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REVIEW

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How does gestational weight gain influence short- and long-term postpartum weight retention? An updated systematic review and meta-analysis

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Summary

This systematic review and meta-analysis provide an update of an earlier meta-analysis examining the impact of gestational weight gain (GWG) on postpartum weight retention (PPWR). Thirty-four observational studies were included, and results from 18 studies were combined in meta-analyses. We found that women with excessive GWG retained an additional 2.98 kg (95% CI: 0.59, 5.37 kg, $I^2 = 91\%$) at 0.5 years, 1.89 kg (95% CI: 0.90, 2.88 kg, $I^2 = 61\%$) at > 0.5–1 year and 2.89 kg (95% CI: 1.74, 4.04 kg, $I^2 = 0\%$) at 2–4 years, compared to women who met the National Academy of Medicine GWG recommendations. Moreover, synthesis of confounder-adjusted regression coefficients showed that each 1 kg increase of GWG corresponded to 0.62 kg (95% CI: 0.22, 1.02 kg, $I^2 = 96\%$) additional PPWR at 6–9 months, 0.48 kg (95% CI: 0.14, 0.81 kg, $I^2 = 93\%$) at 1–3 years, and 0.31 kg (95% CI: −0.24, 0.86 kg, $I^2 = 89\%$) at 5–7 years postpartum. Findings suggest that higher GWG contributes to increased maternal body weight in the short- and long-term after childbirth, independent of prepregnancy body mass index. The heterogeneity of reported data and methodological differences across studies complicate the ability to synthesize data and interpret findings.

KEYWORDS
gestational weight gain, GWG, long-term weight retention after delivery, postpartum weight retention, PPWR, pregnancy

1 | INTRODUCTION

Obesity is a global health concern. The World Health Organization reports that 39% of adults have overweight and 13% have obesity.[1] Women in their childbearing years are particularly vulnerable to weight gain.[2] Around 1/3 of women enter pregnancy with overweight or obesity,[3–5] which increases their risk of adverse perinatal health outcomes and obesity-related diseases later in life.[6,7] In addition,

Abbreviations: BMI, body mass index; CI, confidence interval; GWG, gestational weight gain; HKSJ, Hartung–Knapp–Sidik–Jonkman; IOM, Institute of Medicine; NAM, National Academy of Medicine; NOS, Newcastle–Ottawa Scale; PI, prediction interval; PPWR, postpartum weight retention; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PROSPERO, International Prospective Register of Systematic Reviews.; REML, restricted maximum likelihood effect; SES, socio-economic status.

epidemiological data suggest that the average gestational weight gain (GWG) has steadily increased over the past decades, independent of prepregnancy BMI category.[8,9] Pregnancy-related weight gain has been linked to changes in maternal long-term weight trajectories. Follow-up studies have shown that GWG is associated with higher maternal BMI and obesity development up to two decades after childbirth.[10–12]

The National Academy of Medicine (NAM), formerly known as the Institute of Medicine (IOM), set GWG guidelines in a report published in 1990, that were revised in 2009 in response to the increase in maternal prepregnancy overweight and obesity.[9] The updated guidelines established recommended ranges of GWG for women in all four BMI categories. Since the NAM/IOM guidelines were established, there has been considerable interest in research that investigates the effect of GWG on short- and long-term maternal health and obesity risk. Evidence suggests that nearly half of women, across all BMI categories, gain weight in excess of recommendations.[13] Importantly, those who begin their pregnancies with a high BMI are particularly vulnerable to gaining weight above the recommendations.[14]

In 2011, we published a meta-analysis of nine studies that showed that women who gained in excess of the NAM/IOM recommendations retained, on average, an additional 2.45 kg (95% CI: 1.95, 2.95 kg) between 0.5 and 1 year postpartum, 3.06 kg (95% CI: 1.50, 4.63 kg) ∼ 3 years postpartum and 4.72 kg (95% CI: 2.94, 6.50 kg) ≥ 15 years postpartum, compared to women who gained pregnancy weight within the NAM/IOM recommendations.[15] After reporting our findings, many other studies with larger and more sociodemographically diverse cohorts have sought to deepen the understanding of the relationship between GWG and maternal weight retention. The aim of this analysis was two-fold: First, we wanted to update our previous meta-analysis to include studies published up to 2021. Further, we were interested in investigating beyond the impact of GWG according to NAM/IOM recommendations on PPWR by including all available evidence from observational studies that examined this association using various methodological approaches.

2 | MATERIALS AND METHODS

2.1 | Search strategy and study selection

This systematic review and meta-analysis was registered in the International Prospective Register of Systematic Reviews (PROSPERO) registration ID CRD42020199128 and reported according to PRISMA guidelines[16] (Table S1).

On June 10–11, 2021, articles were sourced from four electronic databases: PubMed, Embase, Web of Science, and CINAHL. A search was also performed in Google Scholar. In line with our aim to update our previous meta-analysis,[15] we considered peer-reviewed, published, or unpublished articles from January 1, 2011. Keywords and MeSH terms related to GWG and PPWR were applied. In this review and meta-analysis, PPWR refers to the difference between prepregnancy weight and maternal weight after childbirth, both in the short and long terms. Table S2 presents the complete search strategy and search hits by database. Two researchers (EG and DM) manually searched the reference lists of included articles to identify further relevant studies.

EndNote software X9 (Thomson Reuters, New York City, NY) was used to export the identified references. After removing duplicates, study screening and data extraction were performed independently by two researchers (EG and DM). Discrepancies were resolved by consensus or with further researchers (RR and SM) when necessary. Studies were included if they met the following criteria: (1) observational cohort studies published in English, German, or French and (2) cohorts comprised primarily healthy adult women with singleton pregnancies, GWG classified as a categorical variable (such as according to NAM/IOM recommendations) or documented as a continuous variable, and PPWR documented at 0.5 years postpartum and/or later. PPWR was considered if the study defined this term as the difference between maternal weight before (or at early) pregnancy and weight at the follow-up time point. We considered studies that presented PPWR as either a continuous or categorical variable, for instance, no weight retention versus any or substantial weight retention. Inclusion criteria are outlined in Table S3.

2.2 | Data abstraction and quality assessment

The following data were extracted and recorded with Excel software independently by two researchers: study and population characteristics, follow-up time period, statistical methods, and main findings. Prepregnancy BMI, GWG, and PPWR were extracted for measurements reported as continuous and categorical values. GWG was defined differently in studies but was generally understood to be the amount of weight gained during pregnancy. Authors of articles were also contacted to obtain additional data or if we were unable to access the full text.

