32 y at delivery | 100 | Self-reported lactation (no duration) in index pregnancy | T2D diagnosed by OGTT at 6 wk postpartum and annually thereafter | Lactation was not associated with risk of T2D postpartum |
| Gunderson 2015, SWIFT<sup>31</sup> | Prospective cohort | United States | 1035 | 2 y | Women of diverse race/ethnicity groups diagnosed | Mean 34 y at baseline | 100 | Self-reported lactation, including intensity duration | T2D diagnosed by OGTTs at 6–9 wk after delivery | Higher lactation intensity and longer duration were independently associated in |
| First author, year, study | Type of study | Country | Number of participants | Follow-up duration (median) | Population characteristics | Age | % GD | Lactation definition | Type 2 diabetes definition and evaluation | Key findings |
|--------------------------|---------------|---------|------------------------|----------------------------|---------------------------|-----|------|---------------------|------------------------------------------|-------------|
| Martens 201616           | Retrospective cohort | Canada  | 334 553               | 24 y                       | First nations and non-first nations women with and without GD who delivered a child between 1987 and 2011 in Manitoba | 27 y at delivery | 3    | Lactation initiation in the hospital recorded by nurses | T2D diagnosis on population-based databases | Lactation initiation is associated with a reduced risk of subsequent T2D. This association is independent of family income, rural residence, first nation status, GD, parity, gestational hypertension, and age of the mother |
| Chamberlain 201623        | Retrospective cohort | Australia | 483                  | 7 y                        | Women with GD in regional hospital cohort in far North Queensland who gave birth in 2004–2010 (indigenous and non-indigenous) | NA | 100  | Self-reported lactation at discharge according to hospital records | T2D defined if documented T2D after OGTT during follow-up, laboratory results identifying the woman as having T2D, subsequent coding of a pregnancy as T2D or documentation of T2D in the pregnancy or medical records | Increased rate of progression from gestational to T2D among women partially lactating at discharge from hospital in comparison with those who were exclusively lactating |
| Benhalima 201622         | Retrospective cohort | Belgium  | 135                   | 14 wk                      | Women with GD in hospital cohort in Leuven | 32 y at delivery | 100  | Self-reported lactation but no duration | T2D based on OGTT performed at 3–6 mo postpartum according to | Compared with women with a normal OGTT postpartum, fewer women were lactating in the group with glucose |
| First author, year, study | Type of study | Country | Number of participants | Follow-up duration (median) | Population characteristics | Age | % GD | Lactation definition | Type 2 diabetes definition and evaluation | Key findings |
|---------------------------|--------------|---------|------------------------|----------------------------|---------------------------|-----|------|---------------------|------------------------------------------|-------------|
| Bajaj 2017,21             | Prospective cohort | Canada | 330 women              | 3 y                        | Cohort of pregnant women recruited at prenatal glucose tolerance test in hospital in Ontario | 35 y at delivery | 30 | Self-reported lactation, including duration for index pregnancy (no other pregnancies were considered) | Prediabetes/diabetes diagnosed using a 2-h OGTT at 3 mo, 1 y and 3 y postpartum | Lactation for ≥12 mo and exclusive lactation for ≥6 mo are associated with lower risk of prediabetes/diabetes at 3 y postpartum |
| Gunderson 2018, CARDIA13   | Prospective cohort | United States | 1238 | 25 y | Women from the Coronary Artery Risk Development in Young Adults (CARDIA) study of young Black and White women aged 18–30 y without T2D at baseline (1985–1986) who had one or more live births after baseline, reported lactation duration, and were screened for diabetes up to seven times during 30 y after baseline (1986–2016) | Mean age 24 y at index GD pregnancy | 12.5 | Self-reported lactation, including duration at year 7 and yearly thereafter. Lifetime duration | Self-report T2D with medication treatment or elevated OGTT and/or HbA1c | Lactation duration showed a strong, graded inverse association with diabetes incidence with no evidence of effect modification by race, GD or parity |
| Nam 2019, KNHANES26       | Cross-sectional | South Korea | 9960 | NA | Women who participated in the Korea National Health and Nutritional Examination Survey (KNHANES) from 2010 to 2013 | NA | NA | Self-reported lactation, including duration in questionnaire. Lifetime and average duration per child | Self-reported physician diagnosed T2D, antidiabetic medication in questionnaire or fasting plasma glucose level on blood sample | Any range of lactation duration and having breastfed a greater number of infants may be beneficial for preventing T2D. Longer duration of lactation may improve glycaemic control in parous women with T2D, particularly a total lactation duration of >36 mo |
| First author, year, study | Type of study | Country | Number of participants | Follow-up duration (median) | Population characteristics | Age | % GD | Lactation definition | Type 2 diabetes definition and evaluation | Key findings |
|---------------------------|---------------|---------|------------------------|-----------------------------|---------------------------|-----|------|----------------------|------------------------------------------|-------------|
| Mazariegos 2019, MTC23     | Prospective cohort | Mexico | 66 573 | 2 y | Women from the Mexican Teachers’ cohort free of diabetes at baseline, a prospective cohort of female teachers of 25 y and older from 12 states of Mexico enrolled in 2006–2008 | 25 y at first delivery | 1 | Self-reported lactation, including duration at baseline questionnaire. Average duration per child | Self-reported T2D at triennial questionnaires, with validation for a sample | There is an inverse association between mean duration of lactation per child and risk of T2D up to 12 mo. This association is stronger for women with age at first pregnancy of <25 y, those with current BMI of <27 kg/m², and those without a history of GD |
| Ley 2020, NHS II32         | Prospective cohort | United States | 4372 | 25 y | Women participating in the Nurses’ Health Study II (prospective cohort of 116 671 female registered nurses from the United States aged 25–42 y in 1989) who reported a history of GD in 1991 or incident GD through the biennial questionnaires up to 2001 or through a 2009 pregnancy questionnaire | Mean 32 y at index GD pregnancy | 100 | Self-reported lactation, including duration obtained from three NHS II follow-up questionnaires. Lifetime duration | Self-reported physician diagnosed T2D using validated questionnaire at baseline questionnaire and at biennial follow-up questionnaires | Longer lifetime lactation duration was associated with a lower risk of T2D and with lower concentrations of HbA1c, fasting insulin and C-peptide among middle-aged women without T2D |

