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Original Research Article

NUTRITIONAL TRAJECTORIES AND ASSOCIATED FACTORS AMONG CHILDREN WITH TUBERCULOSIS: A PROSPECTIVE COHORT STUDY

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ABSTRACT

Background: Tuberculosis and undernutrition can reinforce each other, compromising childhood growth and recovery. This study assessed longitudinal changes in nutritional status and factors associated with nutritional trajectories among children receiving tuberculosis treatment.

Materials and Methods: A prospective longitudinal observational study included 67 children aged six months to fourteen years recruited consecutively from selected National Tuberculosis Elimination Programme treatment centres in India. Monthly assessments were conducted over six months. Anthropometric indices were standardised using age-appropriate World Health Organization growth standards and references. Dietary intake, household food insecurity and clinical characteristics were assessed. Paired comparisons evaluated nutritional changes, while random-intercept linear mixed-effects models examined adjusted associations with nutritional trajectories.

Results: Participants had a mean age of 7.44±3.89 years; 56.7% were male and 68.7% resided in rural areas. Mean BMI-for-age z score increased from −2.04±1.15 to −1.16±1.20, representing an improvement of 0.88 units (95% CI: 0.75–1.01; p<0.001). Low BMI-for-age declined from 56.7% to 29.9%, while stunting decreased non significantly from 31.3% to 28.4% (p=0.625). Height-for-age improved by only 0.02 units (p=0.001). Of 38 children with initially low BMI-for-age, 18 (47.4%) reached a z score ≥−2. Baseline household food insecurity was associated with lower adjusted month-six BMI-for-age (coefficient: −0.39; p<0.001), whereas each ten-percentage-point increase in baseline energy intake was associated with a higher value (coefficient: +0.12; p<0.001).

Conclusion: Weight-related nutritional indices improved during follow-up, while linear-growth deficits persisted. Repeated anthropometric assessment and attention to household food insecurity and dietary intake are warranted alongside tuberculosis care.

Keywords: Childhood tuberculosis; nutritional status; food insecurity; anthropometry; prospective cohort.

INTRODUCTION

Tuberculosis (TB) and undernutrition constitute an interconnected challenge to child health, particularly in resource-constrained settings. The World Health Organization (WHO) estimated that 1.2 million children and young adolescents developed TB globally in 2024; India accounted for approximately 25% of cases across all ages.[1] Childhood TB occurs during periods of rapid growth, making nutritional deterioration particularly consequential for physical development and recovery.

The relationship between TB and undernutrition is bidirectional. Protein–energy deficiency impairs innate and cell-mediated immunity, compromising host defence against Mycobacterium tuberculosis. Conversely, TB-associated inflammation, anorexia and increased tissue catabolism can aggravate pre-

existing nutritional deficits.[2,3] An Indian multicentre study identified pulmonary TB in 4.3% of severely malnourished children admitted to nutritional rehabilitation centres, highlighting the clinical overlap between these conditions.[4]

Nutritional status during treatment is dynamic, and weight improvement does not necessarily indicate complete growth recovery. Mexitalia and colleagues documented increases in weight and body fat during antitubercular therapy,[5] while Chiang and colleagues found that changes in weight-for-age z scores were associated with treatment outcomes.[6] More recently, longitudinal evidence demonstrated improvement in weight-for-age without significant improvement in height-for-age, suggesting persistence of chronic growth deficits despite treatment.[7] These findings support repeated assessment using age-appropriate anthropometric indices rather than reliance on body weight alone.

Potential determinants of nutritional recovery include age, baseline undernutrition, disease severity, HIV status, dietary adequacy, household food insecurity and treatment adherence. WHO guidance supports integrating nutritional assessment and appropriate support into TB care.[8,9] However, their relative contributions to nutritional trajectories require context-specific investigation. Accordingly, the present longitudinal study aimed to assess changes in nutritional status among children with TB and identify sociodemographic, dietary and clinical determinants of recovery, thereby informing timely, targeted nutritional interventions alongside antitubercular treatment.