Studies were assessed for quality independently by two researchers (EG and DM). We achieved this with the Newcastle–Ottawa scale (NOS), which is based on three characteristics: (1) selection of participants, (2) comparability of groups, and (3) ascertainment of outcomes.[17] The highest score a study can achieve is 9.

2.3 | Statistical analysis

We used mean GWG and PPWR for each primary study in descriptive analyses. Where only medians were reported, means were estimated assuming an unknown non-normal distribution.[18]

Prior to meta-analysis, standard deviations were derived from standard errors, 95% confidence intervals (CIs), and *p*-values, as needed.[19] Stratified outcome data were pooled.[19]

Given the clinical and methodological heterogeneity between primary studies as well as the inferential goals of this systematic review, a random-effects model was considered most appropriate for meta-analysis.[20] As is recommended for meta-analyses with few studies and higher heterogeneity, we used the Hartung–Knapp–Sidik–Jonkman (HKSJ) method for random-effects meta-analyses, rather than the DerSimonian and Laird approach. This approach was chosen because the

HKSJ method has been shown to result in more adequate error rates and CIs with better coverage.[21,22] Both CIs and 95% prediction intervals (PIs) were computed. PIs indicate where 95% of true effect sizes fall in the hypothetical population of studies and are thereby helpful in understanding the uncertainty surrounding effect sizes.[23]

The data were stratified according to the length of follow-up with separate analyses conducted for each range. This was done due to clinical differences between various postpartum periods and to avoid a unit-of-analysis error from pooling multiple follow-ups from one primary study. The ranges were selected to make the most comprehensive use of the available data.

Based on the available data, the following effect sizes were selected for meta-analyses:

- fully adjusted regression coefficients from linear mean models, treating GWG as a continuous variable, rescaled to reflect a 1 kg increase in GWG,
- fully adjusted regression coefficients from logistic regression models, for any (>0 kg) or substantial (≥∼5 kg) PPWR, where GWG was categorized based on NAM/IOM guidelines, and
- crude differences in mean PPWR between groups based on NAM/IOM GWG categories (excessive vs. adequate GWG and inadequate vs. adequate GWG).

The respective types of effect sizes were synthesized in separate random-effects meta-analytical models.

The method of restricted maximum likelihood (REML) was used to estimate statistical heterogeneity, as simulation studies have indicated this method provides approximately unbiased estimates more reliably than other methods.[24] Subsequently, heterogeneity between studies was assessed based on the I^2 statistic and interpreted according to the Handbook of the Cochrane Collaboration.[25]

To assess publication bias, we planned to visually assess funnel plots and conduct Egger's regression test.[26]

Subgroup analyses were conducted based on whether studies considered two potentially confounding variables, prepregnancy BMI and parity, through methods including participant eligibility restrictions, stratification, and adjustment in multivariable regression. Sensitivity analyses were conducted by (1) excluding lower quality studies, (2) assessing the role of missing outcome data by excluding studies based on whether they were missing >40% of data, and (3) examining outliers that we identified based on the interquartile range criterion. For tests of subgroup differences, $p < 0.1$ was considered statistically significant. RStudio software version 2022.07.1 (RStudio Inc., Boston, MA, USA) was used for all analyses.

3 | RESULTS

3.1 | Study selection

The screening process identified 16,373 records in four databases. After deduplication, 9583 records remained for title screening, 577 records for abstract screening, and 175 records for full-text screening. In total, 34 studies met the inclusion criteria for the systematic review (Figure 1). Web searches and hand-searching of the reference lists of included articles yielded no additional references. A list of excluded studies with reasons is available in Table S4. Eight authors of the included studies were contacted by email for additional data (Figure 1).

3.2 | Study characteristics

Table S5 summarizes the main characteristics of the 34 included studies. Two studies were cross-sectional,[27,28] one was a retrospective cohort,[29] and the remaining 31 were longitudinal cohorts. Nineteen countries were represented. Fourteen studies took place in North America,[29–43] six in Europe,[44–51] four in Australia,[52–55] seven in East/Southeast Asia,[27,56–61] one in Turkey,[28] 1 in Lebanon/Qatar,[62] and one in Brazil.[63] The mean age of participants ranged from 23.8 to 33.3 years. The sample size ranged from 37 to 115,651 women. Although most studies only assessed PPWR at one time point ($n = 19$), nine studies investigated two time points, and four studies assessed three time points (Table S5). Three studies assessed interpregnancy weight retention as a proxy for PPWR.[29,34,36,43] The last follow-up time point for 10 studies was 0.5 years postpartum,[30,32,37,47,48,56,60–63] >0.5 to 1 year postpartum for 14 studies,[27,36,39–41,43–45,52–55,57–59] >1 to 3 years postpartum for five studies,[28,31,34,38,49,50] and beyond 3 years postpartum for five studies (Table S5).[29,33,35,42,46,51] Socioeconomic status (SES) of women varied across studies. Six studies comprised predominantly women with low SES, defined as low educational attainment and/or low income,[30,32,33,40,41,56] whereas two studies reported that about half of the women in their cohort had low SES status.[29,37] Only primiparous women were recruited for four studies,[27,31,34,36,43] whereas one study recruited only multiparous women.[30] One study did not report this information,[58] and the remaining studies ($n = 28$) included both primiparous and multiparous women.

3.3 | Measurement of prepregnancy BMI, GWG, and PPWR

The majority of studies ($n = 27$) used self-reported weight and height to calculate prepregnancy BMI (Table S5). Although most included women from all BMI categories, seven studies either excluded women with underweight or combined them with normal weight for analysis,[30–32,36,37,41–43] whereas one study was confined to only women with obesity.[39] Three studies measured maternal weight in the first trimester to serve as a proxy for prepregnancy weight,[59,61,62] and one study measured women ≤15 weeks' gestation.[39] All studies except two[45,47] defined the meaning of GWG (Table S5). Generally, this measurement was defined as the total weight gained in pregnancy. Maternal weight was measured by hospital or research staff and used to calculate GWG in 13 studies.[31,33,35,39,41,42,45,48,55,57–60]

