Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Preconception Metabolic Bariatric Surgery and Offspring Infant Growth Trajectories and Body Size from Birth to Age at School Entry: The POSIT Study

Jonathan Purnell

purnellj@ohsu.edu

Oregon Health & Science University https://orcid.org/0000-0001-5505-6333

Janne Boone-Heinonen

University of San Francisco

Jiaxiao Shi

Kaiser Permanente Southern California

Sijia Qiu

Kaiser Permanente Southern California

Darios Getahun

Kaiser Permanente Southern California

Caryn Oshiro

Kaiser Permanente Center for Integrated Health Care Research

Carmen Wong

Kaiser Permanente Center for Integrated Health Care Research

Padma Koppolu

Kaiser Permanente Center for Health Research

Kimberly Vesco

Kaiser Permanente Northwest, Kaiser Permanente Center for Health Research, Portland, OR, USA.

Article

Keywords:

Posted Date: October 23rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11226093/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations:
There is **NO** Competing Interest.

Participants were given the option to be completely excluded from any type of research, allow their data to be used, and/or to receive active recruitment contact. If you don’t opt of any but then opt out later, that gets documented on the exclusion list.

Tables are available in the Supplementary Files section

Preconception Metabolic Bariatric Surgery and Offspring Infant Growth Trajectories and Body Size from Birth to Age at School Entry: The POSIT Study

Janne Boone-Heinonen, PhD, MPH*[1]

Jiaxiao M Shi, PhD[2]

Sijia Qiu, MS, MPP[2]

Caryn ES Oshiro, PhD, MS, RD[3]

Darios Getahun, MD, PhD, MPH[2,4]

Padma Koppolu, MPH[5]

Kimberly K Vesco, MD, MPH[5]

Carmen P Wong, MBA[3]

Jonathan Q Purnell, MD[6]

*Corresponding author

[1]University of California at San Francisco, San Francisco, California

[2]Department of Research & Evaluation, Kaiser Permanente Southern California, Pasadena, California

[3]Kaiser Permanente Center for Integrated Health Care Research, Honolulu, Hawaii;

[4]Department of Health Systems Science, Kaiser Permanente Bernard J. Tyson School of Medicine, Pasadena, California

[5]Kaiser Permanente Center for Health Research, Portland, Oregon

[6]Oregon Health & Science University, Portland, Oregon.

ABSTRACT

Preconception metabolic bariatric surgery (MBS) improves weight status and metabolic health in women, but its impact on infant and child weight status is unclear. Using data from a US integrated healthcare system, we compared children born to women with preconception Roux-en-Y gastric bypass or sleeve gastrectomy with control groups matched by pre-surgical (primary) or pre-pregnancy (secondary) body mass index. Compared to pre-surgical and pre-pregnancy control groups, children in the MBS group had higher adjusted risk of being small for gestational age (83 and 73%, respectively) and lower adjusted risk of being large for gestational age (68 and 57%, respectively). In contrast, offspring infant growth trajectories from birth to 2 years and child BMI at 12 months, 3 years, and 5 years of age were similar for the MBS and pre-surgical control groups, but higher in the MBS compared to pre-pregnancy control group. At 5 years, child BMI was similar in MBS and pre-surgical control groups, while the adjusted risk of severe obesity was 2.70 (95% CI: 2.21, 3.19) times higher in the MBS than in the pre-pregnancy control group. Study findings suggest that despite improved maternal health, preconception MBS and weight loss are not associated with lower child obesity risk.

INTRODUCTION

In 2021-2023, obesity (Body mass index [BMI] ≥ 30 kg/m^2) and severe obesity (BMI ≥ 40 kg/m^2) prevalence reached 40% and 12.3%, respectively, among women in the United States (U.S.),[1] a large proportion of which comprises women of childbearing age.[2] Maternal obesity is associated with multiple maternal-fetal complications, including increased risk for gestational diabetes (GDM), hypertensive disorders of pregnancy (HDP), small for gestational age (SGA) delivery, and large for gestational age (LGA) delivery, as well as greater offspring risk for obesity and chronic diseases.[3,4] Given the limited benefit of weight management interventions during pregnancy for maternal and fetal health, weight loss prior to conception is now recommended.[5,6] Metabolic-bariatric surgery (MBS) is the most effective treatment for obesity, inducing long-term weight loss averaging 20-30% following the two now-most commonly used procedures, sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB).[7,8] However, the effects of preconception MBS on child obesity risk remain uncertain.

Metabolic-bariatric surgery and subsequent weight loss improve metabolic health and obesity-related complications in non-pregnant patients.[7-10] In women who become pregnant, preconception MBS is associated with a lower risk of many adverse pregnancy outcomes, including GDM, HDP, and LGA delivery.[11-13] However, preconception MBS is also associated with a higher risk of SGA delivery,[12] possibly through maternal micronutrient malabsorption. Each of these changes in maternal and fetal health risks could influence an offspring's subsequent risk for obesity and weight-related health throughout childhood.[14,15]

However, evidence exploring the risks and benefits of preconception MBS on infant and child body weight following delivery is sparse and mixed. Published results range from lower obesity risk in children of mothers who underwent MBS prior to pregnancy versus those who did not, to small differences depending on child sex, to no difference overall.[16] However, these studies have key limitations, including small sample sizes (e.g., n=19 to 96 women),[17-20] varied or unstated surgical types, and differing child ages or maternal comparison groups (e.g., compared to normal weight, overweight, or BMI-matched controls).[19,21-23] A few studies have examined child BMI in association with maternal RYGB or SG, finding higher child BMI in the MBS groups, with variation by surgery type and comparison group.[19,24]

Understanding whether preconception weight loss benefits include lower offspring obesity risk has implications for current models of intergenerational transmission of chronic disease risk, clinical recommendations for mothers with obesity, and future research priorities. The objective of this study is to determine associations between preconception maternal RYGB or SG and offspring body size across multiple developmental phases, including at birth (SGA and LGA, birth weight z-score), infant growth trajectories (2 weeks to 2 years), and BMI (z-score and classification) up to 5 years of age.

METHODS

Study population

The preconception metabolic bariatric surgery and child health outcomes (POSIT) study includes patients from Kaiser Permanente's (KP) Hawaii, Northwest, and Southern California regions. We used enrollment, outpatient, and hospital data from KP's Virtual Data Warehouse (VDW) and linked state birth certificate data. KPSC IRB and Oregon Health & Science University IRBs ceded to the Kaiser Permanente's interregional Institutional Review Board. Each participating KP region obtained approval to utilize data elements from state-issued birth certificates.