MATERIALS AND METHODS

Study design and setting: This prospective longitudinal observational study was conducted in the department of Community Medicine in collaboration with department of Paediatrics, India, and included tuberculosis treatment centres operating under the National Tuberculosis Elimination Programme (NTEP), attached to district hospital and participating community health centres and primary health centres in district. Participants were recruited for a period of 12 months between June 2024 to May 2025 and followed for six months from treatment initiation. Repeated assessments examined changes in nutritional status and their sociodemographic, dietary and clinical determinants.

Study population and eligibility: Children aged six months to fourteen years with newly diagnosed, drug-sensitive pulmonary or extrapulmonary tuberculosis were eligible. Diagnosis was established by the treating paediatrician using microbiological evidence, where available, or guideline-based clinical and radiological assessment. Children who had commenced treatment within the preceding seven days were enrolled after parental consent. Children with drug-resistant tuberculosis or conditions preventing valid anthropometric assessment, such as major skeletal deformities, were excluded. HIV infection and severe undernutrition were retained and documented as potential determinants.

Sampling and Sample Size: Eligible children were enrolled consecutively until the required sample of 67 participants was achieved. Sample size was calculated to detect an expected mean within-child improvement of 0.40 units in body mass index-for-age z score between baseline and month six, assuming a standard deviation of paired differences of 1.10 units, a two-sided significance level of 5% and 80% power. Using the formula $n = [(Z\alpha/2 + Z\beta) \times SD/\Delta]^2$, the minimum requirement was approximately 60 participants. After allowing for 10% attrition, the recruitment target was increased to 67 participants (60/0.90). Screening, exclusions, refusals and recruitment were documented.

Baseline assessment and potential determinants: A pretested interviewer-administered questionnaire recorded age, gender, residence, parental education, household income, family size, crowding and tuberculosis contact history. Household food insecurity was assessed using a locally adapted Household Food Insecurity Access Scale. Clinical records provided diagnostic classification, disease site, symptom duration, HIV status, comorbidities and prescribed treatment. Caregiver-assisted dietary assessment included two non-consecutive 24-hour recalls, with age-appropriate documentation of breastfeeding and complementary feeding. Energy and protein intake were estimated using Indian food-composition data.

Anthropometric measurements and definitions: Trained investigators measured weight to the nearest 0.1 kg using calibrated scales and length or height to the nearest 0.1 cm using an infantometer or stadiometer. Recumbent length was measured below two years and standing height thereafter. Duplicate measurements were averaged. WHO Anthro and AnthroPlus generated gender- and age-standardised indices using the 2006 standards and 2007 reference. Underweight and stunting were defined as weight-for-age and height-for-age below −2 z scores, respectively. Wasting below five years was defined as weight-for-length/height below −2; thinness in older children was defined as BMI-for-age below −2. Values below −3 indicated severe deficits. Weight-for-age was not calculated beyond ten years. Bilateral pitting oedema was documented separately.

Follow-up and outcome assessment: Follow-up assessments were conducted monthly, within a seven-day visit window, through month six. Anthropometry, appetite, intercurrent illness, adverse effects, missed treatment doses and nutritional support received were recorded. Dietary recalls and food-insecurity assessments were repeated at months two and six. Treatment adherence was assessed using treatment records and caregiver reports. Routine treatment, nutritional counselling and referral followed programme guidance. The primary outcome was change in BMI-for-age z score; secondary

outcomes included other anthropometric trajectories and transitions between nutritional categories.

Statistical analysis: Data were analysed using IBM SPSS Statistics version 20.0. Continuous variables were summarised as mean±standard deviation or median with interquartile range, and categorical variables as frequencies and percentages. Baseline-to-month-six changes in anthropometric indices and dietary intake were assessed using paired-samples t tests, with mean changes and 95% confidence intervals reported. Changes in the prevalence of nutritional deficits were evaluated using exact McNemar tests. Exploratory subgroup comparisons of six-month change in BMI-for-age z score employed Welch independent-samples t tests. Nutritional trajectories were assessed using linear mixed-effects models fitted by restricted maximum likelihood, with participant-specific random intercepts and categorical follow-up visit. Baseline BMI-for-age z score, age and gender were included as adjustment variables. Baseline household food insecurity, energy intake and symptom duration interacted with elapsed time expressed as month/6; their coefficients represented adjusted differences in BMI-for-age z score at month six. Model coefficients were reported with 95% confidence intervals and approximate Wald p values. Age-specific anthropometric indices were analysed using their eligible denominators. Follow-up completeness and analysis-specific sample sizes were reported. Subgroup comparisons and determinant analyses were considered exploratory, without adjustment for multiple testing. A two-sided $p<0.05$ was considered statistically significant.