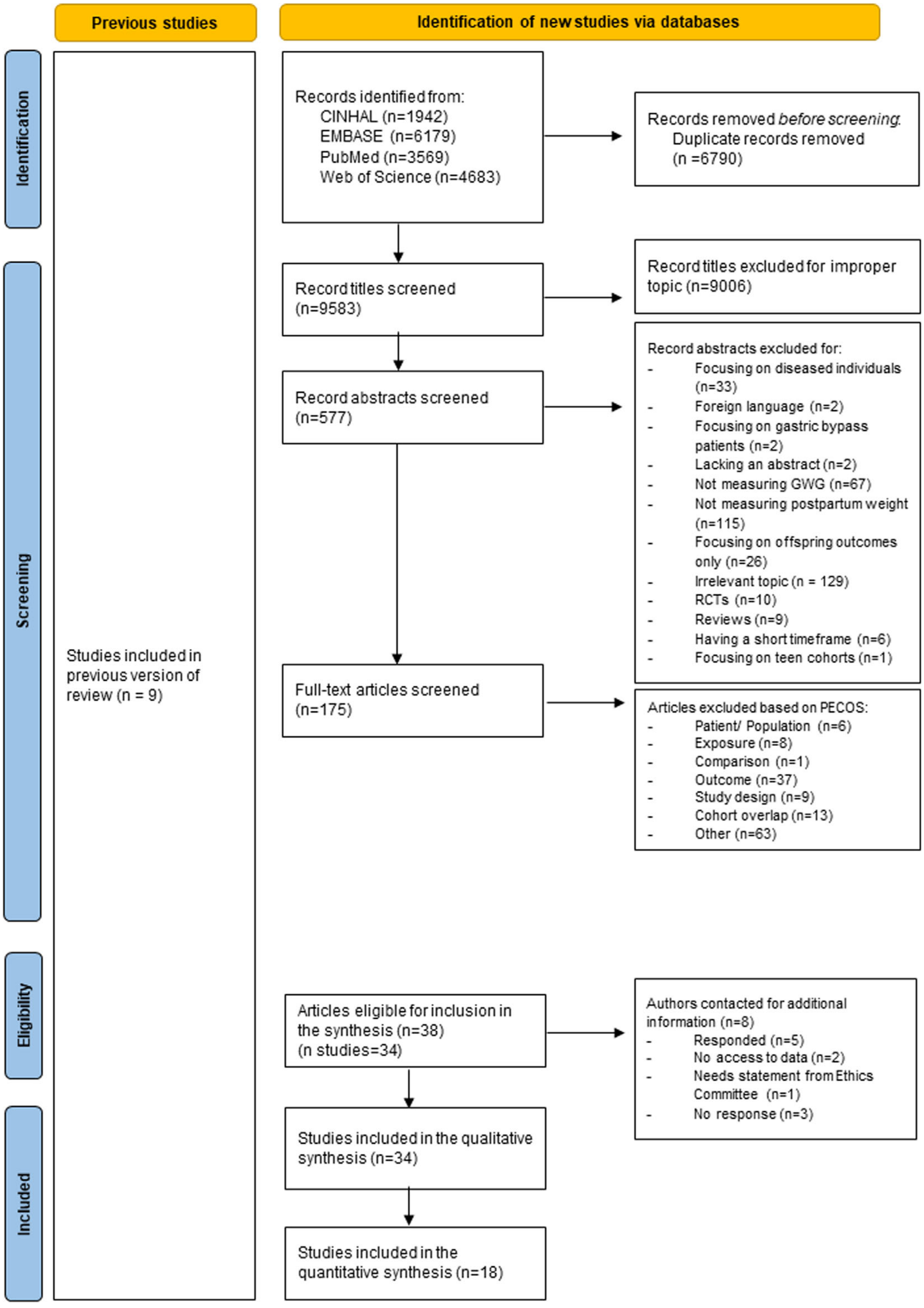
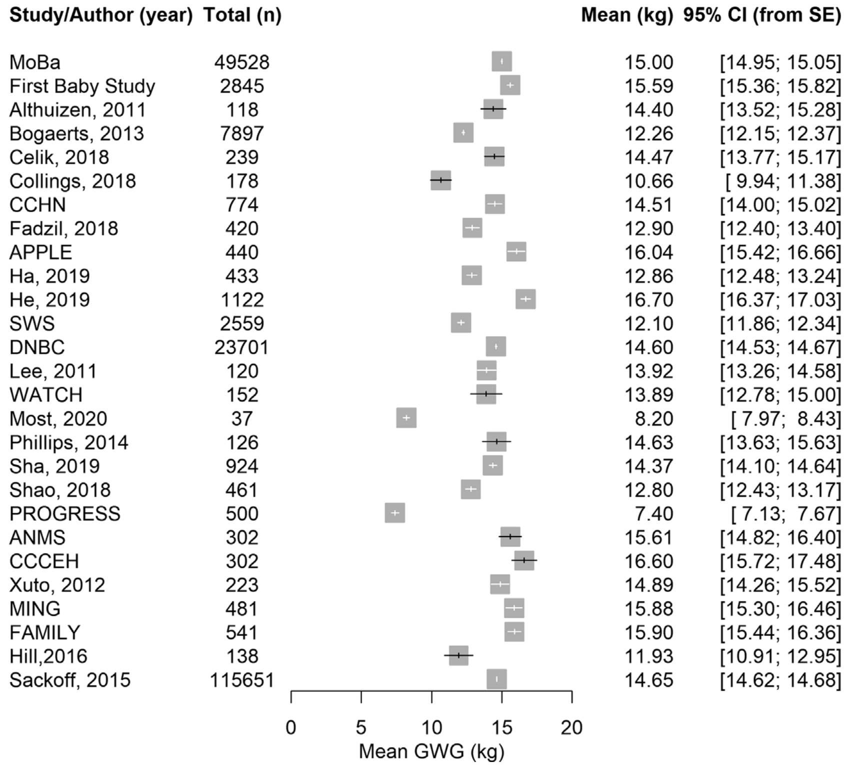


FIGURE 1 **PRISMA flow chart detailing database searches, records screened, and articles/studies retrieved and included in the systematic review.** *N*, number.

Six studies obtained weight from medical records,[34,36,38,40,61,62] one from a national database,[29] and 13 studies relied on self-reported late pregnancy weight.[27,28,30,37,44,46,47,49–54,56,63] One study obtained weights from both birth records and self-report and conducted analyses on both values for comparison.[32] Two studies used formulas to estimate GWG at delivery,[29,48] whereas the remaining studies used late pregnancy or pre-delivery weight to calculate GWG. The range of mean GWG across studies was between 7.4–16.7 kg (Figure 2).

FIGURE 2 **Mean (kg) GWG across studies.** GWG, gestational weight gain; *n*, number.



