

Social Determinants of Health and Immune Response to Routine Childhood Vaccination

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Received: 08-12-2025 / Revised: 05-01-2026 / Accepted: 07-02-2026

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Conflict of interest: Nil

Abstract:

Background: Childhood vaccination remains one of the most effective public health interventions globally. However, variability in immune responses among vaccinated children suggests that factors beyond vaccine formulation and administration influence immunogenicity. Social determinants of health (SDOH)—including household income, parental education, nutritional status, housing conditions, and access to healthcare—may modulate vaccine-induced immunity through complex biological and behavioral pathways. Despite growing recognition of health inequities, the relationship between SDOH and vaccine immunogenicity in children remains insufficiently characterized.

Methods: A cross-sectional analytical study was conducted among 412 children aged 12–24 months attending primary healthcare centers in an urban setting. Sociodemographic data were collected using a structured questionnaire addressing household income, parental education, housing density, food security, and healthcare access. Nutritional status was assessed anthropometrically. Serum antibody titers against measles, diphtheria, and hepatitis B were measured using enzyme-linked immunosorbent assay (ELISA). Multivariate logistic regression was used to identify independent predictors of suboptimal immune response.

Results: Among participants, 23.1% demonstrated suboptimal antibody titers to at least one antigen. Children from low-income households had significantly lower geometric mean titers (GMTs) for measles ($1,245 \pm 487$ vs. $2,118 \pm 612$ mIU/mL; $p < 0.001$) and diphtheria (0.82 ± 0.34 vs. 1.47 ± 0.51 IU/mL; $p < 0.001$) compared to higher-income counterparts. Stunting (OR = 2.31; 95% CI: 1.42–3.76; $p = 0.001$), low maternal education (OR = 1.89; 95% CI: 1.18–3.02; $p = 0.008$), and food insecurity (OR = 2.14; 95% CI: 1.33–3.44; $p = 0.002$) were independent predictors of suboptimal immune response.

Conclusion: Social determinants of health significantly influence immune responses to routine childhood vaccinations. Addressing socioeconomic inequities may enhance vaccination effectiveness and reduce disparities in vaccine-preventable disease burden.

Keywords: Social Determinants of Health; Childhood Vaccination; Immune Response; Antibody Titers; Health Equity; Immunogenicity; Nutritional Status.

DOI: 10.25258/ijcpr.18.2.34

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Introduction

Vaccination is widely recognized as one of the most cost-effective public health interventions, preventing an estimated 2–3 million deaths annually from vaccine-preventable diseases [1]. The Expanded Programme on Immunization (EPI), established by the World Health Organization (WHO) in 1974, has dramatically improved global immunization coverage, yet disparities in vaccine effectiveness persist across populations [2]. While immunization coverage has been the primary metric for evaluating vaccination programs, growing evidence suggests that achieving high coverage does not universally translate into adequate population immunity [3].

Immune responses to vaccination are influenced by a multitude of factors, including host genetics, age at vaccination, nutritional status, co-infections, and environmental exposures [4]. The concept of social determinants of health (SDOH), defined by the WHO as the conditions in which people are born, grow, live, work, and age, has gained considerable traction in public health discourse [5]. These determinants—encompassing socioeconomic status, education, neighborhood and physical environment, employment, social support networks, and access to healthcare—shape health outcomes through interrelated biological, behavioral, and systemic pathways [6].

Several studies have demonstrated that socioeconomic disadvantage is associated with impaired immune function. Chronic psychosocial stress associated with poverty has been shown to elevate cortisol levels and promote a pro-inflammatory state that may attenuate vaccine-induced adaptive immunity [7]. Nutritional deficiencies, particularly in micronutrients such as zinc, vitamin A, and iron, are prevalent among socioeconomically disadvantaged populations and have been linked to diminished antibody responses following vaccination [8]. A landmark study by Grassly et al. demonstrated that oral polio vaccine immunogenicity was significantly lower in low-income settings, attributable in part to enteropathy and concurrent enteric infections [9].

