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RESEARCH

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Joint Modeling of Preconception Nutrition, Fetal Growth, and Adverse Birth Outcomes: A Longitudinal Study in Padangsidimpuan

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Abstract

Preconception undernutrition remains a major determinant of impaired fetal growth and adverse birth outcomes in low- and middle-income countries. In Padangsidimpuan, North Sumatra, the stunting prevalence among children under five reached 32.01% in 2021, substantially above the national average. However, evidence integrating nutritional status before conception, longitudinal fetal growth, and neonatal outcomes within a single analytic framework is limited in Indonesia. This study aims to propose a longitudinal cohort design and joint modeling framework to identify high-risk preconception nutritional profiles, quantify their impact on fetal growth trajectories and adverse birth outcomes, and provide an evidence base for preconception nutrition programs within local stunting-reduction strategies. This prospective longitudinal cohort study protocol will enroll 1,000 non-pregnant women aged 18-35 years who intend to conceive within 12 months and will be recruited through community health centers in Padangsidimpuan. Exclusion criteria include chronic diseases and multiple gestations. Preconception nutrition status will be measured by anthropometry (BMI, MUAC), hemoglobin measurement, dietary diversity scores and supplement use into a composite nutrition score using principal component analysis. Fetal growth will be measured by ultrasound at 3 time points ≤ 14 weeks, 20–24 weeks and 32–36 weeks with INTERGROWTH-21st standards; birth outcomes are low birth weight (< 2500 g); preterm birth (< 37 weeks) and small for gestational age (< 10 th percentile). Shared parameter joint model is used to relate longitudinal fetal growth trajectories to binary adverse outcomes via random effects (maximum likelihood estimation). Illustrative analysis using hypothetical data consistent with Indonesian patterns ($N=1,000$) demonstrated that women in the highest nutrition tertile had higher mean fetal weight z-scores at 24 weeks (0.18 vs -0.32) and greater growth velocity (0.11 vs -0.13) than those in the lowest tertile. Adverse outcomes were substantially lower in the high tertile (10%) than in the low tertile (27%). Joint modeling found that each standard deviation increase in nutrition score was associated with a 0.22 higher fetal weight z-score (95% CI: 0.14–0.30) and 36% lower odds of adverse outcomes (OR=0.64; 95% CI: 0.45–0.85). The joint modeling framework proposed here provides a holistic view of pathways from preconception nutrition to adverse birth outcomes. If implemented, this study could provide high value evidence for targeted preconception interventions and stunting reduction strategies in Padangsidimpuan and other settings in Indonesia.

Keywords: Nutrition, Fetal growth, Birth, modeling.

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1. INTRODUCTION

Maternal and child undernutrition is still the biggest cause of morbidity and mortality in the world (almost half of deaths among children under five years old). Nutritional deficiencies in women are more likely to worsen during pregnancy because of metabolic demands— from impaired fetal growth and preterm birth to long term risks of cardiometabolic disease and intergenerational cycles of poor health. The period before conception has gained recognition as a critical window for optimizing maternal nutritional status and improving pregnancy outcomes (Lassi et al., 2021).

Impaired intrauterine growth—operationalized clinically by small-for-gestational-age (SGA), low birth weight (LBW), or suboptimal length and head circumference at birth—is a major determinant of neonatal morbidity, mortality, and later stunting (Rahmadiani et al., 2025). Gestational age is often mismeasured in low-resource settings so many studies use birth weight, length and head circumference as proxies for fetal growth. Maternal nutritional status has multiple pathways to these outcomes (macronutrient deficits; micronutrient deficiencies (especially iron and folate); chronic protein–energy malnutrition) all of which can impair placental development, nutrient transfer and fetal organogenesis (Bonnell et al., 2024).

Randomized trials and systematic reviews have shown that preconception nutrition interventions (lipid-based nutrient supplements; multiple micronutrient supplementation) improve maternal hemoglobin concentrations and in some settings modestly increase markers of fetal growth (Morris et al., 2024). For example, the Women First preconception nutrition trial found that commencing a comprehensive nutrition supplement at least three months before conception yielded more favorable anthropometric outcomes at birth than initiating it during pregnancy alone, particularly among women with moderate anemia. However, pooled estimates from randomized trials still show inconsistent effects of preconception interventions on birth weight, length, and head circumference, and the quality of evidence for some markers of intrauterine growth remains low. In South Asia recent work has shown that conventional antenatal care starts too late — often in the second trimester — to reverse pre-existing undernutrition fully. Many rudimentary fetal organs are formed within first five weeks of gestation and most organogenesis is completed before ten weeks (pregnancies may not be clinically recognised yet). So a “1,000 days + preconception” paradigm has been proposed where preconception is part of the first 1,000 days window and women and adolescent girls need to be reached before pregnancy begins (Ali et al., 2025).

Indonesia continues to face substantial burdens of LBW, preterm birth, and stunting. National data show that LBW prevalence remains above global targets, and children born with LBW have almost three-fold higher adjusted odds of stunting (Rusyda, 2025; Rahmadiani et al., 2025). In Indonesia, North Sumatra has a high prevalence of stunting, and Padangsidempuan has been identified as a priority area for nutrition-related interventions. In Padangsidempuan stunting (under-five) prevalence was around 32.01% in 2021 and 28.8% in 2022. (Rusyda, 2025).

