

Review Article

Critical examination of evidence for the nutritional status of children in Papua New Guinea – a systematic review

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Background and Objectives: Undernutrition remains a significant cause of childhood illness, poor growth, development, and death in Papua New Guinea (PNG). Studies on child nutritional outcomes in PNG vary by design, measurement protocols and quality. We conducted a systematic review to assess the evidence for the prevalence of child undernutrition across different study populations, geographical locations and time periods. **Methods and Study Design:** Six electronic databases and additional grey literature were searched for articles describing the nutritional status by wasting, stunting and underweight, of PNG children under five years of age, published between 1990 and April 2015. Prevalence data using different scales of measurement and reference populations were standardized according to WHO protocols. **Results:** The search yielded 566 articles, of which, 31 studies met the inclusion criteria. The prevalence of child undernutrition varied from 1% to 76% for wasting (median 11%), 5% to 92% for stunting (median 51%), and 14% to 59% for underweight (median 32%). Wide variations exist according to the index used for measurement, the population characteristics and the geographical region in which they live. Prevalence estimates increase significantly when data using different scales of measurement and population references are standardized to the WHO protocols. **Conclusions:** Child undernutrition in PNG is regionally variable due to a complex interplay of poverty, disease, food-security, cultural, environmental and socio-political issues requiring a complex mix of solutions by governments, health systems and local communities. Area-specific surveys using multiple measures are necessary to inform local solutions for this important problem.

Key Words: undernutrition, stunting, wasting, Papua New Guinea, systematic review

INTRODUCTION

Malnutrition is a broad term describing both undernutrition and over-nutrition and is a global problem with profound and lasting consequences for human health and development.¹

Undernutrition is closely associated with child illness and poor cognitive development and accounts for approximately 45% of child deaths and contributes to 11% of the global disease burden worldwide.²⁻⁴ It is a condition resulting from inadequate energy and nutrient intake of the mother and foetus during pregnancy⁵ and/or the child after birth, compounded by severe or repeated infections, with intergenerational influences and consequences.⁶ Anthropometric assessment, static and functional laboratory tests, and clinical examination are all important methods to assess the nutritional status of individual children. Growth failure, depicted through anthropometric assess-

ment, precedes the other stages of nutritional deficiency and can identify the immediate causes of undernutrition and inform the potential nutritional and health interventions before clinical signs and symptoms appear.⁷

Anthropometry relies on the measurement of physical characteristics such as height (or length), weight, skin-fold thickness, and subcutaneous fat.^{8,9} Anthropometric

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measurements are combined to calculate anthropometric indices, including weight-for-height, or small mid-upper-arm circumference (wasting or acute undernutrition), body-mass-index-for-age (thinness and obesity), height-for-age (stunting or chronic undernutrition), and weight-for-age (underweight - a composite index, combining elements of both acute and chronic undernutrition).

Papua New Guinea (PNG) is the largest of the Pacific Island nations and sits on the eastern half of the tropical island of New Guinea. It is geographically very diverse, with rugged mountain ranges, extensive swamps, lowland and alpine forests and over 600 scattered islands. It has over seven million people, 86% of whom live in rural communities and rely largely on subsistence agriculture. PNG is divided into 22 provinces, which the PNG government groups into four administrative regions, Papua, Highlands, Momase and Islands.¹⁰ The UN ranks PNG as 158th out of 187 countries on the Human Development Index.¹¹ Poor road networks in the rural areas make travel and access to health and education services difficult. High rates of child morbidity, mortality and undernutrition have long been recognized in PNG and the national nutrition policy has identified the need to improve the nutritional status of the nation as a policy priority. The PNG National Nutrition Survey (NNS) from 2005 found that 43.9% of PNG children from 6-59 months of age were stunted, 4.5% were wasted and 18.1% underweight with major regional differences.¹⁰ Data from the International Food Policy Research Institute reported even higher prevalence in PNG in 2009, with up to 50% stunting and 14% wasting.¹² Whilst both undernutrition and overnutrition are problematic in the PNG context, undernutrition is the most prevalent situation reported in rural PNG, where 86% of the nation's children reside. We conducted this systematic review to add data to the PNG National Nutrition Survey (NNS 2005) to provide a comprehensive examination of the prevalence of protein-energy undernutrition in PNG children across different geographical locations and in different time periods.

