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Maternal characteristics associated with gestational weight gain in France: a population-based, nationally representative study

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Complete List of Authors:	<p>Amyx, Melissa; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team, (Epopé). Center for Epidemiology and Statistics Sorbonne Paris Cité</p> <p>Zeitlin, Jennifer; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team, (Epopé). Center for Epidemiology and Statistics Sorbonne Paris Cité</p> <p>Hermann, Monika; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team, (Epopé). Center for Epidemiology and Statistics Sorbonne Paris Cité</p> <p>Castetbon, Katia; ULB École de Santé Publique, Centre de Recherche en Epidémiologie, Biostatistique et Recherche Clinique</p> <p>Blondel, Béatrice; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team, (Epopé). Center for Epidemiology and Statistics Sorbonne Paris Cité</p> <p>Le Ray, Camille; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team, (Epopé). Center for Epidemiology and Statistics Sorbonne Paris Cité; APHP</p>
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3 Maternal characteristics associated with gestational weight gain in France: a population-
4 based, nationally representative study
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10 Melissa Amyx;¹ Jennifer Zeitlin;¹ Monika Hermann;¹ Katia Castetbon;² Béatrice Blondel;¹

11
12
13 Camille Le Ray^{1,3}
14
15
16

17 Author affiliations

18
19
20 1. Université de Paris, CRESS, Obstetrical Perinatal and Pediatric Epidemiology Research

21
22 Team, EPOPé, INSERM, INRA, F-75004 Paris, France
23
24

25 2. Université libre de Bruxelles, Ecole de Santé Publique, Centre de Recherche en

26
27 Epidémiologie, Biostatistique et Recherche Clinique, Bruxelles, Belgique.
28
29

30 3. Hôpital Cochin Port Royal, Port Royal Maternity, Department of Obstetrics, Cochin Port

31
32 Royal Hospital, Assistance Publique-Hôpitaux de Paris, Université de Paris, Paris, France
33
34
35
36

37 Correspondence to: Melissa Amyx, PhD, MPH, e-mail: melissa.amyx@inserm.fr

38
39 Address: INSERM U1153

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41 53 Avenue de l'Observatoire

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Abstract

Objectives: To provide nationally-representative estimates of gestational weight gain (GWG) and GWG adequacy and identify maternal characteristics associated with insufficient or excessive GWG in France.

Design: French National Perinatal Survey 2010 and 2016, a population-based, nationally representative study

Setting: all maternity units in metropolitan, mainland France (n=535 in 2010; n=493 in 2016)

Participants: singleton live-births with GWG data (N=24,850)

Primary outcome measures: GWG was calculated as end of pregnancy minus prepregnancy weight (kg) and categorized as “insufficient”, “adequate”, or “excessive” using 2009 Institute of Medicine thresholds. Classification accounted for prepregnancy body mass index (kg/m²; underweight [<18.5], normal weight [$18.5-24.9$], overweight [$25-29.9$], obese [≥ 30]) and gestational age at delivery. We estimated average GWG and the percentage of women in each GWG category. Polytomous logistic regression identified characteristics associated with GWG adequacy.

Results: Average GWG was 13.0 (standard deviation 5.6) kg, with 26.8% of women gaining insufficiently and 36.1% excessively. Among other factors, insufficient GWG was associated with underweight (versus normal weight; adjusted OR [aOR] 1.4, 95%CI 1.2, 1.5) and obese (aOR 1.5, 95%CI 1.4, 1.7) BMI. Excessive GWG was associated with overweight (aOR 2.8, 95%CI 2.6, 3.1) and obese BMI (aOR 3.3, 95%CI 2.9, 3.6). Additionally, excessive GWG was associated with decreased or stopped smoking compared to no smoking, with stronger associations with greater decreases (≥ 10 cigarettes/day, stopped: aOR 2.6, 95%CI 2.3, 2.9; aORs 1.4-1.5 for lesser decreases). Additional characteristics associated with excessive GWG included primiparity (aOR 1.2, 95%CI 1.2, 1.3), lower education level (aORs 1.1-1.5), and not

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3 working/stopping working earlier in pregnancy (versus working until 32+0 weeks gestation
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5 or later: aORs 1.1-1.6).

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8 Conclusions: In France, insufficient and excessive GWG are common. For optimal outcomes,
9
10 support is needed for women with characteristics associated with insufficient and excessive
11
12 GWG, including nutritional advice for women quitting smoking or with high or low BMI.
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18 Strengths and limitations of this study

- 19
20 • This is the first nationally representative study of risk factors for gestational weight
21
22 gain (GWG) in France
- 23
24 • The French National Perinatal Survey (NPS) includes all maternity units in
25
26 metropolitan, mainland France
- 27
28 • Specially trained study midwives collected extensive, rigorous data through
29
30 maternal interview and chart abstraction
- 31
32 • The definition of GWG adequacy incorporated length of gestation, limiting
33
34 potential bias due to the correlation between GWG and length of gestation
- 35
36 • Some data (including prepregnancy BMI and GWG) was self-reported and collected
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38 retrospectively, which could result in measurement error
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Introduction

Due to demographic and lifestyle changes, women are entering pregnancy with higher body mass index (BMI) and gaining excessive pregnancy weight,¹⁻⁴ concerning trends as adequate gestational weight gain (GWG) is important for optimal fetal growth and pregnancy/birth outcomes. Specifically, excessive GWG is associated with cesarean delivery,^{5,6} postpartum weight retention/obesity,^{7,8} increased infant size^{6,9} and childhood overweight/obesity.^{10,11} Conversely, insufficient GWG is associated with decreased infant size^{6,9,12} and preterm birth.⁶ In 2009, the United States' Institute of Medicine (IOM; now National Academy of Medicine), updated its GWG guidelines¹ which are stratified by prepregnancy BMI, considered simultaneously a risk factor GWG, an independent risk factor for adverse perinatal outcomes, and a modifier of associations between GWG and several adverse outcomes^{1,8,13} (e.g., the association between GWG and postpartum weight retention was strongest among underweight women).⁸ Because GWG is modifiable and pregnant women interact frequently with healthcare providers, identification of factors associated with total GWG and inadequate GWG (insufficient or excessive) is necessary to target context-specific recommendations for GWG interventions/counselling. In addition to maternal prepregnancy BMI, numerous maternal factors, including socio-demographic characteristics, are potentially associated with GWG.^{7,14-26} However, evidence gaps exist, as these studies of GWG risk factors were largely conducted in the United States,^{7,15,16,19,21,23,24} with further evidence needed in diverse populations,¹ and are not nationally-representative. Further, many had a relatively small sample size (N<1,000),^{18,21,22,25,26} used GWG guidelines^{7,15,16,18,21} or data collected prior to the 2009 IOM guidelines,^{14,17,24} or focused narrowly on specific risk factors.²¹⁻²⁵

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3 In France, BMI and inadequate GWG prevalence are increasing.^{3,27,28} While previous French
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5 GWG studies evaluated adverse outcomes of GWG^{11,29-31} or reported overviews of the main
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7 pregnancy indicators,^{27,28} no study has comprehensively assessed GWG risk factors in
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9 France. Thus, factors previously identified may not be relevant in France, which compared to
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11 the United States, has lower BMI and GWG, higher rates of smoking, and stronger social
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13 security and public healthcare systems. To build upon prior evidence within a more
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15 contemporary, robust, nationally-representative cohort in a unique location and thereby
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17 inform local medical professionals providing care to pregnant women and international
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19 researchers evaluating consistency of risk factors across different cultural and organizational
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21 settings, our objectives were to provide population-based estimates of average GWG and
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23 the proportion of women achieving insufficient, adequate, or excessive GWG and identify
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25 maternal characteristics and social factors associated with mean GWG and insufficient and
26
27 excessive GWG in France.
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34 35 Methods

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37 We combined data from the 2010²⁸ and 2016²⁷ French National Perinatal Surveys (NPSs),
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39 routine, nationally-representative surveys including all live and stillbirths in all maternity
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41 units in metropolitan, mainland France (n=535 in 2010; n=493 in 2016) during 1 week (all
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43 births every other day over a 2-week period for maternity units with >2000 births/year).
44
45 Data collection, performed by trained study midwives, includes a face-to-face interview of
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47 women prior to hospital discharge (2-3 days following delivery) using a standardized
48
49 questionnaire to obtain information related to sociodemographic characteristics and
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51 antenatal care and chart abstraction to obtain information on maternal and neonatal health
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53 and delivery.
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3 After combining data from both years, the survey sample included 27,828 women (n=14,681
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5 in 2010; n=13,147 in 2016). We excluded multiple births (n=221 in 2010; n=234 in 2016),
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7 pregnancy terminations (n=53 in 2010; n=52 in 2016) and stillbirths (n=76 in 2010; n=73 in
8
9 2016), which may have distinct GWG patterns. We also excluded women with missing
10
11 (n=872 in 2010; n=1392 in 2016) or implausible GWG, defined as gain >50kg or loss >30kg^{8,32}
12
13 (n=4 in 2010; n=1 in 2016). Based on missing/implausible GWG, <10% of women with
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15 singleton livebirths in the NPS were excluded. Our final analysis included 24,850 women
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17 (n=13,455 in 2010; n=11,395 in 2016; Figure 1).

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23 *Observed GWG* (kg) was calculated based on women's self-reported end of pregnancy minus
24
25 prepregnancy weight. Then, as described previously,^{33,34} *GWG adequacy*, accounting for
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27 gestational age (GA) at delivery, was determined by maternal prepregnancy BMI (kg/m²;
28
29 using self-reported height and prepregnancy weight; underweight [<18.5], normal weight
30
31 [18.5-24.9], overweight [25-29.9], obese [≥ 30]),³⁵ based on the 2009 IOM guidelines
32
33 assumptions. To compute *expected GWG*, the following formula was used:
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35

$$\begin{aligned} \text{Expected GWG} = & \text{recommended first trimester gain} + [(GA \text{ at delivery} - \\ & 13) * \text{recommended rate of GWG per week in second and third trimesters}] \end{aligned}$$

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42 Thresholds by prepregnancy BMI for 1st trimester GWG are: 2 kg (underweight, normal), 1 kg
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44 (overweight), and 0.5 kg (obese), and for rates of GWG per week: 0.51 kg/week
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46 (underweight), 0.42 kg/week (normal), 0.28 kg/week (overweight), and 0.22 kg/week (obese
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48 BMI).³⁴ For example, a woman with normal weight BMI and GA at delivery of 40 weeks
49
50 would have an expected GWG of 13.34kg (2+[40-13]*0.42).
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54 To standardize published IOM recommended ranges of GWG for 40 weeks gestation across
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56 all GAs, each woman's *proportion of recommended GWG achieved* (*observed* divided by
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58 *expected GWG*) was utilized. To derive ranges for *proportion of recommended GWG*
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3 *achieved*, for each BMI group, lower and upper bounds of the range provided by IOM for 40
4 weeks gestation were divided by the *expected GWG* at 40 weeks. For example, the
5 recommended range of GWG for a woman with normal weight BMI is 11.5-16kg, which
6 based on the *expected GWG* of 13.34kg (calculated above) corresponds to *proportions of*
7 *recommended GWG achieved* of 0.86-1.20 (11.5/13.34; 16/13.34). Based on the *proportions*
8 *of recommended GWG achieved* specific to each BMI group as calculated based on
9 recommendations for 40 weeks and considered constant across GAs, *GWG adequacy* was
10 classified as (per range of proportions): *insufficient* (below lower bound), *adequate* (within
11 recommended range), or *excessive GWG* (above upper bound).
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25 French guidelines for GWG (2007 French National Nutrition and Health Program [Programme
26 National Nutrition et Santé])³⁶ differ from IOM guidelines, recommending GWG of 12kg for
27 women with normal prepregnancy BMI, lower GWG (not under 7kg) for women with
28 overweight or obese prepregnancy BMI, and higher GWG for women with underweight
29 prepregnancy BMI. However, as French guidelines do not provide upper and lower ranges
30 and IOM guidelines establish clear categories of GWG adequacy and are routinely used in
31 clinical practice and research in other countries, we used the IOM guidelines in our analysis.
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42 Maternal characteristics collected by interview prior to hospital discharge utilized are:
43 prepregnancy BMI (defined above; obesity further categorized as obese class I [BMI 30-34.9],
44 II [BMI 35-39.9], and III [BMI \geq 40]),³⁵ parity (primiparous, multiparous), and age (<25, 25-29,
45 30-34, >35 years). Maternal social characteristics included: country/region of birth (France,
46 Europe, Northern Africa, Sub-Saharan Africa, other), employment and timing of maternity
47 leave during pregnancy (none; stopped working before 14+0, 28+0, 32+0, at/after 32+0
48 weeks gestation, or at an unknown time point), and education (<high school; high school
49 completed; 1-2, 3-4, or 5/more years post-graduation). Smoking was evaluated based on
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3 smoking prior to pregnancy versus in the 3rd trimester (for each time point: non-
4 smoker/stopped smoking, <10 cigarettes per day [cig/d], ≥10cig/d), categorized as: non-
5 smoker at both time points; <10cig/d, stopped; ≥10cig/d, stopped; ≥10cig/d, reduced to
6 <10cig/d; <10cig/d, maintained at <10cig/d; ≥10cig/d, maintained at ≥10cig/d; increased
7 smoking [combined groups of: non-smoker, increased to <10cig/d; non-smoker, increased to
8 ≥10cig/d; <10cig/d, increased to ≥10cig/d). Social deprivation was based on an index derived
9 within the 2010 NPS based on: receipt of social benefits (household receiving Revenu de
10 Solidarité Active allowance; woman receiving Couverture Maladie Universelle, French social
11 security, or not insured), not living in her own accommodation, or not living with a partner.³⁷
12
13 Insufficient prenatal care was defined as late pregnancy declaration or insufficient
14 sonograms or prenatal visits based on GA at delivery. Prepregnancy conditions/pregnancy
15 complications, obtained from chart abstraction and used for descriptive purposes, included
16 diabetes in pregnancy (no; diet controlled; insulin controlled) and preexisting hypertension.

17 *Statistical analysis*

18
19 Mean GWG and the proportion of women in each GWG adequacy category, overall and by
20 BMI category and parity, were estimated, by survey year and overall. The characteristics of
21 included women and women excluded for missing GWG were determined. To determine
22 factors associated with GWG, linear regression models were used to estimate unadjusted
23 GWG within and adjusted differences in GWG between categories of maternal
24 characteristics. Based on covariates previously associated with GWG, multivariable models
25 adjusted for all maternal characteristics listed (BMI obesity classes combined), and
26 additionally adjusted for maternal height (meters), GA at delivery (days), and survey year. A
27 mean GWG difference of >1kg was considered clinically significant. Prepregnancy
28 conditions/pregnancy complications were not included in adjusted models as our primary
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3 interest was identifying social factors and because diabetes and hypertension may be
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5 mediators of the association between maternal characteristics and GWG. Polytomous
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7 logistic regression models, adjusted on the same covariates (except GA at delivery, which
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9 was accounted for in of the GWG adequacy definition), were used to examine the
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11 association between maternal characteristics and GWG adequacy.
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15 For descriptive analyses of GWG and GWG adequacy, means and standard deviations (SDs)
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17 or percentages are reported, as appropriate. For comparative analyses, appropriate
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19 measures of association (adjusted mean difference or odds ratio [aOR]) and 95% confidence
20
21 intervals (CIs) are reported. Though GWG differed between survey years, patterns of
22
23 associations between GWG and maternal characteristics were similar regardless of survey
24
25 year (data not shown) and we did not make inferences or conclusions about changes in GWG
26
27 over time. Thus, for analyses of associations between maternal characteristics and GWG,
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29 data from the 2010 and 2016 surveys were combined and survey year was included in the
30
31 models as a covariate rather than stratification variable.
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35 Due to the small amounts of missing data for covariates in the analytic sample (<5% of
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37 women missing data for any covariate included in the multivariable analyses), multiple
38
39 imputation was not conducted. Covariates with the highest percentages of missing data
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41 were: maternal prepregnancy BMI (1%), employment during pregnancy (1%), education
42
43 (1%), smoking status (1%), and diabetes (1%; not included in multivariable models).
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47 We used SAS software version 9.4 for Windows (SAS Institute Inc., Cary, NC) for statistical
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49 analyses.
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52 Patient and public involvement

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54 A network representing French user associations on questions related to
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56 pregnancy, childbirth and infancy were involved in the development of the questions on
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3 pregnancy and birth in the NPS and a website is maintained to disseminate results to
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5 participants and the wider public. However, there was no patient or public engagement for
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7 this research study.
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10 Results

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12 In our nationally-representative sample of French women, 29.1% were overweight or obese
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14 (respectively 18.4%, 10.7%), entering pregnancy, increasing from 27.0% in 2010 to 31.6% in
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16 2016. Overall, women's average GWG was 13.0kg (SD 5.6), decreasing from 13.2kg (SD 5.6)
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18 in 2010 to 12.7kg (SD 5.7) in 2016. GWG decreased with increasing BMI and though
19
20 primiparas weighed less prepregnancy (62.7kg, SD 13.2 versus 65.0kg, SD 14.1), they gained
21
22 more (13.7kg, SD 5.6 versus 12.4kg, SD 5.6) than multiparas. Only 37.0% of women attained
23
24 adequate GWG, decreasing slightly from 37.7% in 2010 to 36.2% in 2016. Excessive GWG
25
26 was more common among overweight (56.2%) and obese women (51.7%), while insufficient
27
28 GWG was more common among women with underweight (38.9%) or obese class III BMI
29
30 (54.7%). Primiparas (38.8%) were slightly more likely to gain excessively than multiparas
31
32 (34.2%), but slightly less likely to gain insufficiently (24.6% versus 28.6%, respectively; Table
33
34 1; eTable 1).

