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JAMA. 2009;301(16):1691-1701 (doi:10.1001/jama.2009.548)

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Association of Maternal Height With Child Mortality, Anthropometric Failure, and Anemia in India

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Context Prior research on the determinants of child health has focused on contemporaneous risk factors such as maternal behaviors, dietary factors, and immediate environmental conditions. Research on intergenerational factors that might also predispose a child to increased health adversity remains limited.

Objective To examine the association between maternal height and child mortality, anthropometric failure, and anemia.

Design, Setting, and Population We retrieved data from the 2005-2006 National Family Health Survey in India (released in 2008). The study population constitutes a nationally representative cross-sectional sample of singleton children aged 0 to 59 months and born after January 2000 or January 2001 (n=50 750) to mothers aged 15 to 49 years from all 29 states of India. Information on children was obtained by a face-to-face interview with mothers, with a response rate of 94.5%. Height was measured with an adjustable measuring board calibrated in millimeters. Demographic and socioeconomic variables were considered as covariates. Modified Poisson regression models that account for multistage survey design and sampling weights were estimated.

Main Outcome Measures Mortality was the primary end point; underweight, stunting, wasting, and anemia were included as secondary outcomes.

Results In adjusted models, a 1-cm increase in maternal height was associated with a decreased risk of child mortality (relative risk [RR], 0.978; 95% confidence interval [CI], 0.970-0.987; $P<.001$), underweight (RR, 0.971; 95% CI, 0.968-0.974; $P<.001$), stunting (RR, 0.971; 95% CI, 0.968-0.0973; $P<.001$), wasting (RR, 0.989; 95% CI, 0.984-0.994; $P<.001$), and anemia (RR, 0.998; 95% CI, 0.997-0.999; $P=.02$). Children born to mothers who were less than 145 cm in height were 1.71 times more likely to die (95% CI, 1.37-2.13) (absolute probability, 0.09; 95% CI, 0.07-0.12) compared with mothers who were at least 160 cm in height (absolute probability, 0.05; 95% CI, 0.04-0.07). Similar patterns were observed for anthropometric failure related to underweight and stunting. Paternal height was not associated with child mortality or anemia but was associated with child anthropometric failure.

Conclusion In a nationally representative sample of households in India, maternal height was inversely associated with child mortality and anthropometric failure.

JAMA. 2009;301(16):1691-1701 www.jama.com

More than 2 million children younger than 5 years died in India in 2006, more than in any other country, comprising one-quarter of all child deaths in the world.[1] Most recent estimates also show very high prevalences of underweight (42.5%), stunting (48.0%), wasting (19.8%), and anemia (69.5%) among children younger than 5 years in India.[2] Prior research on the determinants of child mortality and nutritional outcomes have primarily focused on contemporaneous factors such as breastfeeding, medical care,[3] and birth spacing.[4] Research on intergenerational factors that might also predispose a child to increased health adversity remains limited. Maternal height can be a useful marker for characterizing intergenerational linkages in health because adult height reflects a mother's health stock accumulated through her life course, especially the social and environmental exposures in her early childhood.[5] Although a few studies have shown associations between maternal height and mortality[6] and stunting,[7,8] studies conducted in India to date have investigated only the association between

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maternal height and preterm birth and low birth weight.[9-12] Previous studies were conducted in nonrepresentative convenience samples or local populations, thereby limiting the generalizability of the findings. Thus, using a large, nationally representative sample of children younger than 5 years, we investigated the association between maternal height and child mortality, anthropometric failure, and anemia in India.

METHODS

Data Source

The data for this study came from the 2005-2006 National Family Health Survey (NFHS) conducted in India and released in 2008. The NFHS was established to generate representative data at the national and state levels on population and health indicators, with special emphasis on maternal and child health outcomes.[2] The NFHS is the equivalent of the Demographic and Health Surveys (DHS) that are operational in more than 80 countries (http://www.measuredhs.com/aboutsurveys/dhs/start.cfm) and was also conducted in 1992-1993 and in 1998-1999. The target population for the 2005-2006 NFHS was children aged 0 to 59 months, women aged 15 to 49 years, and men aged 15 to 54 years.

Sampling Plan

Respondents were selected through a multistage stratified sample survey conducted in all 29 states of India.[2,13] In each state, populations were stratified by urban and rural area of residence, and the sample size at the state level was proportional to the size of the state's urban and rural populations. The rural sample was obtained through a selection of primary sampling units, which were villages or clusters of villages, based on a probability proportional to population size, followed by a random selection of households. In urban areas, at the first stage, wards were selected with probability proportional to population size sampling, followed by a random selection of 1 census enumeration block within the sample ward, followed by a random selection of households. Within the urban and rural households, all women aged 15 to 49 years who resided the previous night in the household were eligible to be respondents in the survey. Data collection for the 2005-2006 NFHS was carried out in 2 phases. The first phase of data collection (covering 12 states) occurred between November 2005 and May 2006, and the second phase of data collection (covering the remaining 17 states) occurred between April and August 2006.[2]

A total of 131 596 women were eligible (based on age cutoffs) for participation in the survey from a random sample of 116 652 households.[13] Of the 131 596 eligible women, 124 385 participated in the survey, yielding a response rate of 94.5%. The response rate for eligible women varied between 90% and 99% between states and was 93.3% and 95.5% in urban and rural areas, respectively.[13] Of the 124 385 women who participated in the survey, 36 850 reported having 1 or more live births since January 2000 (in states where data collection started in 2005) or January 2001 (in states where data collection started in 2006) (hereafter January 2000/2001) and had children aged between 0 and 59 months. A total of 51 555 live births were recorded since January 2000/2001, and we restricted the sample to singleton births (n = 50 750).

Study Population and Sample Size

The study population constitutes a nationally representative cross-sectional sample of singleton children aged 0 to 59 months and born after January 2000/2001 to mothers aged 15 to 49 years from all 29 states of India.[2]

The sample for child mortality analysis was based on mothers' self-report of birth and death history of children born after January 2000/2001. A total of 50 750 singleton live births were recorded since January 2000/2001. In the sample, 2090 children were missing data on maternal height and 617 children were missing information on any of the mother/household covariates. The total number of observations missing was 2675, yielding a final analytic sample of 48 075 children.