Ethical considerations: Approval was obtained from the Institutional Ethics Committee. Written parental consent and age-appropriate assent were obtained before enrolment. Confidentiality was maintained using coded identifiers and restricted data access. Nutritional deterioration prompted clinical assessment and appropriate referral.

RESULTS

The mean age of participants was 7.44±3.89 years, and 38 (56.7%) were male. Most children resided in rural areas (68.7%), while 58.2% belonged to households earning less than ₹10,000 monthly. Household food insecurity affected 37 children (55.2%), including 10.4% with severe food insecurity. Pulmonary tuberculosis accounted for 67.2% of cases, and 37.3% were microbiologically confirmed. Symptoms had persisted for more than four weeks before treatment in 47.8%. Mean baseline energy and protein intakes were 77.45±16.72% and 81.65±16.08% of reference requirements, respectively [Table 1].

Table 1: Baseline sociodemographic, clinical and dietary characteristics of children with tuberculosis (N=67).

Characteristic	Frequency (%)/mean ± SD
Age, years	7.44 ± 3.89
Age groups	
6 months–<5 years	21 (31.3%)
5–<10 years	24 (35.8%)
10–14 years	22 (32.8%)
Gender	
Male	38 (56.7%)
Female	29 (43.3%)
Rural residence	46 (68.7%)
Monthly household income <₹10,000	39 (58.2%)
Maternal education below secondary level	31 (46.3%)
Food secure	30 (44.8%)
Mild household food insecurity	13 (19.4%)
Moderate household food insecurity	17 (25.4%)
Severe household food insecurity	7 (10.4%)
Pulmonary tuberculosis	45 (67.2%)
Extrapulmonary tuberculosis	22 (32.8%)
Microbiologically confirmed tuberculosis	25 (37.3%)
Household contact with a tuberculosis patient	28 (41.8%)
HIV infection	2 (3.0%)
Symptom duration before treatment >4 weeks	32 (47.8%)
Baseline energy intake, % of reference requirement	77.45 ± 16.72
Baseline protein intake, % of reference requirement	81.65 ± 16.08

TB: Tuberculosis; HIV: Human Immunodeficiency Virus. Food-insecurity categories were mutually exclusive.

Mean BMI-for-age z score increased from −2.04±1.15 at baseline to −1.16±1.20 at month six, representing an improvement of 0.88 units (95% CI: 0.75–1.01; $p<0.001$). Weight-for-age and weight-for-length/height z scores increased by 0.66 and 0.87 units, respectively (both $p<0.001$). Height-for-age improved by only 0.02 units despite statistical significance ($p=0.001$). Energy and protein intake increased by 16.51 and 16.37 percentage points, respectively (both $p<0.001$), indicating greater improvement in dietary intake and weight-related indices than in linear growth [Table 2].

Table 2: Longitudinal changes in anthropometric indices and dietary intake between baseline and six months.

Parameter	Eligible Frequency	Baseline mean ± SD	Month 2	Month 6	Baseline-to-month-6 change (95% CI)	p value
BMI-for-age z score	67	−2.04 ± 1.15	−1.61 ± 1.11	−1.16 ± 1.20	+0.88 (+0.75 to +1.01)	<0.001
Height-for-age z score	67	−1.57 ± 1.00	−1.57 ± 1.01	−1.55 ± 1.00	+0.02 (+0.01 to +0.04)	0.001
Weight-for-age z score	45	−2.27 ± 1.25	−1.95 ± 1.18	−1.62 ± 1.26	+0.66 (+0.55 to +0.76)	<0.001
Weight-for-length/height z score	21	−2.02 ± 1.02	−1.55 ± 1.07	−1.15 ± 1.00	+0.87 (+0.63 to +1.12)	<0.001
Energy intake, % of reference requirement	67	77.45 ± 16.72	86.61 ± 17.86	93.96 ± 17.78	+16.51 (+15.38 to +17.63)	<0.001
Protein intake, % of reference requirement	67	81.65 ± 16.08	89.72 ± 17.10	98.01 ± 17.38	+16.37 (+15.03 to +17.70)	<0.001