Twenty-five of the included studies reported GWG as recommended by the updated NAM/IOM guidelines, whereas one study applied recommendations similar to NAM/IOM guidelines.[63] The remaining studies examined GWG as a continuous variable.

Postpartum weight was measured by trained staff in 18 studies,[27,30,31,33,35,40–42,45,47,48,55–58,61–63] self-reported in 14 studies[28,32,34,36–38,44,46,49–54,59,60] and obtained from national records in one study.[29] One study instructed women to weigh themselves with a home scale that directly transmitted the data to the research center.[39] PPWR was explicitly defined in all studies. Generally, this measurement was defined as the difference between maternal weight at the postpartum follow-up time point and prepregnancy (or early pregnancy) weight. Five studies also defined weight retention of around ≥5 kg (i.e., ≥ 4.5 or 5 kg) as substantial PPWR.[37,44,52,54,58] Across the 34 included studies, PPWR data were available for 37 to 115,651 women. Mean PPWR ranged from 0.20 kg to 9.20 kg, from 6 months to 7 years after childbirth (Figure 3). The highest maternal weight retention was observed 7 years postpartum.[33] The distribution of mean PPWR was found to be non-normal (Shapiro–Wilk normality test *p*-value: 0.02) and right-skewed; therefore, we conducted sensitivity analyses excluding two outliers.

The results of the NOS quality assessment are depicted in Table S6. Out of a maximum of 9 points, all of the studies had a score of 6 points or above. The mean score was 7.5. The main weaknesses were self-reported exposure and/or outcome. Twenty-nine studies adjusted for prepregnancy BMI, and one study only included women with obesity. Of these, 27 additionally adjusted for other confounders, such as age, parity, and SES. Adjustment variables are reflected in the NOS comparability category. Studies that controlled for prepregnancy BMI received 1 point, and those controlling for additional factors received an additional point, for a maximum of 2 points in this category.

3.4 | Data analysis methods and effect sizes

Fifteen studies used multivariable linear mean models[30,32,33,35,36,42–44,47,48,51,52,54,56,57,61] to assess the association between GWG and PPWR, where PPWR was treated as a continuous outcome variable. Eleven of these studies used continuous GWG (e.g., per 1 kg additional GWG) as the predictor variable,[30,33,35,36,42–44,47,51,52,54,61] whereas four studies[32,48,56,57] analyzed GWG as a binary or categorical variable (e.g., using NAM/IOM GWG categories).

Twelve studies analyzed associations between GWG and PPWR using logistic regression models, where PPWR was treated as a binary endpoint.[28,30,36–38,41,44,49,58,60,62,64] This endpoint was defined in numerous ways, including any PPWR (>0 kg), or substantial PPWR (sPPWR), specified using eight different cut-off points ranging from 2 to 9 kg. Three studies defined ≥4.5 or ≥ 5 kg as sPPWR, which we combined in logistic models and labeled as ≥∼5 kg. Further, GWG as a predictor was entered into regression models either as a continuous variable[44,60,64] or as a categorical variable,[28,30,36–38,41,49,58,62] generally based on the NAM/IOM GWG categories.

Nine studies[27,29–31,36,43,57–59,63] reported mean PPWR grouped by NAM/IOM-based GWG categories. However, one study[58] did not report a measure of dispersion, whereas another[63] did not report the

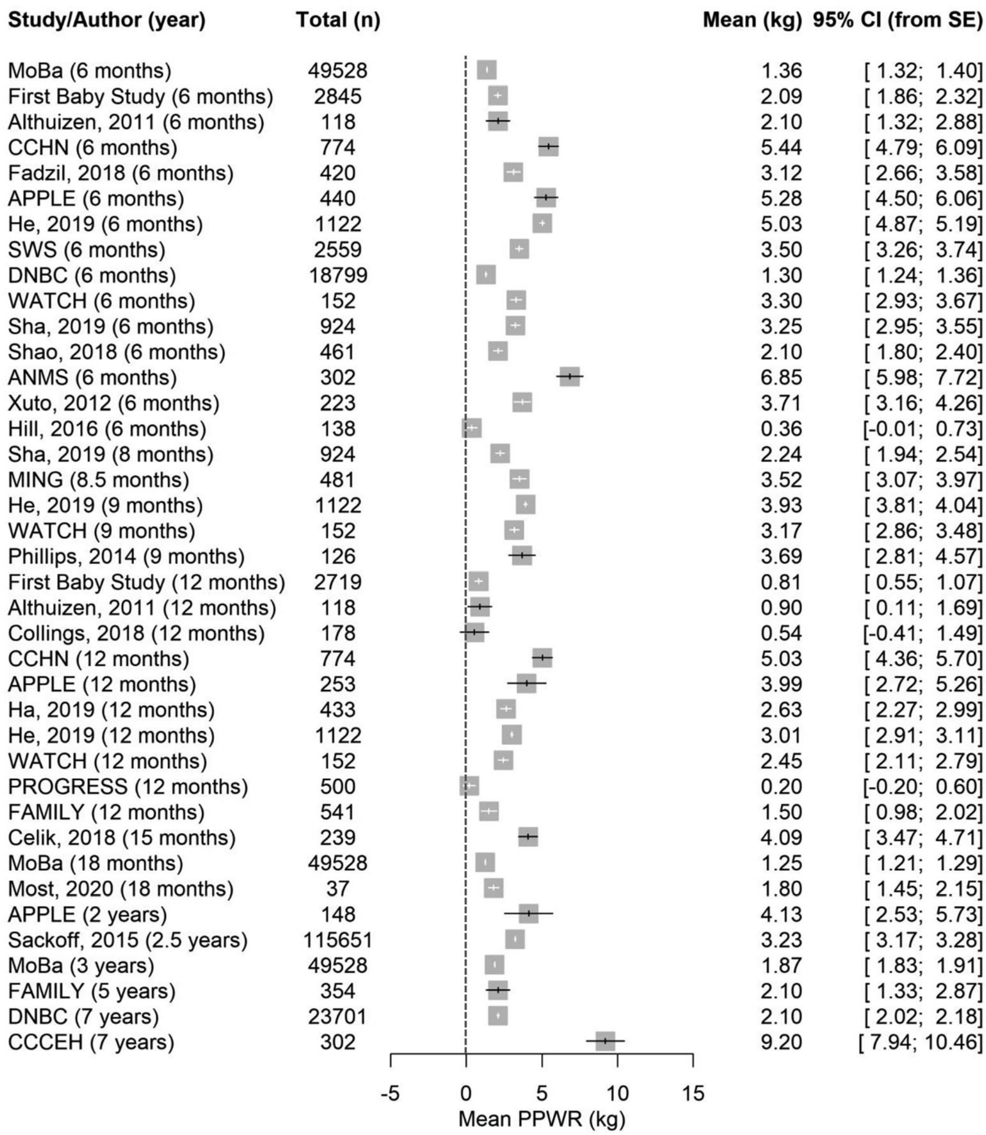


FIGURE 3 **Mean (kg) postpartum weight retention across studies.** PPWR, postpartum weight retention; *n*, number.

number of participants in each NAM/IOM GWG category and could therefore not be included in our meta-analyses.