Maternal education has emerged as a critical determinant of child health outcomes, influencing healthcare-seeking behavior, adherence to vaccination schedules, nutritional practices, and hygiene standards [10]. Housing conditions, including overcrowding and inadequate sanitation, increase exposure to infectious agents that may compete with vaccine antigens for immune system resources [11]. Food insecurity, a manifestation of socioeconomic deprivation, contributes to chronic undernutrition and micronutrient deficiencies that compromise immune competence [12].

Despite this theoretical framework, empirical evidence directly linking specific social determinants to quantitative measures of vaccine-induced immunity in children remains limited. Most existing studies have focused on vaccine coverage or clinical disease outcomes rather than serological markers of immune response [13]. Furthermore, the majority of available evidence originates from high-income settings, limiting generalizability to populations where the burden of SDOH-related health inequities is greatest [14].

The aim of this study was to investigate the association between social determinants of health—including household income, parental education level, nutritional status, food security, housing density, and healthcare accessibility—and immune response to routine childhood vaccinations (measles, diphtheria, and hepatitis B) among children aged 12–24 months attending primary healthcare facilities.

Materials and Methods

Study Design and Setting: A cross-sectional analytical study was conducted at six primary healthcare centers serving diverse socioeconomic populations within a urban area.

Study Population and Sample Size: The target population comprised children aged 12–24 months who had completed their primary vaccination series according to the national immunization schedule,

including at least one dose of measles-containing vaccine (MCV1), three doses of diphtheria-tetanus-pertussis (DTP) vaccine, and three doses of hepatitis B vaccine. Sample size was calculated using the formula for estimating a single proportion, assuming a prevalence of suboptimal immune response of 25%, a 95% confidence level, a margin of error of 5%, and a 15% non-response rate, yielding a minimum required sample of 398 participants. A total of 412 children were enrolled.

Inclusion and Exclusion Criteria: Inclusion criteria were: age 12–24 months, completion of primary vaccination series with documented proof, and parental or guardian consent for participation. Exclusion criteria were: known primary or secondary immunodeficiency, chronic systemic illness (e.g., congenital heart disease, chronic renal failure), receipt of immunosuppressive therapy or blood products within the preceding six months, and acute febrile illness at the time of enrollment.

Data Collection Tools: A structured, interviewer-administered questionnaire was used to collect sociodemographic data, including child age and sex, household monthly income (categorized as low: <\$500, middle: \$500–1,500, high: >\$1,500), highest parental education level (primary/none, secondary, tertiary), housing density (persons per room), food security status (assessed using the Household Food Insecurity Access Scale [HFIAS]), and healthcare access (distance to nearest health facility and frequency of well-child visits). Nutritional status was assessed by measuring weight-for-age (WAZ), height-for-age (HAZ), and weight-for-height (WHZ) z-scores according to WHO growth standards. Stunting was defined as HAZ < -2, underweight as WAZ < -2, and wasting as WHZ < -2.

Serological Assessment: Venous blood samples (3 mL) were collected from each participant by trained phlebotomists under aseptic conditions. Serum was separated by centrifugation at 3,000 rpm for 10 minutes and stored at -20°C until analysis. Antibody titers were measured using commercially available ELISA kits (Euroimmun AG, Lübeck, Germany). Measles-specific IgG was quantified in mIU/mL, with a seroprotective threshold of ≥200 mIU/mL. Diphtheria antitoxin IgG was measured in IU/mL, with full protection defined as ≥0.1 IU/mL and long-term protection as ≥1.0 IU/mL. Anti-hepatitis B surface antibody (anti-HBs) was measured in mIU/mL, with seroprotection defined as ≥10 mIU/mL.

Statistical Analysis: Data were analyzed using SPSS version 28.0 (IBM Corp., Armonk, NY). Continuous variables were expressed as mean ± standard deviation (SD) or geometric mean titers (GMTs) with 95% confidence intervals. Categorical variables were expressed as frequencies and

percentages. Independent samples t-tests and one-way ANOVA were used for between-group comparisons of continuous variables. Chi-square tests were used for categorical variables. Multivariate binary logistic regression was performed to identify independent predictors of suboptimal immune response, defined as failure to achieve seroprotective thresholds for at least one antigen. Variables with $p < 0.1$ on univariate analysis were entered into the multivariate model. A p -value < 0.05 was considered statistically significant.