BMI: Body Mass Index; CI: Confidence Interval. Paired-samples t tests compared baseline with month six. Anthropometric denominators were 67 for BMI-for-age and height-for-age, 45 for weight-for-age, and 21 for weight-for-length/height.

The proportion of children with low BMI-for-age declined from 56.7% at baseline to 29.9% at month six (p<0.001), while severely low BMI-for-age decreased from 19.4% to 4.5% (p=0.002). Underweight declined from 64.4% to 46.7% among eligible children (p=0.008). Wasting among children younger than five years decreased from 57.1% to 28.6% (p=0.031), and thinness among older children declined from 54.3% to 30.4% (p<0.001). Stunting remained relatively persistent, decreasing from 31.3% to 28.4% without statistical significance (p=0.625) [Table 3].

Table 3: Changes in the prevalence of anthropometric deficits during six-month follow-up.

Nutritional indicator	Eligible	Baseline	Month 2	Month 6	p value
	Frequency	Frequency (%)			
Low BMI-for-age: BAZ <−2	67	38 (56.7%)	25 (37.3%)	20 (29.9%)	<0.001
Severely low BMI-for-age: BAZ <−3	67	13 (19.4%)	7 (10.4%)	3 (4.5%)	0.002
Stunting: HAZ <−2	67	21 (31.3%)	22 (32.8%)	19 (28.4%)	0.625
Underweight: WAZ <−2	45	29 (64.4%)	25 (55.6%)	21 (46.7%)	0.008
Wasting among children <5 years: WHZ <−2	21	12 (57.1%)	7 (33.3%)	6 (28.6%)	0.031
Thinness among children ≥5 years: BAZ <−2	46	25 (54.3%)	17 (37.0%)	14 (30.4%)	<0.001

BAZ: BMI-for-Age Z score; HAZ: Height-for-Age Z score; WAZ: Weight-for-Age Z score; WHZ: Weight-for-Length/Height Z score; overlapping deficits were not mutually exclusive.

Among 13 children with baseline BAZ below −3, nine (69.2%) improved to the −3 to below −2 category, one (7.7%) reached BAZ ≥−2, and three (23.1%) remained below −3. Of 25 children initially classified between −3 and below −2, 17 (68.0%) reached BAZ ≥−2. All 29 children with baseline BAZ ≥−2 remained in that category. Overall, 18 of the 38 children with initially low BAZ (47.4%) reached BAZ ≥−2, increasing the total proportion without a low-BAZ deficit to 70.1% [Table 4].

Table 4: Individual transitions in BMI-for-Age nutritional categories from baseline to month six.

Baseline category	Baseline	Month 6: BAZ <−3	Month 6: −3 ≤ BAZ <−2	Month 6: BAZ ≥−2
	Frequency	Frequency (%)		
BAZ <−3	13	3 (23.1%)	9 (69.2%)	1 (7.7%)
−3 ≤ BAZ <−2	25	0 (0.0%)	8 (32.0%)	17 (68.0%)
BAZ ≥−2	29	0 (0.0%)	0 (0.0%)	29 (100.0%)
Total	67	3 (4.5%)	17 (25.4%)	47 (70.1%)

BAZ ≥−2 indicated absence of a low-BAZ deficit rather than complete nutritional recovery.