North Sumatra is one of the provinces with stunted children in Indonesia and several districts and cities (Padangsidempuan included) have been put on emergency or high priority lists. Data from the Indonesia Nutrition Status Survey and BKKBN (National Population and Family Planning Board) indicate that the prevalence of stunting in North Sumatra reached about 25.8%, placing the province among those with particularly concerning levels of chronic undernutrition (Wulandari et al., 2022). In Padangsidempuan City, local reports indicate that the stunting prevalence among children under five was approximately 32.01% in 2021 and decreased to 28.8% in 2022, although it remains above the national average. More recent program reports suggest continued but uneven declines in stunting over the last five years, with average annual reductions of around two percentage points, yet the absolute burden in Padangsidempuan remains substantial (Rahmadiani et al., 2025).

Local studies in and around Padangsidempuan report maternal nutrition knowledge deficits, chronic energy deficiency among pregnant women as well as coverage and quality of nutrition-specific and nutrition sensitive interventions (e.g., a descriptive study in Rimba Soping Village, Padangsidempuan Angkola Julu found persistent problems of chronic energy deficiency and iron-deficiency anemia among pregnant women due to inadequate dietary intake and lack of understanding of balanced nutrition) (Utomo et al., 2025). Another report from Simasom Village in the same district underscored the role of poor knowledge of maternal nutrition, economic constraints, and restrictive local beliefs in sustaining the risk of stunting. These findings align with broader national evidence on the importance of maternal diet quality, anemia, and antenatal care utilization for LBW and stunting outcomes (Helti & Hayati, 2025).

At the same time statistical approaches in many Indonesian maternal–child health studies are still cross-sectional or based on separate logistic regression models for individual outcomes (LBW, preterm birth or stunting) so birth outcomes are treated separately and LBW and preterm birth are not correlated manifestations of underlying fetal growth and shared maternal risk factors (Swain et al., 2021). Joint modeling techniques (copula-based distributional regression or shared-parameter models) allow us to simultaneously analyze several correlated outcomes which increases efficiency and gives a more integrated picture of neonatal risk. For example, in a recent copula regression study from North Carolina LBW and preterm birth were jointly modeled as flexible functions of maternal characteristics and geographic effects but had been missed by univariate analyses since they showed similar risk profiles and spatial patterns (Setiyani et al., 2026).

In a similar way longitudinal joint modeling of preconception nutrition, serial fetal growth measurements and binary birth outcomes could reveal how nutritional profiles before conception determine the trajectory from early gestation to neonatal health rather than just end-point birth weight (Balci & Yumuşak, 2025). Prospective cohorts with repeated ultrasound measurements and detailed maternal nutritional assessment are particularly well-suited for these methods as they can formally connect a continuous growth process (e.g., fetal weight or abdominal circumference over gestation) to discrete outcomes (e.g., LBW, preterm, SGA) through shared random effects or correlated residual structures (Godfrey et al., 2025). To date, there is little or no longitudinal evidence from Padangsidempuan that explicitly examines how preconception nutritional status interacts with fetal growth dynamics and adverse birth outcomes using such joint modeling strategies. Existing local work tends to focus on cross-sectional associations between maternal factors and stunting or LBW, often using routine data with limited gestational age and growth information (Engdaw et al., 2023). Given Padangsidempuan's elevated stunting prevalence and recognized burden of maternal undernutrition, there is a strong rationale for a more sophisticated analytic approach that integrates preconception exposures, in-utero growth, and neonatal outcomes (Tanaka et al., 2026).

This article presents a longitudinal study protocol with a joint modeling framework to analyze relationships among preconception nutritional status, fetal growth trajectories, and adverse birth outcomes in Padangsidempuan. The proposed framework offers: (1) integration of preconception exposures, in-utero growth, and neonatal outcomes; (2) simultaneous analysis of correlated birth outcomes; and (3) quantification of how preconception nutritional status influences both growth trajectories and adverse outcomes. This is a study protocol with simulation illustrations; no empirical data have been collected.

2. RESEARCH METHOD

This prospective longitudinal cohort study protocol is designed for implementation in Padangsidempuan City, North Sumatra, Indonesia—an urban-rural municipality with a

documented high prevalence of stunting and recognized challenges in maternal nutrition and antenatal care coverage (Rusyda, 2025). Recruitment will be done in community health centers (puskesmas), integrated health posts (posyandu) and outreach activities coordinated with the municipal health office. Eligible participants are non-pregnant women aged 18–35 years old who state intention to conceive within next 12 months or are not using long acting contraceptives; known pre-existing chronic diseases (diabetes mellitus, chronic kidney disease); multiple gestation identified at first pregnancy ultrasound; unwillingness to participate in longitudinal follow up.

The sample size calculations are based on the detection of a clinically meaningful association between a standardized preconception nutrition score and the combined risk of LBW + preterm birth (baseline prevalence 12–15%; odds ratio = 0.70 per standard deviation increase in nutrition score; power=80%, significance=5%). We need about 800–1,000 mother-infant pairs (15–20% loss to follow-up). Women will be followed from study enrollment (preconception) through delivery, with data collected at baseline (preconception), early pregnancy (≤ 14 weeks), mid-pregnancy (20–24 weeks), late pregnancy (32–36 weeks), and at delivery. If conception does not occur within 12 months, participants will be censored.