35
36 Table 2 describes the maternal socio-economic characteristics of the sample, average GWG
37
38 within each group, and differences in GWG between groups. Almost 20% of women in our
39
40 sample were born outside of France, 17.8% were socially deprived, 30% smoked before or
41
42 during pregnancy, and 5.3% had insufficient prenatal care. In unadjusted analysis, clinically
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44 significant differences (>1kg) in mean GWG were found for all maternal characteristics
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46 except social deprivation and maternal age. In adjusted models, clinically significant
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48 decreases in GWG were noted as BMI increased (compared to women with normal
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50 prepregnancy BMI), whereas clinically significant increases in GWG were noted among
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3 women quitting or reducing smoking (compared to non-smokers) and women who stopped
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5 working before 14 weeks gestation (compared to women continuing working until at least
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7 32 weeks). Compared to women excluded due to missing or implausible GWG, women
8
9 included in our analytic sample were more likely to be primiparous, have a lower
10
11 prepregnancy BMI, have modified their smoking habits during pregnancy, and have
12
13 characteristics indicative of higher socio-economic status (eTable 2).
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15

16
17 In polytomous logistic regression models (Table 3), underweight (aOR 1.4, 95% CI 1.2, 1.5)
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19 and obese BMI (increasing by class; class I: aOR 1.2; 95% CI 1.0, 1.4; class II: aOR 1.9, 95% CI
20
21 1.5, 2.4; class III: aOR 3.4, 95% CI 2.4, 4.7) were associated with increased odds of insufficient
22
23 GWG. Additionally, maternal social characteristics associated with increased odds of
24
25 insufficient GWG included birth in Northern or sub-Saharan Africa, not being employed in
26
27 pregnancy, less than high school education, and insufficient prenatal care. Conversely,
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29 overweight BMI (aOR 0.69, 95% CI 0.62, 0.77) and stopped or reduced smoking (aORs
30
31 ranging from 0.66-0.90 depending on levels of smoking and reduction) were associated with
32
33 decreased odds insufficient GWG. Additional characteristics associated with decreased odds
34
35 of insufficient GWG included primiparity, stopping work between 14+0 and 31+6 weeks
36
37 gestation, and education of 1-2 years post-graduation.
38
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40
41 Maternal characteristics associated with increased odds of excessive GWG were overweight
42
43 (aOR 2.8, 95% CI 2.6, 3.1) or obese prepregnancy BMI (decreasing by class; class I: aOR 3.8,
44
45 95% CI 3.4, 4.3; class II: aOR 2.4, 95% CI 2.0, 3.0; class III aOR 1.3, 95% CI 0.90, 2.0) and
46
47 reduced or continued/increased smoking (aORs ranging from 1.2 to 2.6 depending on levels
48
49 of smoking and reduction). Additional characteristics associated with excessive GWG
50
51 included primiparity, not working or stopping work before 32 weeks gestation, and lower
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53 education level. Conversely, underweight prepregnancy BMI (aOR 0.67, 95% CI 0.59, 0.76)
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3 was protective against excessive GWG. Additional characteristics associated with excessive
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5 GWG included maternal age over 35 years and insufficient prenatal care.
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8 Discussion

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10 In France in 2010 and 2016, the majority of women did not achieve adequate GWG based on
11
12 the 2009 IOM guidelines. Insufficient GWG was associated with underweight or obese
13
14 prepregnancy BMI; excessive GWG was associated with overweight or obese prepregnancy
15
16 BMI and reducing/quitting smoking. Additionally, many social factors (education, working
17
18 during pregnancy, insufficient prenatal care, maternal birth location) were associated with
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20 either insufficient or excessive GWG.
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24 The NPSs provide extensive, rigorous data obtained by specially trained study personnel
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26 on maternal socio-demographic characteristics and behavioral factors obtained through
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28 interview as well as health and delivery information obtained through chart abstraction.
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30 Previous studies have confirmed that the NPSs are nationally representative based on
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32 comparisons of selected perinatal indicators (e.g., maternal age, GA) available from birth
33
34 certificate and hospital discharge statistics in the corresponding years.^{27,28} By accounting for
35
36 GA at delivery in our definition of GWG adequacy and controlling for GA at delivery in
37
38 linear models of GWG, we limited potential biases due to the inherent correlation
39
40 between GWG and length of gestation.^{38,39} Additionally, our population included few
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42 preterm deliveries (5.3%) and preliminary sensitivity analyses of term pregnancies within our
43
44 cohort were consistent with our main analyses (data not reported), providing further
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46 evidence that biases due to GA at delivery were minimized. Additional methodological
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48 strengths are the large sample size and low level of missing data (<5% in multivariable
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50 analyses).
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3 With its comprehensive analysis of factors contributing to GWG within a large,
4 contemporary, nationally-representative French cohort, our study builds upon prior
5 literature. As previous French studies focused on other aspects of GWG,^{11,29-31} the
6 unique study location permits the comparison of risk factors across different settings,
7 providing insight into underlying mechanisms and their amenability to intervention,
8 generating hypotheses regarding biologic versus environmental/social etiology, and
9 informing public health policies and interventions. Descriptive studies such as ours are a
10 prerequisite for research to determine causal pathways or develop predictive models.
11 Measurement error is probable as some data was self-reported and collected
12 retrospectively. Specifically, though self-reported prepregnancy weight may be biased due to
13 underestimation,⁴⁰ self-report reflects typical clinical practice. Only total GWG, not
14 longitudinal GWG, was collected, reducing precision⁴¹ and not allowing us to examine
15 variations in GWG trajectory across pregnancy or timing of GWG. GWG data in the NPSs
16 used for our analysis was available for more than 90% of women and less than 5% of
17 included women had missing data for covariates in our analysis. However, because
18 differences were noted between included and excluded women, with excluded women
19 being more likely to have characteristics indicative of lower SES, we may have
20 underestimated the association between these characteristics and GWG.
21
22 The percentages of women within IOM GWG adequacy categories in our population (26.8%
23 insufficient, 36.1% excessive) were relatively similar to those found in recent meta-analyses
24 (LifeCycle: 21.5% insufficient, 42.0% excessive;⁴² Goldstein et al.: 23% insufficient, 47%
25 excessive⁶). Nonetheless, the majority of women in our study gained either insufficiently or
26 excessively and the average GWG of women with normal weight BMI (13.8kg, SD 4.8)
27 exceeded the current French guidelines, suggesting additional research within nationally-
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3 representative samples of the French population is necessary to define adequate GWG and
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5 clarify national guidelines.
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8 Compared to a recent systematic review of North American and European pregnant
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10 women,⁴² our population had a similar prepregnancy BMI profile. However, compared to a
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12 separate systematic review which was not limited to North American and European women,⁶
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14 our French population had a lower percentage entering pregnancy with overweight or obese
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16 prepregnancy BMI (29% versus 38%). Though some previous studies also reported increased
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18 GWG in primiparous compared to multiparous,^{25,32,42-44} a recent systematic review
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20 concluded that the evidence is inconsistent and that the role of parity on GWG is likely
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22 indirect and complex.⁴⁵
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27 Within our population, prepregnancy BMI was one of the most important maternal
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29 characteristics associated with GWG. The noted trends of an inverse relationship between
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31 prepregnancy BMI and GWG,^{1,42-44,46-48} higher likelihood of insufficient GWG among women
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33 with underweight or obese BMI and of excessive GWG among women with overweight or
34
35 obese BMI^{13-15,19,32,49} compared to women with normal weight prepregnancy BMI, and
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37 generally lower percentages of women achieving adequate GWG with increasing BMI
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39 category^{47,50} were also consistent with previous studies, including studies within French
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41 populations.^{11,29,30} Though some differences were noted related to average GWG (with
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43 lower,²⁹ higher¹¹, and similar estimates³⁰) and GWG adequacy (varying results depending
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45 on BMI category)^{11,29,31} compared to the other French studies, differences may be
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47 attributed to differences in study design (retrospective versus prospective; nationally-
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49 representative versus limited/local hospital-based), location, GWG classification method
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51 (accounting for GA at delivery), and inclusion/exclusion criteria (women with pre-
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53 existing conditions excluded or not), with our study being the first in France to provide
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3 nationally-representative estimates. Regardless, special attention should be paid to the
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5 specific needs of women entering pregnancy with overweight or obese prepregnancy BMI,
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7 including information related to GWG recommendations and the importance of physical
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9 activity and nutritional support to optimize GWG and neonatal outcomes.^{1,51} Lastly, future
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11 research should address uncertainties regarding GWG guidelines in this population.^{48,52,53}
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15 Additionally, smoking reduction or cessation was associated with increased absolute GWG
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17 and excessive GWG. Prior studies also found increased absolute GWG^{21,22,54} and increased
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19 excessive GWG^{14,19,21,54} among women who quit smoking in pregnancy due to physiologic
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21 changes to the metabolism and central nervous system resulting in increased appetite and
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23 the behavioral substitution of cigarettes with consumption of sugary foods.⁵⁵ Given the
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25 obvious benefits of quitting smoking during pregnancy, smokers intending to reduce/stop
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27 smoking during pregnancy should be provided additional nutritional and psychological
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29 support to avoid adverse effects of excessive GWG and educated on the use of nicotine
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31 replacement therapies (e.g., nicotine patches).
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37 We identified several social factors associated with GWG in France. In line with previous
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39 studies, we found that insufficient prenatal care was associated with insufficient GWG.^{15,20,23}
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43 Though some previous studies also found lower education was associated with
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45 insufficient^{16,50,56}/low⁷ or excessive weight gain,^{13,16,56} others found that the associations
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47 between education and GWG differed by maternal BMI^{19,24} or no differences.¹⁷ In line with
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49 previous studies which found increased excessive GWG with younger maternal age,^{13,14,18,50}
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51 we note a small decrease in excessive GWG among mothers over 35 years of age. Conflicting
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53 results have been found related to immigration: some previous research has reported higher
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55 GWG and increased excessive GWG in foreign nationals²⁶ or recent immigrants.¹⁴ Similar to
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57 our findings, previous studies found insufficient GWG increased among foreign-born
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3 women¹⁵ or excessive GWG decreased among women of non-European ancestry living in
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5 The Netherlands.¹⁷ In addition to social factors, a deeper understanding of the underlying
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7 cultural context and social conditions, both in the origin and arrival country, is important to
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9 develop specific strategies to improve care for vulnerable populations and ensure low-
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11 income women can achieve a nutritionally adequate diet. As midwives and obstetricians
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13 have limited knowledge of GWG recommendations,⁵⁷ informing clinicians on guidelines is
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15 also vital.
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20 Conclusions

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22 In France, a minority of women achieves adequate GWG. Maternal prepregnancy BMI and
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24 quitting smoking in pregnancy were associated with not achieving GWG recommendations,
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26 with additional associations found for maternal social factors. To promote adequate GWG
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28 and optimize pregnancy outcomes, support tailored to the specific needs of these at-risk
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30 groups is needed, including education related to appropriate GWG, physical activity, and
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32 nutrition in pregnancy and social support for disadvantaged/vulnerable populations. Given
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34 the uncertainties regarding the current IOM recommendations and their applicability in the
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36 non-United States populations of pregnant women, additional research within nationally-
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38 representative samples is needed to evaluate the associations between GWG and pregnancy
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40 outcomes and to ensure recommendations are appropriate for use outside the United
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42 States.
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5 acquisition of the French National Perinatal Surveys. MH designed and MA, CLR, and JZ
6
7 finalized the concept of the current study. MA conducted data analysis, interpreted the
8
9 results, and developed the draft manuscript under the supervision of CLR and JZ and with
10
11 input from BB, KC, and MH. All authors critically reviewed and approved the final
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15 manuscript.

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3 Supplementary materials
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6 eTable 1. Nationally-representative estimates of GWG and GWG adequacy^a in France by
7 survey year (French National Perinatal Survey 2010 and 2016; N=24850)
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10 eTable 2: Characteristics of the study population, in comparison to those of women excluded
11 for missing or implausible GWG (French National Perinatal Survey 2010 and 2016)
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13 Footnotes
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15 Patient consent for publication: Not required
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18 Ethics approval: Each survey cycle was approved by the National Council on Statistical
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22 on Information Technology and Liberties ([CNIL]; 2016 registration number 915197), and the
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25 Inserm ethics committee (2016 approval IRB00003888 no. 14-191).
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Table 1. Nationally-representative estimates of GWG and GWG adequacy^a in France (French National Perinatal Survey 2010 and 2016; N=24850)

	n (%)	GWG (kg) mean (SD)	Insufficient GWG n (%)	Adequate GWG n (%)	Excessive GWG n (%)
Overall	24850	13.0 (5.6)	6606 (26.8)	9106 (37.0)	8892 (36.1)
BMI^b					
Underweight	1960 (8.0)	13.9 (4.8)	762 (38.9)	785 (40.1)	411 (21.0)
Normal weight	15506 (62.9)	13.8 (4.8)	4473 (28.9)	6438 (41.6)	4574 (29.5)
Overweight	4545 (18.4)	12.2 (6.0)	687 (15.1)	1303 (28.7)	2552 (56.2)
All obese	2625 (10.7)	8.6 (7.4)	684 (26.1)	580 (22.1)	1355 (51.7)
Obese class I	1802 (7.3)	9.8 (6.7)	355 (19.8)	392 (21.8)	1050 (58.4)
Obese class II	589 (2.4)	7.0 (7.7)	201 (34.2)	138 (23.5)	249 (42.3)
Obese class III	234 (0.95)	3.6 (8.3)	128 (54.7)	50 (21.4)	56 (23.9)
Parity					
Multiparous	14061 (56.7)	12.4 (5.6)	3972 (28.6)	5180 (37.2)	4755 (34.2)
Primiparous	10722 (43.3)	13.7 (5.6)	2617 (24.6)	3897 (36.6)	4123 (38.8)

Abbreviations: GWG=Gestational Weight Gain; BMI= Body mass index; SD: standard deviation; IOM= Institute of Medicine

^aBased on 2009 IOM thresholds,¹ accounting for gestational age at delivery;^{33,34} considered insufficient GWG if below recommendation, adequate if within recommendation, or excessive if above recommendation

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])³⁵

Table 2. Maternal characteristics and association with GWG (French National Perinatal Survey 2010 and 2016; N=24026 in adjusted model)

	N	% of the sample	GWG (kg) mean (SD)	Adjusted^a difference in GWG (kg) diff (95% CI)
Parity				
Multiparous	14061	56.7	12.4 (5.6)	0.00 (Reference)
Primiparous	10722	43.3	13.7 (5.6)	0.69 (0.54, 0.83)
BMI^b				
Underweight	1960	8.0	13.9 (4.8)	0.00 (-0.30, 0.31)
Normal weight	15506	62.9	13.8 (4.8)	0.00 (Reference)
Overweight	4545	18.4	12.2 (6.0)	-1.6 (-1.8, -1.4)
All obese	2625	10.7	8.6 (7.4)	-5.1 (-5.4, -4.8)
Obese class I	1802	7.3	9.8 (6.7)	-3.9 (-4.3, -3.6)
Obese class II	589	2.4	7.0 (7.7)	-6.7 (-7.3, -6.2)
Obese class III	234	0.9	3.6 (8.3)	-10.2 (-11.1, -9.3)
Age				
<25 years	3716	15.0	13.4 (6.3)	-0.04 (-0.30, 0.23)
25-29 years	8126	32.7	13.2 (5.7)	0.00 (Reference)
30-34 years	8079	32.5	12.9 (5.4)	0.05 (-0.15, 0.26)
>35 years	4918	19.8	12.5 (5.5)	-0.02 (-0.25, 0.22)
Country or region of birth				
France	20398	82.2	13.2 (5.5)	0.00 (Reference)
Europe	957	3.9	13.0 (5.7)	0.32 (-0.13, 0.76)
Northern Africa	1720	6.9	12.1 (6.1)	-0.20 (-0.55, 0.16)
Sub-Saharan Africa	1024	4.1	11.2 (6.8)	-0.58 (-1.0, -0.14)
Other	719	2.9	12.5 (5.2)	0.05 (-0.47, 0.56)
Employment during pregnancy				
None	7089	28.7	12.3 (6.4)	0.06 (-0.23, 0.35)
Stopped working before 14+0 wks gestation	1595	6.5	13.8 (6.3)	1.2 (0.76, 1.5)
Stopped working 14+0 to 27+6 wks gestation	6701	27.1	13.5 (5.5)	0.62 (0.36, 0.88)
Stopped working 28+0 to 31+6 wks gestation	4243	17.2	13.2 (4.9)	0.26 (-0.02, 0.54)
Work working at or after 32+0 wks gestation	4743	19.2	13.0 (4.9)	0.00 (Reference)
Work with unknown stop point	317	1.3	12.8 (5.6)	0.13 (-0.68, 0.93)
Education				
Less than high school	2158	8.7	11.9 (6.8)	0.58 (0.18, 0.98)
High school	9157	37.1	13.1 (6.3)	0.85 (0.57, 1.1)
1-2 years post graduation	5086	20.6	13.2 (5.3)	0.65 (0.36, 0.93)
3-4 years post graduation	4466	18.1	13.0 (4.9)	0.18 (-0.10, 0.46)
≥5 years post graduation	3798	15.4	12.9 (4.5)	0.00 (Reference)
Social deprivation^c				
No	20424	82.2	13.1 (5.4)	0.00 (Reference)
Yes	4414	17.8	12.5 (6.6)	-0.06 (-0.26, 0.14)
Smoking habits before, during pregnancy				
Non smoker	17216	69.9	12.4 (5.3)	0.00 (Reference)
<10 cig/d, stopped	1855	7.5	14.4 (5.3)	1.5 (1.1, 1.8)
≥10 cig/d, stopped	1402	5.7	16.2 (5.9)	3.3 (2.9, 3.7)

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3	≥10 cig/d, <10 cig/d	2185	8.9	14.0 (6.2)	1.3 (0.93, 1.6)
4	<10 cig/d, <10 cig/d	845	3.4	13.4 (6.4)	0.87 (0.38, 1.4)
5	≥10 cig/d, ≥10 cig/d	1081	4.4	12.4 (6.5)	0.10 (-0.36, 0.55)
6	Increased smoking ^d	47	0.2	13.6 (5.4)	1.1 (-0.87, 3.2)
7	<hr/>				
8	Insufficient care ^e				
9	No	23515	94.7	13.1 (5.6)	0.00 (Reference)
10	Yes	1328	5.3	11.5 (6.4)	-0.91 (-1.2, -0.60)
11	<hr/>				
12	Diabetes ^f				
13	No	22414	91.5	13.2 (5.5)	
14	Yes, diet controlled	633	2.6	10.2 (7.0)	
15	Yes, insulin controlled	1458	5.9	11.1 (6.5)	
16	<hr/>				
17	Preexisting hypertension ^f				
18	No	24229	98.0	13.0 (5.6)	
19	Yes	504	2.0	11.7 (7.3)	
20	<hr/>				

Abbreviations: GWG=Gestational Weight Gain; BMI= Body mass index; SD= standard deviation; CI= confidence interval; IOM= Institute of Medicine

^aAdjusted on all covariates (except diabetes and pre-existing hypertension), survey year, gestational age at delivery, and mother's height; BMI included in models for other covariates as 4-level variable (underweight, normal weight, overweight, obese)

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])³⁵

^cNo stable home (homeless or living in a hotel or caravan) and/or no salary nor unemployment allowance

^dNon-smoker, <10 cig/d; non-smoker, ≥10 cig/d; <10 cig/d, ≥10 cig/d

^eLate declaration of pregnancy or insufficient sonograms or prenatal visits based on gestational age at delivery

^fNot included in adjusted models because medical conditions are mediators of the relationship between maternal characteristics/social factor, the focus of this study.

Table 3. Associations between maternal characteristics and insufficient or excessive GWG^a in multivariable logistic regression models (French National Perinatal Survey 2010 and 2016; N=23931)

	Insufficient GWG aOR ^b (95% CI)	Excessive GWG aOR ^b (95% CI)
Parity		
Multiparous	1.00 (Reference)	1.00 (Reference)
Primiparous	0.92 (0.86, 0.99)	1.2 (1.2, 1.3)
BMI^c		
Underweight	1.4 (1.2, 1.5)	0.67 (0.59, 0.76)
Normal weight	1.00 (Reference)	1.00 (Reference)
Overweight	0.69 (0.62, 0.77)	2.8 (2.6, 3.1)
All obese	1.5 (1.4, 1.7)	3.3 (2.9, 3.6)
Obese class I	1.2 (1.0, 1.4)	3.8 (3.4, 4.3)
Obese class II	1.9 (1.5, 2.4)	2.4 (2.0, 3.0)
Obese class III	3.4 (2.4, 4.7)	1.3 (0.90, 2.0)
Age (years)		
<25 years	1.1 (0.96, 1.2)	1.0 (0.94, 1.1)
25-29 years	1.00 (Reference)	1.00 (Reference)
30-34 years	0.98 (0.90, 1.1)	0.98 (0.91, 1.1)
>35 years	0.99 (0.90, 1.1)	0.94 (0.85, 1.0)
Country or region of birth		
France	1.00 (Reference)	1.00 (Reference)
Europe	0.90 (0.75, 1.1)	1.1 (0.93, 1.3)
Northern Africa	1.1 (1.0, 1.3)	1.1 (0.98, 1.3)
Sub-Saharan Africa	1.2 (1.0, 1.5)	1.1 (0.93, 1.3)
Other	1.0 (0.83, 1.2)	1.1 (0.87, 1.3)
Employment during pregnancy		
None	1.2 (1.0, 1.3)	1.2 (1.1, 1.3)
Stopped working before 14+0 weeks gestation	0.98 (0.83, 1.1)	1.6 (1.4, 1.8)
Stopped working 14+0 to 27+6 weeks gestation	0.91 (0.82, 1.0)	1.2 (1.1, 1.4)
Stopped working 28+0 to 31+6 weeks gestation	0.93 (0.84, 1.0)	1.1 (0.96, 1.2)
Work working at or after 32+0 weeks gestation	1.00 (Reference)	1.00 (Reference)
Work with unknown stop point	1.1 (0.78, 1.4)	1.0 (0.76, 1.4)
Education		
Less than high school	1.2 (1.0, 1.4)	1.5 (1.3, 1.7)
High school	1.0 (0.90, 1.1)	1.5 (1.3, 1.6)
1-2 years post-graduation	0.93 (0.83, 1.0)	1.3 (1.2, 1.5)
3-4 years post-graduation	1.0 (0.90, 1.1)	1.1 (1.0, 1.2)
≥5 years post-graduation	1.00 (Reference)	1.00 (Reference)
Social deprivation^d		
No	1.00 (Reference)	1.00 (Reference)
Yes	1.1 (0.97, 1.2)	1.0 (0.92, 1.1)
Smoking habits before, during pregnancy		
Non smoker	1.00 (Reference)	1.00 (Reference)
<10 cig/d, stopped	0.66 (0.57, 0.75)	1.4 (1.3, 1.6)
≥10 cig/d, stopped	0.60 (0.49, 0.72)	2.6 (2.3, 2.9)