Children from food-insecure households showed smaller BAZ improvements than those from food-secure households (0.61±0.43 versus 1.21±0.42; p<0.001). Improvement was also lower among children with baseline energy intake below 80% of reference requirements (0.65±0.48 versus 1.16±0.42; p<0.001). Boys exhibited greater improvement than girls (1.00±0.43 versus 0.72±0.58; p=0.031). Differences by age, residence, tuberculosis classification and baseline BAZ category were not statistically significant. Symptom duration exceeding four weeks was associated with numerically smaller improvement, although the comparison did not reach significance (p=0.053) [Table 5].

Table 5: Unadjusted associations between participant characteristics and six-month improvement in BMI-for-Age Z score.

Factor	Category	Frequency	Change in BAZ mean ± SD	p value
Age group	<5 years	21	0.87 ± 0.54	0.966
	≥5 years	46	0.88 ± 0.51	—
Gender	Male	38	1.00 ± 0.43	0.031

	Female	29	0.72 ± 0.58	—
Residence	Rural	46	0.81 ± 0.54	0.1
	Urban	21	1.02 ± 0.44	—
Baseline household food insecurity	Present	37	0.61 ± 0.43	<0.001
	Absent	30	1.21 ± 0.42	—
Baseline energy intake	<80% of reference requirement	37	0.65 ± 0.48	<0.001
	≥80% of reference requirement	30	1.16 ± 0.42	—
Symptom duration before treatment	>4 weeks	32	0.75 ± 0.48	0.053
	≤4 weeks	35	1.00 ± 0.53	—
Tuberculosis classification	Pulmonary	45	0.94 ± 0.51	0.138
	Extrapulmonary	22	0.74 ± 0.51	—
Baseline BMI-for-age deficit	BAZ <−2	38	0.87 ± 0.56	0.804
	BAZ ≥−2	29	0.90 ± 0.46	—

After adjustment, baseline household food insecurity was associated with a 0.39-unit lower BAZ at month six (95% CI: −0.53 to −0.24; p<0.001). Each 10-percentage-point increase in baseline energy intake was associated with a 0.12-unit higher month-six BAZ (95% CI: 0.07–0.16; p<0.001). Male gender was associated with higher BAZ across follow-up (coefficient: 0.25; p=0.003), while baseline BAZ strongly predicted subsequent values (coefficient: 0.92; p<0.001). Associations with prolonged symptom duration and age were not statistically significant [Table 6].

Table 6: Adjusted associations with nutritional trajectories during follow-up.

Variable	Adjusted coefficient	95% CI	p value
Baseline household food insecurity: present versus absent	−0.39	−0.53 to −0.24	<0.001
Baseline energy intake: per 10-percentage-point increase	0.12	+0.07 to +0.16	<0.001
Symptom duration >4 versus ≤4 weeks	−0.10	−0.22 to +0.03	0.118
Baseline BAZ: per one-unit increase	0.92	+0.85 to +0.99	<0.001
Age: per five-year increase	−0.08	−0.18 to +0.03	0.142
Male versus female	0.25	+0.09 to +0.41	0.003

The random-intercept linear mixed-effects model included 402 follow-up observations from 67 children and was estimated using restricted maximum likelihood. Visit was categorical. Food insecurity, energy intake and symptom duration interacted with elapsed month/6; their coefficients represented adjusted differences at month six. Baseline BAZ, age and gender coefficients applied across follow-up. CI, confidence interval.

DISCUSSION

The principal finding was improvement in weight-related nutritional indices over six months, accompanied by persistent linear-growth deficits. Baseline underweight affected 64.4% of eligible children, broadly comparable with the 68.4% reported by Chhetri et al. in Nepal; however, stunting was less frequent in our cohort (31.3% versus 53.3%).[10] Differences in age composition, disease severity and referral patterns limit direct comparison. The coexistence of tuberculosis and nutritional deficits is biologically plausible: inadequate nutrient intake compromises immune development, while infection-associated inflammation increases metabolic demands and impairs tissue synthesis.[11]

BMI-for-age z score increased by 0.88 units (95% CI: 0.75–1.01; p<0.001), while weight-for-age and weight-for-length/height improved by 0.66 and 0.87 units, respectively. Resolution of inflammation and restoration of appetite could contribute to these changes. Schaaf et al. documented declining inflammatory activity during treatment in HIV-uninfected children, although muscle deficits persisted.[12] Nevertheless, improvement cannot be attributed to supplementation alone. Lodha et al.'s Indian trial involving 403 children found no additional weight-gain benefit from micronutrient supplementation,[13] similarly, Mehta et al.'s Tanzanian trial involving 255 children found no overall benefit for its primary weight-gain endpoint.[14]