The sample for child anthropometric failure analysis was based on singleton children aged 0 to 59 months born after January 2000/2001 and alive during the time of the survey (n = 48 065). In the sample, 5334 children were missing information on height or weight measurements, 2318 had implausible height or weight measurements, 1989 were missing data on maternal height, and 583 were missing information on mother/household covariates (TABLE 1). The total number missing was 7976, yielding a final analytical sample of 40 089 children. Children for whom reported weight for age was more than 6 SDs below or 5 SDs above the mean, height for age was more than 6 SDs below or 6 SDs above the mean, or weight for height was more than 5 SDs below or 5 SDs above the mean were considered to have implausible data.[14]

For child anemia analysis, the sample was based on singleton children aged 6 to 59 months born after January 2000/2001 and alive during the time of the survey (n = 43 484). Anemia was based on concentration of hemoglobin in capillary blood, and blood samples were taken only for children aged 6 months or older. In the sample, 6277 children were missing information on anemia, 1774 were missing data on maternal height, and 530 were missing information on mother/household covariates (Table 1). The total number missing was 6935, yielding a final analytical sample of 36 549 children.

We compared the prevalence of the demographic and clinical characteristics between the original and analytical data sets and did not find notable differences between them.

Outcome Measures

The primary end point for this study was child mortality. Mortality was a binary variable indicating whether a child who was born after January 2000/2001 was alive (0) or dead (1) at the time of interview.

Anthropometric failure and anemia were secondary end points for this

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study. Anthropometric failure was defined along 3 dimensions: underweight, stunting, and wasting.[15,16] Underweight was measured by dividing a child's weight by the median weight for a child of that age and sex; stunting was measured by dividing a child's height by the median height for a child of that age and sex; and wasting was measured by dividing a child's weight by the median weight for a child of that height and sex. Each of these numbers was then standardized as a *z* score with a mean of 0 and an SD of 1. Trained investigators weighed each child with a solar-powered scale accurate to within 100 g and measured each child's height with an adjustable measuring board calibrated in millimeters.[17] Each anthropometric measure of malnutrition was defined as more than 2 SDs under the World Health Organization–determined mean scores,[18] capturing any anthropometric failure. We also considered severe anthropometric failure, defined as more than 3 SDs under the World Health Organization–determined mean scores.[18]

Anemia was ascertained by measuring the concentration of hemoglobin in capillary blood. Trained investigators removed the first 2 drops of blood after a fingerstick and drew the third drop into a cuvette for analysis using the HemoCue system (Lake Forest, California).[2] The HemoCue Hb 201+ analyzer that was used has been validated against major automatic cell counters and correlated highly with all tested systems.[19] Children with a hemoglobin concentration of less than 11 g/dL were categorized as anemic, while severely anemic was defined as less than 7 g/dL (to convert to grams per liter, multiply by 10).[20]

Exposure

Maternal adult height was measured by trained investigators using an adjustable measuring board calibrated in millimeters.[17] Maternal height was specified both as continuous exposure (expressed in centimeters) and as a categorical exposure with the following cut points: less than 145 cm, 145-149.9 cm,

Table 1. Weighted Frequency and Distribution of Children Aged 0 to 59 Months Across Maternal Height and Other Maternal, Child, and Household Covariates

Characteristics	No. (Weighted %)		
	Mortality (n = 48 075)	Anthropometric Failure (n = 40 089)	Anemia (n = 36 549)
Maternal covariates			
Height, cm			
<145	5382 (12.2)	4321 (11.7)	3968 (11.7)
145-149.9	12 602 (27.1)	10 452 (27.1)	9527 (27.0)
150-154.9	16 164 (33.2)	13 585 (33.4)	12 327 (33.4)
155-159.9	9924 (19.9)	8356 (20.1)	7608 (20.0)
≥160	4003 (7.6)	3375 (7.7)	3119 (7.8)
Age at birth, y			
<17	3274 (8.6)	2589 (8.2)	2427 (8.4)
17-19	9594 (22.3)	7943 (22.1)	7209 (21.9)
20-24	18 518 (38.4)	15 604 (39.0)	14 212 (38.9)
25-29	10 671 (19.7)	8978 (19.8)	8131 (19.8)
≥30	6018 (10.9)	4975 (10.9)	4570 (11.1)
Marital status			
Married	47 315 (98.7)	39 516 (98.8)	35 989 (98.7)
Unmarried	760 (1.3)	573 (1.2)	560 (1.3)
Occupation			
Not working	30 908 (62.4)	25 853 (62.6)	23 132 (61.3)
Nonmanual	2162 (2.8)	1793 (2.8)	1641 (2.8)
Agricultural	10 578 (25.9)	8794 (25.8)	8310 (26.7)
Manual	4427 (9.0)	3649 (8.9)	3466 (9.3)
Education, y			
None	19 498 (49.6)	15 979 (49.1)	14 729 (49.5)
1-5	6980 (14.1)	5790 (14.1)	5322 (14.2)
6-10	14 849 (26.4)	12 514 (26.7)	11 457 (26.6)
11-12	3174 (4.9)	2727 (5.1)	2410 (4.9)
≥13	3574 (4.9)	3079 (5.0)	2631 (4.8)
Child covariates			
Birth order			
First	15 550 (30.6)	12 800 (30.0)	11 474 (29.6)
Second	13 503 (27.3)	11 438 (27.7)	10 370 (27.5)
Third	7710 (16.1)	6548 (16.4)	6003 (16.5)
Fourth	4653 (10.1)	3880 (10.1)	3616 (10.4)
Fifth or higher	6659 (15.9)	5423 (15.7)	5086 (16.0)
Sex			
Female	23 068 (47.9)	19 245 (47.7)	17 335 (47.1005)
Male	25 007 (52.1)	20 844 (52.3)	19 214 (52.8995)
Age, mo[a]	29.9 (0.08)	30.0 (0.10)	32.7 (0.09)
Household covariates			
Wealth, quintile			
First (lowest)	8593 (25.4)	7022 (24.9)	6483 (25.4)
Second	8967 (22.5)	7318 (22.3)	6779 (22.5)
Third	10 035 (20.0)	8369 (20.1)	7659 (19.9)
Fourth	10 543 (18.0)	8953 (18.4)	8159 (18.2)
Fifth	9937 (14.1)	8427 (14.3)	7469 (14.0)
Caste			
Scheduled caste	8630 (20.9)	7177 (20.7)	6570 (20.9)
Scheduled tribe	7941 (9.6)	6335 (9.2)	6160 (9.5)
Other backward class	15 828 (40.7)	13 289 (41.0)	12 045 (40.8)
General class	15 676 (28.8)	13 288 (29.1)	11 774 (28.7)
Religion			
Hindu	33 205 (78.7)	27 862 (78.7)	25 183 (78.9)
Muslim	7775 (16.6)	6451 (16.5)	5771 (16.3)
Christian	4837 (2.0)	3892 (2.0)	3843 (2.0)
Sikh	838 (1.3)	743 (1.4)	664 (1.3)
Other/missing data	1420 (1.4)	1141 (1.4)	1088 (1.5)