≥10 cig/d, <10 cig/d	0.90 (0.79, 1.0)	1.5 (1.4, 1.7)
<10 cig/d, <10 cig/d	1.1 (0.90, 1.3)	1.5 (1.3, 1.8)
≥10 cig/d, ≥10 cig/d	1.2 (0.99, 1.4)	1.2 (1.0, 1.4)
Increased smoking ^e	0.67 (0.30, 1.5)	1.4 (0.72, 2.7)
Insufficient care ^f		
Yes	1.2 (1.1, 1.4)	0.86 (0.74, 1.0)
No	1.00 (Reference)	1.00 (Reference)

Abbreviations: GWG=Gestational Weight Gain; BMI= Body mass index; SD= standard deviation; CI= confidence interval; IOM= Institute of Medicine; aOR= adjusted odds ratio

^aBased on 2009 IOM thresholds,¹ accounting for gestational age at delivery;^{33,34} considered insufficient GWG if below recommendation, adequate if within recommendation, or excessive if above recommendation

^bAdjusted on all covariates, survey year, and mother's height; BMI included in models for other covariates as 4-level variable (underweight, normal weight, overweight, obese)

^cBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])³⁵

^dNo stable home (homeless or living in a hotel or caravan) and/or no salary nor unemployment allowance

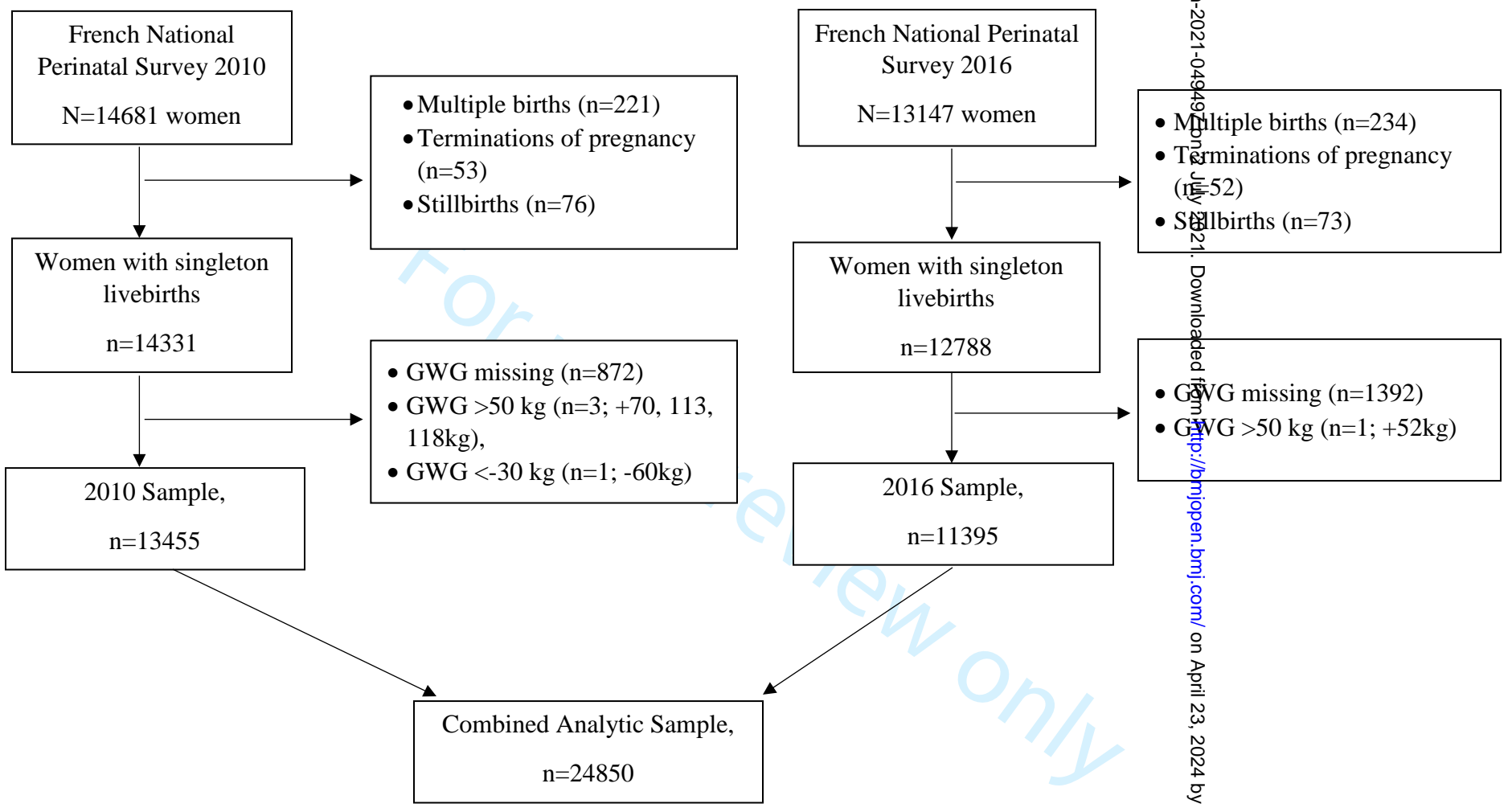
^eNon-smoker, <10 cig/d; non-smoker, ≥10 cig/d; <10 cig/d, ≥10 cig/d

^fLate declaration of pregnancy or insufficient sonograms or prenatal visits based on gestational age at delivery

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2
3 **Figure legends**
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5 Figure 1: Participant flow chart
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eTable 1. Nationally-representative estimates of GWG and GWG adequacy^a in France by survey year (French National Perinatal Survey 2010 and 2016; N=24850)

	2010					2016				
	N (%)	GWG (kg) mean (SD)	Insufficient GWG n (%)	Adequate GWG n (%)	Excessive GWG n (%)	N (%)	GWG (kg) mean (SD)	Insufficient GWG n (%)	Adequate GWG n (%)	Excessive GWG n (%)
Total	13455	13.2 (5.6)	3443 (25.9)	5006 (37.7)	4839 (36.4)	11395	12.7 (5.7)	3163 (28.0)	4100 (36.2)	4053 (35.8)
BMI ^b										
Underweight	1110 (8.3)	14.0 (4.7)	415 (37.5)	454 (41.0)	239 (21.6)	850 (7.5)	13.7 (4.9)	347 (40.8)	331 (38.9)	172 (20.2)
Normal weight	8601 (64.7)	13.9 (4.8)	2394 (27.9)	3614 (42.1)	2583 (30.1)	6905 (60.9)	13.7 (4.9)	2079 (30.2)	2824 (41.0)	1991 (28.9)
Overweight	2289 (17.2)	12.4 (5.9)	310 (13.6)	662 (28.9)	1315 (57.5)	2256 (19.9)	12.0 (6.0)	377 (16.7)	641 (28.4)	1237 (54.9)
All obese	1303 (9.8)	8.9 (7.4)	324 (24.9)	276 (21.2)	702 (53.9)	1322 (11.7)	8.4 (7.3)	360 (27.3)	304 (23.1)	653 (49.6)
Obese class I	893 (6.7)	10.2 (6.7)	162 (18.2)	190 (21.3)	540 (60.5)	909 (8.0)	9.5 (6.7)	193 (21.3)	202 (22.3)	510 (56.4)
Obese class II	280 (2.1)	7.0 (8.0)	92 (32.9)	64 (22.9)	124 (44.3)	309 (2.7)	7.0 (7.4)	109 (35.4)	74 (24.0)	125 (40.6)
Obese class III	130 (0.98)	4.2 (8.1)	70 (53.8)	22 (16.9)	38 (29.2)	104 (0.92)	2.8 (8.6)	58 (55.8)	28 (26.9)	18 (17.3)
Parity										
Multiparous	7510 (56.1)	12.6 (5.5)	2055 (27.7)	2821 (38.1)	2530 (34.2)	6551 (57.5)	12.2 (5.8)	1917 (29.5)	2359 (36.3)	2225 (34.2)
Primiparous	5881 (43.9)	13.9 (5.5)	1371 (23.5)	2156 (37.0)	2295 (39.4)	4841 (42.5)	13.4 (5.7)	1246 (25.9)	1741 (36.2)	1828 (38.0)

Abbreviations: GWG=Gestational Weight Gain; BMI= Body mass index; SD: standard deviation; IOM= Institute of Medicine

^aBased on 2009 IOM thresholds,¹ accounting for gestational age at delivery;^{2,3} considered insufficient GWG if below recommendation, adequate if within recommendation, or excessive if above recommendation

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])⁴

eTable 2: Characteristics of the study population, in comparison to those of women excluded for missing or implausible GWG (French National Perinatal Survey 2010 and 2016)

	Included (N=24850) n (%)	Excluded (N=2269) n (%)
Parity		
Multiparous	14061 (56.7)	1100 (63.5)
Primiparous	10722 (43.3)	632 (36.5)
BMI^a		
Underweight	1960 (8.0)	7 (4.2)
Normal weight	15506 (62.9)	92 (55.1)
Overweight	4545 (18.4)	33 (19.8)
All obese	2625 (10.7)	35 (21.0)
Obese class I	1802 (7.3)	25 (15.0)
Obese class II	589 (2.4)	7 (4.2)
Obese class III	234 (0.95)	3 (1.8)
Age		
<25 years	3716 (15.0)	370 (22.0)
25-29 years	8126 (32.7)	482 (28.6)
30-34 years	8079 (32.5)	476 (28.3)
>35 years	4918 (19.8)	356 (21.1)
Country or region of birth		
France	20398 (82.2)	280 (53.6)
Europe	957 (3.9)	47 (9.0)
Northern Africa	1720 (6.9)	63 (12.1)
Sub-Saharan Africa	1024 (4.1)	101 (19.3)
Other	719 (2.9)	31 (5.9)
Employment during pregnancy		
None	7089 (28.7)	404 (60.3)
Stopped working before 14+0 wks gestation	1595 (6.5)	20 (3.0)
Stopped working 14+0 to 27+6 wks gestation	6701 (27.1)	58 (8.7)
Stopped working 28+0 to 31+6 wks gestation	4243 (17.2)	24 (3.6)
Work working at or after 32+0 wks gestation	4743 (19.2)	40 (6.0)
Work with unknown stop point	317 (1.3)	124 (18.5)
Education		
Less than high school	2158 (8.7)	217 (37.0)
High school	9157 (37.1)	226 (38.5)
1-2 years post graduation	5086 (20.6)	67 (11.4)
3-4 years post graduation	4466 (18.1)	50 (8.5)
≥5 years post graduation	3798 (15.4)	27 (4.6)
Social deprivation^b		
No	20424 (82.2)	304 (60.9)
Yes	4414 (17.8)	195 (39.1)
Smoking habits before, during pregnancy		
Non smoker	17216 (69.9)	297 (72.1)
<10 cig/d, stopped	1855 (7.5)	18 (4.4)
≥10 cig/d, stopped	1402 (5.7)	17 (4.1)
≥10 cig/d, <10 cig/d	2185 (8.9)	21 (5.1)
<10 cig/d, <10 cig/d	845 (3.4)	32 (7.8)
≥10 cig/d, ≥10 cig/d	1081 (4.4)	26 (6.3)
Increased smoking ^c	47 (0.19)	1 (0.24)
Insufficient care^d		
No	23515 (94.7)	673 (83.3)
Yes	1328 (5.3)	135 (16.7)
Diabetes		
No	22414 (91.5)	1490 (89.4)
Yes, diet controlled	633 (2.6)	42 (2.5)
Yes, insulin controlled	1458 (5.9)	134 (8.0)
Preexisting hypertension		
No	24229 (98.0)	1656 (97.5)
Yes	504 (2.0)	42 (2.5)

Abbreviations: BMI= Body mass index

^aBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])⁴

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3 ^bNo stable home (homeless or living in a hotel or caravan) and/or no salary nor
4 unemployment allowance

5 ^cNon-smoker, <10 cig/d; non-smoker, ≥10 cig/d; <10 cig/d, ≥10 cig/d

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7 ^dLate declaration of pregnancy or insufficient sonograms or prenatal visits based on
8 gestational age at delivery
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STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*
Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	5-6
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	6-7; 8-9
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6-9
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	8-9
		(b) Describe any methods used to examine subgroups and interactions	n/a
		(c) Explain how missing data were addressed	9
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed	n/a

		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	
		€ Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage © Consider use of a flow diagram	6 n/a Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest © <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	10; Table 1-2; eTable 1 9 n/a
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time <i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure <i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	n/a n/a 10; Table 1-2; eTable 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	10-12; Tables 2-3 Tables 2-3 n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	n/a
Discussion			
Key results	18	Summarise key results with reference to study objectives	12
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-16
Generalisability	21	Discuss the generalisability (external validity) of the study results	13
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	24

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

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2 **Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE
3 checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at
4 <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.
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Maternal characteristics associated with gestational weight gain in France: a population-based, nationally representative study

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Manuscript ID	bmjopen-2021-049497.R1
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Complete List of Authors:	Amyx, Melissa; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris Zeitlin, Jennifer; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris Hermann, Monika; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris Castetbon, Katia; ULB École de Santé Publique, Centre de Recherche en Epidémiologie, Biostatistique et Recherche Clinique Blondel, Béatrice; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris Le Ray, Camille; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris; APHP, Hôpital Cochin Port Royal, Port Royal Maternity, Department of Obstetrics, Université de Paris
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3 Maternal characteristics associated with gestational weight gain in France: a population-
4 based, nationally representative study
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10 Melissa Amyx;¹ Jennifer Zeitlin;¹ Monika Hermann;¹ Katia Castetbon;² Béatrice Blondel;¹

11
12
13 Camille Le Ray^{1,3}
14
15
16

17 Author affiliations

18
19
20 1. Université de Paris, CRESS, Obstetrical Perinatal and Pediatric Epidemiology Research

21
22 Team, EPOPé, INSERM, INRA, F-75004 Paris, France
23
24

25 2. Université libre de Bruxelles, Ecole de Santé Publique, Centre de Recherche en

26
27 Epidémiologie, Biostatistique et Recherche Clinique, Bruxelles, Belgique.
28
29

30 3. Hôpital Cochin Port Royal, Port Royal Maternity, Department of Obstetrics, Cochin Port

31
32 Royal Hospital, Assistance Publique-Hôpitaux de Paris, Université de Paris, Paris, France
33
34
35
36

37 Correspondence to: Melissa Amyx, PhD, MPH, e-mail: melissa.amyx@inserm.fr

38
39 Address: INSERM U1153

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41 53 Avenue de l'Observatoire

42
43 75014 Paris

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Abstract

Objectives: To provide nationally-representative estimates of gestational weight gain (GWG) and identify maternal characteristics associated with inadequate GWG in France.

Design: French National Perinatal Survey 2010 and 2016, a population-based, nationally representative study

Setting: all maternity units in metropolitan, mainland France (n=535 in 2010; n=493 in 2016)

Participants: singleton live-births with GWG data (N=24,850)

Primary outcome measures: GWG was calculated as end of pregnancy minus prepregnancy weight (kg) and categorized as “insufficient”, “adequate”, or “excessive” using 2009 Institute of Medicine thresholds. Classification accounted for prepregnancy body mass index (kg/m²; underweight [<18.5], normal weight [$18.5-24.9$], overweight [$25-29.9$], obese [≥ 30]) and gestational age at delivery. We estimated average GWG and the percentage of women in each GWG category. Polytomous logistic regression identified characteristics associated with GWG adequacy.

Results: Average GWG was 13.0kg (standard deviation 5.6), with 26.8% of women gaining insufficiently, 37.0% adequately, and 36.1% excessively. Among other factors, insufficient GWG was associated with underweight (versus normal weight; adjusted OR [aOR] 1.4, 95%CI 1.2, 1.5) and obese (aOR 1.5, 95%CI 1.4, 1.7) BMI. Excessive GWG was associated with overweight (aOR 2.8, 95%CI 2.6, 3.1) and obese BMI (aOR 3.3, 95%CI 2.9, 3.6). Examining obesity classes separately, odds of insufficient GWG increased from obesity class I to III, while odds of excessive GWG decreased from obesity class I to III. Primiparity (insufficient: aOR 0.9, 95% CI 0.9, 1.0; excessive: aOR 1.2, 95% CI 1.2, 1.3), maternal characteristics indicative of lower socioeconomic status, and continuing or quitting smoking during pregnancy were also associated with inadequate GWG.

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3 Conclusions: In France, insufficient and excessive GWG are common. For optimal outcomes,
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5 support is needed for women with characteristics associated with insufficient and excessive
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8 GWG, including nutritional advice for women smoking during pregnancy or with high or low
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10 BMI.
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15 Strengths and limitations of this study 16

- 17 • This is the first nationally representative study of risk factors for gestational weight
18 gain (GWG) in France
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- 20 • The French National Perinatal Survey (NPS) includes all maternity units in
21 metropolitan, mainland France
22
- 23 • Specially trained study midwives collected extensive, rigorous data through
24 maternal interview and chart abstraction
25
- 26 • The definition of GWG adequacy incorporated length of gestation, limiting
27 potential bias due to the correlation between GWG and length of gestation
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- 29 • Some data (including prepregnancy BMI and GWG) was self-reported and collected
30 retrospectively, which could result in measurement error
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Introduction

Due to demographic and lifestyle changes, women are entering pregnancy with higher body mass index (BMI) and gaining excessive pregnancy weight,¹⁻⁴ concerning trends as both BMI^{1,5} and adequate gestational weight gain (GWG) are important for optimal fetal growth and pregnancy/birth outcomes. Specifically, excessive GWG is associated with cesarean birth,^{6,7} postpartum weight retention/obesity,^{8,9} increased infant size,^{7,10} and childhood overweight/obesity.^{11,12} Conversely, insufficient GWG is associated with decreased infant size^{7,10,13} and preterm birth.⁷ In 2009, the United States' Institute of Medicine (IOM; now National Academy of Medicine), provided updated GWG guidelines, stratified by maternal prepregnancy BMI, to improve care for the contemporary obstetric population.¹ While the current IOM guidelines provide a single recommendation for GWG for all women with obese prepregnancy BMI, whether separate guidelines are needed by obesity class is unclear due to a lack of evidence and subsequent studies suggest that women with severe obesity gaining below the recommendations should not be encouraged to increase their GWG.¹⁴ Because GWG is modifiable and pregnant women interact frequently with healthcare providers, identification of factors associated with total GWG and inadequate GWG (insufficient or excessive) is necessary to target context-specific recommendations for GWG interventions/counselling. In addition to maternal prepregnancy BMI, numerous maternal factors, including socio-demographic characteristics, are potentially associated with GWG.^{8,15-27} However, evidence gaps exist, as these studies of GWG risk factors were largely conducted in the United States,^{8,16,17,20,22,24,25} with further evidence needed in diverse populations,¹ and are not nationally-representative. Further, many had a relatively small sample size (N<1,000),^{19,22,23,26,27} used GWG guidelines^{8,16,17,19,22} or data collected prior to the 2009 IOM guidelines,^{15,18,25} or focused narrowly on specific risk factors.²²⁻²⁶

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3 In France, BMI and inadequate GWG prevalence are increasing.^{3,28,29} While previous French
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5 GWG studies evaluated adverse outcomes of GWG^{12,30-32} or reported overviews of the main
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7 pregnancy indicators,^{28,29} no study has comprehensively assessed GWG risk factors in
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9 France. Compared to the United States (where most previous studies on the association
10
11 between risk factors for GWG were conducted), the French obstetric population differs on
12
13 key factors related to weight and GWG (e.g., lower BMI^{28,33} and higher rates of smoking^{28,34}
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15 in the French obstetric population) and benefits from the world's highest performing
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17 healthcare system based on a WHO study of overall efficiency.³⁵ Thus, the risk factors
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19 previously identified may not be relevant in France. To build upon prior evidence within a
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21 more contemporary, robust, nationally-representative cohort in a unique location and
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23 thereby inform local medical professionals providing care to pregnant women and
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25 international researchers evaluating consistency of risk factors across different cultural and
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27 organizational settings, our objectives were to provide population-based estimates of
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29 average GWG and the percentage of women achieving insufficient, adequate, or excessive
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31 GWG and identify maternal characteristics and social factors associated with mean GWG and
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33 insufficient and excessive GWG in France.
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41 42 Methods