Height-for-age increased by only 0.02 units despite statistical significance (p=0.001), and stunting prevalence remained statistically unchanged (31.3% to 28.4%; p=0.625). This distinction illustrates why statistical significance should not be equated with meaningful nutritional recovery. Linear-growth restriction reflects cumulative nutritional deprivation, recurrent infection and disturbances in growth regulation, which may resolve more slowly than wasting.[15] Martinez et al. demonstrated lasting health consequences following early-life tuberculosis, supporting assessment beyond treatment completion.[16] More directly, Ghosh et al.'s longitudinal study from Purulia reported persistent height-for-age deficits during follow-up.[17] Together, these findings favour monitoring both weight and height rather than interpreting weight gain as complete recovery.

Household food insecurity affected 55.2% of participants and was associated with a 0.39-unit lower adjusted month-six BMI-for-age z score (p<0.001). Each ten-percentage-point increase in baseline energy intake was associated with a 0.12-unit higher month-six value (p<0.001). Limited food availability may constrain recovery despite effective antimicrobial treatment. The Indian RATIONS trial

found a 39% reduction in tuberculosis incidence among nutritionally supported household contacts.[18] This preventive effect supports addressing household nutrition, although it does not establish a paediatric treatment effect. Sinha et al.'s Indian cohort also associated severe undernutrition with unfavourable treatment outcomes (adjusted incidence rate ratio: 2.05), providing complementary evidence from an adult-dominated population.[19]

Individual transitions further demonstrated incomplete recovery: 18 of 38 children with initially low BMI-for-age (47.4%) reached a z score ≥−2, while 20 remained below this threshold. Residual deficits therefore warrant attention even when average indices improve. In the adult RATIONS cohort, a 5% weight gain at two months was associated with lower mortality (adjusted hazard ratio: 0.39; 95% CI: 0.18–0.86), yet 54.8% remained underweight after follow-up.[20] Grobler et al.'s review likewise distinguished possible benefits for weight gain from uncertain effects on treatment outcomes.[21] Adult prognostic thresholds should not, however, be transferred directly to children.

Male gender was associated with higher follow-up BMI-for-age (adjusted coefficient: 0.25; p=0.003), but this exploratory association does not establish a biological advantage or differential feeding. Pubertal stage and unmeasured household factors could influence the estimate. Age and prolonged symptom duration were not independently significant, while only two HIV-positive participants precluded reliable subgroup inference. The small cohort and multiple comparisons also limit precision. Damanik et al.'s recent scoping review identified heterogeneous and limited paediatric nutritional evidence.[22] Overall, the findings support repeated anthropometry, household food-security assessment and continued nutritional follow-up, while the observational design prevents causal attribution of recovery to specific interventions.

Limitations: This study was limited by its small sample size and recruitment from selected treatment centres, restricting generalisability. Dietary recalls and caregiver-reported adherence were susceptible to reporting errors. Six months of follow-up may have been insufficient to capture linear-growth recovery. The absence of a comparison group limited causal interpretation. Residual confounding, multiple exploratory comparisons and only two HIV-positive participants further constrained adjusted estimates and subgroup analyses.

CONCLUSION

Nutritional status improved during six months of tuberculosis follow-up, particularly in weight-related indices, while stunting remained relatively persistent. Household food insecurity and lower baseline energy intake were associated with poorer nutritional trajectories, highlighting the importance of assessing dietary and household circumstances alongside clinical care. Weight gain alone should not be interpreted as complete nutritional recovery. Repeated age-appropriate anthropometry, dietary counselling and access to nutritional support should accompany tuberculosis management. Children with persistent deficits may require continued assessment beyond treatment completion. Larger studies with longer follow-up are needed to confirm these associations and determine whether targeted nutritional interventions improve growth and clinical outcomes.

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