(continued)

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Table 1. Weighted Frequency and Distribution of Children Aged 0 to 59 Months Across Maternal Height and Other Maternal, Child, and Household Covariates (continued)

Characteristics	No. (Weighted %)		
	Mortality (n = 48 075)	Anthropometric Failure (n = 40 089)	Anemia (n = 36 549)
Household covariates			
Father's education, y			
None	11 548 (29.2)	9323 (28.4)	8696 (28.9)
1-5	7201 (15.3)	5934 (15.2)	5474 (15.3)
6-10	18 911 (37.2)	15 945 (37.6)	14 477 (37.4)
11-12	4610 (8.6)	3917 (8.7)	3553 (8.7)
≥13	5805 (9.8)	4970 (10.0)	4349 (9.7)
Location			
Rural	30 353 (75.4)	25 322 (75.3)	23 228 (75.7)
Urban	17 722 (24.6)	14 767 (24.7)	13 321 (24.3)

[a] Child age is reported as mean (SE).

150-154.9 cm, 155-159.9 cm, and 160.0 cm or greater. These cut points were chosen based on prior use in maternal anthropometric studies.[12,21,22]

Covariates

Age, sex, and birth order of the child; mother's age at birth of the child, marital status, education, occupation, caste, and religion; paternal education; and household wealth and urban/rural status were included as covariates in the study (Table 1). Marital status was classified as married or as unmarried if a woman was divorced, separated, widowed, or never married. Education was defined using years of schooling and was categorized using important benchmarks in the Indian educational system: 0 (no schooling), 1 to 5 (primary), 6 to 10 (secondary), 11 to 12 (higher secondary), or 13 or more (some college or more). Maternal occupation was classified according to whether the mother was not working or was working in a manual, nonmanual, or agricultural profession. Caste identification was based on the household head and was grouped as scheduled caste, scheduled tribe, other backward class, or general caste. Scheduled castes are those whose members have the greatest burden of deprivation within the caste system.[23] Scheduled tribes include approximately 700 officially recognized social groups that have historically been geographically and socially isolated and represent the "indigenous" groups in India.[24] "Other backward class" is a legislatively defined group representing those who have historically been subject to significant deprivation that is not as severe as that of scheduled castes and tribes. The general caste is a residual category containing those not identifying themselves as members of legislatively recognized marginalized classes and constitutes the "high"-caste groups. Religion of the child was based on the head of household's self-identification as Hindu, Muslim, Christian, Sikh, or other religion. Household wealth was defined in terms of ownership of material possessions,[25] with each child assigned a wealth score based on a combination of 33 different household characteristics that were weighted according to a factor analysis procedure. For this procedure, *z* scores were calculated for each indicator variable and a principle components analysis was performed using these *z* scores. For each household, the values of the indicator variables was multiplied by the factor loadings and summed to produce a standardized household index value with a mean of 0 and an SD of 1. This standardized score was then divided into quintiles.[2,26] Using the 2001 Indian National Census definition, households were grouped based on location in either an urban area or a rural village.

Households that were selected to contribute information to the woman-and-child health survey (regardless of whether there was an eligible woman or child present) were also eligible for random selection into the HIV/AIDS subsample. In households that were further selected for the HIV/AIDS subsample, eligible women were asked questions about HIV/AIDS and were asked to give blood samples for testing. Men aged 15 to 54 years in households in the HIV/AIDS subsample were also asked questions about HIV/AIDS, were asked to give blood samples, and had their height measured. Men's height was measured by trained investigators using an adjustable measuring board calibrated in millimeters.[17] The household sample size needed to accurately assess HIV prevalence and related knowledge and behaviors among men and women was considerably smaller than that required to study maternal and child health topics.[2,13] Using this smaller subset of children in households in which both mothers and fathers provided height data, we conducted a sensitivity analysis by including paternal height as a covariate. Since paternal height was available only for 42.8% of the children, we did not include this variable in the main analyses.

In another sensitivity analysis, we used covariate information on mother's body mass index (BMI) and whether the mother was HIV-positive. Body mass index was calculated as weight in kilograms divided by height in meters squared, and weight was measured by using a solar-powered scale calibrated to ±100 g. We used the BMI cut point of less than 18.5 to define underweight women.

Maternal HIV serostatus was ascertained based on blood spot samples from a fingerstick that were collected on special filter paper cards. Testing for HIV was conducted in a central laboratory, SRL Ranbaxy in Mumbai, India, by following a standard testing algorithm designed to maximize the sensitivity and specificity of HIV test results and an approved quality assurance and quality control plan.[27] Over-

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all, 21 549 children had mothers who tested negative for HIV, 63 had mothers who tested positive for HIV, and 29 943 had mothers who were not tested. The sample size for determining national prevalence of HIV infection among women was much smaller than that required to study maternal and child health issues. To save money on blood tests, only women from selected households provided blood samples for testing, while many more provided information regarding maternal and child health. For this reason, there are a large amount of mothers missing information on HIV status for our sensitivity analysis.[2,13]

Statistical Analysis

Except for mortality, the secondary outcomes in this study were not rare. Consequently, the use of odds ratios estimated from a conventional logistic regression model to directly represent relative risk (RR) was problematic.[28] We used a modified Poisson regression approach with robust error variance to model the different binary outcomes associated with mortality, anthropometric failure, and anemia, which in turn provides a direct assessment of the RRs along with their 95% confidence intervals (CIs).[28] We estimated models that took account of the sample weights and the multistage cluster survey sampling design of the 2005-2006 National Family Health Survey.[13] Models were fitted using SAS software, version 9.1 (SAS Institute Inc, Cary, North Carolina). Statistical precision was ascertained using 2-tailed Wald tests and results are presented with 95% CIs and exact *P* values except when $P<.001$.