43 44 *Study design and population*

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46 We combined data from the 2010²⁹ and 2016²⁸ French National Perinatal Surveys (NPSs),
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48 which are routine, nationally-representative surveys including all live and stillbirths in all
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50 maternity units in metropolitan, mainland France (n=535 in 2010; n=493 in 2016). In each
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52 survey, data were collected during 1 week. Data collection, performed by trained study
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54 midwives, included a face-to-face interview of women prior to hospital discharge (2-3 days
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56 following delivery) using a standardized questionnaire to obtain information related to
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3 sociodemographic characteristics and antenatal care and chart abstraction to obtain
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5 information on maternal and neonatal health and delivery.
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8 After combining data from both years, the survey sample included 27,828 women (n=14,681
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10 in 2010; n=13,147 in 2016). We excluded multiple births (n=221 in 2010; n=234 in 2016),
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12 pregnancy terminations (n=53 in 2010; n=52 in 2016) and stillbirths (n=76 in 2010; n=73 in
13
14 2016), which may have distinct GWG patterns. We also excluded women with missing
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16 (n=872 in 2010; n=1392 in 2016) or implausible GWG, defined as gain >50kg or loss >30kg^{9,36}
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18 (n=4 in 2010; n=1 in 2016). Based on missing/implausible GWG, <10% of women with
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20 singleton livebirths in the NPS were excluded. Our final analysis included 24,850 women
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22 (n=13,455 in 2010; n=11,395 in 2016; Figure 1).
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26 27 *GWG variables*

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30 *Observed GWG* (kg) was calculated based on women's self-reported end of pregnancy minus
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32 prepregnancy weight. Then, *GWG adequacy* (insufficient, adequate, excessive) was
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34 determined by maternal prepregnancy BMI (kg/m²; using self-reported height and
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36 prepregnancy weight; underweight [<18.5], normal weight [18.5-24.9], overweight [25-29.9],
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38 obese [≥ 30])³⁷ and was standardized across gestational ages using a previously described
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40 method^{38,39} based on the assumptions underlying the 2009 GWG IOM guidelines (Panel 1).
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Panel 1: GWG adequacy determination using a previously described method^{38,39}

BMI (kg/m ²)	IOM recommendations/assumptions for GWG at 40 weeks gestation			Conversion to proportions of GWG achieved	
	1 st trimester GWG (kg)	Rate of GWG (kg/week)	Recommended range (kg)	Expected GWG at 40 weeks	Recommended <i>range of proportion of GWG</i> ³⁹
Underweight (<18.5)	2	0.51	12.5-18	15.77	0.79-1.14
Normal weight (18.5-24.9)	2	0.42	11.5-16	13.34	0.86-1.20
Overweight (25-29.9)	1	0.28	7.0-11.5	8.56	0.81-1.34
Obese (≥30)	0.5	0.22	5.0-9.0	6.44	0.78-1.41

- Expected GWG* at 40 weeks computed: Recommended first trimester gain + [(GA at delivery – 13)*Recommended rate of GWG]
Example: Normal weight BMI: *Expected GWG*=13.34kg = (2+[40-13]*0.42)
- Recommended ranges of total GWG for each BMI group converted to *ranges of proportions*: lower and upper bounds of the IOM recommended range divided by the *expected GWG* at 40 weeks
Example: Normal weight BMI: 0.86-1.20 (11.5/13.34; 16/13.34)
- For each woman, her *individual proportion of recommended GWG* achieved determined: *observed GWG* divided by her *expected GWG* (using formula from step 1)
- Individual proportion of recommended GWG achieved* compared to *ranges of proportions* for her BMI group
GWG adequacy classified as:
 - *Insufficient*: below lower bound
 - *Adequate*: within recommended range
 - *Excessive*: above upper bound

French guidelines for GWG (2007 French National Nutrition and Health Program [Programme National Nutrition et Santé])⁴⁰ differ from IOM guidelines, recommending GWG of 12kg for women with normal prepregnancy BMI, lower GWG (not under 7kg) for women with overweight or obese prepregnancy BMI, and higher GWG for women with underweight prepregnancy BMI. However, as French guidelines do not provide upper and lower ranges and IOM guidelines establish clear categories of GWG adequacy, are routinely used in clinical practice and research in other countries, and are better known by French clinicians and therefore likely more widely utilized in clinical practice, we used the IOM guidelines in our analysis.

Covariates

Maternal characteristics collected by interview prior to hospital discharge utilized are:

prepregnancy BMI (defined above; obesity further categorized as obese class I [BMI 30-34.9], II [BMI 35-39.9], and III [BMI \geq 40]),³⁷ parity (primiparous, multiparous), and age (<25, 25-29, 30-34, \geq 35 years). Maternal social characteristics included: country/region of birth (France, Europe, Northern Africa, Sub-Saharan Africa, other), employment and timing of maternity leave during pregnancy (none; stopped working before 14+0, 28+0, 32+0, at/after 32+0 weeks gestation, or at an unknown time point), and education (<high school; high school completed; 1-2, 3-4, or 5/more years post-graduation). Smoking was evaluated based on smoking prior to pregnancy versus in the 3rd trimester (for each time point: non-smoker/stopped smoking, <10 cigarettes per day [cig/d], \geq 10cig/d), categorized as: non-smoker at both time points; <10cig/d, stopped; \geq 10cig/d, stopped; \geq 10cig/d, reduced to <10cig/d; <10cig/d, maintained at <10cig/d; \geq 10cig/d, maintained at \geq 10cig/d; increased smoking [combined groups of: non-smoker, increased to <10cig/d; non-smoker, increased to \geq 10cig/d; <10cig/d, increased to \geq 10cig/d]. Social deprivation was based on an index derived within the 2010 NPS based on: receipt of social benefits (household receiving Revenu de Solidarité Active allowance; woman receiving Couverture Maladie Universelle, French social security, or not insured), not living in her own accommodation, or not living with a partner.⁴¹ Insufficient prenatal care was defined as late pregnancy declaration (national health insurance not notified in first three completed months and no nuchal translucency measurement in first trimester) or insufficient sonograms (<2 if GA at delivery 24-33 weeks; <3 if GA at delivery 34 weeks or later) or prenatal visits (<3 if GA at delivery 24-27 weeks; <4 if GA at delivery 28-31 weeks; <5 if GA at delivery 32-35 weeks; <6 if GA at delivery 36 weeks or later), consistent with French guidelines for low risk women.⁴² Prepregnancy

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3 conditions/pregnancy complications, obtained from chart abstraction and used for
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5 descriptive purposes, included diabetes in pregnancy (no; diet controlled; insulin controlled)
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7 and preexisting hypertension.
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10 *Statistical analysis*

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12 To describe the GWG profile of our cohort, for both survey years combined and individually,
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14 mean GWG (with standard deviations [SD]) and prevalence of insufficient, adequate, and
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16 excessive GWG were reported, overall and by BMI category. The characteristics of included
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18 women and women excluded for missing GWG were determined and compared.
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22 Next, the associations between maternal characteristics and GWG and GWG adequacy were
23
24 evaluated. First, unadjusted linear regression models were used to estimate mean GWG (SD)
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26 within levels of maternal characteristics. Then, adjusted linear regression models were used
27
28 to estimate adjusted mean differences in GWG (and 95% confidence intervals [CIs])
29
30 between categories of maternal characteristics, with a mean GWG difference of >1kg
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32 considered clinically significant. Similarly, adjusted polytomous logistic regression models
33
34 were used to examine the association between maternal characteristics and GWG adequacy
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36 (adjusted odds ratio [aOR], 95% CI calculated). Based on covariates previously associated
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38 with GWG, adjusted regression models adjusted for all maternal characteristics listed
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40 previously as covariates (BMI obesity classes combined), as well as maternal height (meters),
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42 GA at delivery (days; linear models only, as GA at delivery accounted for in definition of GWG
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44 adequacy), and survey year. Prepregnancy conditions/pregnancy complications were not
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46 included in adjusted models as our primary interest was identifying social factors and
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48 because diabetes and hypertension may be mediators of the association between maternal
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50 characteristics and GWG. To determine whether the associations between obesity classes
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52 and GWG and GWG adequacy differed, the adjusted analysis was repeated but with BMI
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3 included in the models as a 6-level variable (underweight, normal weight, overweight, obese
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5 class I, II, and III).

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8 Though GWG differed between survey years, patterns of associations between GWG and
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10 maternal characteristics were similar regardless of survey year (data not shown) and we did
11
12 not make inferences or conclusions about changes in GWG over time. Thus, for analyses of
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14 associations between maternal characteristics and GWG, data from the 2010 and 2016
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16 surveys were combined and survey year was included in the models as a covariate rather
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18 than stratification variable. Due to the small amounts of missing data for covariates in the
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20 analytic sample (<5% of women missing data for any covariate included in the multivariable
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22 analyses), multiple imputation was not conducted. Covariates with the highest percentages
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24 of missing data were: maternal prepregnancy BMI (1%), employment during pregnancy (1%),
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26 education (1%), smoking status (1%), and diabetes (1%; not included in multivariable
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28 models).

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31 We used SAS software version 9.4 for Windows (SAS Institute Inc., Cary, NC) for statistical
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33 analyses.

34 35 *Patient and public involvement*

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38 A network representing French user associations on questions related to
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40 pregnancy, childbirth and infancy were involved in the development of the questions on
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42 pregnancy and birth in the NPS and a website is maintained to disseminate results to
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44 participants and the wider public. However, there was no patient or public engagement for
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46 this research study.

47 48 *Results*

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51 In our nationally-representative sample of French women, women's average GWG was
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53 13.0kg (SD 5.6; Table 1), decreasing from 13.2kg (SD 5.6) in 2010 to 12.7kg (SD 5.7) in 2016
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3 (eTable 1). GWG decreased with increasing BMI, including across obesity classes. Only 37.0%
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5 of women attained adequate GWG, decreasing slightly from 37.7% in 2010 to 36.2% in 2016.
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7 Excessive GWG was more common among women with overweight and obese BMI, while
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9 insufficient GWG was more common among women with underweight BMI. However, when
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11 examining obesity classes separately, excessive GWG decreased from obese class I to III,
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13 while insufficient GWG increased from obese class I to III.
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17 In our cohort (Table 2), almost 20% of women were born outside of France, a majority were
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19 normal weight BMI entering pregnancy, 30% smoked either before or during pregnancy,
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21 2.0% had preexisting hypertension, and 8.5% had diabetes in pregnancy. Compared to
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23 women excluded due to missing or implausible GWG, women included in our analytic
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25 sample were more likely to be primiparous, have a lower prepregnancy BMI, have modified
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27 their smoking habits during pregnancy, and have characteristics indicative of higher socio-
28
29 economic status (eTable 2).
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35 In unadjusted analysis, clinically significant differences (>1kg) in mean GWG were found for
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37 all maternal characteristics except maternal age and social deprivation (Table 2), with higher
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39 GWG associated with characteristics indicative of higher socioeconomic status (maternal
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41 birth in France or Europe, higher education level, sufficient care) and reduced smoking in
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43 pregnancy. For pregnancy complications, mean GWG was lower among women with
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45 diabetes during pregnancy (11.1kg, SD 6.5 among women with insulin controlled and 10.2kg,
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47 SD 7.0 among women with diet controlled diabetes versus 13.2kg, SD 5.5 among women
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49 without diabetes during pregnancy) or preexisting hypertension (11.7kg, SD 7.3 versus
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51 13.0kg, SD 5.6 among women without preexisting hypertension). In adjusted models,
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53 clinically significant differences in mean GWG persisted for maternal prepregnancy BMI,
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55 employment in pregnancy, and smoking habits only.
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3 In polytomous logistic regression models (Table 3), underweight and obese BMI were
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5 positively associated with insufficient GWG. Additional characteristics positively associated
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7 with insufficient GWG included birth in sub-Saharan Africa, not being employed in
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9 pregnancy, less than high school education, and insufficient prenatal care. Conversely,
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Overweight and obese prepregnancy BMI were positively associated with excessive GWG.
Additional characteristics positively associated with excessive GWG included primiparity, not
working or stopping work before 28 weeks gestation, lower education level, and reduced or
continued smoking. Conversely, underweight prepregnancy BMI was inversely associated
with excessive GWG.

When adjusted analyses were repeated to evaluate obesity classes I-III separately (Table 4),
the trend of greater decreases in GWG compared to women with normal weight BMI
persisted. Similarly, the odds of insufficient GWG increased across obesity classes, but the
odds of excessive GWG decreased.

Discussion

In France in 2010 and 2016, the majority of women did not achieve adequate GWG based on
the 2009 IOM guidelines. Insufficient GWG was increased among women with underweight
or obese prepregnancy BMI, while excessive GWG was increased among women with
overweight or obese prepregnancy BMI. When examining obesity classes separately,
insufficient GWG increased from obesity class I to III, while excessive GWG decreased from
obesity class I to III. Excessive GWG was also increased among women who maintained or
reduced their smoking levels in pregnancy. Primiparity and maternal characteristics

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3 indicative of lower socioeconomic status (low education level, insufficient prenatal care,
4 maternal birth in sub-Saharan Africa) were also associated with inadequate GWG.
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8 Though the majority of women in our study had inadequate GWG, our results (26.8%
9 insufficient, 36.1% excessive GWG) were similar to those found in recent meta-analyses
10 (LifeCycle: 21.5% insufficient, 42.0% excessive;⁴³ Goldstein et al.: 23% insufficient, 47%
11 excessive⁷). Examining GWG by BMI class, our findings (inverse relationship between
12 prepregnancy BMI and mean GWG^{1,43-47}; positive association between insufficient GWG and
13 underweight or obese BMI; positive association between excessive GWG and overweight or
14 obese BMI^{15,16,20,36,48-50}) were generally consistent with previous studies. Clinicians providing
15 prenatal care should counsel women regarding appropriate GWG for their prepregnancy
16 BMI and provide information related to and nutritional and physical activity support to meet
17 recommendations,¹ in particular for women with underweight, overweight, or obese BMI as
18 these groups are more likely to have inadequate GWG and are therefore at higher risk of
19 related adverse outcomes. As midwives and obstetricians have limited knowledge of GWG
20 recommendations,⁵¹ informing clinicians on guidelines is also vital.
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39 The average GWG (13.8kg, SD 4.8) of women with normal weight BMI in our cohort
40 exceeded the current French guidelines and mean GWG (with lower,³⁰ higher¹², and similar
41 estimates³¹) and GWG adequacy (varying results depending on BMI category)^{12,30,32} in the
42 French population differed between studies. The differences between the French study
43 results may be attributed to differences in study design (retrospective versus
44 prospective; nationally-representative versus limited/local hospital-based), location,
45 GWG classification method (accounting for GA at delivery or not), and
46 inclusion/exclusion criteria (women with pre-existing conditions excluded or not). While
47 our study is the first in France to provide nationally-representative estimates of GWG
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3 and GWG adequacy, additional research within nationally-representative samples of the
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5 French population is necessary to define adequate GWG in relation to adverse outcomes and
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7 clarify national guidelines.
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10 Due to the lack of evidence to determine whether separate guidelines may be necessary in
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12 this population,¹⁴ we extended our analyses to compare mean GWG and GWG adequacy
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14 between obesity classes. Our results are consistent with previous studies, finding
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16 insufficient GWG increased and excessive GWG decreased from obesity class I to III^{20,52,53}
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18 and supporting evidence that lower GWG guidelines may be appropriate for higher
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20 obesity.^{43,52,54,55} Future research should address uncertainties regarding GWG guidelines for
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22 different obesity classes.
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27 In line with previous research, we also found increased absolute GWG^{22,23,56} and increased
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29 excessive GWG^{15,20,22,56} among women who quit smoking in pregnancy, likely due to
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31 physiologic changes to the metabolism and central nervous system resulting in increased
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33 appetite and the behavioral substitution of cigarettes with consumption of sugary foods.⁵⁷
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37 Given the obvious benefits of quitting smoking before or during pregnancy due to the
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39 adverse effects of smoking (e.g., reduced fetal growth and birth size),^{58,59} smokers should be
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41 encouraged to reduce/stop smoking during pregnancy, be provided additional nutritional
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43 and psychological support to avoid adverse effects of excessive GWG, and be educated on
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45 the use of nicotine replacement therapies (e.g., nicotine patches).
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49 Finally, we found that a number of maternal and social characteristics were associated with
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51 GWG adequacy, though consistency with prior literature was mixed. While we found
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53 increased GWG in primiparas compared to multiparas, a recent systematic review concluded
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55 that the evidence is inconsistent and that the role of parity on GWG is likely indirect and
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57 complex.⁶⁰ Overall, our results suggest that French women of lower socioeconomic status
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3 are more likely to have inadequate GWG, though the evidence for these factors is
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5 inconsistent. In contrast to our results, some studies have found increased excessive GWG
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7 with younger maternal age.^{15,19,49,50} Results for education have been mixed, with some
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9 previous studies also finding lower education was associated with insufficient^{5,17,50}/low⁸ or
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11 excessive weight gain^{5,17,49} but others finding that the associations between education and
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13 GWG differed by maternal BMI^{20,25} or no differences.¹⁸ Conflicting results have also been
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15 found related to immigration, with some previous research reporting higher GWG and
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17 increased excessive GWG in foreign nationals²⁷ or recent immigrants¹⁵ but others finding
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19 insufficient GWG increased among foreign-born women¹⁶ or excessive GWG decreased
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21 among women of non-European ancestry living in The Netherlands,¹⁸ similar to our finding
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23 of increased insufficient GWG among women born in sub-Saharan Africa. In contrast,
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25 insufficient prenatal care was associated with insufficient GWG consistently across
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27 studies,^{16,21,24} in line with our results. Given the disparate results across study settings, a
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29 deeper understanding of the underlying cultural context and social conditions is important
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31 to develop specific strategies to improve care for vulnerable populations and ensure all
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33 women, in particular those of lower socioeconomic status, can achieve a nutritionally
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35 adequate diet.
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39 With its comprehensive analysis of factors contributing to GWG within a large,
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41 contemporary, nationally-representative French cohort, our study builds upon prior
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43 literature. As previous French GWG studies investigated different research
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45 questions,^{12,30-32} we provide evidence of risk factors in a unique setting which could
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47 inform interventions locally and future research related to mechanisms underlying the
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49 observed associations. Additional strengths of our study include the extensive, rigorous
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51 data obtained in the NPSs by specially trained study personnel, which previous studies
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3 have confirmed are nationally representative based on comparisons of selected perinatal
4 indicators (e.g., maternal age, GA) available from birth certificate and hospital discharge
5 statistics in the corresponding years.^{28,29} By accounting for GA at delivery in our definition
6 of GWG adequacy and controlling for GA at delivery in linear models of GWG, we limited
7 potential biases due to the inherent correlation between GWG and length of
8 gestation.^{61,62} Additionally, our population included few preterm deliveries (5.3%) and
9 preliminary sensitivity analyses of term pregnancies within our cohort were consistent with
10 our main analyses (data not reported), providing further evidence that biases due to GA at
11 delivery were minimized. Additional methodological strengths are the large sample size
12 and low level of missing data (<5% in multivariable analyses).