3.5 | Associations between GWG and PPWR: primary study findings

Greater GWG was largely associated with higher maternal weight retention at all postpartum time points, from 0.5 to 7 years after childbirth (Table S5). For instance, of the 10 studies that assessed the last follow-up time point at 0.5 years postpartum, nine reported that higher GWG was significantly associated with greater PPWR.[32,37,47,48,56,60–63] The one exception was a study that reported that women with excess GWG were more likely to lose weight in the postpartum period up to 0.5 years (aOR = 2.40; 95% CI: 1.10, 5.21).[30] All 14 studies that investigated the last maternal weight measurement between 0.5 and 1 year postpartum reported significant or nearly significant ($n = 1$, $p = 0.06$[39]) positive associations between GWG and PPWR.[27,36,41,43–45,52–55,57–59,64] Similar findings were observed long-term, both between >1–3 years (five studies) and >3 years (five studies) postpartum (Table S5), although one study reported that significant relationships were only seen at 1 year postpartum but were no longer present at the 2-year follow-up.[31]

3.6 | Meta-analyses of estimates from linear mean models

Table 1 provides an overview of the 11 studies that were included in linear mean models assessing the relationship between GWG and PPWR. Due to the availability of data from included studies, we grouped PPWR data into three timeframes for the following analyses:

TABLE 1 Studies included in meta-analyses for linear mean models.

Time postpartum			
Study or author	**6–9 months**	**1–3 years**	**5–7 years**
Althuizen et al[44]		*	
ANMS[30]	*		
CCCEH[33]			*
Collings et al[52]		*	
DNBC[51]			*
Dujmović et al[47]	*		
FAMILY[35]		*	*
First Baby Study[36,43]	*	*	
Phillips et al[54]	*		
Project Viva[42]		*	*
Xuto et al[61]	*		

Note: All studies except Dujmović et al[47] adjusted for prepregnancy BMI.

6–9 months, 1–3 years, and 5–7 years. The meta-analysis of adjusted coefficients showed that each additional kilogram of GWG resulted in a 0.62 kg increase in PPWR at 6–9 months ($n = 5$ studies, 95% CI: 0.22, 1.02 kg, 95% PI: −0.36 to 1.60 kg, $I^2 = 96\%$), a 0.48 kg increase at 1–3 years ($n = 5$ studies, 95% CI: 0.14, 0.81 kg, 95% PI: −0.32 to 1.27 kg, $I^2 = 93\%$), and a 0.31 kg increase at 5–7 years after childbirth ($n = 4$ studies, 95% CI: −0.24, 0.86 kg, 95% PI: −0.65 to 1.27 kg, $I^2 = 89\%$) (Figure 4A).

3.7 | Meta-analyses of results from logistic regression models

Data were available from 3 studies for meta-analyses of adjusted logistic regression coefficients assessing the odds of sPPWR (≥~5 kg) at 1 year postpartum. Women with excessive GWG had 3.13 times the odds of sPPWR ($n = 3$ studies, 95% CI: 1.69, 5.79, 95% PI: 1.08 to 9.04, $I^2 = 52\%$), compared to women with adequate GWG (Figure 4B). For the odds of any (>0 kg) PPWR, women with excessive GWG had 2.05 times the odds of any PPWR at 0.5–2 years postpartum, compared to women with adequate GWG ($n = 3$ studies, 95% CI: 0.83, 5.04, 95% PI: 0.67 to 6.30, $I^2 = 22\%$).[65]

3.8 | Meta-analyses of mean PPWR by GWG group (excessive vs. adequate, inadequate vs. adequate)

Table 2 presents the studies ($n = 7$) that report crude mean PPWR values by IOM/NAM GWG categories. Due to the availability of data for meta-analyses, studies that reported postpartum weight were grouped into the following timeframes: 0.5 years, >0.5–1 years, and 2–4 years postpartum.

Meta-analyses of differences in crude mean PPWR between women with excessive versus adequate GWG showed that at 0.5 years postpartum, women with excessive GWG had 2.98 kg higher PPWR ($n = 4$ studies, 95% CI: 0.59, 5.37 kg, 95% PI: −2.06 to 8.02 kg, $I^2 = 91\%$), at >0.5 to 1 year postpartum, 1.89 kg higher PPWR ($n = 5$ studies, 95% CI: 0.90, 2.88 kg, 95% PI: 0.30 to 3.47 kg, $I^2 = 61\%$) and at 2–4 years postpartum, 2.89 kg higher PPWR ($n = 2$ studies, 95% CI: 1.74, 4.04 kg, $I^2 = 0\%$) compared to women with adequate GWG[65] (Figure 5A).

Meta-analyses examining crude mean differences of PPWR in women with inadequate versus adequate GWG showed that women with inadequate GWG had 2.45 kg lower PPWR ($n = 3$ studies, 95% CI: −4.73, −0.18 kg, 95% PI: −6.38 to 1.47 kg, $I^2 = 66\%$) at 0.5 years postpartum and 1.79 kg lower PPWR at >0.5 to 1 year postpartum ($n = 4$ studies, 95% CI: −2.71, −0.86 kg, 95% PI: −3.40 to −0.18 kg, $I^2 = 55\%$) compared to women with adequate GWG (Figure 5B).

3.9 | Tests for publication bias

Due to the inadequate number of studies in each meta-analytical model ($n = 2$–5 studies), publication bias was not formally assessed. However, funnel plots were generated and Egger's test was performed, and these materials have been included in Supplementary Material S7.