| First author, year, study | Type of study | Country | Number of participants | Follow-up duration (median) | Population characteristics | Age | % GD | Lactation definition | Type 2 diabetes definition and evaluation | Key findings |
|---------------------------|---------------|---------|------------------------|-----------------------------|---------------------------|-----|------|----------------------|------------------------------------------|-------------|
| Kjos 199335               | Prospective cohort | United States | 809 | 4–12 wk | Women with recent GD after delivery in hospital in California | 31 y at delivery | 100 | Self-reported lactation at 12 wk postpartum for index pregnancy | T2D diagnosed by OGTT at 4–12 wk postpartum | Lactation has a positive effect on glucose metabolism postpartum in women with GD. Women who breastfeed are less probable to have T2D than those who do not breastfeed |

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| First author, year, study | Type of study | Country | Number of participants | Follow-up duration (median) | Population characteristics | Age | % GD | Lactation definition | Type 2 diabetes definition and evaluation | Key findings |
|--------------------------|--------------|---------|------------------------|---------------------------|---------------------------|-----|------|---------------------|------------------------------------------|-------------|
| Nelson 200811            | Retrospective cohort | United States | 592 | 12–24 mo | Indigent, primarily Latina women who had been diagnosed with GD in hospital in Los Angeles. | 32 y at delivery | 100 | Self-reported lactation (no duration) on medical records for index pregnancy | T2D diagnosed by OGTT at the first post partum visit, at the last visit within the first 12 mo after delivery, and at the last visit during 12–24 mo postpartum. Information retrieved from medical records | Lactation did not protect women from worsening of glucose tolerance postpartum |
| Kim 201110              | Prospective cohort | South Korea | 381 | 6–12 wk | Women diagnosed with GD in hospital in Seoul | 34 y at delivery | 100 | Self-reported lactation at 12 wk postpartum for index pregnancy | T2D diagnosed by OGTT at 6–12 wk postpartum | Lactation irrespective of duration did not influence glucose metabolism in the first 3 mo postpartum in women with GD |
| Capula 201412           | Retrospective cohort | Italy | 454 | 6–12 wk | Women with GD in hospital cohort in Catanzaro | 36 y at delivery | 100 | Self-reported lactation at 6–12 wk postpartum for index pregnancy | T2D diagnosed by OGTT at 6–12 wk postpartum (based on medical records) | The proportion of lactation was not significantly different between the women with and without postpartum T2D |
| Urs 201536              | Cross-sectional | United States | 6503 | NA | Women aged 20–75 y with at least one live birth in the National Health and Nutrition Examination Survey (NHANES) 2007–2008, 2009–2010 and 2011–2012 | NA | NA | Self-reported lactation in questionnaire | Self-reported T2D on questionnaire or fasting plasma glucose level on blood test | The association between GD and subsequent T2D was stronger in women who did not breastfeed than in those who did breastfeed |