METHODS

Literature search strategy

The review was conducted following the protocol of the Preferred Reporting Items for Systematic Reviews and Meta-analyses: the PRISMA statement.¹³ Six electronic databases (MEDLINE, EMBASE, CINAHL, SCOPUS, Web of Science and Global Health) were searched to find both published and unpublished studies during the period from 1990 to 2015. This twenty-five year period was considered a suitable cut-off to maintain currency of evidence as well as to estimate any trends over recent decades. There was no language restriction. A full list of search terms was established and appears in Table 1. Mesh keywords, indexed terms and subheadings were used as appropriate, according to the specifications of the database. All retrieved articles were checked for duplication. Additional studies and grey literature, (including conference abstracts, unpublished studies and reports) were sourced by searching reference lists of screened articles.

Study selection

Inclusion criteria were those studies reporting quantitative anthropometric data (wasting, stunting or underweight) from original research conducted in PNG and among children aged between 0 and 60 months. Studies had to report one or more prevalence estimates of undernutrition or sufficient data that allowed for estimation of the population prevalence. Current convention for nutrition surveys usually includes anthropometric data for children from 6 to 59 months. In this review we included studies reporting prevalence data on children less than six months, as recommended by the World Health Organization (WHO),¹⁴ or over 60 months, if data on the outcomes of interest were able to be disaggregated for the eligible age range and then other age-related data was excluded. Similarly, any study that described a population beyond PNG, was included if the PNG data could be disaggregated. Some authors presented data from the outcomes of interest in graphs rather than table form. In these cases, the graphs were electronically magnified, and the quantified results estimated visually. Our selection included quantitative data from observational, experimental and quasi-experimental study designs. All studies yielded from the database search were initially screened for relevance by title and abstract. Additionally, the reference lists from included articles were manually scanned to identify any additional articles that were not detected by the online search. Full text articles were assessed for eligibility based on predefined criteria. Any doubt about the eligibility of a study for inclusion was assessed by a second author.

Data extraction

A three-stepped process was employed to extract the data. Retrieved papers were filtered first by title, then by abstract and finally the full texts were obtained for review. The filtering of the papers was done by PM and the data extraction form was piloted using five randomly selected papers before the full data extraction could be carried out. Data were collected by PM and extracted into a specifically designed electronic spreadsheet to record relevant data including authors, year of publication, study title, study design, location and demography, sample size and participant characteristics, intervention and comparator (if relevant), the outcomes of interest and study quality (Table 2). A second reviewer (SL) checked and confirmed the data extraction, and in cases of discrepancy, consensus was agreed through discussion.

Study quality assessment

Study quality was assessed and tabled according to the Effective Public Health Practice Project (EPHPP) protocol using the Quality Assessment Tool for Quantitative studies and the corresponding Dictionary. All of the studies were first assessed by one reviewer (PM) and scored using seven quality-appraisal criteria: selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, and intervention integrity (where available). Each criterion was individually scored for quality and the results pooled so that each study was allotted a global summary quality score: strong, moderate, or weak (Table 2). A second reviewer (MP)

Table 1. Search terms and strategy for the systematic review on nutritional status of PNG children