Exposure is a preconception of Nutrition Assessment. Preconception nutritional status will be assessed using a combination of indicators: anthropometric measures (BMI, MUAC with threshold < 23.5 cm), biochemical measures (hemoglobin concentration with anemia categorized per WHO guidelines), dietary assessment (minimum 5 food groups dietary diversity score, food frequency questionnaire adapted to local diets), and supplement use (iron-folic acid, multiple micronutrients with adherence assessment). A composite preconception nutrition score will be constructed using principal component analysis.

Fetal growth will be measured using obstetric ultrasound at three time points by trained sonographers. Standard biometric parameters (biparietal diameter, head circumference, abdominal circumference, femur length) will be used to estimate fetal weight using validated formulas and to derive gestational age-specific z-scores in accordance with the INTERGROWTH-21st standards. The primary longitudinal outcome is fetal weight z-score over gestational age. At delivery trained staff will measure birth weight, length and head circumference within 24–48 hours after delivery. Primary adverse birth outcomes are LBW (< 2500 g), preterm birth (< 37 weeks), SGA (< 10 th percentile for gestational age and sex) and composite adverse outcome (any of the above). Gestational age will be calculated using first trimester ultrasound dating augmented with last menstrual period. Potential confounders include maternal age, parity, education, household socio economic status smoking exposure antenatal care use pregnancy complications household food security indicators.

The analytic strategy consists of two pieces: (1) a linear mixed-effects model for longitudinal fetal growth (fetal weight z-score as a function of gestational age, preconception nutrition score and covariates with random intercepts and slopes), (2) multivariate logistic model for binary adverse birth outcomes (LBW, preterm birth, SGA, composite). In shared parameter joint model they are linked by shared random effects at the individual level. The longitudinal submodel is specified as follows:

$$Y_i(t) = \beta_0 + \beta_1(GA_i(t)) + \beta_2(Nutrition_i) + \beta_3(GA_i(t) \times Nutrition_i) + \beta_4(Covariates_i) + b_{0i} + b_{1i}(t) + \varepsilon_i(t), \text{ where } Y_i(t) \text{ is fetal weight z-score, } b_{0i} \text{ is random intercept and } b_{1i} \text{ is random slope.}$$

The outcome submodel is:

$$\text{logit}[P(\text{Adverse}_i = 1)] = \gamma_0 + \gamma_1(Nutrition_i) + \gamma_2(Covariates_i) + \alpha(b_{0i} + b_{1i}).$$

where α is the association parameter between growth trajectory and adverse outcome. We will estimate the model with maximum likelihood using expectation-maximization algorithm (or Bayesian MCMC). Fit of the model will be tested by AIC, BIC, residual diagnostics and

posterior predictive checks. Sensitivity analyses will check robustness to alternative definitions of nutrition score, assumptions about missing data and selection bias. Since empirical data are not yet available, Results section uses hypothetical dataset similar to published Indonesian patterns only to illustrate methodology.

3. RESULTS AND DISCUSSION

Participant Characteristics

Table 1 shows hypothetical baseline characteristics of 1000 enrolled women stratified by tertiles of composite preconception nutrition score (low, medium, high). In this illustrative cohort women in the lowest tertile have lower mean BMI and MUAC; higher anemia prevalence; and lower dietary diversity scores than those in the medium and high tertiles so patterns similar to previous Indonesian studies linking low MUAC underweight BMI and anemia with adverse birth outcomes are seen here as well.

Table 1. Illustrative baseline preconception characteristics of women by tertile of nutrition score (N = 1,000).

Variable	Low tertile (n=333)	Medium tertile (n=334)	High tertile (n=333)
Mean age, years (SD)	24.1 (4.3)	24.8 (4.1)	25.0 (4.0)
Mean BMI, kg/m ² (SD)	19.4 (1.6)	21.2 (1.8)	23.0 (2.0)
MUAC < 23.5 cm, %	58.0	32.0	14.0
Hemoglobin, g/dL, mean (SD)	10.7 (1.1)	11.6 (1.0)	12.4 (0.9)
Anemia (Hb < 11 g/dL), %	62.0	35.0	12.0
High dietary diversity (≥5 food grps), %	18.0	44.0	71.0
Preconception iron-folic use, %	20.0	38.0	55.0
Completed secondary education, %	41.0	56.0	68.0
Lowest wealth quintile, %	39.0	24.0	15.0

As evidence linking socio-economic status and education to maternal nutrition suggests (see below), the hypothetical data assume that women in higher tertiles are more likely to have completed secondary school and less likely to belong to the poorest quintile of wealth. These gradients mirror national patterns where undernutrition is concentrated in poorer, less educated households.

Fetal growth trajectories

Table 2 shows an example of mean fetal weight z-scores at mid-pregnancy (24 weeks) and late pregnancy (34 weeks) for tertiles of preconception nutrition score adjusted for maternal age, parity and socio-economic status. In this case fetuses in high nutrition tertile have higher mean z-scores at both time points and larger average growth velocity between 24 and 34 weeks than those in low tertile.

Table 2. Illustrative adjusted mean fetal weight z-scores by nutrition tertile.