Abbreviations: BMI, body mass index; GD, gestational diabetes; OGTT, oral glucose tolerance test; T2D, type 2 diabetes.
Sensitivity analyses, including the study that compared lactation for under with over 12 months, and studies with a sample size of less than 500 participants, did not have a substantial impact on the effect size estimates (Figures S3 and S4). There was significant heterogeneity in the meta-analysis (I² = 69%), which was completely explained by high heterogeneity among cross-sectional studies (I² = 72%), as there was no heterogeneity among cohort studies (I² = 0%). The protective association between lactation and type 2 diabetes was more marked in cohort than in cross-sectional studies (0.73 [0.88, 0.78] and 0.81 [0.67, 0.98] for cohort and cross-sectional studies, respectively; P = .01 for heterogeneity). Despite the contradictory findings reported by studies conducted in the initial months after birth, there was no evidence of heterogeneity according to duration of follow-up (P = .35) (Figure S5). However, only two studies contributed to the meta-analysis of the association between lactation and the risk of type 2 diabetes within 3 months of delivery, as effect size estimates were not available for the other studies.

Funnel plot asymmetry and Egger’s test (P = .003) suggested that there could be publication bias (Figures S11 and S13). Applying the trim and fill method reduced the size of the risk reduction but did not have a material impact on the key conclusion of this meta-analysis (observed studies 0.73 [0.64, 0.83] and observed plus imputed studies 0.80 [0.71, 0.91]; Figure S12).

Overall, the dose–response meta-analysis showed that each additional month of lactation was associated with a 1% reduction in the risk of developing type 2 diabetes (0.990 [0.984, 0.996], P = .008) (Figure 3). Sensitivity analyses did not have a material impact on the estimates of the dose–response association, albeit CIs were wider for analyses with a smaller number of studies. The estimate for the risk

| Study                  | Risk ratio with 95% CI | Weight (%) |
|------------------------|------------------------|------------|
| **Cohort**             |                        |            |
| Gunderson, 2015        | 0.48 [0.25, 0.92]      | 3.21       |
| Martens, 2016 (1)      | 0.73 [0.68, 0.79]      | 17.94      |
| Martens, 2016 (2)      | 0.78 [0.69, 0.89]      | 16.08      |
| Ziegler, 2012          | 0.54 [0.34, 0.85]      | 5.54       |
| Chamberlain, 2016      | 0.75 [0.23, 2.47]      | 1.09       |
| Benhalima, 2016        | 0.44 [0.17, 1.12]      | 1.70       |
| Moon, 2015             | 0.61 [0.33, 1.13]      | 3.53       |
| Oreilly, 2011          | 0.42 [0.20, 0.89]      | 2.55       |
| **Cross–sectional**    |                        |            |
| Liu, 2010              | 0.98 [0.85, 1.13]      | 15.46      |
| Nam, 2019              | 0.60 [0.42, 0.86]      | 7.51       |
| Schwartz, 2010         | 0.71 [0.52, 0.97]      | 8.96       |
| Zhang, 2015            | 0.85 [0.76, 0.96]      | 16.44      |
| **Overall**            | 0.73 [0.65, 0.83]      |            |

Test of θ = θj: Q(7) = 7.85, P = .35

Test of θ = θj: Q(3) = 8.46, P = .04

Test of group differences: Qb(1) = 1.18, P = .28
4 | DISCUSSION

This systematic review and aggregate data meta-analysis suggested that lactation is associated with a reduced risk of maternal type 2 diabetes in comparison with no lactation (i.e. use of any breastmilk substitutes), particularly in women with GD. It also suggested that lactation has incremental benefits, with each additional month of lactation being associated with a 1% lower risk of type 2 diabetes, with no evidence that the graded association differs between women with GD and without GD. However, the overall quality of the observational studies, particularly in women without GD, was modest.

A recent meta-analysis in women with prior GD, which included 13 cohort studies, showed that, compared with no lactation, lactation was significantly associated with a lower risk of type 2 diabetes (RR 0.66, 95% CI [0.48, 0.90]).