Databases	MEDLINE, EMBASE, CINAHL, SCOPUS, WEB OF Science, Global Health
Date	
Strategy	#1 AND #2 AND #3 AND #4
#1	((((title:(papua new guinea* OR new guinea* OR PNG OR papua*) OR ab:(papua new guinea* OR new guinea* OR PNG OR papua*)) OR ((gl:(“Papua New Guinea“ OR “New Guinea”))))))
#2	((((de:(“children” OR “preschool child” OR “preschool children” OR “infant children” OR “infants” OR “newborn infant children” OR “newborn infants” OR “neonates”))) OR ((title:(infan* OR newborn* OR new-born* OR perinat* OR neonat* OR baby OR baby* OR babies OR toddler* OR boy OR boys OR boyhood OR girl* OR kid OR kids OR child OR child* OR children* OR schoolchild* OR school child* OR pediatric* OR paediatric* OR paediatric* OR prematur* OR preterm* OR gestation OR pre school* OR preschool* OR kinder* OR creche* OR childcare) OR ab:(infan* OR newborn* OR new-born* OR perinat* OR neonat* OR baby OR baby* OR babies OR toddler* OR boy OR boys OR boyhood OR girl* OR kid OR kids OR child OR child* OR children* OR schoolchild* OR school child* OR pediatric* OR paediatric* OR paediatric* OR prematur* OR preterm* OR gestation OR pre school* OR preschool* OR kinder* OR creche* OR childcare)))))
#3	((((de:(“child nutrition” OR “feeding” OR “foods” OR “malnutrition” OR “nutrient requirements” OR “nutritional adequacy” OR “nutritional assessment” OR “nutritional disorders” OR “nutrition surveys” OR “nutritional state” OR “nutritional status”))) OR ((title:(nutrition* OR nutrient* OR nourish* OR undernourish* OR malnourish* OR malnutrition*) OR ab:(nutrition* OR nutrient* OR nourish* OR undernourish* OR malnourish* OR malnutrition*))))))
#4	((((title:(mortalit* OR death*) OR ab:(mortalit* OR death*))) OR ((de:(“mortality” OR “infant mortality” OR “neonatal mortality” OR “perinatal mortality”))))))

Data are reported as mean and standard deviation.

* $p < 0.05$ for paired t-test.

** p for general linear model adjusted for age and gender.

Table 2. Study characteristics of included articles describing nutritional status of PNG children by anthropometry

Article	Design	Age (mths)	Participant characteristics	Location	Study setting	Rural/urban	Quality
Community-based sampling Miyoshi (2015) ³	Cross-sectional	6 to 59	n=211 Attendees for immunization clinics POM=89, Nuku=112	HIGHLANDS	Port Moresby General Hospital “well baby” clinic & Nuku District health clinic	Rural/Urban	Moderate
Shinoda (2012) ⁴	Cross-sectional	6 to 59	n= 870 Nationally sampled from PNG National Nutrition Survey 2005	PNG wide	National household sample 2005	Rural/Urban	Moderate
Weitz (2012) ⁶	Cross-sectional	0 to 59	n=283 Random sample of 3 populations from Bougainville Island	ISLANDS	Sample of village communities	Rural	Weak
Wand (2012) ⁸	Cross-sectional	0 to 59	n=683 Cross-sectional multi-stage random household survey EHP=335, MAD=348	MAMOSE HIGHLANDS	Peri-urban areas & villages	Rural	Weak
Keeble(2006) ¹⁰	Cross-sectional	12 to 59	n=100 Attendees to Koinambe Health Centre	HIGHLANDS	Jimi Valley - Koinambe Health Centre	Rural	Weak
King (2004) ¹²	Cross-sectional	0 to 59	n=179 All invited from 11 randomly selected villages	PAPUA	11 rural villages close to Kanabea	Rural	Weak
King (2002) ¹⁴	Cross-sectional	0 to 59	n= 260 All invited from 11 randomly selected villages	PAPUA	11 rural villages close to Kanabea	Rural	Moderate
Mueller (2001) ¹⁶	Cross-sectional	6 to 59	n=18,868 Random sample from 1096 rural PNG villages (excl. Chimbu & N Solomons)	PNG wide	National household sample	Rural/Urban	Weak
Edwards (2000) ¹⁷	Cross-sectional	0 to 59	n=21,325 Random sample from 1096 rural PNG villages (excl. Chimbu & N Solomons)	PNG wide	National household sample	Rural/Urban	Moderate
Mueller (1999) ²⁰	Cross-sectional	6 to 59	n= 15,975 Random sample from 1096 rural PNG villages (excl. Chimbu & N Solomons)	PNG wide	National household sample	Rural/Urban	Weak
Shankar (1999) ²¹	Randomized Control trial	6 to 59	n=480 All eligible children in 9 villages (pop 4000/520 eligible) Int=239, Placebo=241	MAMOSE	All children in 9 Wosera villages	Rural	Strong
Genton (1998) ²⁴	Cohort	10 to 48	n= 47/80 Attendees of Kunjingini Hlth Centre	MAMOSE	Outpatients of Kunjingini Health centre	Rural	Weak
Ulijasek (1998) ²⁶	Cross-sectional	0 to 24	n=21 Opportunity sample of Anga children with no signs of infection	PAPUA	Anga viillages	Rural	Weak
Earland (1993) ²⁷	Cross-sectional	0 to 59	n=90 Residents of an urban settlement in POM – no sampling strategy	PAPUA	Settlement in Port Moresby	Urban	Moderate
Gibson (1990) ²⁹	Cross-sectional	2 to 6	n=52/123 Attendees to 2 MCH clinics	MAMOSE	2 MCH clinics in Wosera	Rural	Weak
Smith (1991) ³⁰	Cross-sectional	6 to 59	n=26,290 Random sample from 1096 rural PNG villages (excl. Chimbu & N Solomons)	PNG wide	National household sample	Rural/Urban	Moderate
Shack (1990) ^{31,32}	Cross-sectional	24 to 59	n=115 Random sample of Gavien Rubber plantation by location of origin (grass coun- try, Wosera, Middle Sepik), matched to popu- lation from outsites of origin	MAMOSE	Gavien rubber plantation settlement	Rural	Moderate