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27 Our study has some limitations. Measurement error is possible as some data was self-
28 reported and collected retrospectively. Specifically, self-reported prepregnancy weight and
29 maternal weight at delivery may be biased due to underestimation.⁶³ However, because
30 reporting of weight gain during pregnancy in medical records is not standardized across
31 France, the NPSs obtain this information through maternal self-report in order to have
32 consistently collected and more complete data. While the resulting bias due to
33 misclassification in measuring associations between GWG and adverse outcomes may be
34 minimal, the impact of misclassification in examining risk factors for weight outcomes
35 has not been evaluated.⁶³ Only total GWG, not longitudinal GWG, was collected, reducing
36 precision⁶⁴ and not allowing us to examine variations in GWG trajectory across pregnancy or
37 timing of GWG. GWG data in the NPSs used for our analysis was available for more than 90%
38 of women and less than 5% of included women had missing data for covariates in our
39 analysis. However, because differences were noted between included and excluded women,
40 with excluded women being more likely to have characteristics indicative of lower
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3 socioeconomic status, we may have underestimated the association between these
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5 characteristics and GWG.
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7 8 Conclusions

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10 In France, a minority of women achieves adequate GWG. Maternal prepregnancy BMI,
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12 continuing or quitting smoking in pregnancy, and lower socioeconomic status were
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14 associated with not achieving GWG recommendations. To promote adequate GWG and
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16 optimize pregnancy outcomes, support tailored to the specific needs of these at-risk groups
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18 is needed, including education related to appropriate GWG, physical activity, and nutrition in
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20 pregnancy and social support for disadvantaged/vulnerable populations. Given the
21
22 uncertainties regarding the current IOM GWG recommendations, additional research within
23
24 nationally-representative samples outside the United States and within BMI obesity classes
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26 is needed.
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For peer review only

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3 Supplementary materials
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6 eTable 1. Nationally-representative estimates of GWG and GWG adequacy^a in France by
7 survey year (French National Perinatal Survey 2010 and 2016; N=24850)
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10 eTable 2: Characteristics of the study population, in comparison to those of women excluded
11 for missing or implausible GWG (French National Perinatal Survey 2010 and 2016)
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16 Footnotes
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18 Patient consent for publication: Not required
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21 Ethics approval: Each survey cycle was approved by the National Council on Statistical
22 Information (Comité du Label; 2016 approval number 2016X703SA), the French Commission
23 on Information Technology and Liberties ([CNIL]; 2016 registration number 915197), and the
24 Inserm ethics committee (2016 approval IRB00003888 no. 14-191).
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Table 1. Nationally-representative estimates of GWG and GWG adequacy^a in France (French National Perinatal Survey 2010 and 2016; N=24850)

	n (%)	GWG (kg) mean (SD)	Insufficient GWG n (%)	Adequate GWG n (%)	Excessive GWG n (%)
Overall	24850	13.0 (5.6)	6606 (26.8)	9106 (37.0)	8892 (36.1)
BMI^b					
Underweight	1960 (8.0)	13.9 (4.8)	762 (38.9)	785 (40.1)	411 (21.0)
Normal weight	15506 (62.9)	13.8 (4.8)	4473 (28.9)	6438 (41.6)	4574 (29.5)
Overweight	4545 (18.4)	12.2 (6.0)	687 (15.1)	1303 (28.7)	2552 (56.2)
All obese	2625 (10.7)	8.6 (7.4)	684 (26.1)	580 (22.1)	1355 (51.7)
Obese class I	1802 (7.3)	9.8 (6.7)	355 (19.8)	392 (21.8)	1050 (58.4)
Obese class II	589 (2.4)	7.0 (7.7)	201 (34.2)	138 (23.5)	249 (42.3)
Obese class III	234 (0.9)	3.6 (8.3)	128 (54.7)	50 (21.4)	56 (23.9)

Abbreviations: GWG= gestational weight gain; BMI= body mass index; SD= standard deviation; IOM= Institute of Medicine

^aBased on 2009 IOM thresholds,¹ accounting for gestational age at delivery;^{38,39} considered insufficient GWG if below recommendation, adequate if within recommendation, or excessive if above recommendation

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])³⁷

Table 2. Distribution of maternal characteristics in the sample and GWG associated with these characteristics (French National Perinatal Survey 2010 and 2016)

	n (%)	GWG (kg) mean (SD)	Adjusted ^a difference in GWG (kg) diff (95% CI)
BMI^b			
Underweight	1960 (8.0)	13.9 (4.8)	0.0 (-0.3, 0.3)
Normal weight	15506 (62.9)	13.8 (4.8)	reference
Overweight	4545 (18.4)	12.2 (6.0)	-1.6 (-1.8, -1.4)
Obese	2625 (10.7)	8.6 (7.4)	-5.1 (-5.4, -4.8)
Parity			
Multiparous	14061 (56.7)	12.4 (5.6)	reference
Primiparous	10722 (43.3)	13.7 (5.6)	0.7 (0.5, 0.8)
Age			
<25 years	3716 (15.0)	13.4 (6.3)	-0.0 (-0.3, 0.2)
25-29 years	8126 (32.7)	13.2 (5.7)	reference
30-34 years	8079 (32.5)	12.9 (5.4)	0.1 (-0.1, 0.3)
≥35 years	4918 (19.8)	12.5 (5.5)	-0.0 (-0.3, 0.2)
Country or region of birth			
France	20398 (82.2)	13.2 (5.5)	reference
Europe	957 (3.9)	13.0 (5.7)	0.3 (-0.1, 0.8)
Northern Africa	1720 (6.9)	12.1 (6.1)	-0.2 (-0.6, 0.2)
Sub-Saharan Africa	1024 (4.1)	11.2 (6.8)	-0.6 (-1.0, -0.1)
Other	719 (2.9)	12.5 (5.2)	0.0 (-0.5, 0.6)
Employment during pregnancy			
None	7089 (28.7)	12.3 (6.4)	0.1 (-0.2, 0.3)
Stopped working during pregnancy			
Before 14+0 wks gestation	1595 (6.5)	13.8 (6.3)	1.2 (0.8, 1.5)
14+0 to 27+6 wks gestation	6701 (27.1)	13.5 (5.5)	0.6 (0.4, 0.9)
28+0 to 31+6 wks gestation	4243 (17.2)	13.2 (4.9)	0.3 (-0.0, 0.5)
Unknown stop point	4743 (19.2)	12.8 (5.6)	0.1 (-0.7, 0.9)
Continued working to ≥32 wks gestation	317 (1.3)	13.0 (4.9)	reference
Education			
Less than high school	2158 (8.7)	11.9 (6.8)	0.6 (0.2, 1.0)
High school	9157 (37.1)	13.1 (6.3)	0.8 (0.6, 1.1)
1-2 years post-graduation	5086 (20.6)	13.2 (5.3)	0.6 (0.4, 0.9)
3-4 years post-graduation	4466 (18.1)	13.0 (4.9)	0.2 (-0.1, 0.5)
≥5 years post-graduation	3798 (15.4)	12.9 (4.5)	reference
Social deprivation^c			
No	20424 (82.2)	13.1 (5.4)	reference
Yes	4414 (17.8)	12.5 (6.6)	-0.1 (-0.3, 0.1)
Smoking habits before, during pregnancy			
Non smoker	17216 (69.9)	12.4 (5.3)	reference
Decreased smoking in pregnancy			
<10 cig/d, stopped	1855 (7.5)	14.4 (5.3)	1.5 (1.1, 1.8)
≥10 cig/d, stopped	1402 (5.7)	16.2 (5.9)	3.3 (2.9, 3.7)
≥10 cig/d, <10 cig/d	2185 (8.9)	14.0 (6.2)	1.3 (0.9, 1.6)

Maintained smoking level in pregnancy			
<10 cig/d, <10 cig/d	845 (3.4)	13.4 (6.4)	0.9 (0.4, 1.4)
≥10 cig/d, ≥10 cig/d	1081 (4.4)	12.4 (6.5)	0.1 (-0.4, 0.5)
Increased smoking in pregnancy ^d	47 (0.2)	13.6 (5.4)	1.1 (-0.9, 3.2)

Insufficient care^e

No	23515 (94.7)	13.1 (5.6)	reference
Yes	1328 (5.3)	11.5 (6.4)	-0.9 (-1.2, -0.6)

Abbreviations: GWG= gestational weight gain; SD= standard deviation; CI= confidence interval; BMI= body mass index; cig/d= cigarettes per day; GA= gestational age

^aEstimated using adjusted linear regression models; adjusted on all covariates in table, survey year, GA at delivery, and mother's height

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30³⁷

^cNo stable home (homeless or living in a hotel or caravan) and/or no salary nor unemployment allowance

^dNon-smoker, <10 cig/d; non-smoker, ≥10 cig/d; <10 cig/d, ≥10 cig/d

^eLate pregnancy declaration (national health insurance not notified in first three completed months and no nuchal translucency measurement in first trimester) or insufficient sonograms (<2 if GA at delivery 24-33 weeks; <3 if GA at delivery 34 weeks or later) or prenatal visits (<3 if GA at delivery 24-27 weeks; <4 if GA at delivery 28-31 weeks; <5 if GA at delivery 32-35 weeks; <6 if GA at delivery 36 weeks or later), consistent with French guidelines for low risk women

BOLD: clinically (>1kg) and statistically significant mean difference

Table 3. Associations between maternal characteristics and insufficient or excessive GWG^a in multivariable logistic regression models (French National Perinatal Survey 2010 and 2016; N=23931)

	Insufficient GWG aOR ^b (95% CI)	Excessive GWG aOR ^b (95% CI)
BMI^c		
Underweight	1.4 (1.2, 1.5)	0.7 (0.6, 0.8)
Normal weight	reference	reference
Overweight	0.7 (0.6, 0.8)	2.8 (2.6, 3.1)
Obese	1.5 (1.4, 1.7)	3.3 (2.9, 3.6)
Primiparity (versus multiparous)	0.9 (0.9, 1.0)	1.2 (1.2, 1.3)
Age		
<25 years	1.1 (1.0, 1.2)	1.0 (0.9, 1.1)
25-29 years	reference	reference
30-34 years	1.0 (0.9, 1.1)	1.0 (0.9, 1.1)
≥35 years	1.0 (0.9, 1.1)	0.9 (0.9, 1.0)
Country or region of birth (versus France)		
Europe	0.9 (0.8, 1.1)	1.1 (0.9, 1.3)
Northern Africa	1.1 (1.0, 1.3)	1.1 (1.0, 1.3)
Sub-Saharan Africa	1.2 (1.0, 1.5)	1.1 (0.9, 1.3)
Other	1.0 (0.8, 1.2)	1.1 (0.9, 1.3)
Employment during pregnancy		
None	1.2 (1.0, 1.3)	1.2 (1.1, 1.3)
Stopped working during pregnancy		
Before 14+0 wks gestation	1.0 (0.8, 1.1)	1.6 (1.4, 1.8)
14+0 to 27+6 wks gestation	0.9 (0.8, 1.0)	1.2 (1.1, 1.4)
28+0 to 31+6 wks gestation	0.9 (0.8, 1.0)	1.1 (1.0, 1.2)
Unknown stop point	1.1 (0.8, 1.4)	1.0 (0.8, 1.4)
Continued working to ≥32 wks gestation	reference	reference
Education (versus ≥5 years post-graduation)		
Less than high school	1.2 (1.0, 1.4)	1.5 (1.3, 1.7)
High school	1.0 (0.9, 1.1)	1.5 (1.3, 1.6)
1-2 years post-graduation	0.9 (0.8, 1.0)	1.3 (1.2, 1.5)
3-4 years post-graduation	1.0 (0.9, 1.1)	1.1 (1.0, 1.2)
Social deprivation^d	1.1 (1.0, 1.2)	1.0 (0.9, 1.1)
Smoking habits before, during pregnancy (versus non-smokers)		
Decreased smoking in pregnancy		
<10 cig/d, stopped	0.7 (0.6, 0.8)	1.4 (1.3, 1.6)
≥10 cig/d, stopped	0.6 (0.5, 0.7)	2.6 (2.3, 2.9)
≥10 cig/d, <10 cig/d	0.9 (0.8, 1.0)	1.5 (1.4, 1.7)
Maintained smoking level in pregnancy		
<10 cig/d, <10 cig/d	1.1 (0.9, 1.3)	1.5 (1.3, 1.8)
≥10 cig/d, ≥10 cig/d	1.2 (1.0, 1.4)	1.2 (1.0, 1.4)
Increased smoking in pregnancy ^e	0.7 (0.3, 1.5)	1.4 (0.7, 2.7)
Insufficient care^f	1.2 (1.1, 1.4)	0.9 (0.7, 1.0)

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3 Abbreviations: GWG= gestational weight gain; aOR= adjusted odds ratio; CI= confidence
4 interval; BMI= body mass index; cig/d= cigarettes per day; IOM= Institute of Medicine; GA=
5 gestational age

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7 ^aBased on 2009 IOM thresholds,¹ accounting for GA at delivery;^{38,39} considered insufficient
8 GWG if below recommendation, adequate if within recommendation, or excessive if above
9 recommendation

10 ^bEstimated using polytomous logistic regression models; adjusted on all covariates in table,
11 survey year, and mother's height

12 ^cBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese:
13 ≥30³⁷

14 ^dNo stable home (homeless or living in a hotel or caravan) and/or no salary nor
15 unemployment allowance

16 ^eNon-smoker, <10 cig/d; non-smoker, ≥10 cig/d; <10 cig/d, ≥10 cig/d

17 ^fLate pregnancy declaration (national health insurance not notified in first three completed
18 months and no nuchal translucency measurement in first trimester) or insufficient sonograms
19 (<2 if GA at delivery 24-33 weeks; <3 if GA at delivery 34 weeks or later) or prenatal visits (<3
20 if GA at delivery 24-27 weeks; <4 if GA at delivery 28-31 weeks; <5 if GA at delivery 32-35
21 weeks; <6 if GA at delivery 36 weeks or later), consistent with French guidelines for low risk
22 women

23 **BOLD:** statistically significant association (does not cross null)

Table 4. Association between maternal prepregnancy BMI^a and GWG and GWG adequacy,^b accounting for obesity classes I-III in adjusted regression models^c (French National Perinatal Survey 2010 and 2016)

	N	GWG (kg) mean (SD)	Adjusted difference in GWG (kg) diff (95% CI)	Insufficient GWG aOR ^b (95% CI)	Excessive GWG aOR ^b (95% CI)
Underweight	1960	13.9 (4.8)	0.0 (-0.3, 0.3)	1.4 (1.2, 1.5)	0.7 (0.6, 0.8)
Normal weight	15506	13.8 (4.8)	reference	reference	reference
Overweight	4545	12.2 (6.0)	-1.6 (-1.8, -1.4)	0.7 (0.6, 0.8)	2.8 (2.6, 3.1)
Obese class I	1802	9.8 (6.7)	-3.9 (-4.3, -3.6)	1.2 (1.0, 1.4)	3.8 (3.4, 4.3)
Obese class II	589	7.0 (7.7)	-6.7 (-7.3, -6.2)	1.9 (1.5, 2.4)	2.4 (2.0, 3.0)
Obese class III	234	3.6 (8.3)	-10.2 (-11.1, -9.3)	3.4 (2.4, 4.7)	1.3 (0.9, 2.0)

Abbreviations: BMI= body mass index; GWG= gestational weight gain; SD= standard deviation; aOR= adjusted odds ratio; CI= confidence interval; IOM= Institute of Medicine; GA= gestational age at delivery

^aBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese class I: 30-34.9; obese class II: 35-39.9; obese class III: ≥40³⁷

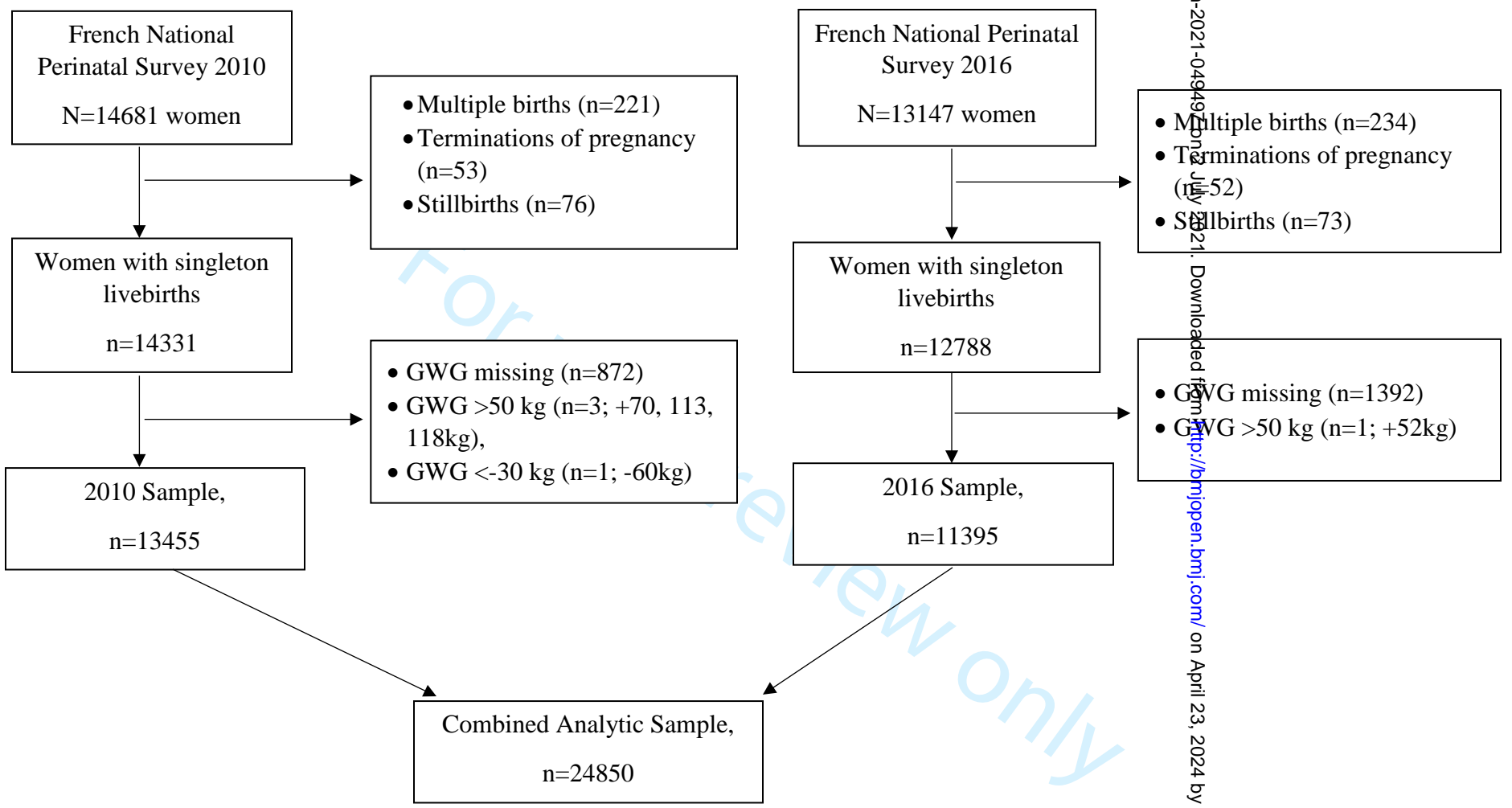
^bBased on 2009 IOM thresholds,¹ accounting for GA at delivery;^{38,39} considered insufficient GWG if below recommendation, adequate if within recommendation, or excessive if above recommendation

^cLinear regression used to estimated differences and polytomous logistic regression used to estimated aORs; adjustment variables: parity, maternal age, maternal country/region of birth, employment during pregnancy, education, social deprivation, smoking habits, insufficient care, survey year, mother's height (all models), and GA at delivery (linear models only)

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3 **Figure legends**
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5 Figure 1: Participant flow chart
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eTable 1. Nationally-representative estimates of GWG and GWG adequacy^a in France by survey year (French National Perinatal Survey 2010 and 2016; N=24850)

	2010					2016				
	N (%)	GWG (kg) mean (SD)	Insufficient GWG n (%)	Adequate GWG n (%)	Excessive GWG n (%)	N (%)	GWG (kg) mean (SD)	Insufficient GWG n (%)	Adequate GWG n (%)	Excessive GWG n (%)
Total	13455	13.2 (5.6)	3443 (25.9)	5006 (37.7)	4839 (36.4)	11395	12.7 (5.7)	3163 (28.0)	4100 (36.2)	4053 (35.8)
BMI^b										
Underweight	1110 (8.3)	14.0 (4.7)	415 (37.5)	454 (41.0)	239 (21.6)	850 (7.5)	13.7 (4.9)	347 (40.8)	331 (38.9)	172 (20.2)
Normal weight	8601 (64.7)	13.9 (4.8)	2394 (27.9)	3614 (42.1)	2583 (30.1)	6905 (60.9)	13.7 (4.9)	2079 (30.2)	2824 (41.0)	1991 (28.9)
Overweight	2289 (17.2)	12.4 (5.9)	310 (13.6)	662 (28.9)	1315 (57.5)	2256 (19.9)	12.0 (6.0)	377 (16.7)	641 (28.4)	1237 (54.9)
All obese	1303 (9.8)	8.9 (7.4)	324 (24.9)	276 (21.2)	702 (53.9)	1322 (11.7)	8.4 (7.3)	360 (27.3)	304 (23.1)	653 (49.6)
Obese class I	893 (6.7)	10.2 (6.7)	162 (18.2)	190 (21.3)	540 (60.5)	909 (8.0)	9.5 (6.7)	193 (21.3)	202 (22.3)	510 (56.4)
Obese class II	280 (2.1)	7.0 (8.0)	92 (32.9)	64 (22.9)	124 (44.3)	309 (2.7)	7.0 (7.4)	109 (35.4)	74 (24.0)	125 (40.6)
Obese class III	130 (1.0)	4.2 (8.1)	70 (53.8)	22 (16.9)	38 (29.2)	104 (0.9)	2.8 (8.6)	58 (55.8)	28 (26.9)	18 (17.3)

Abbreviations: GWG= gestational weight gain; BMI= body mass index; SD= standard deviation; IOM= Institute of Medicine

^aBased on 2009 IOM thresholds,¹ accounting for gestational age at delivery;^{2,3} considered insufficient GWG if below recommendation, adequate if within recommendation, or excessive if above recommendation