Identification of POSIT study groups is described in detail elsewhere.[25] Briefly, study groups were identified from pregnancies with documented and valid pregnancy parameters; onset on or after 1/1/2006; maternal age ≥18 years at pregnancy onset; pregnancy outcome date 12/31/2020 or earlier (to enable sufficient follow-up time); singleton, live births with linked child data in the VDW; and ≥1 valid adult height measures and ≥1 valid pre-pregnancy weight measures. Among eligible pregnancies, first observed post-MBS pregnancies were identified and matched to two sets of control women without prior MBS within each KP site using nearest-neighbor matching (1:10 ratio), based on maternal age, calendar year of pregnancy onset, and BMI. The primary control group consisted of women matched to the pre-surgical BMIs of women who underwent MBS (pre-surgical controls) and the secondary control group consisted of women match to their post-surgical, pre-pregnancy BMIs (pre-pregnancy controls).[25]

The POSIT MBS, pre-surgical control, and pre-pregnancy control groups included 1,374, 13,740, and 13,740 mother-child dyads, respectively (**Figure 1**). For this study, we additionally required gestational age (GA) ≥ 22 weeks at delivery (n=6 excluded). Outcome specific

analyses required additional data ascertainment: analyses of size for GA required a known and plausible birth weight (n=186 [0.6%] excluded); analysis of infant growth trajectory modeling required ≥2 BMI measures between 14 days and 100 weeks (n=2,587 [9.0%] excluded); and analyses of child BMI required at least one same-day, valid height and weight measurement within 90 days prior to and 180 days after 12, 36, or 60 months of age (n=5,379 [18.6%], n=11,620 [40.3%], and n=14,574 [50.5%] excluded, respectively) (**Figure 1**).

Study variables

Metabolic-bariatric surgery (exposure) was identified based on International Classification of Diseases (ICD-9, ICD-10) diagnosis codes and Current Procedural Terminology (CPT-4) procedure codes recorded during clinical encounters.[25]

Maternal anthropometry: Clinically recorded heights and weights were extracted for the base population, then cleaned using the growthcleanr package (adult module) in R.[26] Height was calculated as the median height among all valid height measures from age 18 years onward. Pre-pregnancy BMI was calculated from median height and the weight selected in the following order of priority: measured weight closest to pregnancy onset (a) within 90 days before or (b) 180 days before pregnancy onset; (c) self-reported weight at the first prenatal visit, or (d) measured weight within 84 days after pregnancy onset. For the MBS group, pre-surgical BMI was calculated from the median height and the highest weight recorded within 12 months prior to the surgical date; this timeframe accounts for the requirement by some surgical programs or health insurance companies for mandated pre-surgical weight loss prior to eligibility or coverage approval.

Size for gestational age (outcome). We extracted birth weight and GA at delivery from the VDW, or, if missing or invalid in the VDW, the state birth certificate record. Plausible birth weights were defined based on GA- and sex-specific z-scores: -5 to +5 standard deviations (SD), adapted from prior research[27-29] to account for more rapid fetal growth in offspring of women with severe obesity. We calculated size for GA as an indicator of intrauterine growth velocity using a previously published reference curve,[27] then categorized this value as SGA (< 10th percentile), appropriate for

GA (AGA), and LGA (> 90th percentile).[30] We categorized birth as preterm (GA < 37 completed weeks) or term/post-term (GA ≥ 37 completed weeks) and report it here as a descriptive variable.

Child BMI trajectory in infancy and at 12 months, 3 years, and 5 years of age (outcomes). Clinically recorded heights and weights were extracted for linked children, then cleaned using the child module of growthcleanr in R. We calculated BMI from valid, same-day heights and weights from 14 days to 100 weeks; and from measures closest to 12, 36, 60 months of age, among measures within 90 days prior to and 180 days after the defined time point. Infant BMI peak characteristics, including age at BMI peak, BMI at peak, and average velocity prior to peak, were determined using trajectory analysis of BMI from 14 days to 100 weeks (see Statistical Analysis). BMI z-scores were calculated using the World Health Organization growth standards for the 12-month time point[30] and the Centers for Disease Control and Prevention's age- and sex-specific extended BMI growth charts[31] for the 3-and 5-year timepoints. In descriptive and secondary analyses, we examined BMI classification: underweight (<5th percentile), normal weight (≥5th to <85th), overweight (85th to <95th), obesity (95th to <120% of the 95th), and severe obesity (≥120% of the 95th percentile).[31,32]

Covariates. Maternal ***race and ethnicity*** (Hispanic; Non-Hispanic [NH] White, NH Black, NH Asian; due to small numbers, NH American Indian or Alaska Native, NH Native Hawaiian or Pacific Islander, and NH multi-racial or other were combined into "other" to facilitate statistical stability) and ***parity*** (nulliparous, multiparous) were determined from the birth certificate or, if missing, the VDW. ***Insurance type*** (Medicare/Medicaid only, any commercial, self-pay only) was determined at the time of delivery. ***Preconception tobacco use*** (smoker, nonsmoker, missing) was determined primarily from data collected at clinical encounters (-180 to +84 days relative to pregnancy onset): preconception smoking was defined as ≥1 report of tobacco use, non-smoking as 0 reports of tobacco use and ≥1 report of no tobacco use, or otherwise as missing. If tobacco use was missing based on VDW data, birth certificate data were used as a secondary source. ***Neighborhood deprivation index (NDI)*** was defined using the census tract of residence in which the participant lived for the longest duration during the preconception period, linked to Census data from the year

of pregnancy onset; for pregnancies between 2006-2011, we used the earliest NDI data available in the VDW (2012). ***Child sex*** (male/female) was extracted from the VDW.

Breast feeding data were collected routinely starting in 2015 and were adjusted in the secondary analyses among participants for whom data were available; we defined breastfeeding as any breastfeeding within 148-210 days (5-7 months) after birth. Maternal ***exercise*** during the pregnancy period was ascertained from encounter data in a subset, categorized as 0-149 min/week, ≥150 min/week, or unknown.

Statistical analysis

In descriptive analysis, we compared the distributions of clinical and sociodemographic characteristics across study groups (MBS, pre-surgical control, pre-pregnancy control) and evaluated the magnitude of differences between groups by calculating absolute standardized differences (ASD >0.15 indicating meaningful differences).

Infant BMI trajectories from 14 days through 100 weeks of age were characterized using mixed-effect models with random intercepts and random slopes for child age (weeks). Cubic B-Splines were used to model the nonlinear relationship between the BMI and child age. Eight spline knots were positioned at 1, 2, 3, 4, 6, 8, 12, and 18 months to provide more flexibility in time periods with the greatest BMI changes based on prior literature.[33] Using the trajectory model coefficients and random components for each child, we constructed estimated BMI trajectories by calculating predicted BMI at each week from 14 days to 100 weeks of age. The infant BMI peak was identified as the first weekly predicted value that represented a local maximum before 75 weeks of age. This age range was chosen to avoid potentially including higher BMIs occurring during adiposity rebound. Then we determined the *age at peak* (weeks) and *BMI at peak* (kg/m^2) based on the instance identified. The *average pre-peak BMI velocity* (kg/m^2/week) was defined as the difference in predicted BMI from 14 days to the estimated BMI peak, divided by the difference in time (weeks). Those with no peak prior to 75 weeks were classified as “no infant BMI peak”.

We used modified Poisson regression to model size for GA (SGA vs AGA; LGA vs AGA) and linear regression to model infant BMI trajectory characteristics (age at peak, BMI at peak, average pre-peak velocity) and BMIz at 12 months, 3 years, or 5 years of age as a function of study group (MBS vs pre-surgical control, or MBS vs pre-pregnancy control), matching variables (site, calendar year of pregnancy onset, maternal age, pre-pregnancy or presurgical BMI),[34,35] and confounders (see above). In secondary analyses, we (a) analyzed BMI categories at 3 and 5 years (child overweight vs normal weight; obesity vs normal weight; and severe obesity vs normal weight) as secondary outcomes and (b) conducted subgroup analysis by estimating MBS-child outcome associations by stratifying the final MBS-child outcome models according to maternal pre-surgical BMI category (normal weight, overweight, or obesity class 1, 2, or 3).