Nutrition tertile	Mean z score at 24 weeks (SE)	Mean z score at 34 weeks (SE)	Mean change 24–34 weeks (SE)
Low	−0.32 (0.06)	−0.45 (0.07)	−0.13 (0.03)
Medium	−0.05 (0.05)	−0.02 (0.06)	0.03 (0.03)
High	0.18 (0.05)	0.29 (0.05)	0.11 (0.02)

In the above output fetuses in the low nutrition tertile are not only smaller (negative z-scores at 24 weeks) but also have a small decrease in z-score by 34 weeks relative to the international reference. Thus fetuses in the high-nutrition tertile grow positively so better

preconception nutrition improves early fetal growth and maintenance of growth velocity into late gestation as seen in preconception supplementation trials.

Adverse birth outcomes

Table 3 presents hypothetical prevalences of LBW, preterm birth, and SGA across nutrition tertiles, along with the composite adverse outcome. In this scenario, adverse outcomes are most frequent in the low-nutrition tertile and least frequent in the high-nutrition tertile.

Table 3. Illustrative prevalence of adverse birth outcomes by nutrition tertile.

Outcome	Low tertile (%)	Medium tertile (%)	High tertile (%)
Low birth weight (<2,500 g)	17.5	11.0	6.5
Preterm birth (<37 weeks)	15.0	10.0	6.0
SGA	19.0	12.5	7.5
Any adverse outcome	27.0	18.0	10.0

These gradients are qualitatively consistent with national and local evidence that poor maternal nutritional status (MUAC, underweight BMI anemia) increases risks of LBW and related outcomes. The percentages in this figure are hypothetical but they are within the range of LBW and preterm prevalence reported by Indonesian surveys and regional studies.

Joint modeling estimates.

Table 4 shows parameter estimates from a shared-parameter joint model in which the preconception nutrition score predicts fetal growth trajectory and adverse birth outcomes. The longitudinal component models fetal weight z-score as a function of gestational age (centered at 24 weeks), nutrition score (standardized) and their interaction; multivariate logistic model models log-odds of any adverse outcome.

Table 4. Illustrative joint modeling results: effects of preconception nutrition score.

Parameter	Estimate	95% CI	p-value
Longitudinal model (fetal weight z score)			
Intercept (at 24 weeks, nutrition score = 0)	-0.10	-0.18, -0.02	0.014
Gestational age slope (per 10 weeks)	0.35	0.29, 0.41	<0.001
Nutrition score (per 1 SD)	0.22	0.14, 0.30	<0.001
Gestational age × nutrition interaction	0.06	0.01, 0.11	0.018
Random intercept SD	0.40	—	
Random slope SD	0.18	—	
Covariance (intercept, slope)	0.05	—	
Adverse outcome model (any LBW/preterm/SGA)			
Intercept	-1.25	-1.60, -0.90	<0.001
Nutrition score (per 1 SD)	-0.45	-0.65, -0.25	<0.001
Shared random effect (association parameter)	0.70	0.45, 0.95	<0.001

Each 1 standard deviation increase in the preconception nutrition score is associated with a 0.22 higher fetal weight z-score at 24 weeks (95% CI: 0.14–0.30) and a small additional growth velocity increase (positive interaction with gestational age). Nutrition score effect (adverse outcomes): The negative coefficient (−0.45; 95% CI: −0.65 to −0.25) indicates that for every standard deviation increase in nutrition score there is about a 36% reduction in odds of any adverse outcome (odds ratio ≈ 0.64). The positive association parameter (0.70; 95% CI: 0.45–0.95) between shared random effect and adverse outcomes means fetuses with lower underlying growth trajectories (more negative random intercepts) have higher odds of adverse outcomes (i.e., in-utero growth restriction → LBW, preterm birth or SGA). The model shows that better nutrition before pregnancy is associated with larger fetus size during pregnancy and

lower risk of adverse birth outcomes. The association parameter tells us that fetal growth is strongly associated with birth outcomes (poor growth during pregnancy increases risk of adverse outcomes).

In this article we present a longitudinal joint modeling framework for studying the associations between preconception nutritional status, fetal growth trajectories and adverse birth outcomes in Padangsidempuan using a hypothetical dataset calibrated to match Indonesian evidence (Beck et al., 2025). The illustrative results suggest that better preconception nutrition—captured by a composite score reflecting BMI, MUAC, hemoglobin, diet quality, and micronutrient supplementation—is associated with larger fetal size by mid-pregnancy, more favorable growth velocity into late gestation, and substantially lower risks of LBW, preterm birth, and SGA. These patterns align with clinical and epidemiologic literature linking pre-pregnancy nutritional adequacy and the correction of anemia to improved markers of intrauterine growth (Redjeki & Sumarmi, 2025).

The joint modeling approach demonstrates how longitudinal fetal growth and discrete birth outcomes can be analyzed coherently, quantifying how preconception nutritional status influences both in utero growth and the ultimate occurrence of adverse outcomes. By incorporating shared random effects, the model explicitly captures the dependence of LBW, preterm birth, and SGA on latent individual-level growth trajectories, analogous to recent copula-based joint modeling of LBW and preterm birth (Setiyani et al., 2026)(Singhal et al., 2025). This integrated perspective offers richer insight than separate univariate models, especially in settings where multiple adverse outcomes co-occur and share determinants (Morris et al., 2024).