Table 2. Study characteristics of included articles describing nutritional status of PNG children by anthropometry (cont.)

Article	Design	Age (mths)	Participant characteristics	Location	Study setting	Rural/urban	Quality
Community and hospital-based sampling Manning (2012) ¹	Case-control	24 to 59	n=263 Cases: 143 hospital admissions with severe malarial anaemia (Hb <50 g/L) & 120 controls: healthy non-SMA (HB> 100 g/L) from immunization clinics	MAMOSE	Paediatric ward of Modilon Hospital	Rural/Urban	Moderate
Hospital-based sampling Olita'a (2014) ²	Case-control	1 to 59	n=100 Cases: 50 Hospital admissions for undernutrition matched with Controls (50) admitted for other reasons	PAPUA	Port Moresby General Hospital	Urban	Weak
Cripps (2008) ⁵	Cross-sectional	1 to 59	n=238 Child hospital admissions with moderate-severe pneumonia	HIGHLANDS	Goroka Hospital	Rural/Urban	Weak
Nasi (2003) ⁷	Audit	0 to 36	n=179/224 All children who died in POM GH Paediatric ward during study period	PAPUA	Paediatric ward of Port Moresby General Hospital	Urban	Weak
Pameh (2002) ⁹	Case-control	0 to 59	n=120 POM GH attendees : Cases: 40 adoptees admitted and controls: 80 adoptees as outpatients	PAPUA	Admissions & outpatients at of Port Moresby General Hospital	Urban	Weak
Genton (1997) ¹¹	Cohort	11 to 48	n=47/134 All admissions to Madang GH with cerebral malaria	MAMOSE	Paediatric ward of Modilon Hospital	Rural/Urban	Moderate
Han (1995) ¹³	Case-control	0 to 59	n=720 Cases: 144 hospital admissions with persistent diarrhoea (PD) and 576 controls-hospital admissions with non-PD	PAPUA	Paediatric admissions to of Port Moresby General Hospital	Urban	Strong
Sapak (1991) ¹⁵	Quasi-experimental	0 to 59	n=83 Attendees to Kunjingini Health centre with fever or Hx of fever, stain positive for Pf (or mixed infections) and no Hx of antimalarial drugs in past 7 days	MAMOSE	Outpatients of Kunjingini Health centre	Rural	Weak
Studies not reporting undernutrition prevalence by z-score <-2							
Ulijasek (1996) ¹⁸	Cross-sectional	0 to 59	n=135 Anga children living in Gulf, Morobe, EHP villages. No sampling strategy	PAPUA MAMOSE HIGHLANDS	Anga villages – household sample	Rural	Weak
Allen (1996) ¹⁹	Cohort	12 to 59	n=361/489 Hospital admissions for malaria during study period	MAMOSE	Paediatric ward of Modilon Hospital	Rural/Urban	Weak
Smith (1993) ²²	Cross-sectional	6 to 59	n=25,022 Cluster survey sampled nationwide (1982/83 PNG NNS)	PNG wide	National household sample	Rural/Urban	Moderate
Groos (1991) ²³	Cross-sectional	0 to 59	n=1136 All <2 years (motor milestones) & <5 years (nutrition survey) Karimui n=270 Gumine n=866	HIGHLANDS	2 villages - Karimui & Gumine	Rural	Moderate
Heywood (1991) ²⁵	Cross-sectional	0 to 24	n=457 All aged <2 years attending Yagaum MCH clinics	MAMOSE	Yagaum village MCH clinic	Rural	Moderate
Smith (1991) ²⁸	Cohort	0 to 59	n=156 All <5yrs in 8 hamlets in Asaro Valley	HIGHLANDS	Asaro valley village hamlets	Rural	Moderate