We formally tested if associations differed across preconception BMI strata by testing multiplicative interaction terms between MBS status and BMI category. Additional analysis examined modification by child sex by including a statistical interaction between sex and MBS status in the regression models. We also examined if MBS-child outcome associations differed by time from MBS to pregnancy and by MBS procedure types. For time since surgery, exposure categories were MBS <6, 6 to <12, 12 to <24, ≥24 months prior to pregnancy, with the relevant pre-surgical or pre-pregnancy control. For procedure type, exposure categories were RYGB, SG, and the relevant control groups.

In sensitivity analyses, we refit the primary models (a) on a more inclusive cohort, including supplemental MBS patients and pre-surgical controls matched within a larger range of BMI (4 or 10 BMI units)[25] or (b) additionally adjusting for breastfeeding or exercise in the subsets for which they were available.

RESULTS

With respect to matching variables, MBS and control groups were similar with regard to maternal age (mean: 32.1-32.7 years), KP site, and maternal matching BMI (mean pre-surgical BMI was 45.1 kg/m^2 in the MBS group and pre-pregnancy BMI was 44.5 kg/m^2 in the pre-surgical controls; mean pre-pregnancy BMI was 33.0 kg/m^2 in both the MBS and pre-pregnancy control groups) (**Table 1**). Pre-surgical controls included more pregnancies from an earlier period than MBS (9.6% vs 3.6% in 2006-2009). Focusing on analysis with the largest exclusion (BMI at 5 years of

age), compared to children included analysis, those excluded due to missing data had slight differences by calendar year, site, race and ethnicity, and insurance type; and for the MBS group, parity; however, those excluded were similar with respect to key variables including maternal BMI, birth outcomes (preterm birth, birthweight, size for GA), child BMI at 12 months and 3 years of age, and other covariates (**Supplemental Table 1**).

The most performed MBS procedure was SG (62.4%), which occurred within 24 months of pregnancy for 52.7% of MBS patients and resulted in a mean (SD) of 26.6% (11.5%) post-surgical weight loss prior to pregnancy (data not shown). The MBS group was more likely to be nulliparous than either of the control groups (42.9% vs 32.8% and 32.6%) (**Table 1**). Preconception tobacco use was low overall but highest in the pre-surgical control group (7.0%). The pre-pregnancy control group had higher representation of more advantaged sociodemographic subgroups (race/ethnicity, insurance type, NDI) than MBS and pre-surgical controls, which were more closely aligned with each other. MBS and control groups were similar with respect to child sex (47.9-48.6% female) and preterm birth (8.7-10.4%). Breastfeeding was highest in the pre-pregnancy control group (38.6% at 5-7 months).

Associations between MBS and size for GA at birth

Compared to both the pre-surgical and pre-pregnancy control groups, children of women who underwent preconception MBS had a higher risk of SGA (12.2% vs 5.6% and 5.9%) and a lower risk of LGA (5.6% vs 19.2% and 15.0%) (**Supplemental Table 2**). In adjusted analysis, relative risks for SGA were 1.83 (95% CI: 1.56, 2.14) and 1.73 (1.48, 2.03) for MBS versus pre-surgical and pre-pregnancy control groups, respectively; and for LGA were 0.32 (0.26, 0.40) and 0.43 (0.34, 0.53), respectively (**Figure 2, Supplemental Table 2**).

These associations were strongest for those who underwent MBS within 6 months prior to pregnancy (**Supplemental Table 3**): compared to pre-surgical controls, the MBS group had 2.16 times higher risk of SGA (95% CI: 1.33, 3.51) and 89% lower risk of LGA (RR 0.11, 95% CI: 0.03, 0.45). Associations with SGA were slightly stronger for RYGB than SG: RRs were 1.90 for RYGB and 1.79 for SG when compared to pre-surgical controls. Analogous associations for pre-pregnancy controls were similar (**Supplemental Table 3**).

Associations between MBS and Infant Growth Trajectories

In the analysis of infant growth trajectory (14 days to 100 weeks) characteristics, age at infant BMI peak was slightly greater in the MBS group (9.82 months) than the pre-surgical controls (9.56 months, adjusted difference [95% CI]: 0.21 (0.07,0.35) (**Figure 2, Supplemental Table 2**). BMI at peak was similar in the MBS (17.56 kg/m^2) group to the pre-surgical controls (17.50 kg/m^2, adjusted difference [95% CI]: 0.06 [-0.03, 0.14]). Pre-peak BMI velocity in the MBS group (5.78 kg/m^2/year) was greater than pre-surgical controls (5.14 kg/m^2/year, adjusted difference [95% CI]: 0.63 [0.60, 0.67]). Analogous associations for pre-pregnancy controls were stronger for age at infant BMI peak (adjusted difference [95% CI]: 1.18 (1.09,1.28) and BMI at peak (adjusted difference [95% CI]: 0.32 (0.24,0.40); and weaker for pre-peak BMI velocity (adjusted difference [95% CI]: 0.20 [0.17, 0.24]) (**Figure 2, Supplemental Table 2**).

Examination of fitted growth curves in the pre-pregnancy controls shows clear separation of infant trajectories when grouped by maternal pre-pregnancy weight status (from normal weight through obesity class 3) (**Figure 3A**). Even though they were matched for pre-pregnancy BMI, infant weight trajectories in the MBS group remained above that of the pre-pregnancy controls and, despite a mean weight difference of -26.6% at the time of pregnancy, were similar to the pre-surgery controls, who also remained elevated above the pre-pregnancy controls (**Figure 3B**).

Associations between MBS (vs pre-surgical controls) and for age and BMI at peak BMI were stronger with increasing duration between MBS and pregnancy, reaching statistical significance for those born 2 years or more after surgery; these associations were stronger and more consistently significant when comparing MBS vs pre-pregnancy groups (**Supplemental Table 3**). Pre-peak BMI velocity associations between MBS and both control groups were consistently positive and significant, with no clear trend, regardless of duration between MBS and pregnancy (**Supplemental Table 3**). These associations were similar for RYGB and SG.

Associations between MBS and Child BMI

Study group differences in growth trajectory patterns continued into early childhood. BMIz at 12 months, 3 years, and 5 years of age were higher in the MBS compared to the pre-pregnancy control group but similar for MBS and pre-surgical control groups. By 5 years of age, BMIz (mean

[SD]) was 1.18 [1.35] and 1.11 [1.35] in the MBS and presurgical control group vs 0.62 [1.22] in the pre-pregnancy control group (**Supplemental Table 2**). Adjusted BMIz differences between the MBS and presurgical control group were small and not significant (**Supplemental Table 2, Figure 4**). In contrast, adjusted BMIz was 0.27, 0.44, and 0.53 units higher in the MBS group compared to the pre-pregnancy control group at 12 months and at 3 and 5 years of age (**Supplemental Table 2, Figure 4**).