We first estimated the unadjusted association between maternal height and child mortality, anthropometric failure, and anemia separately. We then re-estimated this association by including variables that were considered potential confounders to the association between maternal height and child outcomes. Among the variables that were observed in the NFHS, the direct and indirect measures of adult socioeconomic status were considered to be important confounders, along with the demographic variables at the child and maternal level.

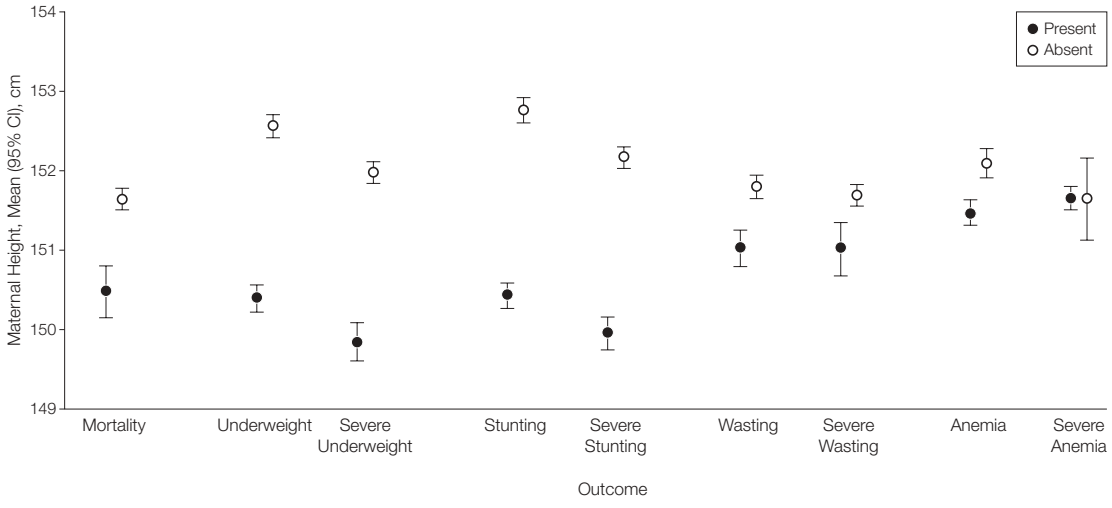
Ethical Review

The 2005-2006 NFHS was conducted under the scientific and administrative supervision of the International Institute for Population Sciences, Mumbai, India, a regional center for teaching, training, and research in population studies that is associated with the Ministry of Health and Family Welfare of the government of India. The institute conducted an independent ethics review of the 2005-2006 NFHS protocol. Data collection procedures were also approved by the ORC Macro (Calverton, Maryland) institutional review board. Oral informed consent for the interview/survey and tests for child

Table 2. Sample Size and Weighted Estimates for Mortality, Anthropometric Failure Measures, and Anemia Among Children Aged 0 to 59 Months

	Mortality	Underweight	Severe Underweight	Stunting	Severe Stunting	Wasting	Severe Wasting	Anemia	Severe Anemia
Sample size	48 075	40 089	40 089	40 089	40 089	40 089	40 089	36 549	36 549
No. of events	2550	14 791	5189	17 428	8205	7236	2417	22 249	823
Weighted % (95% CI)	6.0 (5.7-6.3)	42.2 (41.2-43.2)	15.5 (14.9-16.2)	47.8 (46.9-48.7)	23.6 (22.8-24.3)	19.7 (19.0-20.4)	6.4 (6.0-6.7)	69.1 (68.2-69.9)	2.7 (2.5-2.9)

Figure. Unadjusted, Weighted Mean Maternal Height Among Children Aged 0 to 59 Months Who Experienced vs Did Not Experience Mortality, Anthropometric Failure Measures, and Anemia



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Table 3. Distribution of Covariates Across Categories of Maternal Height in the Mortality Data Set