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])⁴

eTable 2: Characteristics of the study population, in comparison to those of women excluded for missing or implausible GWG (French National Perinatal Survey 2010 and 2016)

	Included (N=24850) n (%)	Excluded (N=2269) n (%)
BMI^a		
Underweight	1960 (8.0)	7 (4.2)
Normal weight	15506 (62.9)	92 (55.1)
Overweight	4545 (18.4)	33 (19.8)
All obese	2625 (10.7)	35 (21.0)
Obese class I	1802 (7.3)	25 (15.0)
Obese class II	589 (2.4)	7 (4.2)
Obese class III	234 (0.9)	3 (1.8)
Parity		
Multiparous	14061 (56.7)	1100 (63.5)
Primiparous	10722 (43.3)	632 (36.5)
Age		
<25 years	3716 (15.0)	370 (22.0)
25-29 years	8126 (32.7)	482 (28.6)
30-34 years	8079 (32.5)	476 (28.3)
≥35 years	4918 (19.8)	356 (21.1)
Country or region of birth		
France	20398 (82.2)	280 (53.6)
Europe	957 (3.9)	47 (9.0)
Northern Africa	1720 (6.9)	63 (12.1)
Sub-Saharan Africa	1024 (4.1)	101 (19.3)
Other	719 (2.9)	31 (5.9)
Employment during pregnancy		
None	7089 (28.7)	404 (60.3)
Stopped working during pregnancy		
Before 14+0 wks gestation	1595 (6.5)	20 (3.0)
14+0 to 27+6 wks gestation	6701 (27.1)	58 (8.7)
28+0 to 31+6 wks gestation	4243 (17.2)	24 (3.6)
Unknown stop point	317 (1.3)	124 (18.5)
Continued working to ≥32 wks gestation	4743 (19.2)	40 (6.0)
Education		
Less than high school	2158 (8.7)	217 (37.0)
High school	9157 (37.1)	226 (38.5)
1-2 years post-graduation	5086 (20.6)	67 (11.4)
3-4 years post-graduation	4466 (18.1)	50 (8.5)
≥5 years post-graduation	3798 (15.4)	27 (4.6)
Social deprivation^b		
No	20424 (82.2)	304 (60.9)
Yes	4414 (17.8)	195 (39.1)
Smoking habits before, during pregnancy		
Non smoker	17216 (69.9)	297 (72.1)
Decreased smoking in pregnancy		
<10 cig/d, stopped	1855 (7.5)	18 (4.4)
≥10 cig/d, stopped	1402 (5.7)	17 (4.1)
≥10 cig/d, <10 cig/d	2185 (8.9)	21 (5.1)
Maintained smoking level in pregnancy		
<10 cig/d, <10 cig/d	845 (3.4)	32 (7.8)
≥10 cig/d, ≥10 cig/d	1081 (4.4)	26 (6.3)
Increased smoking in pregnancy ^c	47 (0.2)	1 (0.2)
Insufficient care^d		
No	23515 (94.7)	673 (83.3)
Yes	1328 (5.3)	135 (16.7)
Diabetes		
No	22414 (91.5)	1490 (89.4)
Yes, diet controlled	633 (2.6)	42 (2.5)
Yes, insulin controlled	1458 (5.9)	134 (8.0)
Preexisting hypertension		
No	24229 (98.0)	1656 (97.5)
Yes	504 (2.0)	42 (2.5)

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3 Abbreviations: GWG= gestational weight gain; BMI= body mass index; cig/d= cigarettes per
4 day; GA= gestational age

5^aBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese:
6 ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])⁴

7^bNo stable home (homeless or living in a hotel or caravan) and/or no salary nor
8 unemployment allowance

9^cNon-smoker, <10 cig/d; non-smoker, ≥10 cig/d; <10 cig/d, ≥10 cig/d

10^dLate pregnancy declaration (national health insurance not notified in first three completed
11 months and no nuchal translucency measurement in first trimester) or insufficient
12 sonograms (<2 if GA at delivery 24-33 weeks; <3 if GA at delivery 34 weeks or later) or
13 prenatal visits (<3 if GA at delivery 24-27 weeks; <4 if GA at delivery 28-31 weeks; <5 if GA at
14 delivery 32-35 weeks; <6 if GA at delivery 36 weeks or later), consistent with French
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3. Liu J, Gallagher AE, Carta CM, Torres ME, Moran R, Wilcox S. Racial differences in gestational weight gain and pregnancy-related hypertension. *Annals of Epidemiology*. 2014;24(6):441-447.
4. World Health Organization. Global database on body mass index: BMI classification. 2006. <https://www.who.int/nutrition/databases/bmi/en/>. Updated 2017.

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*
Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-6
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	5-6
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-9
Bias	9	Describe any efforts to address potential sources of bias	6-7; 9-10
Study size	10	Explain how the study size was arrived at	5-6; Fig 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8-10
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	9-10
		(b) Describe any methods used to examine subgroups and interactions	n/a
		(c) Explain how missing data were addressed	10
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed	n/a

		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	
		€ Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage © Consider use of a flow diagram	5-6 n/a Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest © <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	10-11; Table 1-2; eTable 1 10 n/a
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time <i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure <i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	n/a n/a 10-11; Table 1-2; eTable 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-12; Tables 2-3 Tables 2-3 n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12; Table 4
Discussion			
Key results	18	Summarise key results with reference to study objectives	12-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16-17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-17
Generalisability	21	Discuss the generalisability (external validity) of the study results	13-14
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

1
2 **Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE
3 checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at
4 <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.
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Maternal characteristics associated with gestational weight gain in France: a population-based, nationally representative study

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Complete List of Authors:	Amyx, Melissa; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris Zeitlin, Jennifer; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris Hermann, Monika; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris Castetbon, Katia; ULB École de Santé Publique, Centre de Recherche en Epidémiologie, Biostatistique et Recherche Clinique Blondel, Béatrice; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris Le Ray, Camille; INSERM UMR 1153, Obstetrical, Perinatal and Pediatric Epidemiology Research Team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité (CRESS), Université de Paris; APHP, Hôpital Cochin Port Royal, Port Royal Maternity, Department of Obstetrics, Université de Paris
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3 Maternal characteristics associated with gestational weight gain in France: a population-
4 based, nationally representative study
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10 Melissa Amyx;¹ Jennifer Zeitlin;¹ Monika Hermann;¹ Katia Castetbon;² Béatrice Blondel;¹

11
12 Camille Le Ray^{1,3}
13
14
15
16

17 Author affiliations

18
19
20 1. Université de Paris, CRESS, Obstetrical Perinatal and Pediatric Epidemiology Research

21
22 Team, EPOPé, INSERM, INRA, F-75004 Paris, France
23
24

25 2. Université libre de Bruxelles, Ecole de Santé Publique, Centre de Recherche en

26
27 Epidémiologie, Biostatistique et Recherche Clinique, Bruxelles, Belgique.
28
29

30 3. Hôpital Cochin Port Royal, Port Royal Maternity, Department of Obstetrics, Cochin Port

31
32 Royal Hospital, Assistance Publique-Hôpitaux de Paris, Université de Paris, Paris, France
33
34
35
36

37 Correspondence to: Melissa Amyx, PhD, MPH, e-mail: melissa.amyx@inserm.fr

38
39 Address: INSERM U1153

40
41 53 Avenue de l'Observatoire

42
43 75014 Paris

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Abstract

Objectives: To provide nationally-representative estimates of gestational weight gain (GWG) and identify maternal characteristics associated with inadequate GWG in France.

Design: A population-based study using data from the French National Perinatal Survey: 2010 and 2016

Setting: all maternity units in metropolitan, mainland France (n=535 in 2010; n=493 in 2016)

Participants: singleton live-births with GWG data (N=24,850)

Primary outcome measures: GWG was calculated as end of pregnancy minus prepregnancy weight (kg) and categorized as “insufficient”, “adequate”, or “excessive” using 2009 Institute of Medicine thresholds. Classification accounted for prepregnancy body mass index (kg/m²; underweight [<18.5], normal weight [$18.5-24.9$], overweight [$25-29.9$], obese [≥ 30]) and gestational age at birth. We estimated average GWG and the percentage of women in each GWG category. Polytomous logistic regression identified characteristics associated with GWG adequacy.

Results: Average GWG was 13.0kg (standard deviation 5.6), with 26.8% of women gaining insufficiently, 37.0% adequately, and 36.1% excessively. Among other factors, insufficient GWG was associated with underweight (versus normal weight; adjusted OR [aOR] 1.4, 95%CI 1.2, 1.5) and obese (aOR 1.5, 95%CI 1.4, 1.7) BMI. Excessive GWG was associated with overweight (aOR 2.8, 95%CI 2.6, 3.1) and obese BMI (aOR 3.3, 95%CI 2.9, 3.6). Examining obesity classes separately, odds of insufficient GWG increased from obesity class I to III, while odds of excessive GWG decreased from obesity class I to III. Primiparity (insufficient: aOR 0.9, 95% CI 0.9, 1.0; excessive: aOR 1.2, 95% CI 1.2, 1.3), maternal characteristics indicative of lower socioeconomic status, and continuing or quitting smoking during pregnancy were also associated with inadequate GWG.

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3 Conclusions: In France, insufficient and excessive GWG are common. For optimal outcomes,
4
5 clinician education, with special attention to the needs of higher risk/vulnerable groups, is
6
7
8 needed to ensure all women receive appropriate advice for recommended GWG.
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10

11 12 13 Strengths and limitations of this study

- 14
15 • This is the first nationally representative study of risk factors for gestational weight
16
17 gain (GWG) in France
- 18
19 • The French National Perinatal Survey includes all maternity units in metropolitan,
20
21 mainland France
- 22
23 • Specially trained study midwives collected extensive, rigorous data through
24
25 maternal interview and chart abstraction
- 26
27 • The definition of GWG adequacy incorporated length of gestation, limiting
28
29 potential bias due to the correlation between GWG and length of gestation
- 30
31 • Some data (including prepregnancy BMI and GWG) was self-reported and collected
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33 retrospectively, which could result in measurement error
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Introduction

Due to demographic and lifestyle changes, women are entering pregnancy with a higher body mass index (BMI) and gaining excessive pregnancy weight.¹⁻⁴ These trends are concerning as both healthy BMI^{1,5} and adequate gestational weight gain (GWG) are important for optimal fetal growth and pregnancy/birth outcomes. Specifically, excessive GWG is associated with cesarean birth,^{6,7} postpartum weight retention/obesity,^{8,9} increased infant size,^{7,10} and childhood overweight/obesity.^{11,12} Conversely, insufficient GWG is associated with decreased infant size^{7,10,13} and preterm birth.⁷ In 2009, the United States' Institute of Medicine (IOM; now National Academy of Medicine), updated GWG guidelines, stratified by maternal prepregnancy BMI, to improve care for the contemporary obstetric population.¹ While the current IOM guidelines provide a single recommendation for GWG for all women with obese prepregnancy BMI, whether separate guidelines are needed by obesity class is unclear due to insufficient evidence. Further, the American College of Obstetricians and Gynecologists determined that evidence is lacking to recommend that women with obese BMI with GWG below the IOM recommendations but with an appropriately growing fetus should be encouraged to increase their GWG.¹⁴ Because GWG is modifiable and pregnant women interact frequently with healthcare providers, identification of factors associated with total GWG and inadequate GWG (insufficient or excessive) is necessary to target context-specific recommendations for GWG interventions/counselling. In addition to maternal prepregnancy BMI, numerous maternal factors, including socio-demographic characteristics, are potentially associated with GWG.^{8,15-27} However, evidence gaps exist, as most studies of GWG risk factors were conducted in the United States^{8,16,17,20,22,24,25} and many had a relatively small sample sizes (N<1,000),^{19,22,23,26,27} used GWG guidelines^{8,16,17,19,22} or data collected prior to the 2009 IOM

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3 guidelines,^{15,18,25} or focused narrowly on specific risk factors.²²⁻²⁶ Therefore, additional
4
5 research on risk factors related to GWG is needed in large, contemporary, diverse
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7 populations, specifically in nationally-representative populations outside of the United
8
9 States.

10
11
12 In France, both maternal prepregnancy BMI and the prevalence of inadequate GWG are
13
14 increasing.^{3,28,29} While previous French GWG studies evaluated adverse outcomes of
15
16 GWG^{12,30-32} or reported overviews of the main pregnancy indicators,^{28,29} no study has
17
18 comprehensively assessed GWG risk factors in France. Compared to the United States
19
20 (where most previous studies on the association between risk factors for GWG were
21
22 conducted), the French obstetric population differs on key factors related to weight and
23
24 GWG (e.g., lower BMI^{28,33} and higher rates of smoking^{28,34} in the French obstetric population)
25
26 and benefits from the world's highest performing healthcare system based on a WHO study
27
28 of overall efficiency.³⁵ Thus, the risk factors previously identified may not be relevant in
29
30 France. To build upon prior evidence within a more contemporary, robust, nationally-
31
32 representative cohort in a unique location and thereby inform local medical professionals
33
34 providing care to pregnant women and international researchers evaluating consistency of
35
36 risk factors across different cultural and organizational settings, our objectives were to
37
38 provide population-based estimates of average GWG and the percentage of women
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40 achieving insufficient, adequate, or excessive GWG and identify maternal characteristics and
41
42 social factors associated with mean GWG and insufficient and excessive GWG in France.
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51 Methods

52 *Study design and population*

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54 We combined data from the 2010²⁹ and 2016²⁸ French National Perinatal Surveys (NPSs),
55
56 which are routine, nationally-representative surveys including all live and stillbirths in all
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3 maternity units in metropolitan, mainland France (n=535 in 2010; n=493 in 2016). In each
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5 survey, data were collected during 1 week. Data collection, performed by trained study
6
7 midwives, included a face-to-face interview of women prior to hospital discharge (2-3 days
8
9 following birth) using a standardized questionnaire to obtain information related to
10
11 sociodemographic characteristics and antenatal care and chart abstraction to obtain
12
13 information on maternal and neonatal health and delivery.
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16
17 After combining data from both years, the survey sample included 27,828 women (n=14,681
18
19 in 2010; n=13,147 in 2016). We excluded multiple births (n=221 in 2010; n=234 in 2016),
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21 pregnancy terminations (n=53 in 2010; n=52 in 2016) and stillbirths (n=76 in 2010; n=73 in
22
23 2016), which may have distinct GWG patterns. We also excluded women with missing
24
25 (n=872 in 2010; n=1392 in 2016) or implausible GWG, defined as gain >50kg or loss >30kg^{9,36}
26
27 (n=4 in 2010; n=1 in 2016). Based on missing/implausible GWG, <10% of women with
28
29 singleton livebirths in the NPS were excluded. Our final analysis included 24,850 women
30
31 (n=13,455 in 2010; n=11,395 in 2016; Figure 1).
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37 *GWG variables*

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39 *Observed GWG* (kg) was calculated based on women's self-reported end of pregnancy minus
40
41 prepregnancy weight. Then, *GWG adequacy* (insufficient, adequate, excessive) was
42
43 determined by maternal prepregnancy BMI (kg/m²; using self-reported height and
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45 prepregnancy weight; underweight [<18.5], normal weight [18.5-24.9], overweight [25-29.9],
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47 obese [≥ 30])³⁷ and was standardized across gestational ages using a previously described
48
49 method^{38,39} based on the assumptions underlying the 2009 GWG IOM guidelines, as detailed
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51 in Table 1.
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55
56 French guidelines for GWG (2007 French National Nutrition and Health Program [Programme
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58 National Nutrition et Santé])⁴⁰ differ from IOM guidelines, recommending GWG of 12kg for
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3 women with normal prepregnancy BMI, lower GWG (not under 7kg) for women with
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5 overweight or obese prepregnancy BMI, and higher GWG for women with underweight
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7 prepregnancy BMI. However, as French guidelines do not provide upper and lower ranges
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9 and IOM guidelines establish clear categories of GWG adequacy, are routinely used in clinical
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11 practice and research in other countries, and are better known by French clinicians and
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13 therefore likely more widely utilized in clinical practice, we used the IOM guidelines in our
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15 analysis.
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20 *Covariates*

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22 Maternal characteristics collected by interview prior to hospital discharge utilized are:
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24 prepregnancy BMI (defined above; obesity further categorized as obese class I [BMI 30-34.9],
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26 II [BMI 35-39.9], and III [BMI \geq 40]),³⁷ parity (primiparous, multiparous), and age (<25, 25-29,
27
28 30-34, \geq 35 years). Maternal social characteristics included: country/region of birth (France,
29
30 Europe, Northern Africa, Sub-Saharan Africa, other), employment and timing of maternity
31
32 leave during pregnancy (none; stopped working before 14+0, 28+0, 32+0, at/after 32+0
33
34 weeks gestation, or at an unknown time point), and education (<high school; high school
35
36 completed; 1-2, 3-4, or 5/more years post-graduation). Smoking was evaluated based on
37
38 smoking prior to pregnancy versus in the 3rd trimester (for each time point: non-
39
40 smoker/stopped smoking, <10 cigarettes per day [cig/d], \geq 10cig/d), categorized as: non-
41
42 smoker at both time points; <10cig/d, stopped; \geq 10cig/d, stopped; \geq 10cig/d, reduced to
43
44 <10cig/d; <10cig/d, maintained at <10cig/d; \geq 10cig/d, maintained at \geq 10cig/d; increased
45
46 smoking [combined groups of: non-smoker, increased to <10cig/d; non-smoker, increased to
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48 \geq 10cig/d; <10cig/d, increased to \geq 10cig/d). Social deprivation was based on an index derived
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50 within the 2010 NPS based on: receipt of social benefits (household receiving Revenu de
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52 Solidarité Active allowance; woman receiving Couverture Maladie Universelle, French social
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3 security, or not insured), not living in her own accommodation, or not living with a partner.⁴¹

4
5 Insufficient prenatal care was defined as late pregnancy declaration (national health
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7 insurance not notified in first three completed months and no nuchal translucency
8
9 measurement in first trimester) or insufficient sonograms (<2 if GA at birth 24-33 weeks; <3
10
11 if GA at birth 34 weeks or later) or prenatal visits (<3 if GA at birth 24-27 weeks; <4 if GA at
12
13 birth 28-31 weeks; <5 if GA at birth 32-35 weeks; <6 if GA at birth 36 weeks or later),
14
15 consistent with French guidelines for low risk women.⁴² Prepregnancy conditions/pregnancy
16
17 complications, obtained from chart abstraction and used for descriptive purposes, included
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19 diabetes in pregnancy (no; diet controlled; insulin controlled) and preexisting hypertension.
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22 23 24 25 *Statistical analysis*

26
27 To describe the GWG profile of our cohort, for both survey years combined and individually,
28
29 mean GWG (with standard deviations [SD]) and prevalence of insufficient, adequate, and
30
31 excessive GWG were reported, overall and by BMI category. The characteristics of included
32
33 women and women excluded for missing GWG were determined and compared.
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35

36
37 Next, the associations between maternal characteristics and GWG and GWG adequacy were
38
39 evaluated. First, unadjusted linear regression models were used to estimate mean GWG (SD)
40
41 within levels of maternal characteristics. Then, adjusted linear regression models were used
42
43 to estimate adjusted mean differences in GWG (and 95% confidence intervals [CIs])
44
45 between categories of maternal characteristics, with a mean GWG difference of >1kg
46
47 considered clinically significant. Similarly, adjusted polytomous logistic regression models
48
49 were used to examine the association between maternal characteristics and GWG adequacy
50
51 (adjusted odds ratio [aOR], 95% CI calculated). Based on covariates previously associated
52
53 with GWG, adjusted regression models adjusted for all maternal characteristics listed
54
55 previously as covariates (BMI obesity classes combined), as well as maternal height (meters),
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3 GA at birth (days; linear models only, as GA at birth accounted for in definition of GWG
4
5 adequacy), and survey year. The prepregnancy conditions/pregnancy complications
6
7 (diabetes in pregnancy; preexisting hypertension) reported in the initial descriptive analysis
8
9 were not included in the adjusted models because they may be mediators of the association
10
11 between maternal characteristics and GWG (our primary interest) and could introduce bias if
12
13 included in the models. To determine whether the associations between obesity classes and
14
15 GWG and GWG adequacy differed, the adjusted analysis was repeated but with BMI
16
17 included in the models as a 6-level variable (underweight, normal weight, overweight, obese
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19 class I, II, and III).

