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A HYBRID MATHEMATICAL FRAMEWORK FOR SIMULATING HORMONAL DYNAMICS, STRESS RESILIENCE, AND CORTISOL RHYTHMICITY DURING PREGNANCY

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Abstract. Hormonal dynamics during pregnancy are governed by complex physiological, psychological, and environmental interactions. Cortisol, a key effector of the hypothalamic pituitary adrenal (HPA) axis, plays a critical role in maternal stress adaptation and fetal development. This study presents an integrated mathematical modeling approach that combines deterministic and probabilistic frameworks to simulate hormone behavior and systemic stress responses. The framework includes (1) a Kolmogorov system of differential equations to describe transitions among active, intermediate, and degraded hormone states; (2) a Gompertz-Fréchet distribution to capture the variability in hormone degradation timing; (3) an inverted gamma distribution to evaluate stress-strength reliability; and (4) a Weibull distribution to model hormonal lifetime. Simulated cortisol profiles across three trimesters of pregnancy demonstrate the utility of this hybrid framework in reproducing circadian patterns and gestational elevation in hormone levels. The models collectively support a mechanistic understanding of endocrine kinetics and provide predictive tools for analyzing hormone resilience, therapeutic windows, and risk factors for adverse birth outcomes.