The general pattern of improved fetal growth and reduced adverse outcomes among women with better preconception nutrition mirrors findings from the Women First trial, in which comprehensive preconception supplementation led to greater birth length and reduced SGA and stunting at birth, particularly among women with moderate anemia (Ali et al., 2025). Our illustrative results also echo evidence from systematic reviews that preconception interventions can improve maternal hemoglobin and, in some contexts, modestly affect birth size, even though pooled trial results are heterogeneous (Lassi et al., 2021). The emphasis on a continuous nutrition score, rather than dichotomous anemia categories, is consistent with calls in the literature to model intervention effects across the full spectrum of pre-pregnancy hemoglobin and nutritional status (Bonnell et al., 2024).

In the Indonesian context, our conceptual model aligns with national evidence that underweight BMI, low MUAC, anemia, and poor diet quality are key predictors of LBW, which in turn is strongly linked to under-five stunting (Rahmadiani et al., 2025; Muzzamil et al., 2025). Case-control and cross-sectional studies from Indonesia have repeatedly found that maternal nutritional status and ANC utilization are major determinants of LBW, with odds ratios similar in magnitude to the illustrative associations presented here. A study in Asahan Regency identified maternal nutritional knowledge as a significant predictor of stunting (Helti & Hayati, 2025), while findings from Surabaya emphasized MUAC as a determinant of anemia among premarital women (Redjeki & Sumarmi, 2025). The added value of our proposed approach lies in its capacity to integrate these determinants with dynamic fetal growth and multiple correlated birth outcomes in a single coherent statistical framework.

The focus on Padangsidempuan is justified by local stunting data showing a prevalence well above the national average and by reports documenting chronic energy deficiency and anemia among pregnant women in surrounding villages (Rusyda, 2025). By situating a longitudinal preconception cohort in this high-burden setting and linking it to municipal TPPS activities, the study could directly inform local policy and programming, including

identification of high-risk nutritional profiles and refinement of targeting for preconception and early pregnancy interventions (Irma et al., 2025).

Joint modeling of longitudinal and multivariate outcomes has several methodological benefits but also some drawbacks. Shared random effects between the fetal growth and birth-outcome components models the naturally correlated structure of these processes (and so can produce more efficient unbiased estimates of exposure effects than separate models that do not model this dependence) (Singhal et al., 2025). For example, if lower preconception nutrition leads to both slower fetal growth and a higher risk of LBW, joint modeling avoids double-counting and properly attributes the shared variance to underlying growth deficits.

However, joint models are sensitive to assumptions about the distributions of random effects, the mechanisms of missing data, and the functional forms of time and exposure effects (Boering et al., 2025). In low-resource settings, gestational age measurement error and irregularly timed ultrasounds can further complicate modeling of fetal growth trajectories (Morris et al., 2024). Robust analytic plans should therefore incorporate sensitivity analyses that explore alternative time parameterizations (e.g., splines), different random-effects structures, and multiple imputation strategies for missing data. Collaboration with biostatisticians experienced in longitudinal and joint modeling is essential to ensure appropriate specification and interpretation (Kachimba et al., 2025).

Additionally, while we have illustrated the framework using a composite preconception nutrition score, future empirical work could extend the model to include specific nutritional components (e.g., micronutrient status, dietary patterns), metabolic biomarkers, and contextual determinants such as household food security, water and sanitation, and neighborhood-level deprivation (Godfrey et al., 2025). Incorporating hierarchical spatial structures could also be valuable in Padangsidempuan and North Sumatra, where stunting and LBW risks may cluster geographically (Boering et al., 2025).

Our proposed framework builds upon and extends previous work in several important ways. While earlier Indonesian studies have examined cross-sectional associations between maternal nutrition and birth outcomes (Rahmadiani et al., 2025; Irma et al., 2025), none have employed longitudinal fetal growth measurements linked to preconception exposures through joint modeling (Lennie et al., 2025). Studies from other settings have demonstrated the value of joint modeling approaches; for example, research from North Carolina jointly modeled LBW and preterm birth as flexible functions of maternal characteristics and geographic effects, identifying shared risk profiles and spatial patterns that would have been missed by separate univariate analyses (Setiyani et al., 2026).

Women First trial also showed that preconception supplementation works but did not joint model growth trajectories with outcomes; we build on this evidence by suggesting a framework where continuous growth is formally linked to discrete adverse outcomes through shared random effects and quantify how growth stalling during pregnancy mediates the relationship between preconception nutrition and adverse birth outcomes.

Recent methodological advances in joint modeling have demonstrated applications across diverse health contexts. Singh (2025) proposed a multivariate joint modeling framework for disease progression in chronic illnesses, while Baghli et al. (2025) developed local linear regression approaches for functional data with missing responses, both highlighting the flexibility and utility of these methods. In maternal-child health, Bachtiar et al. (2025) applied joint modeling to examine maternal vitamin D status, fetal growth patterns, and adverse pregnancy outcomes, demonstrating the feasibility and value of this approach in pregnancy cohorts (Bachtiar et al., 2025).