Likewise, BMI weight categories between MBS and pre-surgical control groups were similar at 3 and 5 years of age (**Supplemental Table 2, Figure 5**), except for an adjusted 33% higher risk of severe obesity in the MBS group at 3 years of age that was attenuated and no longer significantly different by 5 years of age. By year 5, the prevalence of obesity was 22.9% and 22.3% vs 14.8% in the MBS, pre-surgery, and pre-pregnancy groups, respectively; and that of severe obesity was 15.8% and 12.9% vs 5.8% in the MBS, pre-surgery, and pre-pregnancy groups, respectively (**Supplemental Table 2**).

Associations of MBS vs pre-surgical controls with child BMIz were similar by MBS type (**Supplemental Table 3**). There was some variation by duration between MBS and pregnancy, but associations remained non-significant with no clear differences by duration or child follow-up time point (**Supplemental Table 3**). Compared to pre-pregnancy controls, associations with child BMIz were weaker and not significant for those who received MBS within 6 months prior to pregnancy; for example, 0.08 (-0.24, 0.41) at 5 years of age.

Sensitivity analyses

Associations were similar by child sex (**Supplemental Table 4**): interaction *p*-values ranged from 0.17 to 0.9 for all associations. Results were also generally similar after including additional MBS patients and pre-surgical controls matched within a wider BMI range or additionally adjusting for breastfeeding or exercise (**Supplemental Table 5**).

DISCUSSION

Rising U.S. maternal overweight and obesity prevalence rates[36] raise risks for adverse maternal-fetal complications.[3,4] Pre-conception weight loss by MBS mitigates many unfavorable pregnancy outcomes, including GDM, HDP, and LGA delivery.[11-13] What remains unclear is the extent to which, if any, these favorable pregnancy effects impact longer-term offspring health, especially since risk for SGA is higher,[12] which may offset other post-MBS benefits.

Consistent with an extensive body of prior research reporting that risk of low birth weight and SGA is higher in pregnancies following MBS[11-13] we demonstrate that among over 1,300 children born to women who received MBS prior to pregnancy, risk of SGA was 73-83% higher, and risk of LGA was 68-57% lower, than children of both groups of BMI-matched women who did not undergo MBS. Pregnancy within 6 months of MBS was more strongly associated with a higher risk of SGA compared to both control groups. With respect to differences in SGA and LGA risk associated with RYGB versus SG, our findings suggest less pronounced differences than those reported in a systematic review (e.g., pooled RR for SGA: 2.56 for RYGB and 1.16 for SG)[12] and in a recent study of a French cohort, which also reported similar findings to ours regarding MBS within 6 months of pregnancy.[37] Collectively, our study and others reinforce that MBS-associated increased SGA and decreased LGA risks are robust in comparison to both weight-matched and lower-weight control groups and extend to contemporary MBS procedures (RYGB and SG).

Although being born SGA and LGA could unfavorably impact a wide range of childhood obesity-related outcomes,[38] associations with offspring birthweight metrics did not persist into childhood. Following a rapid initial weight gain, the BMI of offspring from the MBS cohort caught up to both the pre-surgical and pre-pregnancy cohorts and surpassed the pre-pregnancy cohort, possibly reflecting “catch-up” growth resulting from the higher SGA risk in the MBS group. Having SGA, faster pre-BMI infant peak velocity, and greater BMI at peak infant BMI have all been associated with increased risk for overweight and obesity later in life.[39,40] Yet by one year of age, group trends in child weight were established that persisted to age 5. That is, despite substantial preconception weight loss and an increased risk of SGA, offspring of the MBS maintained a nearly identical BMIz to that of the pre-surgery control group; and both groups were higher than the pre-pregnancy control group, which matched the weights of the MBS group at the time of conception and had identical SGA risk as the pre-surgery group. The MBS and pre-surgical control offspring reached 15.8% and 12.9% with severe obesity by 5 years of age, respectively, despite the MBS group mothers weighing nearly 30% less at the start of pregnancy.

Likewise, despite the MBS group having similar pre-conception weight compared to the pre-pregnancy group, the risk for child severe obesity in the MBS group was still 3-fold higher by 5 years of age. Similar results were noted regardless of child sex and time duration between surgery and conception, even when this duration was less than 6 months.

Women in the MBS and pre-surgical control groups had histories of very high BMIs (mean 45.1 kg/m^2 and 44.5 kg/m^2, respectively). This elevated degree of maternal obesity likely reflects an interaction between a strong genetic predisposition for obesity and obesogenic environmental influences[41] resulting in adverse metabolic consequences.[38] These adverse genetic and in-utero metabolic exposure risks may be passed on to their offspring, as conceived by developmental origins theory.[42] Early manifestations of this risk can appear in infancy and early childhood and, in turn, predict adult obesity risk and obesity-related consequences.[43-45] Indeed, weight trajectories of infants born to the women in the pre-pregnancy control group with a spectrum of maternal BMI categories from normal to class 3 obesity show a clear increasing trends with greater maternal BMI category (**Figure 3A**). We hypothesized that following MBS, both maternal weight loss and improved metabolic health could alter weight trajectories in a direction that would mitigate their offspring obesity risk, thereby separating (in-utero) environmental from genetic influences. However, infant weight growth and child BMIz in the MBS cohort remained consistently above those in the pre-pregnancy weight-matched cohort, suggesting that preconception MBS with attendant weight loss and improved maternal metabolic health is unlikely to reduce child obesity risk. While our study could not definitively separate genetic from in-utero determinants of early growth, these findings are consistent with a large body of evidence identifying predominantly distinct genetic factors influencing attained infant, child, and adult lifetime weights.[46-48]

Our findings help to reconcile a small body of existing literature showing that preconception MBS is associated with lower, [17,18,49]similar,[19,20,22] or higher[19,21,23,24] childhood BMI or obesity status in the offspring. Notably, studies reporting associations with lower weight status in children typically examined offspring of women who underwent preconception biliopancreatic diversion,[17,18,49] which induces more significant malabsorption and is now considerably less commonly performed than other weight loss procedures.[50] In contrast, studies reporting higher child weight status in women with preconception MBS examined only RYGB or SG,[19,24] or do not specify MBS type.[21,23]

Collectively, these findings suggest that in a population of women with a history of severe obesity, offspring birth size is influenced by MBS itself, while infant growth and child BMI are primarily driven by genetic and/or persistent effects of prior high maternal adiposity, regardless of maternal weight status at the time of pregnancy. Moreover, significant preconception weight loss did not alter these relationships. In addition, while pregnancy within 24 months after MBS is not recommended,[53] our findings suggest that a pregnancy occurring within 6-24 months after MBS has similar weight associations to offspring as pregnancies occurring 24 months or later.