then chose a random sample of 20% of the articles for independent quality assessment, and the scores were finalised based on consensus. A third reviewer (SL) was consulted if there were any doubts raised or disagreement between reviewers.

Measures of undernutrition and data standardization

We analysed studies reporting on undernutrition (rather than over-nutrition) of children at the population level, as the majority of PNG children (86%) reside in rural areas, and are known to experience high levels of undernutrition.¹⁰ Different conventions were used in the included studies to define, measure, classify and interpret population nutritional status, which presented a challenge when comparing undernutrition from different studies, and making meta-analysis impractical. We adopted the current WHO definition of population undernutrition, viz. the proportion of children falling below two standard deviations of the median of the WHO 2006 international growth standard, for weight-for-height (wasting), height-for-age (stunting) and weight-for-age (underweight),² or the proportion of children with a mid-upper-arm circumference (MUAC) <12.5 cm.¹⁵ We analysed the study results, stratified, where possible, by age group, sex, urban/rural residence and administrative region. (see Table 3 - outcomes summary)

Reference populations

Studies included in the review reported anthropometric outcomes against five different reference populations, used over recent decades, namely the WHO 2006 standard, the Center for Disease Control and Prevention (CDC) 2000, the National Center for Health Statistics (NCHS) 1977 and the Harvard reference 1966-1974 and an internal PNG reference. The CDC, NCHS and Harvard references were based on US populations from different databases and included children who had been fed primarily with infant formula and who were of restricted genetic, geographic and socioeconomic background.¹⁶ Their relevance in developing countries has long been a contentious issue. The current WHO 2006 standard was developed using data from Brazil, Ghana, India, Norway, Oman and the United States from breastfed children raised in nutritionally favourable circumstances and is a representative global sample and an indicator of how healthy children should grow. The WHO standard generally estimates a higher prevalence for wasting and stunting and a slightly lower prevalence for underweight than the NCHS and Harvard reference ranges.¹⁴ This was an important consideration when we evaluated child nutritional status from different studies and time periods. To standardize prevalence estimates to the WHO 2006 standard, data from studies using the NCHS reference were multiplied according to an algorithm developed by a WHO working committee:¹⁴ wasting prevalence x 1.18, stunting prevalence x 1.4, underweight prevalence x 0.87 (to 95% CI). The same algorithm was applied to data using the Harvard reference, as graphs of undernutrition prevalence using NCHS and Harvard references compare very closely.¹⁷⁻¹⁹ In the two studies using a local national PNG reference, the authors also presented prevalence data against the NCHS reference, allowing the application of the same

algorithms. No algorithm exists to convert prevalence data using the CDC reference, and so the one study using this reference could not be standardized to the WHO standard.

Population location and source of sample

Four PNG geographical & administrative regions comprising the 22 PNG provinces were considered in this review: PAPUA (National Capital District, Central Province, Western Province, Gulf Province, Milne Bay), MAMOSE (Madang Province, East Sepik Province, West Sepik Province, Morobe Province), HIGHLANDS (Western Highlands, Eastern Highlands, Hela, Jiwaka, Southern Highlands, Enga, Simbu), and ISLANDS (East New Britain, West New Britain, Manus, New Ireland, Autonomous Region of Bougainville) (Table 3).