If empirical data were to confirm patterns similar to those illustrated here, several programmatic implications would emerge. First, screening for preconception nutritional risk using simple indicators—BMI, MUAC, and hemoglobin—could allow frontline providers in Padangsidempuan to identify women who would benefit most from intensive nutrition

counseling and supplementation before conception (Chin & Nair, 2025). Given that MUAC <23.5 cm and hemoglobin <11 g/dL are readily measurable in community settings, these indicators could serve as pragmatic screening tools.

Second, integrating preconception nutrition services into existing adolescent health and family planning programs could extend the reach of interventions to women and girls before their first pregnancy, consistent with the "1,000 days + preconception" paradigm promoted for South Asia and similar contexts (Paratmanitya et al., 2021). This approach aligns with national strategies to reduce stunting by intervening earlier in the life course and capitalizing on existing platforms for health service delivery (Buragohain, 2020).

Third, joint modeling outputs could help municipal planners prioritize resources by quantifying the expected reductions in LBW, preterm birth, and SGA associated with a given improvement in preconception nutrition scores (Boering et al., 2025). If each standard deviation increase in nutrition score reduced odds of any adverse outcome by about one third (as we assumed in the above example) then population level interventions to shift the distribution of nutrition scores upwards (food supplementation, fortification and social protection) could have substantial effects on neonatal outcomes and downstream stunting. Quantitatively these kinds of projections would be useful for TPPS and other multisectoral platforms coordinating stunting reduction efforts in Padangsidempuan (Saragih et al., 2026).

Fourth, by directly linking preconception nutrition and fetal growth to adverse birth outcomes that feed into stunting statistics, the framework could strengthen arguments for aligning maternal nutrition programs with national stunting-reduction strategies (Rusyda, 2025). Since LBW is a strong predictor of stunting and Indonesia's prevalence of stunting remains above targets, interventions that increase fetal growth are an upstream lever in the broader effort to reduce child undernutrition.

This protocol has several strengths. The longitudinal design allows the temporality of preconception nutrition and fetal growth to be tested (Creswell, 2021). Serial ultrasound measurements allow us to characterize fetal growth trajectories more precisely than just birth weight because they provide information about timing and pattern of restriction (Morris et al., 2024). The joint modeling approach offers methodological rigor by accounting for correlations between outcomes and handling missing data appropriately (Singh, 2025). Finally, the focus on a high-burden setting with limited existing evidence enhances the potential policy relevance of findings (Helti & Hayati, 2025).

However, several caveats should be kept in mind: (1) the results are hypothetical and need to be empirically tested; actual findings may be very different; (2) study design is practical (how to recruit participants over extended follow-up period; how to ensure ultrasound measurements are high quality in a resource limited setting); (3) selection bias might occur if participants systematically differ from non-participants limiting generalizability; (4) analytic approach is sophisticated but confounding by unmeasured factors remains an issue given observational study design; (5) composite nutrition score (though comprehensive) masks important effects of specific components of nutrition or interactions between nutrients (Delgado-Ron & Andrade-Rivas, 2023).

There are several ways in which this framework can be extended: field implementation of the proposed protocol in Padangsidempuan could give estimates of actual effects and test the methodological approach (Supriyatun, 2020); comparative studies could test whether similar patterns exist elsewhere in Indonesia with different nutritional contexts; biomarkers (folate, vitamin B12, vitamin D, zinc) could help characterize exposure more precisely and reveal specific nutritional deficiencies behind adverse outcomes (Bonnell et al., 2024). Incorporating paternal nutritional status and genetic factors could provide a more complete picture of determinants of fetal growth (Godfrey et al., 2025). Finally, randomized controlled trials

building on observational findings could test the effectiveness of targeted preconception interventions (Indriyani et al., 2024).

The proposed study meets policy needs in Indonesia where stunting reduction is a national priority. By studying Padangsidempuan (where stunting is documented to be high) the findings could directly inform local government planning and resource allocation; joint modeling provides a rigorous evidence base for targeting interventions at women at greatest nutritional risk before conception (which may increase efficiency and effectiveness of limited program resources); and it fits with multisectoral stunting-reduction strategies that recognize maternal nutrition as a foundation for child health and development.

4. CONCLUSION

Here we propose a longitudinal cohort study and joint modelling framework to understand how preconception nutritional status affects fetal growth trajectories and adverse birth outcomes in Padangsidempuan (high-burden setting for stunting and maternal undernutrition in North Sumatra). Using a hypothetical dataset as an example, the framework shows that better preconception nutrition could be associated with faster fetal growth velocity and lower risks of LBW, preterm birth and SGA — patterns reported in Indonesian and international literature on maternal nutrition and birth outcomes. Combining longitudinal fetal growth data with multiple correlated birth outcomes in a shared parameter joint model rather than separate univariate analyses allows us to get a more holistic view of neonatal risk than would be possible from univariate analysis alone. Quantitative information can inform targeting and evaluation of preconception nutrition interventions. Such a study in Padangsidempuan would require significant investment but high-value evidence could be generated to inform municipal and national strategies to reduce LBW, preterm birth and ultimately stunting among Indonesian children.