3.10 | Subgroup and sensitivity analyses

We performed subgroup analyses for linear mean models to study the effect of including studies that either adjusted for or restricted participation eligibility based on (1) parity and (2) prepregnancy BMI. These findings did not substantially differ from those of the primary analyses with the exception of the following: Excluding the First Baby Study

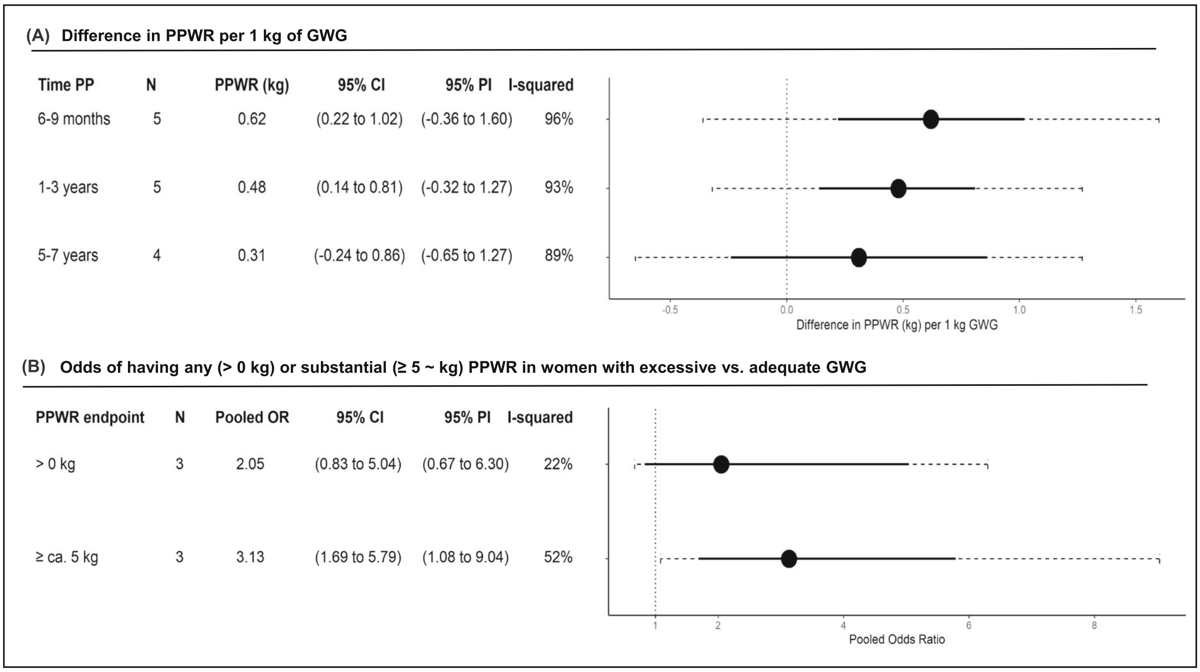


FIGURE 4 **Forest plots of (A) the difference in PPWR per 1 kg of GWG and (B) the odds of having any or substantial PPWR (≥∼5 kg) in women with excessive versus adequate GWG.** CI, confidence intervals; GWG, gestational weight gain; IOM, Institute of Medicine; MD, mean difference; *n*, number; NAM, National Academy of Medicine; PI, prediction interval; pp, postpartum; PPWR, postpartum weight retention.

TABLE 2 Unadjusted PPWR by IOM/NAM GWG category for the individual studies included in the meta-analysis.

Study or author and pp time point	PPWR by GWG category: Inadequate kg	Adequate kg	Excessive kg
ANMS[30]			
6 months	0.35 ± 5.14 (62)	3.81 ± 5.49 (63)	6.85 ± 7.73 (177)
APPLE[31]			
6 months	Not assessed	2.90 ± 5.74 (136)	7.77 ± 9.26 (246)
12 months	Not assessed	1.50 ± 6.80 (80)	6.17 ± 12.17 (143)
24 months	Not assessed	3.36 ± 7.82 (45)	5.16 ± 11.48 (83)
First Baby Study[36,43]			
6 months	−2.28 ± 7.63 (315)	0.57 ± 4.87 (1011)	3.72 ± 7.11 (1544)
12 months	−2.60 ± 7.20 (302)	−0.12 ± 5.29 (966)	2.17 ± 7.57 (1475)
Ha et al, 2018[57]			
12 months	1.32 ± 3.56 (622)	2.93 ± 3.62 (775)	4.79 ± 3.60 (269)
MING[27]			
8.5 months	1.31 ± 5.64 (98)	2.86 ± 3.83 (163)	5.00 ± 5.04 (220)
Nova Scotia Perinatal Database[29]			
3.7 years	0.40 ± 8.20 (2484)	2.10 ± 7.10 (4338)	5.00 ± 8.90 (9447)
Sha et al, 2019[59]			
6 months	1.51 ± 4.51 (190)	3.12 ± 4.25 (429)	4.32 ± 5.18 (305)
8 months	0.85 ± 4.65 (190)	2.23 ± 4.15 (429)	3.24 ± 5.18 (305)

Note: All values are given as mean ± SD (number).
Abbreviations: GWG, gestational weight gain; IOM, Institute of Medicine; NAM, National Academy of Medicine; pp, postpartum, PPWR, postpartum weight retention.