Characteristics	No. (%) in Maternal Height Category, cm				
	<145 (n = 5382)	145-149.9 (n = 12 602)	150-154.9 (n = 16 164)	155-159.9 (n = 9924)	≥160 (n = 4003)
Maternal covariates					
Age at birth, y					
<17	460 (8.6)	940 (7.5)	1113 (6.9)	548 (5.5)	213 (5.3)
17-19	1173 (21.8)	2503 (19.9)	3344 (20.7)	1876 (18.9)	698 (17.4)
20-24	1978 (36.8)	4714 (37.4)	6149 (38.0)	3984 (40.2)	1693 (42.3)
25-29	1077 (20.0)	2813 (22.3)	3508 (21.7)	2310 (23.3)	963 (24.1)
≥30	694 (12.9)	1632 (13.0)	2050 (12.7)	1206 (12.2)	436 (10.9)
Marital status					
Married	5269 (97.9)	12 402 (98.4)	15 930 (98.6)	9768 (98.4)	3946 (98.6)
Unmarried	113 (2.1)	200 (1.6)	234 (1.5)	156 (1.6)	57 (1.4)
Occupation					
Not working	3428 (63.7)	7896 (62.7)	10 411 (64.4)	6465 (65.2)	2708 (67.7)
Nonmanual	174 (3.2)	448 (3.6)	747 (4.6)	541 (5.5)	252 (6.3)
Agricultural	1202 (22.3)	2985 (23.7)	3543 (21.9)	2087 (21.0)	761 (19.0)
Manual	578 (10.7)	1273 (10.1)	1463 (9.1)	831 (8.4)	282 (7.0)
Education, y					
None	2679 (49.8)	5714 (45.3)	6249 (38.7)	3632 (36.6)	1224 (30.6)
1-5	917 (17.0)	1977 (15.7)	2408 (14.9)	1203 (12.1)	475 (11.9)
6-10	1434 (26.6)	3662 (29.1)	5237 (32.4)	3196 (32.2)	1320 (33.0)
11-12	192 (3.6)	683 (5.4)	1058 (6.6)	866 (8.7)	375 (9.4)
≥13	160 (3.0)	566 (4.5)	1212 (7.5)	1027 (10.4)	609 (15.2)
Child covariates					
Birth order					
First	1657 (30.8)	3802 (30.2)	5282 (32.7)	3294 (33.2)	1515 (37.9)
Second	1422 (26.4)	3385 (26.9)	4549 (28.1)	2914 (29.4)	1233 (30.8)
Third	871 (16.2)	2089 (16.6)	2607 (16.1)	1557 (15.7)	586 (14.6)
Fourth	581 (10.8)	1325 (10.5)	1563 (9.7)	887 (8.9)	297 (7.4)
Fifth or higher	851 (15.8)	2001 (15.9)	2163 (13.4)	1272 (12.8)	372 (9.3)
Sex					
Female	2668 (49.6)	6121 (48.6)	7675 (47.5)	4688 (47.2)	1916 (47.9)
Male	2714 (50.4)	6481 (51.4)	8489 (52.5)	5236 (52.8)	2087 (52.1)
Household covariates					
Wealth, quintile					
First (lowest)	1285 (23.9)	2681 (21.3)	2791 (17.3)	1415 (14.3)	421 (10.5)
Second	1297 (24.1)	2598 (20.6)	2952 (18.3)	1608 (16.2)	512 (12.8)
Third	1180 (21.9)	2862 (22.7)	3362 (20.8)	1932 (19.5)	699 (17.5)
Fourth	1028 (19.1)	2665 (21.2)	3678 (22.8)	2226 (22.4)	946 (23.6)
Fifth	592 (11.0)	1796 (14.3)	3381 (20.9)	2743 (27.6)	1425 (35.6)
Caste					
Scheduled caste	1192 (22.2)	2559 (20.3)	2831 (17.5)	1553 (15.7)	495 (12.4)
Scheduled tribe	948 (17.6)	2352 (18.7)	2756 (17.1)	1469 (14.8)	416 (10.4)
Other backward class	1794 (33.3)	4155 (33.0)	5349 (33.1)	3241 (32.7)	1289 (32.2)
General class	1448 (26.9)	3536 (28.1)	5228 (32.3)	3661 (36.9)	1803 (45.0)
Religion					
Hindu	3849 (71.5)	8708 (69.1)	11157 (69.0)	6782 (68.3)	2709 (67.7)
Muslim	796 (14.8)	1906 (15.1)	2609 (16.1)	1749 (17.6)	715 (17.9)
Christian	520 (9.7)	1408 (11.2)	1668 (10.3)	935 (9.4)	306 (7.6)
Sikh	38 (0.7)	111 (0.9)	245 (1.5)	234 (2.4)	210 (5.3)
Other/missing data	179 (3.3)	469 (3.7)	485 (3.0)	224 (2.3)	63 (1.6)
Father's education, y					
None	1729 (32.1)	3396 (27.0)	3707 (22.9)	2069 (20.9)	647 (16.2)
1-5	1031 (19.2)	2127 (16.9)	2384 (14.8)	1237 (12.5)	422 (10.5)
6-10	2007 (37.3)	4932 (39.1)	6454 (39.9)	3909 (39.4)	1609 (40.2)
11-12	294 (5.5)	1070 (8.5)	1611 (10.0)	1127 (11.4)	508 (12.7)
≥13	321 (6.0)	1077 (8.6)	2008 (12.4)	1582 (15.9)	817 (20.4)
Location					
Rural	3571 (66.4)	8311 (66.0)	10 083 (62.4)	6020 (60.7)	2368 (59.2)
Urban	1811 (33.7)	4291 (34.1)	6081 (37.6)	3904 (39.3)	1635 (40.8)

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anemia and maternal HIV infection was obtained from the participating mothers by interviewers.[13(p59)]

The study was reviewed by Harvard School of Public Health Institutional Review Board and was considered exempt from full review because the study was based on an anonymous public use data set with no identifiable information on the survey participants.

RESULTS

Table 1 presents the frequency and the weighted distribution of maternal height and covariates in the population. Approximately one-third of the children had mothers in the middle height category (150-154.9 cm), with 7.6% (4003/48 075) and 12.2% (5382/48 075) of children having mothers in the tallest (≥160 cm) and the shortest (<145 cm) categories, respectively, in the mortality data sets. Similar distribution was observed for the anthropometric failure and anemia data sets.

In the population of all live births, 6% (2550/48 075; 95% CI, 5.7%-6.3%) died before reaching age 5 years. Of the children who survived, 42.2% (14791/40 089; 95% CI, 41.2%-43.2%) were underweight, 47.8% (17428/40 089; 95% CI, 46.9%-48.7%) had stunting, and 19.7% (7236/40 089; 95% CI, 19.0%-20.4%) had wasting. Severe underweight was prevalent among 15.5% (5189/40 089; 95% CI, 14.9%-16.2%) of the children, while severe stunting and wasting had a prevalence of 23.6% (8205/40 089; 95% CI, 22.8%-24.3%) and 6.4% (2417/40 089; 95% CI, 6.0%-6.7%), respectively (TABLE 2). The weighted prevalence of anemia and severe anemia among children younger than 5 years was 69.1% (22 249/36 549; 95% CI, 68.2%-69.9%) and 2.7% (823/36 549; 95% CI, 2.5%-2.9%), respectively (Table 2).

There were differences in maternal height between groups of children who experienced mortality and those who did not. On average, maternal height among children who did not survive the first 5 years of life was 150.5 cm (95% CI, 150.2-150.8 cm), while for those who survived it was 151.6 cm (95% CI, 151.5-151.8 cm) (FIGURE). Similarly, children who experienced anthropometric failure or anemia had mothers who were consistently shorter than those who did not (Figure). Similar differences were observed for severe anthropometric failure but not for severe anemia (Figure).