Following these conclusions, several future research needs become apparent. First, delineating the mechanisms underlying MBS effects on birth outcomes, especially SGA, and effects on fetal body fat versus lean body mass can inform strategies to mitigate these complications before or during pregnancy. Second, while infant trajectories and childhood BMI were not lower in the MBS group (compared to pre-surgical controls) as hypothesized, consistent associations with SGA – a risk factor for adverse health outcomes such as impaired cognitive development, cardiovascular disease, and diabetes[54,55] – suggest the need to understand the effects of MBS on a broader range of health outcomes that typically emerge later in childhood and into adulthood. Third, given the long maternal time frame relevant to pregnancy and child outcomes following MBS, future research should investigate how MBS-related pregnancy and child benefits and risks vary with weight rebound that commonly occurs after MBS and with resolution versus recurrence of obesity comorbidities, such as type 2 diabetes. Finally, these findings emphasize the importance of the broader field of obesity research in determining the contribution of genetics/epigenetics, environmental determinants, and biological effects of severe obesity and its metabolic complications that persist after weight loss. Regarding clinical guidelines aimed at reducing adiposity pre-conception to improve both maternal and child health outcomes,[51,52] given the lack of impact on child obesity risk consideration might be given to initiate successful, long-term weight loss interventions much earlier in the maternal life course, including primary prevention at the overweight stage.

Our study has several limitations. We excluded many potential offspring participants who lacked data later in childhood; however, pregnancy and early childhood outcomes were similar in those included compared to those excluded, suggesting that selection bias is likely minimal. Like other EHR-based studies, we lack data on behavioral (including lifestyle) or socioeconomic factors known to affect body weight and access to MBS, which may thus have confounded the reported associations. Similarly, we lack data on genetic and mechanistic biomolecular factors that might

explain our outcomes. These limitations are balanced by several key strengths. Our large, contemporary study population enabled examination of the two most common MBS approaches – RYGB and SG – compared to large, well-defined control groups with comparable BMI levels, including key outcome subgroups such as offspring sex, duration between surgery and pregnancy, and breastfeeding status. With respect to child weight status, our data were able to examine multiple time points up to 5 years of age, showing stronger associations as children age.

Conclusion

Consistent with prior research, an elevated risk of SGA and a lower risk of LGA were observed in children in the MBS group when compared to control groups matched to either maternal pre-surgical or pre-pregnancy BMI. In contrast, children in the MBS and pre-surgical control groups had similarly high BMI, reaching 15.8% and 12.9% with severe obesity by 5 years of age, while child BMI was lower in the pre-pregnancy control group (5.8% with severe obesity at age 5). These findings suggest that preconception MBS-induced weight loss may impact fetal growth but not reduce postnatal growth or childhood obesity risk. In a population with severe maternal obesity, child obesity may be driven primarily by genetic or persistent effects of prior high maternal adiposity, rather than maternal weight status at conception.

REFERENCES

1. Emmerich, S.D., Fryar, C.D., Stierman, B. & Ogden, C.L. Obesity and Severe Obesity Prevalence in Adults: United States, August 2021-August 2023. *NCHS Data Brief* (2024).
2. Obesity in Pregnancy: ACOG Practice Bulletin, Number 230. *Obstet Gynecol* **137**, e128–e144 (2021).
3. Creanga, A.A., Catalano, P.M. & Bateman, B.T. Obesity in Pregnancy. *N Engl J Med* **387**, 248–259 (2022).
4. Godfrey, K.M.*, et al*. Influence of maternal obesity on the long-term health of offspring. *Lancet Diabetes Endocrinol* **5**, 53–64 (2017).
5. Stang, J. & Huffman, L.G. Position of the Academy of Nutrition and Dietetics: Obesity, Reproduction, and Pregnancy Outcomes. *J Acad Nutr Diet* **116**, 677–691 (2016).
6. ACOG Committee Opinion No. 762: Prepregnancy Counseling. *Obstet Gynecol* **133**, e78–e89 (2019).
7. Maciejewski, M.L.*, et al*. Bariatric Surgery and Long-term Durability of Weight Loss. *JAMA surgery* **151**, 1046–1055 (2016).
8. Courcoulas, A.P.*, et al*. Seven-Year Weight Trajectories and Health Outcomes in the Longitudinal Assessment of Bariatric Surgery (LABS) Study. *JAMA surgery* **153**, 427–434 (2018).
9. Purnell, J.Q.*, et al*. Type 2 Diabetes Remission Rates After Laparoscopic Gastric Bypass and Gastric Banding: Results of the Longitudinal Assessment of Bariatric Surgery Study. *Diabetes Care* **39**, 1101–1107 (2016).
10. Adams, T.D.*, et al*. Weight and Metabolic Outcomes 12 Years after Gastric Bypass. *N Engl J Med* **377**, 1143–1155 (2017).
11. Al-Nimr, R.I.*, et al*. Effects of Bariatric Surgery on Maternal and Infant Outcomes of Pregnancy-An Evidence Analysis Center Systematic Review. *J Acad Nutr Diet* **119**, 1921–1943 (2019).
12. Mustafa, H.J.*, et al*. Prepregnancy Roux-en-Y gastric bypass vs sleeve gastrectomy: a systematic review, pairwise, and network meta-analysis of obstetrical and neonatal outcomes. *Am J Obstet Gynecol MFM* **5**, 100914 (2023).
13. Kwong, W., Tomlinson, G. & Feig, D.S. Maternal and neonatal outcomes after bariatric surgery; a systematic review and meta-analysis: do the benefits outweigh the risks? *Am J Obstet Gynecol* **218**, 573–580 (2018).
14. Van De Maele, K., Ceulemans, D. & Devlieger, R. Is Maternal Metabolic Bariatric Surgery the Best Solution to Tackle the Childhood Obesity Pandemic? *JAMA surgery* **158**, 891–892 (2023).
15. Boone-Heinonen, J., Messer, L., Andrade, K. & Takemoto, E. Connecting the Dots in Childhood Obesity Disparities: A Review of Growth Patterns from Birth to Pre-Adolescence. *Curr Epidemiol Rep* **3**, 113–124 (2016).
16. Yu, Y., Lyo, V. & Groth, S.W. The impact of maternal bariatric surgery on long-term health of offspring: a scoping review. *Pediatr Res* **94**, 1619–1630 (2023).
17. Barisione, M., Carlini, F., Gradaschi, R., Camerini, G. & Adami, G.F. Body weight at developmental age in siblings born to mothers before and after surgically induced weight loss. *Surg Obes Relat Dis* **8**, 387–391 (2012).
18. Smith, J.*, et al*. Effects of maternal surgical weight loss in mothers on intergenerational transmission of obesity. *J Clin Endocrinol Metab* **94**, 4275–4283 (2009).
19. Blume, C.A.*, et al*. Association of Maternal Roux-en-Y Gastric Bypass with Obstetric Outcomes and Fluid Intelligence in Offspring. *Obes Surg* **28**, 3611–3620 (2018).
20. Dell'Agnolo, C.M., Cyr, C., de Montigny, F., de Barros Carvalho, M.D. & Pelloso, S.M. Pregnancy after Bariatric Surgery: Obstetric and Perinatal Outcomes and the Growth and Development of Children. *Obes Surg* **25**, 2030–2039 (2015).