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Though GWG differed between survey years, patterns of associations between GWG and
maternal characteristics were similar regardless of survey year (data not shown) and we did
not make inferences or conclusions about changes in GWG over time. Thus, for analyses of
associations between maternal characteristics and GWG, data from the 2010 and 2016
surveys were combined and survey year was included in the models as a covariate rather
than stratification variable. Due to the small amounts of missing data for covariates in the
analytic sample (<5% of women missing data for any covariate included in the multivariable
analyses), multiple imputation was not conducted. Covariates with the highest percentages
of missing data were: maternal prepregnancy BMI (1%), employment during pregnancy (1%),
education (1%), smoking status (1%), and diabetes (1%; not included in multivariable
models).

We used SAS software version 9.4 for Windows (SAS Institute Inc., Cary, NC) for statistical
analyses.

Patient and public involvement

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3 A network representing French user associations on questions related to
4
5 pregnancy, childbirth and infancy were involved in the development of the questions on
6
7 pregnancy and birth in the NPS and a website is maintained to disseminate results to
8
9 participants and the wider public. However, there was no patient or public engagement for
10
11 this research study.
12
13

14 Results

15
16 In our nationally-representative sample of French women, women's average GWG was
17
18 13.0kg (SD 5.6; Table 2), decreasing from 13.2kg (SD 5.6) in 2010 to 12.7kg (SD 5.7) in 2016
19
20 (eTable 1). GWG decreased with increasing BMI, including across obesity classes. Only 37.0%
21
22 of women attained adequate GWG, decreasing slightly from 37.7% in 2010 to 36.2% in 2016.
23
24 Excessive GWG was more common among women with overweight and obese BMI, while
25
26 insufficient GWG was more common among women with underweight BMI. However, when
27
28 examining obesity classes separately, excessive GWG decreased from obese class I to III,
29
30 while insufficient GWG increased from obese class I to III.
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32

33
34 In our cohort (Table 3), almost 20% of women were born outside of France, a majority were
35
36 normal weight BMI entering pregnancy, 30% smoked either before or during pregnancy,
37
38 2.0% had preexisting hypertension, and 8.5% had diabetes in pregnancy. Compared to
39
40 women excluded due to missing or implausible GWG, women included in our analytic
41
42 sample were more likely to be primiparous, have a lower prepregnancy BMI, have modified
43
44 their smoking habits during pregnancy, and have characteristics indicative of higher socio-
45
46 economic status (eTable 2).
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54 In unadjusted analysis, clinically significant differences (>1kg) in mean GWG were found for
55
56 all maternal characteristics except maternal age and social deprivation (Table 3), with higher
57
58 GWG associated with characteristics indicative of higher socioeconomic status (maternal
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3 birth in France or Europe, higher education level, sufficient care) and reduced smoking in
4
5 pregnancy. For pregnancy complications, mean GWG was lower among women with
6
7 diabetes during pregnancy (11.1kg, SD 6.5 among women with insulin controlled and 10.2kg,
8
9 SD 7.0 among women with diet controlled diabetes to 13.2kg, SD 5.5 among women without
10
11 diabetes during pregnancy) or preexisting hypertension (11.7kg, SD 7.3 to 13.0kg, SD 5.6
12
13 among women without preexisting hypertension). In adjusted models, clinically significant
14
15 differences in mean GWG persisted for maternal prepregnancy BMI, employment in
16
17 pregnancy, and smoking habits only.

18
19 In polytomous logistic regression models (Table 4), underweight and obese BMI were
20
21 positively associated with insufficient GWG. Additional characteristics positively associated
22
23 with insufficient GWG included birth in sub-Saharan Africa, not being employed in
24
25 pregnancy, less than high school education, and insufficient prenatal care. Conversely,
26
27 overweight BMI, stopping smoking, and primiparity were inversely associated with
28
29 insufficient GWG.

30
31 Overweight and obese prepregnancy BMI were positively associated with excessive GWG.
32
33 Additional characteristics positively associated with excessive GWG included primiparity, not
34
35 working or stopping work before 28 weeks gestation, lower education level, and reduced or
36
37 continued smoking. Conversely, underweight prepregnancy BMI was inversely associated
38
39 with excessive GWG.

40
41 When adjusted analyses were repeated to evaluate obesity classes I-III separately (Table 5),
42
43 the trend of greater decreases in GWG compared to women with normal weight BMI
44
45 persisted. Similarly, the odds of insufficient GWG increased across obesity classes, but the
46
47 odds of excessive GWG decreased.

48
49 Discussion
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3 In France in 2010 and 2016, the majority of women did not achieve recommended GWG
4 based on the 2009 IOM guidelines. Inadequate GWG was associated with underweight,
5
6 overweight, or obese prepregnancy BMI, smoking in pregnancy, primiparity, and lower
7
8 socioeconomic status. Differences in the prevalence of insufficient and excessive GWG were
9
10 also noted by obesity class.
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15 Though the majority of women in our study had inadequate GWG, our results (26.8%
16
17 insufficient, 36.1% excessive GWG) were similar to those found in recent multi-national
18
19 meta-analyses (LifeCycle [Europe, North America]: 21.5% insufficient, 42.0% excessive;⁴³
20
21 Goldstein et al. [Europe, United States, and Asia]: 23% insufficient, 47% excessive⁷).
22
23

24
25 Examining GWG by BMI class, our findings (inverse relationship between prepregnancy BMI
26
27 and mean GWG^{1,43-47}; positive association between insufficient GWG and underweight or
28
29 obese BMI; positive association between excessive GWG and overweight or obese
30
31 BMI^{15,16,20,36,48-50}) were generally consistent with previous studies. Though inadequate GWG
32
33 is more common among women with underweight, overweight, or obese BMI, clinicians
34
35 providing prenatal care should counsel all women regarding appropriate GWG for their
36
37 prepregnancy BMI. Given the higher risk profile for adverse outcomes and the particular
38
39 challenges to limit GWG for women entering pregnancy at higher BMI, providing information
40
41 related to nutrition and physical activity for this group is particularly important.¹
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47 Additionally, as a recent systematic review found that midwives and obstetricians had
48
49 insufficient knowledge of the IOM recommendations,⁵¹ educating clinicians on guidelines is
50
51 also vital to ensure evidence-based prenatal counselling for appropriate GWG.
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54
55 The average GWG (13.8kg, SD 4.8) of women with normal weight BMI in our cohort
56
57 exceeded the current French guidelines and mean GWG (with lower,³⁰ higher¹², and similar
58
59 estimates³¹) and GWG adequacy (i.e., insufficient, adequate, or excessive GWG; with varying
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3 results depending on BMI category)^{12,30,32} in the French population differed between
4
5 studies. The differences between the French study results may be attributed to differences
6
7 in study design (retrospective versus prospective; nationally-representative versus
8
9 limited/local hospital-based), location, GWG classification method (accounting for GA at
10
11 birth or not), and inclusion/exclusion criteria (women with pre-existing conditions
12
13 excluded or not). While our study is the first in France to provide nationally-
14
15 representative estimates of GWG and GWG adequacy, additional research within
16
17 nationally-representative samples of the French population is necessary to define adequate
18
19 GWG in relation to adverse outcomes and clarify national guidelines.
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25 Due to the lack of evidence to determine whether separate guidelines may be necessary in
26
27 women with obese prepregnancy BMI,¹⁴ we extended our analyses to compare mean GWG
28
29 and GWG adequacy between obesity classes. Our results are consistent with previous
30
31 studies conducted in Europe, North America, and Reunion Island, finding insufficient GWG
32
33 increased and excessive GWG decreased from obesity class I to III^{20,52,53} and supporting
34
35 evidence that lower GWG guidelines may be appropriate for higher obesity.^{43,52,54,55} Future
36
37 research should address uncertainties regarding GWG guidelines for different obesity
38
39 classes.
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45 In line with previous research conducted in North America, Brazil, and Australia, New
46
47 Zealand, and Ireland, we also found increased absolute GWG^{22,23,56} and increased excessive
48
49 GWG^{15,20,22,56} among women who quit smoking in pregnancy, likely due to physiologic
50
51 changes to the metabolism and central nervous system resulting in increased appetite and
52
53 the behavioral substitution of cigarettes with consumption of sugary foods.⁵⁷ Given the
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55 obvious benefits of quitting smoking before or during pregnancy due to the adverse effects
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57 of smoking (e.g., reduced fetal growth and birth size),^{58,59} smokers should be encouraged to
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3 reduce/stop smoking during pregnancy, be provided additional nutritional and psychological
4 support to avoid adverse effects of excessive GWG, and be educated on the use of nicotine
5 replacement therapies (e.g., nicotine patches).
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10 Finally, we found that a number of maternal and social characteristics were associated with
11 inadequate GWG, though consistency with prior literature was mixed. While we found
12 increased GWG in primiparas compared to multiparas, a recent multi-national systematic
13 review concluded that the evidence is inconsistent and that the role of parity on GWG is
14 likely indirect and complex.⁶⁰ Overall, our results suggest that French women of lower
15 socioeconomic status are more likely to have inadequate GWG, though the evidence for
16 these factors is inconsistent. In contrast to our results, studies from Australia, New Zealand,
17 Ireland, Brazil, and the United States have found increased excessive GWG with younger
18 maternal age.^{15,19,49,50} Results for education have been mixed, with some previous studies
19 from North American and Australia also finding lower education was associated with
20 insufficient^{5,17,50}/low⁸ or excessive weight gain^{5,17,49} but others from the United States and
21 The Netherlands finding that the associations between education and GWG differed by
22 maternal BMI^{20,25} or no differences.¹⁸ Conflicting results have also been found related to
23 immigration, with some previous research reporting higher GWG and increased excessive
24 GWG in foreign nationals in Ireland²⁷ or recent immigrants in Australia, New Zealand, and
25 Ireland¹⁵ but others finding insufficient GWG increased among foreign-born women in the
26 United States¹⁶ or excessive GWG decreased among women of non-European ancestry living
27 in The Netherlands,¹⁸ similar to our finding of increased insufficient GWG among women
28 born in sub-Saharan Africa. In contrast, insufficient prenatal care was associated with
29 insufficient GWG consistently across studies in the United States and Romania,^{16,21,24} in line
30 with our results. Given the disparate results across study settings, a deeper understanding of
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3 the underlying cultural context and social conditions is important to develop specific
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5 strategies to improve care for vulnerable populations and ensure all women, in particular
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7 those of lower socioeconomic status, can achieve a nutritionally adequate diet.
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10 With its comprehensive analysis of factors contributing to GWG within a large,
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12 contemporary, nationally-representative French cohort, our study builds upon prior
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14 literature. As previous French GWG studies investigated different research
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16 questions,^{12,30-32} we provide evidence of risk factors in a unique setting which could
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18 inform interventions locally and future research related to mechanisms underlying the
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20 observed associations. Additional strengths of our study include the extensive, rigorous
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22 data obtained in the NPSs by specially trained study personnel, which previous studies
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24 have confirmed are nationally representative based on comparisons of selected perinatal
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26 indicators (e.g., maternal age, GA) available from birth certificate and hospital discharge
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28 statistics in the corresponding years.^{28,29} By accounting for GA at birth in our definition of
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30 GWG adequacy and controlling for GA at birth in linear models of GWG, we limited
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32 potential biases due to the inherent correlation between GWG and length of
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34 gestation.^{61,62} Additionally, our population included few preterm births (5.3%) and
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36 preliminary sensitivity analyses of term pregnancies within our cohort were consistent with
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38 our main analyses (data not reported), providing further evidence that biases due to GA at
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40 birth were minimized. Additional methodological strengths are the large sample size and
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42 low level of missing data (<5% in multivariable analyses).
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51 Our study has some limitations. Measurement error is possible as some data was self-
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53 reported and collected retrospectively. Specifically, self-reported prepregnancy weight and
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55 maternal weight at birth may be biased due to underestimation.⁶³ However, because
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57 reporting of weight gain during pregnancy in medical records is not standardized across
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3 France, the NPSs obtain this information through maternal self-report in order to have
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5 consistently collected and more complete data. While the resulting bias due to
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7 misclassification in measuring associations between GWG and adverse outcomes may be
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9 minimal, the impact of misclassification in examining risk factors for weight outcomes
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11 has not been evaluated.⁶³ Only total GWG, not longitudinal GWG, was collected, reducing
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13 precision⁶⁴ and not allowing us to examine variations in GWG trajectory across pregnancy or
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15 timing of GWG. GWG data in the NPSs used for our analysis was available for more than 90%
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17 of women and less than 5% of included women had missing data for covariates in our
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19 analysis. However, because differences were noted between included and excluded women,
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21 with excluded women being more likely to have characteristics indicative of lower
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23 socioeconomic status, we may have underestimated the association between these
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25 characteristics and GWG.
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32 Conclusions

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34 In France, a minority of women achieves the IOM recommended GWG. Maternal
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36 prepregnancy BMI, continuing or quitting smoking in pregnancy, and lower socioeconomic
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38 status were associated with not achieving GWG recommendations. To promote adequate
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40 GWG and optimize pregnancy outcomes, clinicians should be trained to ensure all pregnant
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42 women receive evidence-based advice related to GWG and to provide additional support
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44 tailored to the specific needs of at-risk groups. Given the uncertainties regarding the current
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46 IOM GWG recommendations, additional research within nationally-representative samples
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48 outside the United States and within BMI obesity classes is needed.
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7
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9 acquisition of the French National Perinatal Surveys. MH designed and MA, CLR, and JZ
10 finalized the concept of the current study. MA conducted data analysis, interpreted the
11 results, and developed the draft manuscript under the supervision of CLR and JZ and with
12 input from BB, KC, and MH. All authors critically reviewed and approved the final
13 manuscript.
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24
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For peer review only

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3 Supplementary materials
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6 eTable 1. Nationally-representative estimates of GWG and GWG adequacy^a in France by
7 survey year (French National Perinatal Survey 2010 and 2016; N=24850)
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10 eTable 2: Characteristics of the study population, in comparison to those of women excluded
11 for missing or implausible GWG (French National Perinatal Survey 2010 and 2016)
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16 Footnotes
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18 Patient consent for publication: Not required
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21 Ethics approval: Each survey cycle was approved by the National Council on Statistical
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23 on Information Technology and Liberties ([CNIL]; 2016 registration number 915197), and the
24 Inserm ethics committee (2016 approval IRB00003888 no. 14-191).
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Table 1: GWG adequacy determination using a previously described method based on IOM guidelines which incorporates gestational age at delivery^a

BMI ^b	IOM recommendations/assumptions for GWG at 40 weeks gestation			Conversion to proportions of GWG achieved	
	1 st trimester GWG (kg)	Rate of GWG (kg/week)	Recommended range (kg)	Expected GWG at 40 weeks	Recommended range of proportion of GWG
Underweight (<18.5)	2	0.51	12.5-18	15.77	0.79-1.14
Normal weight (18.5-24.9)	2	0.42	11.5-16	13.34	0.86-1.20
Overweight (25-29.9)	1	0.28	7.0-11.5	8.56	0.81-1.34
Obese (≥30)	0.5	0.22	5.0-9.0	6.44	0.78-1.41

Abbreviations: GWG= gestational weight gain; BMI= body mass index; IOM= Institute of Medicine

^aSteps to determine GWG adequacy:

1. *Expected GWG* at 40 weeks computed: Recommended first trimester gain + [(GA at birth – 13)*Recommended rate of GWG]
Example: Normal weight BMI: *Expected GWG*=13.34kg = (2+[40-13]*0.42)
2. Recommended ranges of total GWG for each BMI group converted to *ranges of proportions*: lower and upper bounds of the IOM recommended range divided by the *expected GWG* at 40 weeks
Example: Normal weight BMI: 0.86-1.20 (11.5/13.34; 16/13.34)
3. For each woman, her *individual proportion of recommended GWG* achieved determined: *observed GWG* divided by her *expected GWG* (using formula from step 1)
4. *Individual proportion of recommended GWG* achieved compared to *ranges of proportions* for her BMI group
GWG adequacy classified as:
 - *Insufficient*: below lower bound
 - *Adequate*: within recommended range
 - *Excessive*: above upper bound

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30

Table 2. Nationally-representative estimates of GWG and GWG adequacy^a in France (French National Perinatal Survey 2010 and 2016; N=24850)

	n (%)	GWG (kg) mean (SD)	Insufficient GWG n (%)	Adequate GWG n (%)	Excessive GWG n (%)
Overall	24850	13.0 (5.6)	6606 (26.8)	9106 (37.0)	8892 (36.1)
BMI^b					
Underweight	1960 (8.0)	13.9 (4.8)	762 (38.9)	785 (40.1)	411 (21.0)
Normal weight	15506 (62.9)	13.8 (4.8)	4473 (28.9)	6438 (41.6)	4574 (29.5)
Overweight	4545 (18.4)	12.2 (6.0)	687 (15.1)	1303 (28.7)	2552 (56.2)
All obese	2625 (10.7)	8.6 (7.4)	684 (26.1)	580 (22.1)	1355 (51.7)
Obese class I	1802 (7.3)	9.8 (6.7)	355 (19.8)	392 (21.8)	1050 (58.4)
Obese class II	589 (2.4)	7.0 (7.7)	201 (34.2)	138 (23.5)	249 (42.3)
Obese class III	234 (0.9)	3.6 (8.3)	128 (54.7)	50 (21.4)	56 (23.9)

Abbreviations: GWG= gestational weight gain; BMI= body mass index; SD= standard deviation; IOM= Institute of Medicine

^aBased on 2009 IOM thresholds,¹ accounting for gestational age at birth;^{38,39} considered insufficient GWG if below recommendation, adequate if within recommendation, or excessive if above recommendation

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])³⁷

Table 3. Distribution of maternal characteristics in the sample and GWG associated with these characteristics (French National Perinatal Survey 2010 and 2016)

	n (%)	GWG (kg) mean (SD)	Adjusted ^a difference in GWG (kg) diff (95% CI)
BMI^b			
Underweight	1960 (8.0)	13.9 (4.8)	0.0 (-0.3, 0.3)
Normal weight	15506 (62.9)	13.8 (4.8)	reference
Overweight	4545 (18.4)	12.2 (6.0)	-1.6 (-1.8, -1.4)
Obese	2625 (10.7)	8.6 (7.4)	-5.1 (-5.4, -4.8)
Parity			
Multiparous	14061 (56.7)	12.4 (5.6)	reference
Primiparous	10722 (43.3)	13.7 (5.6)	0.7 (0.5, 0.8)
Age			
<25 years	3716 (15.0)	13.4 (6.3)	-0.0 (-0.3, 0.2)
25-29 years	8126 (32.7)	13.2 (5.7)	reference
30-34 years	8079 (32.5)	12.9 (5.4)	0.1 (-0.1, 0.3)
≥35 years	4918 (19.8)	12.5 (5.5)	-0.0 (-0.3, 0.2)
Country or region of birth			
France	20398 (82.2)	13.2 (5.5)	reference
Europe	957 (3.9)	13.0 (5.7)	0.3 (-0.1, 0.8)
Northern Africa	1720 (6.9)	12.1 (6.1)	-0.2 (-0.6, 0.2)
Sub-Saharan Africa	1024 (4.1)	11.2 (6.8)	-0.6 (-1.0, -0.1)
Other	719 (2.9)	12.5 (5.2)	0.0 (-0.5, 0.6)
Employment during pregnancy			
None	7089 (28.7)	12.3 (6.4)	0.1 (-0.2, 0.3)
Stopped working during pregnancy			
Before 14+0 wks gestation	1595 (6.5)	13.8 (6.3)	1.2 (0.8, 1.5)
14+0 to 27+6 wks gestation	6701 (27.1)	13.5 (5.5)	0.6 (0.4, 0.9)
28+0 to 31+6 wks gestation	4243 (17.2)	13.2 (4.9)	0.3 (-0.0, 0.5)
Unknown stop point	4743 (19.2)	12.8 (5.6)	0.1 (-0.7, 0.9)
Continued working to ≥32 wks gestation	317 (1.3)	13.0 (4.9)	reference
Education			
Less than high school	2158 (8.7)	11.9 (6.8)	0.6 (0.2, 1.0)
High school	9157 (37.1)	13.1 (6.3)	0.8 (0.6, 1.1)
1-2 years post-graduation	5086 (20.6)	13.2 (5.3)	0.6 (0.4, 0.9)
3-4 years post-graduation	4466 (18.1)	13.0 (4.9)	0.2 (-0.1, 0.5)
≥5 years post-graduation	3798 (15.4)	12.9 (4.5)	reference
Social deprivation^c			
No	20424 (82.2)	13.1 (5.4)	reference
Yes	4414 (17.8)	12.5 (6.6)	-0.1 (-0.3, 0.1)
Smoking habits before, during pregnancy			
Non smoker	17216 (69.9)	12.4 (5.3)	reference
Decreased smoking in pregnancy			
<10 cig/d, stopped	1855 (7.5)	14.4 (5.3)	1.5 (1.1, 1.8)
≥10 cig/d, stopped	1402 (5.7)	16.2 (5.9)	3.3 (2.9, 3.7)
≥10 cig/d, <10 cig/d	2185 (8.9)	14.0 (6.2)	1.3 (0.9, 1.6)