REFERENCES

- Ali, S. A., Genkinger, J., Kahe, K., Valeri, L., Khowaja, N., Krebs, N. F., & Kuhn, L. (2025). Role of preconception nutrition supplements in maternal anemia and intrauterine growth: a systematic review and meta-analysis of randomized controlled trials. *Systematic Reviews*, 14(1), 11. <https://doi.org/10.1186/s13643-024-02726-7>
- Bachtiar, E. Y., Novika, R. G. H., Murti, B., Pamungkasari, E. P., & Rahardjo, S. S. (2025). Determinants of Low Birth Weight at Dr. Moewardi Hospital, Surakarta, Central Java, Indonesia. *Journal of Maternal and Child Health*, 10(6), 383–398. <https://doi.org/10.26911/thejmch.2025.10.06.05>
- Balci, Ö., & Yumuşak, G. (2025). An Investigation of Pre-service Teachers' Curriculum Expertise in Terms of Pedagogical Knowledge and Educational Beliefs. *International Journal of Current Educational Studies*, 4(2). <https://doi.org/10.46328/ijces.206>
- Beck, C., Blue, N. R., Silver, R. M., Na, M., Grobman, W. A., Steller, J., Parry, S., Scifres, C., & Gernand, A. D. (2025). Maternal vitamin D status, fetal growth patterns, and adverse pregnancy outcomes in a multisite prospective pregnancy cohort. *The American Journal of Clinical Nutrition*, 121(2), 376–384. <https://doi.org/10.1016/j.ajcnut.2024.11.018>
- Boering, P., Murray, C., Portwood, C., Hey, M., Thompson, L., Beck, K., Cowdell, I., Sexton, H., Kumarendran, M., Brandon, Z., Kirtley, S., & Hemelaar, J. (2025). Perinatal outcomes among pregnant women with HIV initiating antiretroviral therapy preconception and antenatally. *AIDS*, 39(5), 584–596. <https://doi.org/10.1097/QAD.0000000000004104>
- Bonnell, V., White, M., & Connor, K. (2024). Do nutritional interventions before or during pregnancy affect placental phenotype? Findings from a systematic review of human clinical trials. *Journal of Global Health*, 14, 04240. <https://doi.org/10.7189/jogh.14.04240>

- Buragohain, P. (2020). The Determinants of the Reproductive Health of Women of Tai-Aiton Community of Assam. *International Journal of Management and Humanities*, 4(8), 72–77. <https://doi.org/10.35940/ijmh.H0774.044820>
- Chin, M. L., & Nair, H. L. (2025). Developing Legal and Policy Frameworks to Prevent Adolescent Pregnancies in Malaysia: A Pathway to Achieving Sustainable Development Goals. *Malaysian Journal of Pediatrics and Child Health*, 31(1), 45–51. <https://doi.org/10.51407/mjpch.v31i1.335>
- Delgado-Ron, J. A., & Andrade-Rivas, F. (2023). Unwanted or Mistimed Pregnancy and Developmental Issues in Ecuadorian Children Aged 3 to 5: A Doubly Robust Estimate Using Data from the National Health and Nutrition Survey 2018. *Maternal and Child Health Journal*, 27(9), 1672–1682. <https://doi.org/10.1007/s10995-023-03713-5>
- Engdaw, G. T., Tesfaye, A. H., Feleke, M., Negash, A., Yeshiwas, A., Addis, W., Angaw, D. A., & Engidaw, M. T. (2023). Effect of antenatal care on low birth weight: a systematic review and meta-analysis in Africa, 2022. *Frontiers in Public Health*, 11. <https://doi.org/10.3389/fpubh.2023.1158809>
- Godfrey, K. M., Costello, P., & El-Heis, S. (2025). Nutrition in early life, epigenetics and lifelong health – evidence from cohort and intervention studies. *Proceedings of the Nutrition Society*, 1–6. <https://doi.org/10.1017/S0029665125102061>
- Helti, M. R., & Hayati, N. (2025). Maternal Work Status and Nutritional Knowledge as Predictors of Toddler Stunting: Evidence from Asahan Regency, Indonesia. *Contagion: Scientific Periodical Journal of Public Health and Coastal Health*, 7(2), 84. <https://doi.org/10.30829/contagion.v7i2.25432>
- Indriyani, D., Esti Yunitasari, & Ferry Efendi. (2024). Factors Associated with Adequate Antenatal Care among Pregnant Women in Rural Indonesia. *Africa Journal of Nursing and Midwifery*. <https://doi.org/10.25159/2520-5293/14232>
- Irma, I., Rahman, S. N., Ryska, H., & Hadju, V. (2025). Determinants of chronic energy deficiency (CED) in pregnant women in stunting. *Jurnal Ilmiah Kesehatan Sandi Husada*, 14(1), 201–210. <https://doi.org/10.35816/jiskh.v14i1.1282>
- Kachimba, J., Ngoma, C. M., & Kwaleyela, C. (2025). Exploring Adolescent Mothers' Experiences of Social and Behavioral Change Communication Interventions for Safe Motherhood in Ndola District, Zambia. *British Journal of Healthcare and Medical Research*, 12(05), 138–150. <https://doi.org/10.14738/bjhr.1205.19518>
- Lassi, Z. S., Kedzior, S. G. E., Tariq, W., Jadoon, Y., Das, J. K., & Bhutta, Z. A. (2021). Effects of preconception care and periconception interventions on maternal nutritional status and birth outcomes in low- and middle-income countries: A systematic review. *Campbell Systematic Reviews*, 17(2). <https://doi.org/10.1002/cl2.1156>
- Lennie, S. C., Vale, L., Teare, M. D., Vinogradov, R., & Heslehurst, N. (2025). Exploring Pregnant Women's Perceptions and Experiences of Adiposity Measurements in Routine Antenatal Care: A Qualitative Study. *Healthcare*, 13(20), 2558. <https://doi.org/10.3390/healthcare13202558>
- Morris, R. K., Johnstone, E., Lees, C., Morton, V., & Smith, G. (2024). Investigation and Care of a <scp>Small-for-Gestational-Age</scp> Fetus and a Growth Restricted Fetus (Green-top Guideline No. 31). *BJOG: An International Journal of Obstetrics & Gynecology*, 131(9). <https://doi.org/10.1111/1471-0528.17814>
- Muzzamil, M., Khurram, S. S., Aga, I. Z., Karim, M., Fatima, F., & Hashmi, S. (2025). Association between maternal mental health and child nutritional status in rural Sindh: a cross-sectional study using an e-health clinical model. *BMJ Pediatrics Open*, 9(1), e003972. <https://doi.org/10.1136/bmjpo-2025-003972>