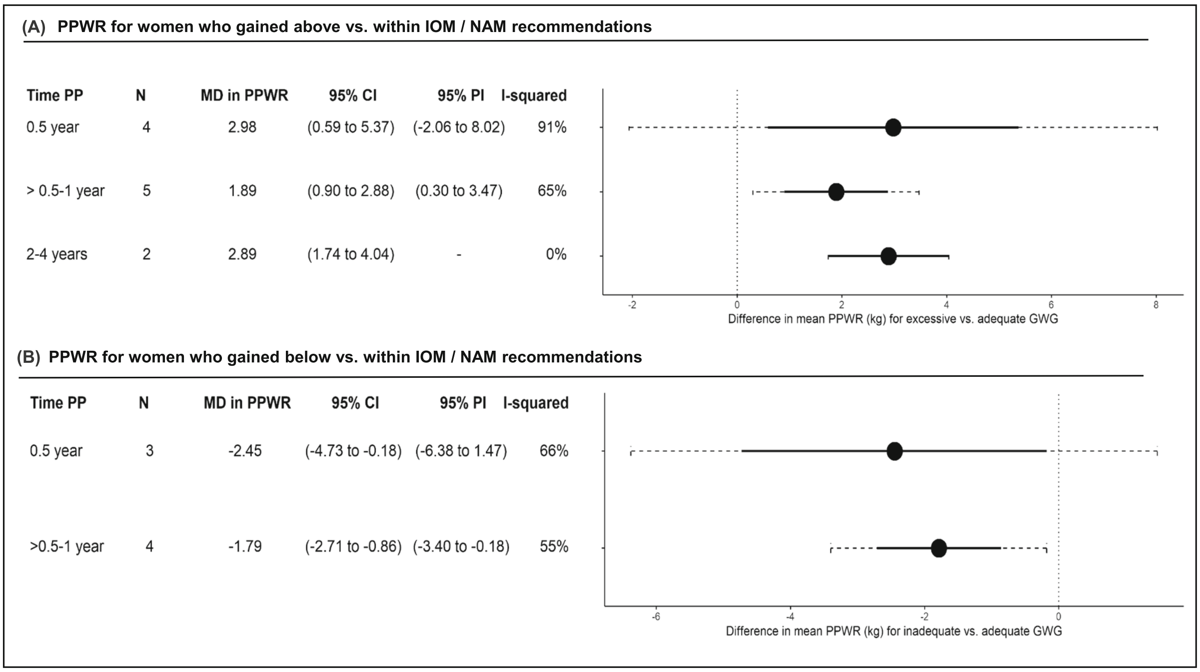


FIGURE 5 **Forest plots of (A) PPWR for women who gained above versus within NAM/IOM recommendations and (B) PPWR for women who gained below versus within NAM/IOM recommendations.** CI, confidence intervals; GWG, gestational weight gain; IOM, Institute of Medicine; MD, mean difference; *n*, number; NAM, National Academy of Medicine; PI, prediction interval; pp, postpartum; PPWR, postpartum weight retention.

(which included only primiparous women) from analyses of linear mean models significantly reduced the estimates of PPWR: For every 1 kg additional GWG, there was a 0.46 kg increase in PPWR at 6 to 9 months postpartum ($n = 4$ studies, 95% CI: 0.37, 0.56 kg, 95% PI: 0.33 to 0.59 kg, $I^2 = 8\%$, p for subgroup difference $= 0.001$). For studies with follow-ups conducted from 1 to 3 years postpartum, the effect estimate was decreased to 0.38 kg ($n = 4$ studies, 95% CI: 0.10, 0.65 kg, 95% PI: -0.17 to 0.92 kg, $I^2 = 76\%$, p for subgroup difference $= 0.069$) (Supplementary Material S8).

Subgroup analyses investigating the effects of restricting study participation based on parity in meta-analyses of differences in crude mean PPWR did not reveal any statistically significant findings, although analyses suggested larger effect sizes in primiparous women, in line with findings conducted in meta-analyses of linear mean models.

Findings of meta-analyses of linear mean models and differences in crude mean PPWR were generally robust in sensitivity analyses that investigated (a) quality assessment by excluding studies that received an NOS rating of 6 and (b) missing outcome data, where studies were excluded if they had less than 60% participant retention. After excluding studies with higher attrition rates, effect sizes, and precision were somewhat reduced in analyses of differences in crude mean PPWR at 0.5 years postpartum but not at later time points. Also, findings of meta-analyses of linear mean model data were largely unchanged after excluding two studies with the highest PPWR (6.85 kg, ANMS, and 9.20 kg, CCCEH study)[30,33] and excluding a study with a very large sample size (DNBC study)[46,51] (Supplementary Material S8).

Due to the small number of studies included in our meta-analyses of logistic regression coefficients ($n = 3$ studies), subgroup and sensitivity analyses for logistic regression models were deemed to be non-informative.

4 | DISCUSSION

4.1 | Summary of main findings

This review presents an update of a meta-analysis published in 2011 that summarized the effect of GWG, grouped by NAM/IOM categories, on PPWR.[15] Consistent with earlier research, we found that pregnancy weight gain had a positive and significant influence on maternal weight retention in the majority of investigated postpartum timeframes. Women with excessive GWG retained an additional 2.98 kg at 0.5 years postpartum, 1.89 kg at >0.5–1 year postpartum, and 2.89 kg at 2–4 years postpartum, compared to women whose GWG was within NAM/IOM recommendations. Our updated estimates are in line with estimates at 0.5–1 year (2.45 kg; CI: 1.95, 2.95) and ~3 years postpartum (3.06 kg; CI: 1.50, 4.63) from the previous meta-analysis.[15] Pooling adjusted logistic regression coefficients, we also observed that women who gained excessive gestational weight had over 3 times the odds of retaining substantial postpartum weight, defined as ≥∼5 kg.

We further synthesized fully adjusted regression coefficients from linear mean models and found that every additional kilogram of GWG corresponded to an additional maternal weight retention of 0.62 kg at 6–9 months and 0.48 kg at 12–36 months postpartum. In other words, after accounting for prepregnancy BMI and other relevant variables, we observed that higher pregnancy weight gain is directly related to increased maternal weight retention up to 3 years after childbirth, assuming no uncontrolled confounding or other biases. This relationship was no longer statistically significant at 5–7 years postpartum but showed a positive trend. Results from the narrative synthesis, presented in this paper, are in agreement with our meta-analyses.

Several factors have been identified as contributing to pregnancy-related weight gain and retention, such as low SES and maternal smoking habits, with the strongest evidence seen in women with a high prepregnancy BMI.[14,66–69] Notably, every study in this review that reported mean PPWR showed that women, on average, do not return to their prepregnancy weight after childbirth (Figure 3), suggesting that women who gain adequate gestational weight may also be vulnerable.

4.2 | Assessment of the certainty of findings

While results consistently suggested a positive association between GWG and PPWR, they should be interpreted cautiously: Due to the irreconcilable approaches for data analysis used by the identified studies, the number of studies in each meta-analysis was very low ($n = 2$–5 studies). Although we used the HKSJ method to reduce the chance of a Type I error/false-positive findings, this cannot be ruled out given the very small number of studies and highly variable sample sizes in some analyses.[21,70] However, sensitivity analyses excluding an especially large study did not change our findings. Further, statistical heterogeneity in most meta-analyses was moderate to very high ($I^2 > 40\%$), possibly suggesting important differences in the primary studies and indicating an associated degree of uncertainty regarding our findings. Because of the small number of studies, statistical heterogeneity, and meta-analytical methods used to address these limitations, the precision of all meta-analytical effect estimates was observed to be very low which greatly diminishes the clinical utility of our findings. Further, due to the low number of studies, we could not reliably assess publication bias. On the other hand, for most studies, no concerns regarding the methodological rigor were indicated by the NOS scale.