21. Van De Maele, K.*, et al*. Adiposity, psychomotor and behaviour outcomes of children born after maternal bariatric surgery. *Pediatr Obes* **16**, e12749 (2021).
22. Willmer, M.*, et al*. Surgically induced interpregnancy weight loss and prevalence of overweight and obesity in offspring. *PloS one* **8**, e82247 (2013).
23. Damti, P., Friger, M., Landau, D., Sergienko, R. & Sheiner, E. Offspring of women following bariatric surgery and those of patients with obesity are at an increased risk for long-term pediatric endocrine morbidity. *Arch Gynecol Obstet* **300**, 1253–1259 (2019).
24. Hilaire, M.J.*, et al*. The association of higher offspring early-childhood weight gain with prepregnancy metabolic and bariatric surgery. *Obesity (Silver Spring)* **32**, 2012–2023 (2024).
25. Purnell, J.Q.*, et al*. Preconception metabolic-bariatric surgery and child health outcomes: Identification and cohort profile of the POSIT study protocol. *medRxiv*, 2026.2004.2022.26351521 (2026).
26. Daymont, C.*, et al*. Automated identification of implausible values in growth data from pediatric electronic health records. *Journal of the American Medical Informatics Association* **24**, 1080–1087 (2017).
27. Talge, N.M., Mudd, L.M., Sikorskii, A. & Basso, O. United States birth weight reference corrected for implausible gestational age estimates. *Pediatrics* **133**, 844–853 (2014).
28. Alexander, G.R., Himes, J.H., Kaufman, R.B., Mor, J. & Kogan, M. A United States national reference for fetal growth. *Obstet Gynecol* **87**, 163–168 (1996).
29. Aris, I.M., Kleinman, K.P., Belfort, M.B., Kaimal, A. & Oken, E. A 2017 US Reference for Singleton Birth Weight Percentiles Using Obstetric Estimates of Gestation. *Pediatrics* **144**(2019).
30. Group, W.H.O.M.G.R.S. WHO Child Growth Standards based on length/height, weight and age. *Acta Paediatr Suppl* **450**, 76–85 (2006).
31. Hales, C.M., Freedman, D.S., Akinbami, L., Wei, R. & Ogden, C.L. Evaluation of Alternative Body Mass Index (BMI) Metrics to Monitor Weight Status in Children and Adolescents With Extremely High BMI Using CDC BMI-for-age Growth Charts. *Vital Health Stat 1*, 1–42 (2022).
32. QuickStats: Prevalence of Obesity* and Severe Obesity(†) Among Persons Aged 2-19 Years - National Health and Nutrition Examination Survey, 1999-2000 through 2017-2018. *MMWR Morb Mortal Wkly Rep* **69**, 390 (2020).
33. Wen, X., Kleinman, K., Gillman, M.W., Rifas-Shiman, S.L. & Taveras, E.M. Childhood body mass index trajectories: modeling, characterizing, pairwise correlations and socio-demographic predictors of trajectory characteristics. *BMC Med Res Methodol* **12**, 38 (2012).
34. Sjolander, A. & Greenland, S. Ignoring the matching variables in cohort studies - when is it valid and why? *Stat Med* **32**, 4696–4708 (2013).
35. Iwagami, M. & Shinozaki, T. Introduction to Matching in Case-Control and Cohort Studies. *Ann Clin Epidemiol* **4**, 33–40 (2022).
36. Kent, L., McGirr, M. & Eastwood, K.A. Global trends in prevalence of maternal overweight and obesity: A systematic review and meta-analysis of routinely collected data retrospective cohorts. *Int J Popul Data Sci* **9**, 2401 (2024).
37. Bel Lassen, P.*, et al*. Maternal and neonatal outcomes of pregnancies after metabolic bariatric surgery: a retrospective population-based study. *Lancet Reg Health Eur* **51**, 101263 (2025).
38. Fazeli, S.A. & Soleimani Samarkhazan, H. Metabolic Memory Following Metabolic Bariatric Surgery: Mechanisms, Clinical Implications, and Strategies for Long-Term Success. *Obes Surg* **35**, 5606–5624 (2025).

39. Wood, C.T., *et al*. Timing and Magnitude of Peak Body Mass Index and Peak Weight Velocity in Infancy Predict Body Mass Index at 2 Years in a Retrospective Cohort of Electronic Health Record Data. *J Pediatr* **257**, 113356 (2023).
40. Silverwood, R.J., De Stavola, B.L., Cole, T.J. & Leon, D.A. BMI peak in infancy as a predictor for later BMI in the Uppsala Family Study. *Int J Obes (Lond)* **33**, 929–937 (2009).
41. Campbell, M.K. Biological, environmental, and social influences on childhood obesity. *Pediatr Res* **79**, 205–211 (2016).
42. Fleming, T.P., *et al*. Origins of lifetime health around the time of conception: causes and consequences. *Lancet* **391**, 1842–1852 (2018).
43. Simmonds, M., Llewellyn, A., Owen, C.G. & Woolacott, N. Predicting adult obesity from childhood obesity: a systematic review and meta-analysis. *Obes Rev* **17**, 95–107 (2016).
44. Zheng, M., *et al*. Rapid weight gain during infancy and subsequent adiposity: a systematic review and meta-analysis of evidence. *Obes Rev* **19**, 321–332 (2018).
45. Geserick, M., *et al*. Acceleration of BMI in Early Childhood and Risk of Sustained Obesity. *N Engl J Med* **379**, 1303–1312 (2018).
46. Couto Alves, A., *et al*. GWAS on longitudinal growth traits reveals different genetic factors influencing infant, child, and adult BMI. *Sci Adv* **5**, eaaw3095 (2019).
47. Vicuna, L., *et al*. New insights from GWAS on BMI-related growth traits in a longitudinal cohort of admixed children with Native American and European ancestry. *iScience* **26**, 106091 (2023).
48. Loos, R.J.F. & Yeo, G.S.H. The genetics of obesity: from discovery to biology. *Nature reviews. Genetics* **23**, 120–133 (2022).
49. Kral, J.G., *et al*. Large maternal weight loss from obesity surgery prevents transmission of obesity to children who were followed for 2 to 18 years. *Pediatrics* **118**, e1644–1649 (2006).
50. Elder, K.A. & Wolfe, B.M. Bariatric surgery: a review of procedures and outcomes. *Gastroenterology* **132**, 2253–2271 (2007).
51. ACOG Practice Bulletin No 156: Obesity in Pregnancy. *Obstet Gynecol* **126**, e112–e126 (2015).
52. Wilkes, J. AAFP Releases Position Paper on Preconception care. *Am Fam Physician* **94**, 508–510 (2016).
53. ACOG practice bulletin no. 105: bariatric surgery and pregnancy. *Obstet Gynecol* **113**, 1405–1413 (2009).
54. Yu, Z.B., *et al*. Birth weight and subsequent risk of obesity: a systematic review and meta-analysis. *Obes Rev* **12**, 525–542 (2011).
55. Fang, F., *et al*. Etiological subgroups of term small-for-gestational-age and childhood health outcomes. *Pediatr Res* **94**, 378–384 (2023).