Maintained smoking level in pregnancy			
<10 cig/d, <10 cig/d	845 (3.4)	13.4 (6.4)	0.9 (0.4, 1.4)
≥10 cig/d, ≥10 cig/d	1081 (4.4)	12.4 (6.5)	0.1 (-0.4, 0.5)
Increased smoking in pregnancy ^d	47 (0.2)	13.6 (5.4)	1.1 (-0.9, 3.2)
Insufficient care^e			
No	23515 (94.7)	13.1 (5.6)	reference
Yes	1328 (5.3)	11.5 (6.4)	-0.9 (-1.2, -0.6)

Abbreviations: GWG= gestational weight gain; SD= standard deviation; CI= confidence interval; BMI= body mass index; cig/d= cigarettes per day; GA= gestational age

^aEstimated using adjusted linear regression models; adjusted on all covariates in table, survey year, GA at birth, and mother's height

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30³⁷

^cNo stable home (homeless or living in a hotel or caravan) and/or no salary nor unemployment allowance

^dNon-smoker, <10 cig/d; non-smoker, ≥10 cig/d; <10 cig/d, ≥10 cig/d

^eLate pregnancy declaration (national health insurance not notified in first three completed months and no nuchal translucency measurement in first trimester) or insufficient sonograms (<2 if GA at birth 24-33 weeks; <3 if GA at birth 34 weeks or later) or prenatal visits (<3 if GA at birth 24-27 weeks; <4 if GA at birth 28-31 weeks; <5 if GA at birth 32-35 weeks; <6 if GA at birth 36 weeks or later), consistent with French guidelines for low risk women

BOLD: clinically (>1kg) and statistically significant mean difference

Table 4. Associations between maternal characteristics and insufficient or excessive GWG^a in multivariable logistic regression models (French National Perinatal Survey 2010 and 2016; N=23931)

	Insufficient GWG aOR ^b (95% CI)	Excessive GWG aOR ^b (95% CI)
BMI^c		
Underweight	1.4 (1.2, 1.5)	0.7 (0.6, 0.8)
Normal weight	reference	reference
Overweight	0.7 (0.6, 0.8)	2.8 (2.6, 3.1)
Obese	1.5 (1.4, 1.7)	3.3 (2.9, 3.6)
Primiparity (versus multiparous)	0.9 (0.9, 1.0)	1.2 (1.2, 1.3)
Age		
<25 years	1.1 (1.0, 1.2)	1.0 (0.9, 1.1)
25-29 years	reference	reference
30-34 years	1.0 (0.9, 1.1)	1.0 (0.9, 1.1)
≥35 years	1.0 (0.9, 1.1)	0.9 (0.9, 1.0)
Country or region of birth (versus France)		
Europe	0.9 (0.8, 1.1)	1.1 (0.9, 1.3)
Northern Africa	1.1 (1.0, 1.3)	1.1 (1.0, 1.3)
Sub-Saharan Africa	1.2 (1.0, 1.5)	1.1 (0.9, 1.3)
Other	1.0 (0.8, 1.2)	1.1 (0.9, 1.3)
Employment during pregnancy		
None	1.2 (1.0, 1.3)	1.2 (1.1, 1.3)
Stopped working during pregnancy		
Before 14+0 wks gestation	1.0 (0.8, 1.1)	1.6 (1.4, 1.8)
14+0 to 27+6 wks gestation	0.9 (0.8, 1.0)	1.2 (1.1, 1.4)
28+0 to 31+6 wks gestation	0.9 (0.8, 1.0)	1.1 (1.0, 1.2)
Unknown stop point	1.1 (0.8, 1.4)	1.0 (0.8, 1.4)
Continued working to ≥32 wks gestation	reference	reference
Education (versus ≥5 years post-graduation)		
Less than high school	1.2 (1.0, 1.4)	1.5 (1.3, 1.7)
High school	1.0 (0.9, 1.1)	1.5 (1.3, 1.6)
1-2 years post-graduation	0.9 (0.8, 1.0)	1.3 (1.2, 1.5)
3-4 years post-graduation	1.0 (0.9, 1.1)	1.1 (1.0, 1.2)
Social deprivation^d	1.1 (1.0, 1.2)	1.0 (0.9, 1.1)
Smoking habits before, during pregnancy (versus non-smokers)		
Decreased smoking in pregnancy		
<10 cig/d, stopped	0.7 (0.6, 0.8)	1.4 (1.3, 1.6)
≥10 cig/d, stopped	0.6 (0.5, 0.7)	2.6 (2.3, 2.9)
≥10 cig/d, <10 cig/d	0.9 (0.8, 1.0)	1.5 (1.4, 1.7)
Maintained smoking level in pregnancy		
<10 cig/d, <10 cig/d	1.1 (0.9, 1.3)	1.5 (1.3, 1.8)
≥10 cig/d, ≥10 cig/d	1.2 (1.0, 1.4)	1.2 (1.0, 1.4)
Increased smoking in pregnancy ^e	0.7 (0.3, 1.5)	1.4 (0.7, 2.7)
Insufficient care^f	1.2 (1.1, 1.4)	0.9 (0.7, 1.0)

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3 Abbreviations: GWG= gestational weight gain; aOR= adjusted odds ratio; CI= confidence
4 interval; BMI= body mass index; cig/d= cigarettes per day; IOM= Institute of Medicine; GA=
5 gestational age

6
7 ^aBased on 2009 IOM thresholds,¹ accounting for GA at birth;^{38,39} considered insufficient GWG
8 if below recommendation, adequate if within recommendation, or excessive if above
9 recommendation

10 ^bEstimated using polytomous logistic regression models; adjusted on all covariates in table,
11 survey year, and mother's height

12 ^cBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese:
13 ≥30³⁷

14 ^dNo stable home (homeless or living in a hotel or caravan) and/or no salary nor
15 unemployment allowance

16 ^eNon-smoker, <10 cig/d; non-smoker, ≥10 cig/d; <10 cig/d, ≥10 cig/d

17 ^fLate pregnancy declaration (national health insurance not notified in first three completed
18 months and no nuchal translucency measurement in first trimester) or insufficient sonograms
19 (<2 if GA at birth 24-33 weeks; <3 if GA at birth 34 weeks or later) or prenatal visits (<3 if GA
20 at birth 24-27 weeks; <4 if GA at birth 28-31 weeks; <5 if GA at birth 32-35 weeks; <6 if GA at
21 birth 36 weeks or later), consistent with French guidelines for low risk women

22 **BOLD:** statistically significant association (does not cross null)

Table 5. Association between maternal prepregnancy BMI^a and GWG and GWG adequacy,^b accounting for obesity classes I-III in adjusted regression models^c (French National Perinatal Survey 2010 and 2016)

	N	GWG (kg) mean (SD)	Adjusted difference in GWG (kg) diff (95% CI)	Insufficient GWG aOR ^b (95% CI)	Excessive GWG aOR ^b (95% CI)
Underweight	1960	13.9 (4.8)	0.0 (-0.3, 0.3)	1.4 (1.2, 1.5)	0.7 (0.6, 0.8)
Normal weight	15506	13.8 (4.8)	reference	reference	reference
Overweight	4545	12.2 (6.0)	-1.6 (-1.8, -1.4)	0.7 (0.6, 0.8)	2.8 (2.6, 3.1)
Obese class I	1802	9.8 (6.7)	-3.9 (-4.3, -3.6)	1.2 (1.0, 1.4)	3.8 (3.4, 4.3)
Obese class II	589	7.0 (7.7)	-6.7 (-7.3, -6.2)	1.9 (1.5, 2.4)	2.4 (2.0, 3.0)
Obese class III	234	3.6 (8.3)	-10.2 (-11.1, -9.3)	3.4 (2.4, 4.7)	1.3 (0.9, 2.0)

Abbreviations: BMI= body mass index; GWG= gestational weight gain; SD= standard deviation; aOR= adjusted odds ratio; CI= confidence interval; IOM= Institute of Medicine; GA= gestational age at birth

^aBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese class I: 30-34.9; obese class II: 35-39.9; obese class III: ≥40³⁷

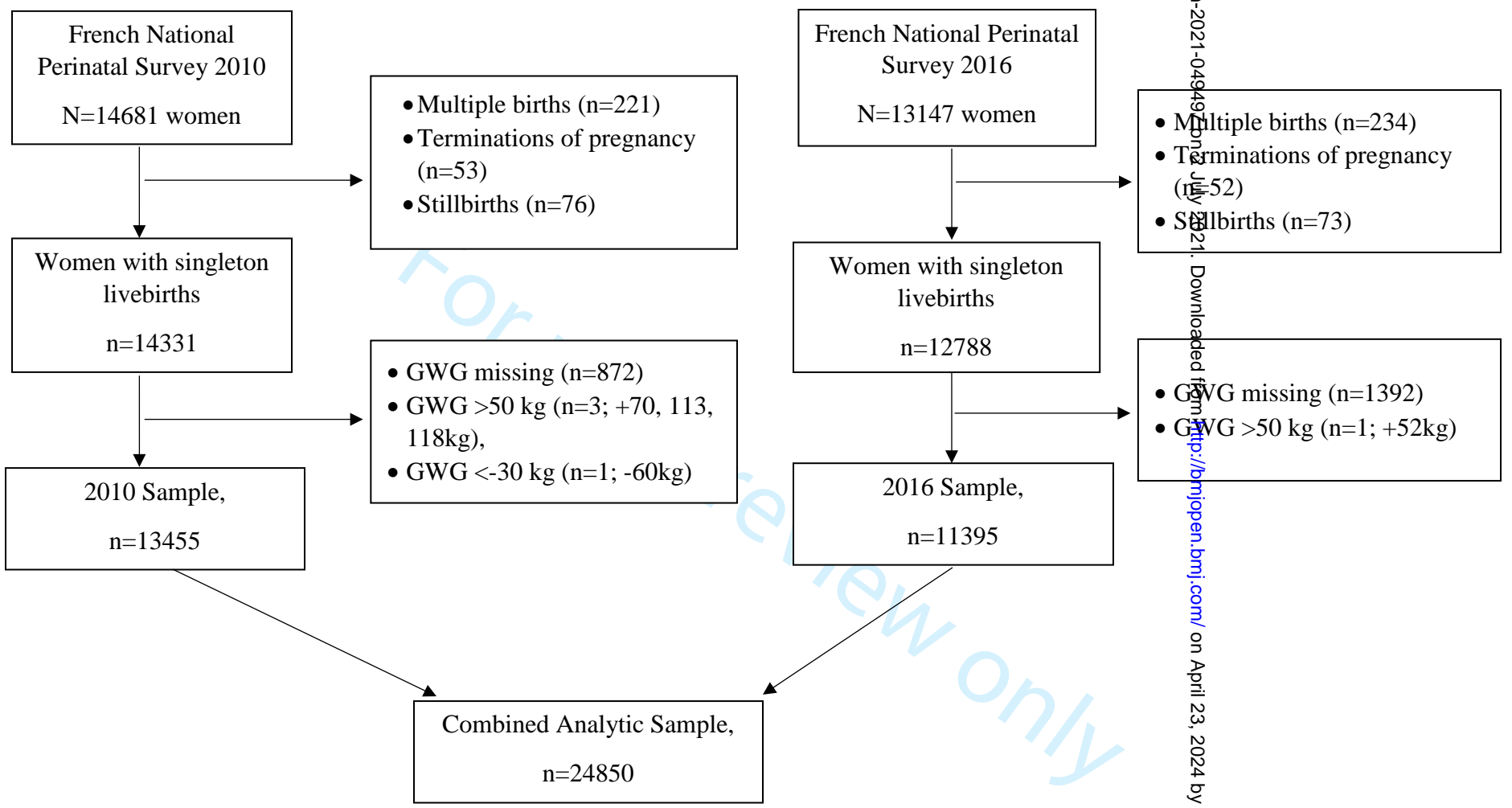
^bBased on 2009 IOM thresholds,¹ accounting for GA at birth;^{38,39} considered insufficient GWG if below recommendation, adequate if within recommendation, or excessive if above recommendation

^cLinear regression used to estimated differences and polytomous logistic regression used to estimated aORs; adjustment variables: parity, maternal age, maternal country/region of birth, employment during pregnancy, education, social deprivation, smoking habits, insufficient care, survey year, mother's height (all models), and GA at birth (linear models only)

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3 **Figure legends**
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5 Figure 1: Participant flow chart
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eTable 1. Nationally-representative estimates of GWG and GWG adequacy^a in France by survey year (French National Perinatal Survey 2010 and 2016; N=24850)

	2010					2016				
	N (%)	GWG (kg) mean (SD)	Insufficient GWG n (%)	Adequate GWG n (%)	Excessive GWG n (%)	N (%)	GWG (kg) mean (SD)	Insufficient GWG n (%)	Adequate GWG n (%)	Excessive GWG n (%)
Total	13455	13.2 (5.6)	3443 (25.9)	5006 (37.7)	4839 (36.4)	11395	12.7 (5.7)	3163 (28.0)	4100 (36.2)	4053 (35.8)
BMI^b										
Underweight	1110 (8.3)	14.0 (4.7)	415 (37.5)	454 (41.0)	239 (21.6)	850 (7.5)	13.7 (4.9)	347 (40.8)	331 (38.9)	172 (20.2)
Normal weight	8601 (64.7)	13.9 (4.8)	2394 (27.9)	3614 (42.1)	2583 (30.1)	6905 (60.9)	13.7 (4.9)	2079 (30.2)	2824 (41.0)	1991 (28.9)
Overweight	2289 (17.2)	12.4 (5.9)	310 (13.6)	662 (28.9)	1315 (57.5)	2256 (19.9)	12.0 (6.0)	377 (16.7)	641 (28.4)	1237 (54.9)
All obese	1303 (9.8)	8.9 (7.4)	324 (24.9)	276 (21.2)	702 (53.9)	1322 (11.7)	8.4 (7.3)	360 (27.3)	304 (23.1)	653 (49.6)
Obese class I	893 (6.7)	10.2 (6.7)	162 (18.2)	190 (21.3)	540 (60.5)	909 (8.0)	9.5 (6.7)	193 (21.3)	202 (22.3)	510 (56.4)
Obese class II	280 (2.1)	7.0 (8.0)	92 (32.9)	64 (22.9)	124 (44.3)	309 (2.7)	7.0 (7.4)	109 (35.4)	74 (24.0)	125 (40.6)
Obese class III	130 (1.0)	4.2 (8.1)	70 (53.8)	22 (16.9)	38 (29.2)	104 (0.9)	2.8 (8.6)	58 (55.8)	28 (26.9)	18 (17.3)

Abbreviations: GWG= gestational weight gain; BMI= body mass index; SD= standard deviation; IOM= Institute of Medicine

^aBased on 2009 IOM thresholds,¹ accounting for gestational age at birth;^{2,3} considered insufficient GWG if below recommendation, adequate if within recommendation, or excessive if above recommendation

^bBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese: ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])⁴

eTable 2: Characteristics of the study population, in comparison to those of women excluded for missing or implausible GWG (French National Perinatal Survey 2010 and 2016)

	Included (N=24850) n (%)	Excluded (N=2269) n (%)
BMI^a		
Underweight	1960 (8.0)	7 (4.2)
Normal weight	15506 (62.9)	92 (55.1)
Overweight	4545 (18.4)	33 (19.8)
All obese	2625 (10.7)	35 (21.0)
Obese class I	1802 (7.3)	25 (15.0)
Obese class II	589 (2.4)	7 (4.2)
Obese class III	234 (0.9)	3 (1.8)
Parity		
Multiparous	14061 (56.7)	1100 (63.5)
Primiparous	10722 (43.3)	632 (36.5)
Age		
<25 years	3716 (15.0)	370 (22.0)
25-29 years	8126 (32.7)	482 (28.6)
30-34 years	8079 (32.5)	476 (28.3)
≥35 years	4918 (19.8)	356 (21.1)
Country or region of birth		
France	20398 (82.2)	280 (53.6)
Europe	957 (3.9)	47 (9.0)
Northern Africa	1720 (6.9)	63 (12.1)
Sub-Saharan Africa	1024 (4.1)	101 (19.3)
Other	719 (2.9)	31 (5.9)
Employment during pregnancy		
None	7089 (28.7)	404 (60.3)
Stopped working during pregnancy		
Before 14+0 wks gestation	1595 (6.5)	20 (3.0)
14+0 to 27+6 wks gestation	6701 (27.1)	58 (8.7)
28+0 to 31+6 wks gestation	4243 (17.2)	24 (3.6)
Unknown stop point	317 (1.3)	124 (18.5)
Continued working to ≥32 wks gestation	4743 (19.2)	40 (6.0)
Education		
Less than high school	2158 (8.7)	217 (37.0)
High school	9157 (37.1)	226 (38.5)
1-2 years post-graduation	5086 (20.6)	67 (11.4)
3-4 years post-graduation	4466 (18.1)	50 (8.5)
≥5 years post-graduation	3798 (15.4)	27 (4.6)
Social deprivation^b		
No	20424 (82.2)	304 (60.9)
Yes	4414 (17.8)	195 (39.1)
Smoking habits before, during pregnancy		
Non smoker	17216 (69.9)	297 (72.1)
Decreased smoking in pregnancy		
<10 cig/d, stopped	1855 (7.5)	18 (4.4)
≥10 cig/d, stopped	1402 (5.7)	17 (4.1)
≥10 cig/d, <10 cig/d	2185 (8.9)	21 (5.1)
Maintained smoking level in pregnancy		
<10 cig/d, <10 cig/d	845 (3.4)	32 (7.8)
≥10 cig/d, ≥10 cig/d	1081 (4.4)	26 (6.3)
Increased smoking in pregnancy ^c	47 (0.2)	1 (0.2)
Insufficient care^d		
No	23515 (94.7)	673 (83.3)
Yes	1328 (5.3)	135 (16.7)
Diabetes		
No	22414 (91.5)	1490 (89.4)
Yes, diet controlled	633 (2.6)	42 (2.5)
Yes, insulin controlled	1458 (5.9)	134 (8.0)
Preexisting hypertension		
No	24229 (98.0)	1656 (97.5)
Yes	504 (2.0)	42 (2.5)

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3 Abbreviations: GWG= gestational weight gain; BMI= body mass index; cig/d= cigarettes per
4 day; GA= gestational age

5 ^aBMI (kg/m²): underweight: <18.5; normal weight: 18.5-24.9; overweight: 25-29.9; obese:
6 ≥30 (class I [30-34.9]; class II [35-39.9]; class III [≥40])⁴

7 ^bNo stable home (homeless or living in a hotel or caravan) and/or no salary nor
8 unemployment allowance

9 ^cNon-smoker, <10 cig/d; non-smoker, ≥10 cig/d; <10 cig/d, ≥10 cig/d

10 ^dLate pregnancy declaration (national health insurance not notified in first three completed
11 months and no nuchal translucency measurement in first trimester) or insufficient
12 sonograms (<2 if GA at birth 24-33 weeks; <3 if GA at birth 34 weeks or later) or prenatal
13 visits (<3 if GA at birth 24-27 weeks; <4 if GA at birth 28-31 weeks; <5 if GA at birth 32-35
14 weeks; <6 if GA at birth 36 weeks or later), consistent with French guidelines for low risk
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STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*
Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-6
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	5-6
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-9
Bias	9	Describe any efforts to address potential sources of bias	6-7; 9-10
Study size	10	Explain how the study size was arrived at	5-6; Fig 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8-10
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	9-10
		(b) Describe any methods used to examine subgroups and interactions	n/a
		(c) Explain how missing data were addressed	10
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed	n/a

		<i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	
		€ Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage © Consider use of a flow diagram	5-6; Figure 1 n/a Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest © <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	10-11; Table 2-3; eTable 1 10; 16 n/a
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time <i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure <i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	n/a n/a 10-11; Table 2-3; eTable 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-12; Tables 3-4 8; Tables 3-4 n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12; Table 5
Discussion			
Key results	18	Summarise key results with reference to study objectives	12-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16-17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-17
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

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2 **Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE
3 checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at
4 <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.
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