Although the authors reported that there was no significant relationship between long-term lactation and type 2 diabetes, this may be explained by the fact that long term was defined as over 3 months. This is at odds with a previous meta-analysis in women with prior GD, which included 13 cohort studies, showed that, compared with no lactation, lactation was significantly associated with a lower risk of type 2 diabetes (RR 0.66, 95% CI [0.48, 0.90]).

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meta-analysis, including 14 reports of nine studies, which had shown that, in women with GD, lactation longer than 4 to 12 weeks was associated with a reduced risk of type 2 diabetes compared with shorter lactation. Furthermore, the protective effect seemed to increase over time, as the risk reduction appeared larger when type 2 diabetes was evaluated more than 5 years after delivery. More recently, another meta-analysis including four studies showed that lactation for more than 12 months was associated with a RR reduction of 30% for type 2 diabetes (odds ratio 0.70, 95% CI [0.62, 0.78]).

This meta-analysis had important limitations as it only considered lactation longer than 12 months, thus it did not take into account variability in effects according to duration of lactation, nor did it perform subgroup analyses according to history of GD, type of study or duration of follow-up.

In this context, our systematic review and aggregate data meta-analysis overcame many of the limitations of previous meta-analyses by including a larger number of studies and performing detailed subgroup analyses and a dose–response meta-analysis. Our overall estimate of a 27% risk reduction is broadly in keeping with previous meta-analyses. Furthermore, our subgroup analyses suggest that the discrepant findings of previous meta-analyses may be at least partially explained by differences between cohort and cross-sectional studies as well as heterogeneity as a result of history of GD. In addition, our dose–response meta-analysis overcame the limitations of the dichotomous categorization of lactation into short and long duration using arbitrary cut-off points by showing a significant association between longer duration of lactation and larger risk reduction in type 2 diabetes. Nonetheless, this association needs to be interpreted cautiously. First, lactation duration was self-reported, often many years after birth, and hence data are of uncertain accuracy. Second, aggregate data with outcomes reported by intervals of duration of lactation introduced uncertainty to the statistical model. Individual participant data would enable a more accurate and valid assessment of the effects of different duration of lactation on the risk of type 2 diabetes.

Albeit acknowledging that the association reported in observational studies may not be causal, the potential mechanisms underlying the beneficial effects of lactation on maternal risk of type 2 diabetes are worth discussing. First, lactation has been associated with less weight retention after pregnancy as well as a lower risk of obesity in later life, which is the main risk factor for diabetes. However, the protective effect of lactation appears to be independent of obesity or BMI. Second, the complex hormonal changes elicited by pregnancy, and the influence of lactation on this hormonal milieu, may influence glucose and insulin metabolism and beta-cell function, thus reducing the risk of developing diabetes in later life. The graded association observed in this meta-analysis would fit with a potentially stronger or long-lasting effect associated with longer or more intensive lactation. Third, it is possible that the observed association is partially confounded, as lactation has been associated with other healthy behaviours. Further research is thus warranted to better clarify the mechanisms underpinning the association between lactation and the reduced risk of type 2 diabetes, including how this association may be modulated by exposure to other risk factors, such as obesity.

This study has important implications for healthcare professionals and policymakers worldwide. Although the WHO recommends exclusive breastfeeding (i.e. no other food or drink, not even water, except breastmilk) for the first 6 months followed by partial breastfeeding for as long as possible, in 2018 only 41% of women were exclusively breastfeeding for 6 months worldwide, and this dropped to 24% in upper-middle income countries. Furthermore, lactation rates appear to be lower in women who develop GD, which may be related to delayed onset of lactogenesis, despite our study showing that they probably afford a larger risk reduction in type 2 diabetes than in women without GD. Reasons for suboptimal lactation rates across the globe, and especially in high-income countries, are multifactorial in that they are influenced by a variety of individual and structural factors. The WHO has acknowledged that poverty, malnutrition and a lack of education and training on infant feeding decrease the prevalence of lactation. Other individual factors include cultural and religious beliefs, lack of support systems and mental health barriers, as women with depression in pregnancy or postpartum are less probable to initiate and continue lactation. Broader structural factors also influence lactation rates, such as more mothers entering the labour force and negative attitudes towards lactation in public. The unavailability of paid maternity leave is a key contributor, as is the lack of employment policies that promote lactation. Finally, aggressive marketing of breastmilk substitutes is a powerful disincentive for lactation, as it shapes perceived social norms and misinforms the public about scientifically recommended infant nutrition.