TABLE 3 presents the distribution of covariates by categories of maternal

Table 4. Adjusted Absolute Probabilities and RRs for the Association Between Maternal Height and Mortality, Anthropometric Failure Measures, and Anemia Among Children Aged 0 to 59 Months[a]

	RR (95% CI)	*P* Value	No. of Events	Absolute Probability (95% CI)
Mortality				
Maternal height per 1-cm increase	0.978 (0.970-0.987)	<.001		
Maternal height, cm				
≥160	1 [Reference]		153	0.053 (0.039-0.071)
155-159.9	1.222 (0.980-1.524)	.08	455	0.065 (0.051-0.083)
150-154.9	1.146 (0.932-1.410)	.20	782	0.061 (0.048-0.077)
145-149.9	1.243 (1.002-1.542)	.05	723	0.066 (0.052-0.084)
<145	1.711 (1.369-2.137)	<.001	437	0.091 (0.071-0.116)
Underweight				
Maternal height per 1-cm increase	0.971 (0.968-0.974)	<.001		
Maternal height, cm				
≥160	1 [Reference]		729	0.249 (0.223-0.278)
155-159.9	1.208 (1.106-1.320)	<.001	2353	0.301 (0.275-0.330)
150-154.9	1.431 (1.317-1.555)	<.001	4798	0.356 (0.327-0.388)
145-149.9	1.661 (1.529-1.806)	<.001	4613	0.414 (0.381-0.450)
<145	1.869 (1.712-2.041)	<.001	2298	0.466 (0.428-0.507)
Stunting				
Maternal height per 1-cm increase	0.971 (0.968-0.973)	<.001		
Maternal height, cm				
≥160	1 [Reference]		844	0.273 (0.247-0.302)
155-159.9	1.252 (1.152-1.359)	<.001	2812	0.342 (0.317-0.370)
150-154.9	1.506 (1.390-1.632)	<.001	5765	0.412 (0.383-0.442)
145-149.9	1.713 (1.580-1.857)	<.001	5375	0.468 (0.437-0.502)
<145	1.947 (1.792-2.116)	<.001	2632	0.532 (0.496-0.571)
Wasting				
Maternal height per 1-cm increase	0.989 (0.984-0.994)	<.001		
Maternal height, cm				
≥160	1 [Reference]		536	0.190 (0.162-0.223)
155-159.9	0.890 (0.793-1.000)	.05	1262	0.169 (0.146-0.196)
150-154.9	1.008 (0.906-1.121)	.89	2407	0.192 (0.167-0.220)
145-149.9	1.099 (0.985-1.226)	.09	2089	0.209 (0.183-0.239)
<145	1.106 (0.978-1.251)	.11	942	0.210 (0.181-0.244)
Anemia				
Maternal height per 1-cm increase	0.998 (0.997-0.999)	.02		
Maternal height, cm				
≥160	1 [Reference]		1789	0.651 (0.615-0.688)
155-159.9	0.999 (0.949-1.052)	.97	4436	0.650 (0.618-0.683)
150-154.9	1.028 (0.979-1.079)	.27	7435	0.669 (0.638-0.701)
145-149.9	1.027 (0.977-1.079)	.30	5974	0.668 (0.636-0.702)
<145	1.049 (0.992-1.109)	.09	2615	0.683 (0.648-0.719)

Abbreviations: CI, confidence interval; RR, relative risk.
[a] Models are adjusted for child age, sex, and birth order; maternal age at birth, marital status, occupation, and education; and wealth, caste, religion, father's education, and location. Adjusted absolute probabilities were computed using the reference as a first-born male child aged 30 months from a family of the middle wealth quintile, Hindu religion, other backward class, living in a rural location, born to a father with 1 to 5 years of education and a mother aged 20 to 24 years at childbirth who is married, not working, and with 1 to 5 years of education.

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height in the mortality data set. Samples were observed across all the different levels of covariates and the different categories of maternal height, including in the shortest (<145 cm) and the tallest (≥160 cm) categories. The covariate distribution between the shortest and tallest groups was less balanced, mainly for socioeconomic covariates. The percentage of children whose mothers had no schooling among the group of children whose mothers were in the shortest category was 49.8% (2679/5328), while it was 30.6% (1224/4003) among children with mothers in the tallest category. Similar distributional patterns were observed across other socioeconomic covariates, such as household wealth, paternal education, and, to a lesser extent, maternal occupation. The covariate distribution was relatively balanced across the remaining demographic covariates. The pattern of covariate distribution was similar to those reported in Table 3 for the anthropometric and anemia data sets, which are shown in eTable 1 and eTable 2, respectively.

The unadjusted association between maternal height and child mortality, anthropometric failure, and anemia, and the association between the outcomes and covariates, respectively, are shown in eTable 3 and eTable 4. The adjusted association between maternal height and outcomes is presented in detail herein.

Table 5. Adjusted Absolute Probabilities and RRs for the Association Between Maternal Height and Severe Anthropometric Failure Measures and Anemia Among Children Aged 0 to 59 Months[a]