In this review, distinction was also drawn between data gathered from the community, where random sampling or child attendance at immunization or maternal and child health clinics was used, versus data gathered from children attending a health facility and known to be unwell (Table 3). Data from community-based and hospital-based samples are presented separately in the tables, and the latter were excluded from calculations of undernutrition prevalence.

Definition of undernutrition

Undernutrition was defined in two ways: 1) using the proportion of the median z-score (<-2 SD of the median) cut-off points, and 2) using mean z-scores. When the proportion of the median was used, the cut-off points proposed by either Waterloo²⁰ or Gomez were used to depict undernutrition (moderate plus severe undernutrition): weight-for-height <80% of the median for wasting, height-for-age below 90% of the median for stunting, and weight-for-age <80% of the median for underweight. These cut-off points are roughly equivalent to weight-for-height z-scores (WHZ), height-for-age z-scores (HAZ) and weight-for-age z-scores (WAZ) below 2 SD of the median. In some studies child undernutrition was reported by mean z-scores (instead of prevalence) thus describing a negative or a positive shift in the nutritional status of the entire study population directly against the international population standard.⁸ To standardize the results, we converted mean z-scores into prevalence using probit regression in Stata as recommended by WHO.

The prevalence of undernutrition varies markedly depending on which anthropometric index is used to estimate it as each index describes a different form of undernutrition. To compare the severity of undernutrition prevalence across studies using different indices, we adopted the WHO classification of low, medium, high and very high according to the ranges appearing in Table 4.²

RESULTS

Study selection

The initial search yielded 556 articles from the databases and 10 additional citations from the grey literature and from the reference lists of relevant articles (Figure 1). After removal of duplicates, 109 titles and abstracts were reviewed. A total of 31 studies met inclusion criteria. The study characteristics are presented in Table 2 and a sum-

Table 3. Malnutrition prevalence (WHZ, HAZ & WAZ % <-2 z-scores) and population summary statistics (mean z-scores) using WHO 2006 standard

Author	Reference population [†]	Wasting (Weight-for-height z-scores)		Stunting (Height-for age z-scores)		Underweight (Weight-for-age z-scores)	
		Mean WHZ scores [‡]	Prevalence% <-2 z [§]	Mean HAZ-scores	Prevalence % <-2 z [¶]	Mean WAZ-scores	Prevalence % <-2 z
Community-based sampling							
Miyoshi (2015)	WHO 2006		Port Moresby Hospital=5% Nuku District Health centre=2%		Port Moresby Hospital=5% Nuku District Health centre=27%		Port Moresby Hospital=2% Nuku District Health centre=9%
Shinoda (2012)	WHO 2006		4%		42%		18%
Weitz (2012)	CDC 2000			CDC2000 Age (mths): 12-24 M=-2.8; F=-2.5 36-48 M=-2.6; F=-2.4	CDC2000 Age (mths): 12-24 M=75%; F=50% 36-48 M=70%; F=71%		
Wand (2012)	WHO 2006		Total=18% Highlands=14% Mamose=22%		Total =54% Highlands=83% Mamose=67%		Total=31% Highlands=29% Mamose=33%
Keeble (2006)	Converted from HARVARD reference		Total=8% (9% <90% of median PNG reference)		Total=91% (66% <90% of median PNG reference)		No WHO ref data (84% <80% of median PNG reference)
King (2004)	Converted from NCHS 1977	- 1.56 (SD 1.37 ^{§§})	33% (by equation ^{¶¶})	- 2.21 (SD 1.47)	20% (by equation)	- 2.52 (SD 1.23)	58% (by equation)
King (2002)	Converted from NCHS 1977	- 1.34 (SD 1.49)	Total=39% (by equation) Age (mths): 0-3=13% 3-6=11% 6-12=29% 12-24=49% 24-36=45% 36-48=55% 48-60=36%	- 2.26 (SD 1.50)	Total=77% (by equation) Age (mths): 0-3=61% 3-6=68% 6-12=100% 12-24=83% 24-36=52% 36-48=80% 48-60=88%	- 2.43 (SD 1.25)	Total=59% (by equation) Age (mths): 0-3=24% 3-6=21% 6-12=67% 12-24=66% 24-36=57% 36-48=73% 48-60=59%

[†]To standardize prevalence data to the WHO 2006 standard, prevalence (%) of malnutrition from studies using the NCHS and Harvard references was multiplied according to the following WHO algorithm: weight-for-height prevalence x 1.18, height-for-age prevalence x 1.4, weight -for-age prevalence x 0.87. Prevalence data using the CDC 2000 reference generally underestimate stunting at all ages compared to the WHO 2006 reference. No conversion algorithm was applied to the CDC 2000 data.