Considering the stark increase in the global burden of disease attributable to type 2 diabetes, this study lends further support to the importance of implementing lactation-friendly policies that enable women and their children to accrue the benefits of lactation for their health and well-being. Ultimately, this will also be positive for healthcare and welfare systems by saving resources and reducing the disproportionate burden of type 2 diabetes on women. On the other hand, equipping healthcare professionals with the skills and knowledge to provide individually tailored advice and support is paramount to improve lactation, particularly for women who experience socioeconomic and cultural barriers.

Although this systematic review and aggregate data meta-analysis suggests that lactation may reduce the risk of type 2 diabetes in parous women, several questions have yet to be answered. First, despite the graded association between duration of lactation and the risk of type 2 diabetes, it remains unclear whether there is a threshold beyond which no further protection is achieved by prolonging lactation. Second, there is uncertainty on how the effects of lactation change over time, that is, whether benefits are evident shortly after birth or if they only accrue as women age. Third, evidence is lacking on the effects of different modalities of lactation. Although there is evidence that exclusive lactation could be more protective against type 2 diabetes than partial lactation, the intensity of lactation that is required to observe a meaningful difference in risk reduction remains unknown. It has also yet to be understood whether there is...
an interaction between intensity and duration in a way that partial lactation could be compensated by prolonging the duration of lactation. Fourth, as large cohort studies were mainly conducted in women with GD, no definite conclusions can be drawn about potential differences between the effects of lactation in women with and without GD. As lactation is an exposure that cannot be randomized, large, prospective cohort studies, including a representative sample of the population (e.g. diverse ethnicities and socioeconomic backgrounds), with detailed and objective assessment of lactation and type 2 diabetes, are warranted to understand the effects of lactation on maternal risk of developing type 2 diabetes. Importantly, these cohort studies should be powered to conduct subgroup analyses according to gestational diabetes status and obesity.

This systematic review summarizes the best evidence currently available on the association between lactation and maternal risk of diabetes. Nonetheless, there are some limitations to acknowledge. First, it is affected by the limitations of the observational studies upon which it is based, such as selection bias, information bias and residual confounding. However, the nature of the exposure means that randomized controlled trials are not ethically feasible, and hence observational studies are the only source of evidence. Second, many studies were of low or modest quality, particularly small studies based at single hospitals and with substantial loss to follow-up. In addition, lactation was self-reported in all studies, and in many of them a long time after birth. However, the nature of this exposure makes it difficult to ascertain accurately. Third, there was significant heterogeneity across studies in some analyses, mainly because of methodological differences among studies. Although we performed subgroup analyses to investigate potential sources of heterogeneity, individual participant data are required to adequately explore heterogeneity and avoid ecological bias that may affect aggregate data meta-analysis. Fourth, the possibility of publication bias cannot be excluded. However, those limitations are unlikely to have a material impact on the key findings of this systematic review, which were robust to comprehensive sensitivity analyses.

In conclusion, lactation is associated with a significantly reduced risk of maternal type 2 diabetes over the life course, particularly in women with GD. The protective effect seems to increase with longer duration of lactation, but it remains uncertain whether there is a threshold above which the benefits become significant, or a ceiling effect above which no further benefits are accrued. Further research is also warranted to understand whether this association is modified by exposure to other risk factors.

ACKNOWLEDGEMENTS
We thank Erica P. Gunderson for her contribution to this study. ACPG is funded by the National Institute for Health Research, UK. The study funder was not involved in the design of the study; the collection, analysis and interpretation of data; writing the report; and did not impose any restrictions regarding the publication of the report.

CONFLICT OF INTEREST
There are no conflicts of interest to declare.

AUTHOR CONTRIBUTIONS
ACPG and MW designed the study; ACPG searched for studies; ACPG and GM selected the studies; and ACPG extracted and analysed the data. All the authors contributed to interpretation of the results, drafting, review and approval of the final manuscript. ACPG and MW are the guarantors and take responsibility for the contents of this article.

PEER REVIEW
The peer review history for this article is available at https://publons.com/publon/10.1111/dom.14417.

DATA AVAILABILITY STATEMENT
No data are available

ORCID
Ana-Catarina Pinho-Gomes https://orcid.org/0000-0001-9895-1493
Mark Woodward https://orcid.org/0000-0001-9800-5296

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Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Pinho-Gomes A-C, Morelli G, Jones A, Woodward M. Association of lactation with maternal risk of type 2 diabetes: A systematic review and meta-analysis of observational studies. Diabetes Obes Metab. 2021;23:1902–1916. https://doi.org/10.1111/dom.14417