	RR (95% CI)	*P* Value	No. of Events	Absolute Probability (95% CI)
Severe underweight				
Maternal height per 1-cm increase	0.959 (0.954-0.964)	<.001		
Maternal height, cm				
≥160	1 [Reference]		229	0.075 (0.059-0.093)
155-159.9	1.131 (0.949-1.348)	.17	732	0.084 (0.070-0.101)
150-154.9	1.427 (1.209-1.684)	<.001	1571	0.107 (0.090-0.126)
145-149.9	1.838 (1.557-2.170)	<.001	1706	0.137 (0.116-0.162)
<145	2.128 (1.790-2.529)	<.001	951	0.159 (0.134-0.189)
Severe stunting				
Maternal height per 1-cm increase	0.961 (0.957-0.965)	<.001		
Maternal height, cm				
≥160	1 [Reference]		347	0.103 (0.087-0.123)
155-159.9	1.275 (1.110-1.465)	.001	1215	0.131 (0.115-0.151)
150-154.9	1.605 (1.406-1.833)	<.001	2594	0.165 (0.145-0.188)
145-149.9	1.921 (1.684-2.192)	<.001	2637	0.198 (0.175-0.224)
<145	2.345 (2.044-2.691)	<.001	1412	0.242 (0.212-0.275)
Severe wasting				
Maternal height per 1-cm increase	0.991 (0.982-0.999)	.03		
Maternal height, cm				
≥160	1 [Reference]		188	0.061 (0.046-0.082)
155-159.9	0.791 (0.644-0.971)	.03	400	0.048 (0.036-0.064)
150-154.9	0.847 (0.700-1.024)	.09	777	0.052 (0.040-0.067)
145-149.9	1.010 (0.830-1.228)	.92	716	0.062 (0.048-0.080)
<145	0.955 (0.768-1.188)	.68	336	0.058 (0.044-0.078)
Severe anemia				
Maternal height per 1-cm increase	1.010 (0.995-1.022)	.19		
Maternal height, cm				
≥160	1 [Reference]		69	0.023 (0.014-0.038)
155-159.9	0.905 (0.659-1.243)	.54	156	0.021 (0.013-0.032)
150-154.9	0.955 (0.708-1.289)	.76	294	0.022 (0.014-0.033)
145-149.9	0.868 (0.631-1.194)	.38	211	0.020 (0.013-0.031)
<145	0.786 (0.543-1.139)	.20	93	0.018 (0.011-0.029)

Abbreviations: CI, confidence interval; RR, relative risk.
[a] Models are adjusted for child age, sex, and birth order; maternal age at birth, marital status, occupation, and education; and wealth, caste, religion, father's education, and urban/rural location. Adjusted absolute probabilities were computed using the reference as a first-born male child aged 30 months from a family of the middle wealth quintile, Hindu religion, other backward class, living in a rural location, born to a father with 1 to 5 years of education and a mother aged 20 to 24 years at childbirth who is married, not working, and with 1 to 5 years of education.

Mortality

In adjusted models, a 1-cm increase in height was associated with a decreased RR for mortality (RR, 0.978; 95% CI, 0.970-0.987; *P*<.001) (TABLE 4). Compared with children with the tallest mothers (≥160 cm), child mortality among mothers shorter than 145 cm was substantially higher (RR, 1.711; 95% CI, 1.369-2.137) (Table 4). The absolute probability of dying among children born to the tallest mothers (≥160 cm) was 0.053 (95% CI, 0.039-0.071), while among those born to the shortest mothers (<145 cm) it was 0.091 (95% CI, 0.071-0.116).

Anthropometric Failure

In adjusted models, a 1-cm increase in height was associated with a decreased RR for underweight (RR, 0.971; 95% CI, 0.968-0.974; *P*<.001), stunting (RR, 0.971; 95% CI, 0.968-0.973; *P*<.001), and wasting (RR, 0.989; 95% CI, 0.984-0.994; *P*<.001) (Table 4). Compared with children with tallest mothers (≥160 cm), anthropometric failure among those with mothers shorter than 145 cm was substantially higher for underweight (RR, 1.869; 95% CI, 1.712-2.041) and stunting (RR, 1.947; 95% CI, 1.792-2.116) (Table 4). In terms of absolute probabilities, children whose mothers were 160 cm or taller had an adjusted underweight and stunting probability of 0.249 (95% CI, 0.223-0.278) and 0.273 (95% CI, 0.247-0.302), respectively, while those with mothers shorter than 145 cm had an adjusted underweight and stunting prevalence of 0.466 (95% CI, 0.428-0.507) and 0.532 (95% CI, 0.496-0.571), re-

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Table 6. Adjusted and Mutually Adjusted RRs for the Association Between a 1-cm Increase in Maternal/Paternal Height and Mortality, Anthropometric Failure Measures, and Anemia Among Children Aged 0 to 59 Months[a]

	Adjusted		Mutually Adjusted for Parental Heights	
	RR (95% CI)	*P* Value	RR (95% CI)	*P* Value
Mortality				
Maternal height	0.978 (0.970-0.987)	<.001	0.976 (0.963-0.989)	<.001
Paternal height	0.997 (0.986-1.008)	.59	1.001 (0.989-1.012)	.93
Underweight				
Maternal height	0.971 (0.968-0.974)	<.001	0.974 (0.970-0.978)	<.001
Paternal height	0.978 (0.974-0.982)	<.001	0.982 (0.978-0.985)	<.001
Stunting				
Maternal height	0.971 (0.968-0.973)	<.001	0.975 (0.972-0.979)	<.001
Paternal height	0.978 (0.975-0.981)	<.001	0.982 (0.979-0.985)	<.001
Wasting				
Maternal height	0.989 (0.989-0.994)	<.001	0.993 (0.985-1.001)	.08
Paternal height	0.992 (0.986-0.999)	.02	0.993 (0.987-1.000)	.04
Anemia				
Maternal height	0.998 (0.997-0.999)	.02	0.998 (0.995-1.000)	.06
Paternal height	1.000 (0.998-1.002)	.77	1.000 (0.998-1.002)	.97

Abbreviations: CI, confidence interval; RR, relative risk.
[a]The models in this series of analyses are based on data sets from which children with missing information for father's height were removed. All models are adjusted for child age, sex, and birth order; maternal age at birth, marital status, occupation, and education; and household wealth, caste, religion, father's education, and urban/rural location.

spectively. An inverse association between maternal height and severe anthropometric failure was also observed; a 1-cm increase in maternal height was associated with a decreased RR for severe underweight (RR, 0.959; 95% CI, 0.954-0.964; $P<.001$), severe stunting (RR, 0.961; 95% CI, 0.957-0.965; $P<.001$), and severe wasting (RR, 0.991; 95% CI, 0.982-0.999; $P=.03$) (TABLE 5). The patterns between categorical measures of maternal height and severe anthropometric failure (especially for severe underweight and severe stunting) were stronger than those observed for moderate anthropometric failure (Table 5).

Anemia

In adjusted models, a 1-cm increase in height was associated with a very small decrease in risk of anemia (RR, 0.998; 95% CI, 0.997-0.999; $P=.02$) (Table 4). However, no association between maternal height categories and anemia was observed. Maternal height was also not associated with severe anemia among children (Table 4 and Table 5).