[‡]The mean z-score describes the nutritional status of the study population directly against the reference population, instead of a subset of individuals below a set cut-off.

[§]Prevalence-based data are reported using a cut-off value, where malnutrition is defined as the percentage of the study population <-2 z-scores against the mean of the reference population or <80% of the median of the reference for wasting and underweight and <90% of the median for stunting

[¶]Where stunting prevalence is reported at 100%, it is due to the application of the WHO algorithm (x 1.4) converting NCHS reference data to the WHO standard, resulting in a value over 100%. (95% CI)

^{§§}SD - Standard Deviation

^{¶¶}Prevalence was calculated from reported data (mean z-score and standard deviation) using an equation and probit regression in Stata software as recommended by WHO.

Table 3. Malnutrition prevalence (WHZ, HAZ & WAZ % < -2 z-scores) and population summary statistics (mean z-scores) using WHO 2006 standard (cont.)

Author	Reference population [†]	Wasting (Weight-for-height z-scores)		Stunting (Height-for age z-scores)		Underweight (Weight-for-age z-scores)	
		Mean WHZ-scores [*]	Prevalence % <-2 z [§]	Mean HAZ-scores	Prevalence % <-2 z [¶]	Mean WAZ-scores	Prevalence % <-2 z
Mueller (2001)	Converted from NCHS 1977		Age (mths): 12=12% 24=12% 36=5% 48=4% 60=2%		Age (mths): 12=46% 24=67% 36=73% 48=76% 60=84%		Age (mths): 12=23% 24=28% 36=21% 48=17% 60=17%
Edwards (2000)	Converted from HARVARD reference		Total=7% Islands=2% Western=15% Highlands=4% Coastal=8%		Total=32% Islands=52% Coastal=21%		Total =33% Highlands=18% Islands=50%
Mueller (1999)	Converted from NCHS 1977		Age (mths): 12=12% 24=12% 36=5% 48=4% 60=2%		Age (mths): 12=46% 24=67% 36=73% 48=76% 60=84%		Age (mths): 12=23% 24=28% 36=21% 48=17% 60=17%
Shankar (1999)	Converted from NCHS 1977	Baseline: • Intervention=-0.72 • Placebo=-0.72 End of study: • Intervention=-0.76 • Placebo=-0.62	Baseline: (by equation) • Intervention=15% • Placebo=6% End of study: • Intervention=6% • Placebo=2%	Baseline: • Intervention=-1.80 • Placebo=-1.81 End of study: • Intervention=-1.86 • Placebo=-2.00	Baseline: (by equation) • Intervention=60% • Placebo=62% End of study: • Intervention=62% • Placebo=70%		
Genton (1998)	Converted from NCHS 1977	-1.03	Total=25% (0-48 mths) Age (mths): <24=54% 24-48=17% 48-72=11%	-1.24	Total=34% (0-48 mths) Age (mths): <24=38% 24-48=32% 48-72=46%		
Ulijasek (1998)	Converted from NCHS 1977	Age (mths): 0-24=-0.86 (SD 0.84) 24-84=-0.62 (SD 0.53)	Age (mths): (by equation) 0-24=11% 24-84=1%	Age (mths): 0-24=-2.57 (SD 0.74) 24-84=-3.28 (SD 0.67)	Age (mths): (by equation) 0-24=100% 24-84=100%		

[†]To standardize prevalence data to the WHO 2006 standard, prevalence (%) of malnutrition from studies using the NCHS and Harvard references was multiplied according to the following WHO algorithm: weight-for-height prevalence x 1.18, height-for-age prevalence x 1.4, weight -for-age prevalence x 0.87. Prevalence data using the CDC 2000 reference generally underestimate stunting at all ages compared to the WHO 2006 reference. No conversion algorithm was applied to the CDC 2000 data.