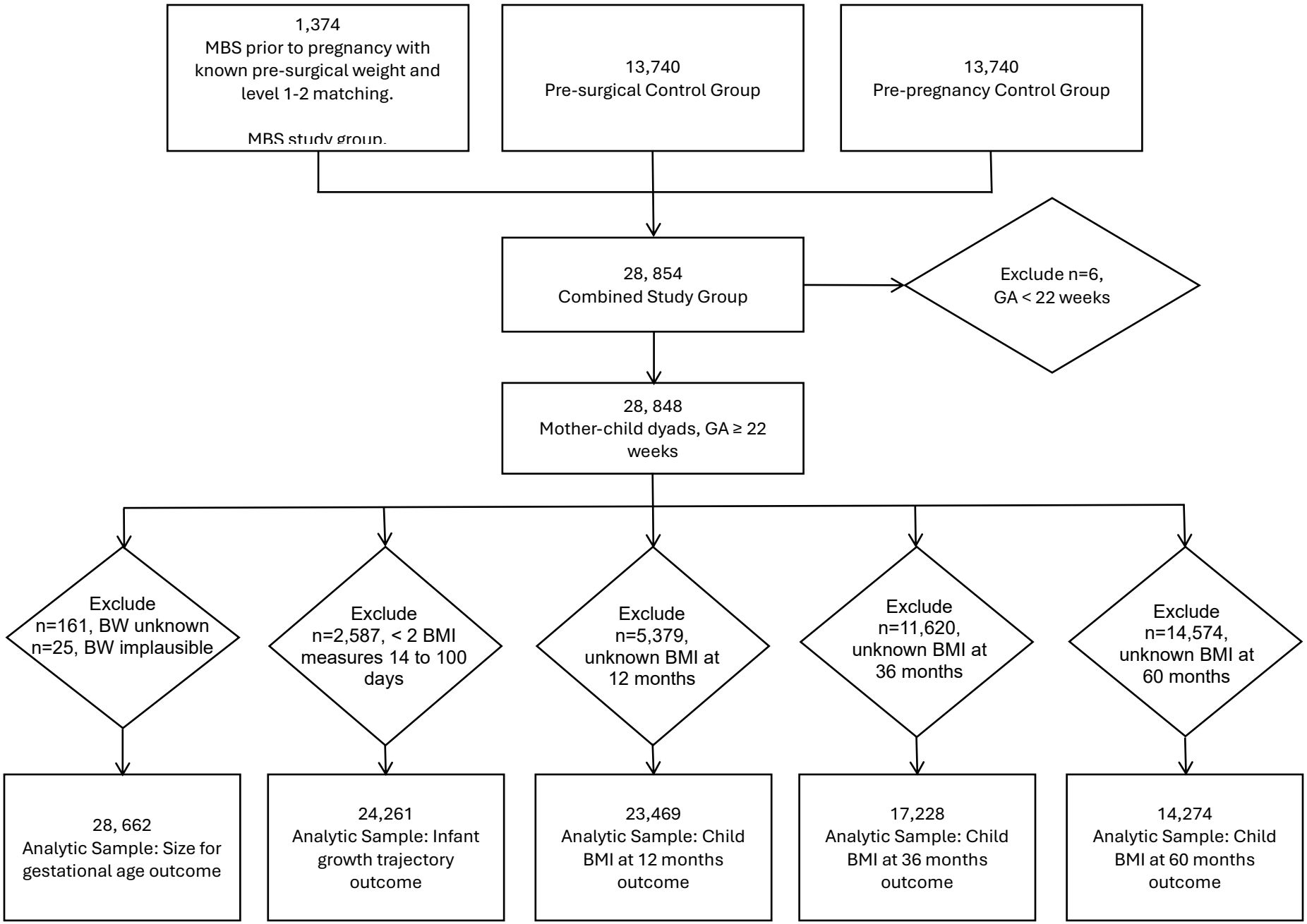
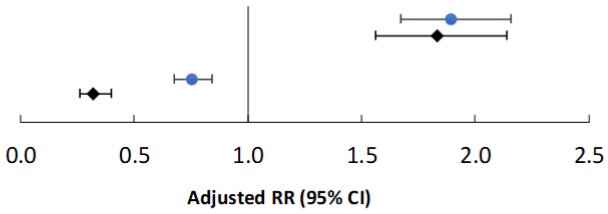


Figure 1. Flowchart of maternal group and offspring selection. Flowchart showing selection process for maternal study groups and their offspring. MBS: metabolic bariatric surgery; PSC: presurgical control group; PPC: pre-pregnancy control group; GA: gestational age; BW: birth weight; BMI: body mass index.

Figure 2. Associations between MBS and size for gestational age and infant growth trajectory characteristics. Values are either relative risk (RR) or β coefficients (95% CI) adjusted for maternal race and ethnicity, insurance type, tobacco use preconception, Neighborhood Deprivation Index, prenatal care visit, parity, study site, child sex, pregnancy onset year, mother's age at delivery and presurgical or pre-pregnancy BMI (continuous). RR, Relative Risk; CI, confidence interval; MBS, Metabolic Bariatric Surgery; BMI, body mass index; AGA, Appropriate for Gestational Age; LGA, Large for Gestational Age; SGA, Small for Gestational Age.

Adjusted RR (95% CI)	MBS vs pre-surgical controls	MBS vs pre-pregnancy controls
SGA (vs AGA)	1.83 (1.56,2.14)	1.73 (1.48,2.03)
LGA (vs AGA)	0.32 (0.26,0.40)	0.43 (0.34,0.53)



Adjusted β coefficient (95% CI)		
Age at BMI peak (month)	0.21 (0.07,0.35)	1.18 (1.09,1.28)
BMI at peak (kg/m²)	0.06 (-0.03,0.14)	0.32 (0.24,0.40)
Average Pre-peak BMI velocity (kg/m²/year)	0.63 (0.60,0.67)	0.20 (0.17,0.24)

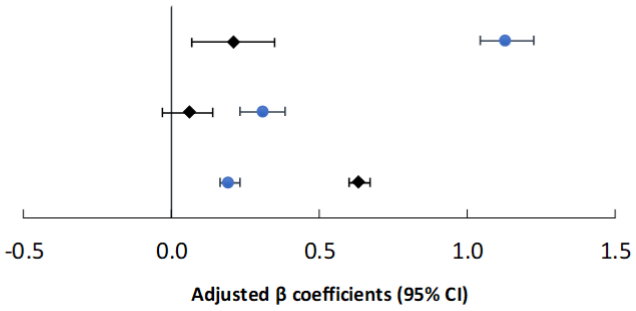


Figure 3: Predicted infant body mass index growth trajectories, ages 2 weeks to 24 months, by maternal study group classification. A) Pre-pregnancy control group only. B) All three maternal groups. BMI: body mass index; MBS: metabolic bariatric surgery; NW: normal weight (BMI 18.5 - 24.9 kg/m^2). OW: overweight (BMI 25 – 29.9 kg/m^2); OB: obesity (BMI ≥ 30 kg/m^2); OB: obesity class 1 (BMI 30 – 34.9 kg/m^2); OB: obesity class 2 (BMI 35 – 39.9 kg/m^2); OB: obesity class 3 (BMI ≥ 40 kg/m^2).