Results

Participant Characteristics: Of the 412 enrolled children, 218 (52.9%) were male and 194 (47.1%)

were female. The mean age was 16.8 ± 3.9 months. Regarding household income, 138 (33.5%) were classified as low, 162 (39.3%) as middle, and 112 (27.2%) as high income. Stunting was present in 78 (18.9%) children, underweight in 52 (12.6%), and wasting in 31 (7.5%). Food insecurity was reported by 126 (30.6%) households.

Seroprotection Rates and Antibody Titers: Overall, 95 (23.1%) children demonstrated suboptimal antibody titers to at least one antigen. Seroprotection rates were 89.3% for measles, 93.4% for diphtheria, and 91.0% for hepatitis B. Table 1 presents GMTs stratified by household income level.

Table 1: Geometric Mean Antibody Titers by Household Income Category

Antigen	Low Income (n=138)	Middle Income (n=162)	High Income (n=112)	p-value (ANOVA)
Measles IgG (mIU/mL)	$1,245 \pm 487$	$1,782 \pm 539$	$2,118 \pm 612$	<0.001
Diphtheria IgG (IU/mL)	0.82 ± 0.34	1.18 ± 0.43	1.47 ± 0.51	<0.001
Anti-HBs (mIU/mL)	87.4 ± 42.6	128.5 ± 58.3	164.2 ± 71.8	<0.001

A clear gradient was observed, with children from low-income households demonstrating significantly lower titers across all three antigens compared to middle- and high-income groups.

Seroprotection by Social Determinants: Table 2 presents the prevalence of suboptimal immune response (failure to achieve seroprotection for ≥ 1 antigen) across categories of social determinants.

Table 2: Prevalence of Suboptimal Immune Response by Social Determinants of Health

Variable	Category	n	Suboptimal Response n (%)	p-value
Household Income	Low	138	48 (34.8%)	<0.001
	Middle	162	31 (19.1%)	
	High	112	16 (14.3%)	
Maternal Education	Primary/None	94	32 (34.0%)	<0.001
	Secondary	186	40 (21.5%)	
	Tertiary	132	23 (17.4%)	
Nutritional Status (Stunting)	Stunted	78	29 (37.2%)	<0.001
	Not Stunted	334	66 (19.8%)	
Food Security	Insecure	126	42 (33.3%)	<0.001
	Secure	286	53 (18.5%)	
Housing Density (persons/room)	>3	104	31 (29.8%)	0.041
	≤ 3	308	64 (20.8%)	
Healthcare Access (distance >5 km)	Yes	89	26 (29.2%)	0.124
	No	323	69 (21.4%)	

Multivariate Analysis: Multivariate logistic regression identified four independent predictors of suboptimal immune response (Table 3)

Table 3: Multivariate Logistic Regression Analysis of Predictors of Suboptimal Immune Response

Variable	Adjusted OR	95% CI	p-value
Low household income (vs. high)	2.48	1.31–4.69	0.005
Low maternal education (primary/none vs. tertiary)	1.89	1.18–3.02	0.008
Stunting (HAZ < -2)	2.31	1.42–3.76	0.001
Food insecurity	2.14	1.33–3.44	0.002
Housing density >3 persons/room	1.52	0.91–2.54	0.108
Healthcare distance >5 km	1.34	0.78–2.29	0.286

Stunting, low household income, food insecurity, and low maternal education remained statistically significant independent predictors after adjustment for all covariates.

Discussion

The findings of this study demonstrate a significant and graded association between social determinants of health and immune response to routine childhood vaccinations. Children from socioeconomically disadvantaged backgrounds exhibited consistently lower antibody titers and higher rates of suboptimal seroprotection against measles, diphtheria, and hepatitis B. These findings underscore the importance of addressing health inequities as a component of comprehensive immunization strategies.