Paternal Height and Child Health

We conducted an analysis on a subset of the sample for whom paternal height was also available (n=21 120 for the mortality analysis, n=17 790 for the anthropometric analysis, and n=16 414 for the anemia analysis). Maternal and paternal height were positively associated ($r=0.25$; $P<.001$) and had similar socioeconomic patterning (eTable 5). In mutually adjusted models, no association was observed between paternal height and child mortality (RR, 1.001; 95% CI, 0.989-1.012; $P=.93$), wasting (RR, 0.993; 95% CI, 0.987-1.000; $P=.04$), or anemia (RR, 1.000; 95% CI, 0.998-1.002; $P=.97$) (TABLE 6). An inverse association was observed between paternal height and underweight (RR, 0.982; 95% CI, 0.978-0.985; $P=<.001$), and stunting (RR, 0.982; 95% CI, 0.979-0.985; $P<.001$) (Table 6).

Sensitivity Analysis

We conducted a sensitivity analyses to confirm the robustness of the findings reported in Table 4 and Table 5. First, we tested for nonlinearity in the relationship between maternal health and child mortality, anthropometric failure, and anemia and did not find support for a nonlinear relationship. Second, we specified interactions between maternal height and child's age, and the interaction effects were neither substantial nor conventionally statistically significant. Finally, we conducted sensitivity analysis by excluding children whose mothers had an HIV-positive diagnosis or had a BMI of less than 18.5, yielding a smaller subset of the data (n=32 345 for the mortality analysis, n=26 918 for the anthropometric analysis, and n=24 295 for the anemia analysis). The results were not substantially different from those reported in Table 4 (eTable 6).

COMMENT

In a large, nationally representative survey of children younger than 5 years in India, we found an inverse association between maternal height and child mortality and anthropometric failure. No association between maternal height and anemia was observed. The association between low maternal height and adverse child health outcomes has a plausible mechanistic basis. Small uterine size, found in shorter mothers, may result in membrane stretching, cervical shortening, or other biological factors that increase the likelihood of preterm delivery and, thus, low birth weight and child morbidity and mortality.[29] Short maternal height has been shown to be a risk factor for low birth weight and intrauterine growth retardation.[30] Low birth weight, meanwhile, has been shown to be associ-

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ated with subsequent risk of mortality, anemia,[31-33] stunting,[33,34] wasting,[34] and underweight.[35,36]

The association between maternal height and child mortality and anthropometric failure suggests an intergenerational transfer of poor health from mother to child. Recent research suggests that a mother's social and nutritional environment during early life is a critical determinant of her children's subsequent health outcomes,[37] perhaps even more than a mother's nutritional status at the time of pregnancy or her diet during pregnancy. Since fetal developmental disturbances may result in the birth of a child with organ systems that remain permanently functionally immature,[38] a mother's capacity to deliver nutrients to her unborn child may be determined in large part when she was herself in utero. Maternal height may be one indicator of the stressful nutritional environment of the mother in early life,[39,40] as well as across the life course, and as such indicates the intergenerational nature of associations that affect her offsprings' health.

Evidence suggesting a role of maternal height in offspring well-being is strengthened from the analysis of paternal height in this study. In models that mutually adjusted for maternal and paternal height, only maternal height was associated with child mortality. Furthermore, even though paternal height was associated with child anthropometric failure, the association was stronger for maternal height. Comparisons of the maternal-offspring and paternal-offspring associations in this manner have been used in several domains to strengthen inference regarding the direct as opposed to confounded nature of maternal influences on offspring outcomes.[41]

One critique of using (maternal) height as target of interest for nutritional intervention is the "small but healthy" hypothesis,[42] which incidentally was first advanced in the context of India. This hypothesis argues that short stature by itself need not be a matter of concern, provided weight for height is normal.[42] The inverse association between maternal height and child mortality and anthropometric failure observed in this study in samples with a BMI of less than 18.5, however, suggests that the "small but healthy" hypothesis may not applicable.

We acknowledge that the availability of only cross-sectional data limits our ability to draw causal inferences with regard to the association between maternal height and child health outcomes. While a reverse association (ie, child mortality or anthropometric failure causing maternal height) can be ruled out, confounding due to unobserved factors (eg, genetic or epigenetic factors that may jointly determine women's adult height and her future offsprings' health) remains. Our study, because of data constraints, cannot demonstrate how maternal height and child health are associated. The data only allowed an assessment of whether they are associated. Furthermore, maternal height in adulthood in this study was conceptualized as a surrogate for a mother's environment when she was in utero and subsequently through critical periods of childhood. While adult height is seen to be a reasonable marker for childhood health and socioeconomic conditions,[5] measures of maternal anthropometric measurements as well as socioeconomic environment during maternal childhood would have facilitated a more direct assessment of the intergenerational linkages in health.

In summary, this study provides evidence that short maternal height is associated with increased mortality and anthropometric failure among children in India, suggesting intergenerational pathways between a mother's health and social well-being during her childhood and her offsprings' health.

Author Contributions: Drs Subramanian and Ackerson had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Subramanian, Ackerson, Davey Smith, John.
Acquisition of data: Subramanian.
Analysis and interpretation of data: Subramanian, Ackerson.
Drafting of the manuscript: Subramanian, Ackerson, John.
Critical revision of the manuscript for important intellectual content: Subramanian, Ackerson, Davey Smith.
Statistical analysis: Subramanian, Ackerson.
Administrative, technical, or material support: John.
Study supervision: Subramanian, Davey Smith.
Financial Disclosures: None reported.
Funding/Support: Dr Subramanian is supported by a National Institutes of Health Career Development Award (NHLBI K25 HL081275).
Role of the Sponsor: The National Institutes of Health and Macro International Inc did not participate in the design and conduct of the study, in the collection, analysis, and interpretation of the data, or in the preparation, review, or approval of the manuscript.
Additional Information: eTables 1-6 are available online at http://www.jama.com
Additional Contributions: We acknowledge the support of Macro International Inc (Washington, DC) for providing access to the 2005-2006 Indian National Family Health Survey 3 data.

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