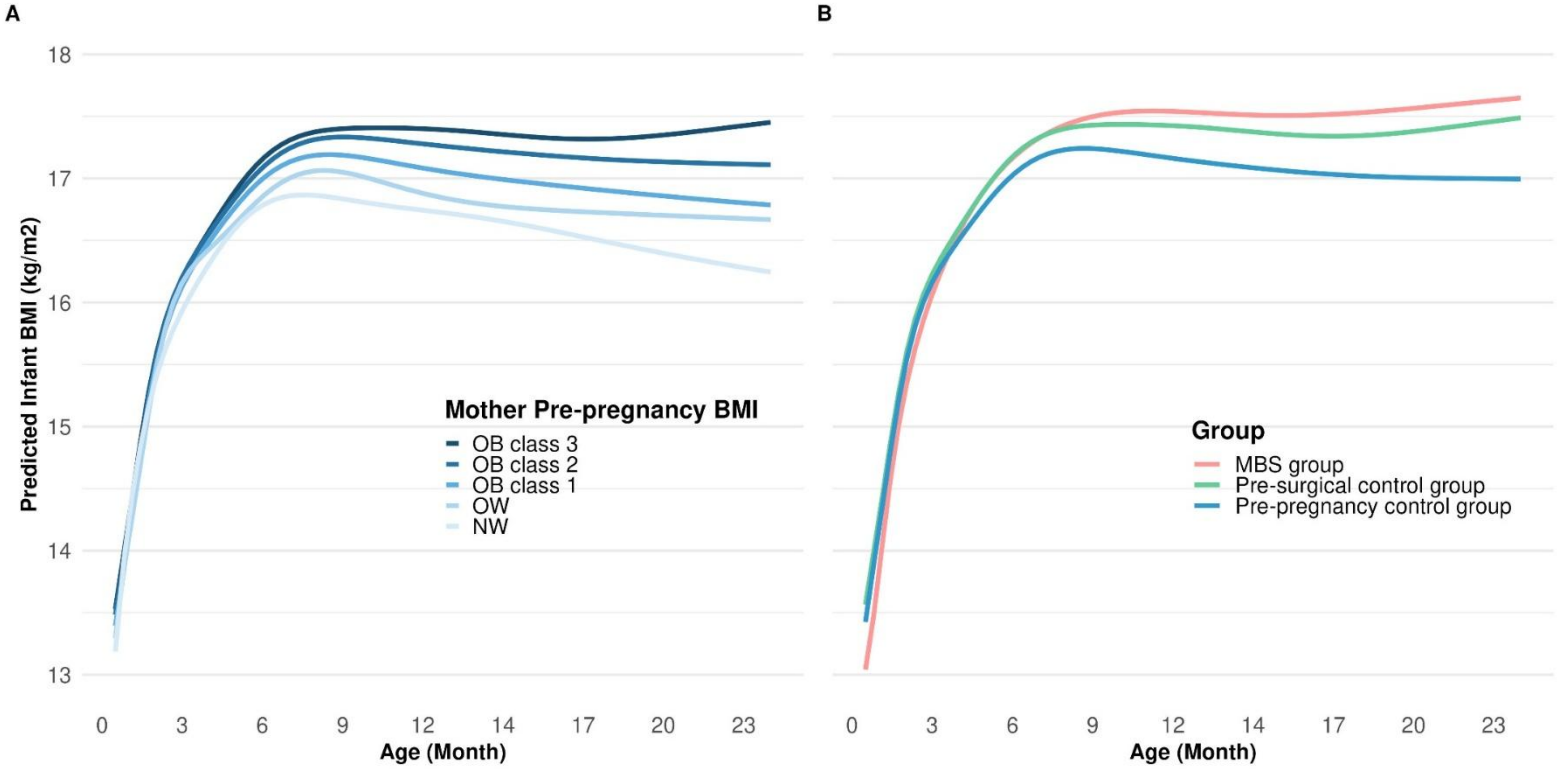


Figure 4. Associations between MBS and differences in child BMI z score at 12 months, 3, and 5 years of age. Values are adjusted β coefficients (95% CI) adjusted for maternal race and ethnicity, insurance type, tobacco use preconception, Neighborhood Deprivation Index, prenatal care visit, parity, study site, child sex, pregnancy onset year, mother's age at delivery and presurgical or pre-pregnancy BMI (continuous). MBS, Metabolic Bariatric Surgery; CI, Confidence Interval.

Adjusted β coefficient (95% CI)	MBS vs pre-surgical controls	MBS vs pre-pregnancy controls
BMIz at 12 months	0.05 (-0.02,0.12)	0.27 (0.20,0.34)
BMIz at 3 years	0.06 (-0.03,0.15)	0.44 (0.36,0.52)
BMIz at 5 years	0.01 (-0.09,0.11)	0.53 (0.44,0.62)

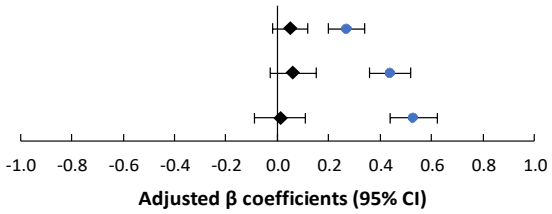
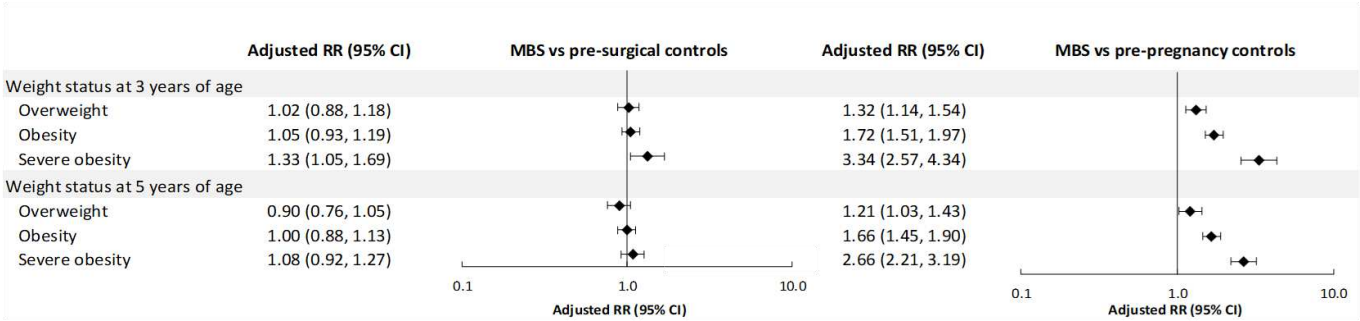


Figure 5. Relative risk (RR) associations between MBS and weight status at 3 and 5 years of age [RR (95% CI)]. Adjusted for maternal race and ethnicity, insurance type, tobacco use preconception, Neighborhood Deprivation Index, prenatal care visit, parity, study site, child sex, pregnancy onset calendar year, mother's age at delivery, and presurgical or pre-pregnancy BMI (continuous). Child weight status defined as: normal weight (≥5th to <85th percentile), overweight (85th to <95th), obesity (95th to <120% of the 95th), and severe obesity (≥120% of the 95th percentile)
MBS, Metabolic Bariatric Surgery; RR, Relative Risk; CI, Confidence Interval.



Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- POSITAim1SupplementaryTablesandFiguresFinalv.2.docx
- POSITAim1TablesFinalv.2.docx