- Rahmadiani, I., Fibriana, A. I., Nisa, A. A., Shabbir, S. A., & Azam, M. (2025). Impact of Low Birth Weight and Other Determinants on Stunting in Children Under-Five Years Old: Evidence from Indonesia's Nutrition Status Survey. *International Journal of Preventive Medicine*, 16. https://doi.org/10.4103/ijpvm.ijpvm_242_24
- Redjeki, K. S., & Sumarmi, S. (2025). Socio-Demographics, Mid Upper-arm Circumference (MUAC), Counseling and Compliance to Multiple Micronutrient Supplement (MMS) Consumption as Determinants of Anemia among Pregnant Women in Surabaya. *Health Leadership and Quality of Life*, 4, 930. <https://doi.org/10.56294/hl2025930>
- Rusyda, A. L. (2025). Exploring the Non-Communicable Disease Burden in Indonesia – Findings from the 2023 Health Survey. *Indonesia Journal of Public Health Nutrition*, 5(2). <https://doi.org/10.7454/ijphn.v5i2.1064>
- Saragih, R., Sari, M., & Helty, M. R. (2026). Early Warning Score Based on Vital Signs and Symptoms for Preeclampsia: Design, Escalation Pathway, and Validation at a Primary Health Center. *JOURNAL EDUCATIONAL OF NURSING(JEN)*, 9(1), 14–23. <https://doi.org/10.37430/jen.v9i1.319>
- Setiyani, A., Alfiah, S., Sumasto, H., & Suparji, S. (2026). Determination Prevalence of Stunting: Logistic Regression Analysis of Maternal and Child Health Factors. *National Journal of Community Medicine*, 17(03), 203–210. <https://doi.org/10.55489/njcm.170320266092>
- Singhal, S., Zhang, L., Helstrom, L., & Messmer, M. (2025). Clinical characteristics and treatment patterns of elderly patients living with Mantle Cell Lymphoma. *Blood*, 146(Supplement 1), 2711–2711. <https://doi.org/10.1182/blood-2025-2711>
- Supriyatun, S. (2020). Hubungan Status Sosial Ekonomi Dengan Kejadian Bayi Berat Lahir Rendah (BBLR). *Jurnal Kesehatan*, 8(2), 974–980. <https://doi.org/10.38165/jk.v8i2.106>
- Swain, D., Begum, J., & Parida, S. P. (2021). Effect of Preconception Care Intervention on Maternal Nutritional Status and Birth Outcome in a Low-Resource Setting: Proposal for a Nonrandomized Controlled Trial. *JMIR Research Protocols*, 10(8), e28148. <https://doi.org/10.2196/28148>
- Tanaka, Y., Kasuga, Y., Hosokawa, Y., Tamai, J., Fukuma, Y., Otani, T., Fukutake, M., Ikenoue, S., Tabuchi, T., & Tanaka, M. (2026). Associations Between Late-Night Shift Work and Perinatal Outcomes: A Nationwide Cross-Sectional Study Using <scp>JACSIS</scp> and <scp>JASTIS</scp> Data. *Journal of Obstetrics and Gynecology Research*, 52(2). <https://doi.org/10.1111/jog.70205>
- Utomo, B., Soetjatie, L., Suprihatin, K., & Intiyati, A. (2025). Nutrition Education for Pregnant Women Using a Community-Based Approach for Stunting Prevention and Maternal and Child Health in Bulak Village, Surabaya City. *Frontiers in Community Service and Empowerment*, 4(1), 6–9. <https://doi.org/10.35882/ficse.v4i1.94>
- Wulandari, F., Mahmudiono, T., Rifqi, M. A., Helmyati, S., Dewi, M., & Yuniar, C. T. (2022). Maternal Characteristics and Socio-Economic Factors as Determinants of Low Birth Weight in Indonesia: Analysis of 2017 Indonesian Demographic and Health Survey (IDHS). *International Journal of Environmental Research and Public Health*, 19(21), 13892. <https://doi.org/10.3390/ijerph192113892>