The inverse relationship between household income and vaccine-induced antibody titers observed in this study aligns with previous investigations. Siegrist and Aspinall reported that socioeconomic deprivation was associated with reduced immunogenicity of various vaccines, potentially mediated through chronic stress-related immunomodulation and nutritional deficits [15]. The biological plausibility of this association is supported by psychoneuroimmunological research demonstrating that chronic stress exposure activates the hypothalamic-pituitary-adrenal axis, resulting in sustained cortisol elevation that suppresses T-helper cell function and antibody production [16].

The strong association between stunting and suboptimal immune response (OR = 2.31) is particularly noteworthy and consistent with the extensive literature on malnutrition and immune function. Prendergast described the concept of "environmental enteric dysfunction" in nutritionally deprived children, characterized by intestinal inflammation, increased permeability, and microbial translocation, which collectively impair both mucosal and systemic immune responses to vaccination [17]. Supplementary evidence from a systematic review by Zimmermann and Curtis demonstrated that undernutrition was associated with reduced vaccine immunogenicity across multiple antigen types, with micronutrient deficiencies in zinc and vitamin A playing particularly prominent roles [18].

The finding that maternal education independently predicted immune response quality extends the well-established relationship between maternal education and child health outcomes into the domain of vaccine immunogenicity. Maternal education likely influences vaccine response through multiple intermediary pathways, including nutritional practices, hygiene behaviors, timely healthcare utilization, and adherence to recommended vaccination schedules [19]. Desai and Alva demonstrated that maternal education was the single strongest predictor of child nutritional status across multiple low- and middle-income countries, establishing a critical link between education, nutrition, and immune competence [20].

Food insecurity emerged as an independent predictor of suboptimal immune response, reflecting its role as both a direct cause of nutritional deficiency and a marker of broader socioeconomic deprivation. Household food insecurity has been associated with elevated inflammatory biomarkers and altered immune cell distributions in children, which may compromise the generation of effective vaccine-specific adaptive immune responses [21]. These findings support the integration of food security interventions within immunization programs, particularly in vulnerable populations.

The lack of statistically significant associations for healthcare distance and housing density in the multivariate model suggests that while these factors may contribute to vaccination access and timing, their influence on immune response quality is mediated through the more proximal determinants of nutrition and socioeconomic status. However, the trend toward significance for housing density ($p = 0.108$) warrants further investigation, as overcrowding increases exposure to endemic pathogens that may induce immune exhaustion or antigenic competition [22].

These findings have important implications for immunization policy and program design. Current vaccination strategies that focus primarily on coverage metrics may overlook significant inequities in vaccine effectiveness across socioeconomic strata. Tailored interventions addressing concurrent nutritional deficiencies, implementing booster dose strategies for high-risk populations, and integrating social support services with immunization delivery may be necessary to

achieve equitable vaccine-induced protection [23]. The concept of "precision public health," which advocates for targeting interventions based on social risk factors, is particularly relevant to optimizing vaccination outcomes [24].

This study has several limitations. The cross-sectional design precludes determination of causal relationships. Antibody titers represent only one dimension of vaccine-induced immunity and do not capture cell-mediated immune responses, which are critical for protection against certain pathogens. Self-reported socioeconomic data may be subject to recall and social desirability biases. Additionally, the urban setting limits generalizability to rural populations, where the burden of SDOH-related disparities may be even more pronounced. Future prospective cohort studies incorporating comprehensive immunological assessments and objective socioeconomic measures are warranted.

Conclusion

This study provides compelling evidence that social determinants of health—specifically low household income, limited maternal education, chronic undernutrition (stunting), and household food insecurity—are independently and significantly associated with suboptimal immune responses to routine childhood vaccinations against measles, diphtheria, and hepatitis B. A clear socioeconomic gradient in antibody titers was observed, with children from the most disadvantaged backgrounds demonstrating the weakest vaccine-induced immunity. These findings highlight that achieving equitable protection through vaccination requires strategies extending beyond coverage optimization to address the underlying social and economic conditions that modulate immune competence. Integrated approaches combining nutritional supplementation, social support services, and targeted booster vaccination strategies for high-risk populations may be essential to closing the immunity gap associated with socioeconomic deprivation. Public health policies must recognize that vaccine effectiveness is not uniform across populations and that addressing structural health inequities is fundamental to maximizing the impact of immunization programs worldwide.

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