4.3 | Strengths and limitations

A major strength of this meta-analysis is that all types of effect sizes were considered, in contrast to our previous work[15] and others, whose analyses were limited to studies that measured GWG in relation to NAM/IOM categories.[71,72] Analyzing regression coefficients from adjusted linear mean and logistic regression models allowed us to quantify the magnitude of the association between GWG and PPWR while considering the effect of potential confounding variables. Notably, these findings should be interpreted with caution, as the computed CIs and PIs highlight the uncertainty surrounding these estimates. Several studies did not assess the relationship between GWG and PPWR as a primary outcome which limits the directness of evidence. Moreover, data were not available from around half of the included studies for meta-analyses. The fact that most subgroup and sensitivity analyses did not provide significantly different findings from those of main analyses may suggest that our findings are somewhat robust. However, we cannot conclude that important differences in the association between GWG and PPWR based on prepregnancy BMI or parity do not exist, or that missing outcome data, lower methodological quality of certain primary studies, and extreme values could not have biased our findings. Rather, it is likely that our analyses lacked statistical power for identifying these differences.[73,74] We are especially cautious about interpreting the potential for selection bias as a result of missing outcome data as a considerable proportion of studies had >40% participant attrition.

The majority of studies show mean GWG and PPWR values for the entire cohort, as seen in Figures 2 and 3. Without knowing the values for each prepregnancy BMI category, we were unable to examine maternal weight data based on demographic or geographical attributes. This limitation impaired our ability to draw comparisons across studies and identify trends in our narrative synthesis.

4.4 | Implications for future research

In the context of the findings of our previous work,[15] we noticed an apparent trend in the data analysis methods used: Published research has shifted from analyzing differences in crude mean PPWR between NAM/IOM GWG categories to using more advanced regression-based techniques for assessing the association between GWG and PPWR. These techniques have clear advantages, including that GWG as an exposure can be treated as a continuous variable and that potential confounders can be included as adjustment variables. However, it is problematic that there is no uniform approach to these regression analyses, as is evident by the highly discordant approaches we identified. For instance, research groups alternately defined the exposure "GWG" as either a continuous or categorical variable in statistical models which made the task of pooling data for meta-analysis rather difficult. Also, studies used various cut-off values to define the outcome of "substantial" PPWR in logistic regression analyses. Without a clinical consensus on what constitutes "significant" maternal weight retention, the value of analyses of this outcome as a binary endpoint is questionable.

The included studies underscore the need to apply a uniform method for calculating maternal weights. The NAM/IOM guidelines define total GWG as the difference between weight at conception and the onset of labor.[9] In practice, however, we found that "conception weight" data are collected in several ways: self-reported, retrieved from medical charts, measured in the clinic, or at the first study visit. We noted similar patterns for assessing maternal weight at the "onset of labor," with considerable variability in measurement timing, ranging from early in the third trimester to just before delivery. The largest studies included in this review relied on maternal recall of prepregnancy weight and total GWG.[46,49–51] Using proxy weights can be subject to several problems affecting the accuracy and reliability of the data. For instance, women may not have a record of their prepregnancy weight and thus rely on estimates or memory. Bias in self-reported weight is also a concern, as several studies note that heavier women tend to under-report their weight and risk being classified in a lower prepregnancy BMI category.[75–77] First-trimester weight can be problematic. Although it is based on the assumption that women, on average, gain under 2 kg in the first 12 weeks' gestation[9] studies show that early weight gain can vary considerably among individuals.[77,78] Accurate records of prepregnancy weight are essential for classifying women in the correct BMI category and thus providing appropriate GWG targets. Likewise, estimates of PPWR depend on reliable preconception weight records. The Southampton Women's Study (SWS) highlighted the complexities and challenges of using proxy weights by comparing three common methods against the "gold standard" of clinically measured weight.[77] In this study, maternal recall, first-trimester weight, and predicted prepregnancy weight using the Thomas method[79] (a mathematical model) were assessed for 198 women and compared to maternal weights taken within 3 months of conception. Of the three, maternal recall was the least reliable. Women underestimated their prepregnancy weight by 1.65 kg on average but with a wide variation among participants ranging from −17.6 to 7.10 kg. Both first-trimester weight and the Thomas method overestimated prepregnancy weight by a mean of 0.88 kg for each method. Here, as well, there was wide variability noted among individuals ranging from −5.80 to 7.40 kg for first-trimester weight and −5.84 to 7.89 for the Thomas estimate. The study findings show that while no method is perfect, the disadvantages of relying on maternal recall are clearly evident, yet this is the data collection method that was used in the majority of the included studies (Table S5).

Gilmore and Redman propose a way to mitigate the biases and limitations of maternal weight data in a comprehensive perspective paper.[80] They recommend that (1) preconception weight should be estimated using mathematical models that include maternal age, race, height, gestational age, and clinically measured first-trimester weight and (2) total GWG should be adjusted for length of gestation since the IOM/NAM guidelines are based on a full-term pregnancy (i.e., 37–40 weeks' gestation). We support these recommendations and believe that applying them may provide more accurate estimates of pregnancy-related weight gain. Standardizing data in this way would also allow comparisons across studies. In this review, only a handful of the included studies ($n = 5$) adjusted for gestational length,[33,37,48,51,60] and one applied mathematical models to estimate prepregnancy weight[41], suggesting that researchers are still far from reaching a consensus on the best methods for estimating pregnancy-related weight.

Results from this meta-analysis and narrative synthesis showed that excess GWG has an impact on both short- and long-term maternal weight retention. The heterogeneity of reported data, limited number of studies per postpartum time point, and methodological differences have complicated the ability to synthesize and interpret data. Our findings highlight the need for consensus and collaboration among research groups investigating pregnancy-related weight gain. Particularly, standards surrounding measurement methods and reported data are needed to better define an optimal range of GWG. Nevertheless, our results suggest that women could benefit from interventions aimed at achieving healthy weight gain in pregnancy.

AUTHOR CONTRIBUTIONS

Dorothy Meyer, Ejona Gjika, Sophie Michel, and Roxana Raab developed the overall research plan and the systematic literature search. Hans Hauner provided research oversight. Dorothy Meyer and Ejona Gjika conducted the literature review, study selection, data extraction, and quality assessment of the articles in consultation with all authors. Sophie Michel carried out statistical analysis and assisted with data interpretation. Dorothy Meyer and Sophie Michel wrote the first draft. All authors were involved in the results presentation, intellectual content contribution, and manuscript revisions and have read and approved the final manuscript. The final draft was approved by all authors.

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CONFLICT OF INTEREST STATEMENT

The authors declare no potential conflicts of interest.

DATA AVAILABILITY STATEMENT

Data described in the manuscript and analytic code will be made available upon request.

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SUPPORTING INFORMATION

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

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