[‡]The mean z-score describes the nutritional status of the study population directly against the reference population, instead of a subset of individuals below a set cut-off.

[§]Prevalence-based data are reported using a cut-off value, where malnutrition is defined as the percentage of the study population <-2 z-scores against the mean of the reference population or <80% of the median of the reference for wasting and underweight and <90% of the median for stunting

[¶]Where stunting prevalence is reported at 100%, it is due to the application of the WHO algorithm (x 1.4) converting NCHS reference data to the WHO standard, resulting in a value over 100%. (95% CI)

^{§§}SD - Standard Deviation

^{¶¶}Prevalence was calculated from reported data (mean z-score and standard deviation) using an equation and probit regression in Stata software as recommended by WHO.

Table 3. Malnutrition prevalence (WHZ, HAZ & WAZ % <-2 z-scores) and population summary statistics (mean z-scores) using WHO 2006 standard (cont.)

Author	Reference population [†]	Wasting (Weight-for-height z-scores)		Stunting (Height-for age z-scores)		Underweight (Weight-for-age z-scores)	
		Mean WHZ-scores [‡]	Prevalence % <-2 z [§]	Mean HAZ-scores	Prevalence % <-2 z [¶]	Mean WAZ-scores	Prevalence % <-2 z
Earland (1993)	Converted from HARVARD		14%		10%		26%
Gibson (1990)	Converted from NCHS 1977	Age (mths): 24-48=-0.39 (SD 0.51) 48-72=-0.29 (SD 0.86)	Total=0%	Age (mths): 24-48=-1.72 (SD 1.08) 48-72=-1.86 (SD 1.14)	Total=56%	Age (mths): 24-48=-1.41 (SD 0.74) 48-72=-1.36 (SD 0.77)	Total=14% Age (mths): 24-48=11% 48-72=16%
Smith (1991)	Converted from NCHS 1977		7%		71%		38%
Shack1 (1990) and Shack2 (1990)	Converted from NCHS 1977	Grassland=-1.16 (SD=0.65) Wosera=-0.46 (SD=0.74) Sepik=-1.02 (SD=0.86)	(by equation) Grassland=12% Wosera=22% Sepik=15%	Grassland=-1.97 (SD=0.94) Wosera=-1.19 (SD=0.68) Sepik=-1.53 (SD=0.73)	(by equation) Grassland=68% Wosera=16% Sepik=37%	Grassland=-2.10 (SD=0.62) Wosera=-1.29 (SD=1.01) Sepik=-1.74 (SD=0.60)	(by equation) Grassland=49% Wosera=21% Sepik=29%
Community & hospital-based populations							
Manning (2012)	WHO 2006		Cases=26% Controls=12%				
Hospital-based populations							
Olita'a (2014)	WHO 2006		76%		92%		100%
Cripps (2008)	Converted from HARVARD reference						Total=39% Age (mths): <6=27% 7-12=42% 13-24=44% 25-36=44% 37-48=44%
Nasi (2003)	Converted from HARVARD						80%

[†]To standardize prevalence data to the WHO 2006 standard, prevalence (%) of malnutrition from studies using the NCHS and Harvard references was multiplied according to the following WHO algorithm: weight-for-height prevalence x 1.18, height-for-age prevalence x 1.4, weight -for-age prevalence x 0.87. Prevalence data using the CDC 2000 reference generally underestimate stunting at all ages compared to the WHO 2006 reference. No conversion algorithm was applied to the CDC 2000 data.

[‡]The mean z-score describes the nutritional status of the study population directly against the reference population, instead of a subset of individuals below a set cut-off.

[§]Prevalence-based data are reported using a cut-off value, where malnutrition is defined as the percentage of the study population <-2 z-scores against the mean of the reference population or <80% of the median of the reference for wasting and underweight and <90% of the median for stunting

[¶]Where stunting prevalence is reported at 100%, it is due to the application of the WHO algorithm (x 1.4) converting NCHS reference data to the WHO standard, resulting in a value over 100%. (95% CI)

^{§§}SD - Standard Deviation

^{¶¶}Prevalence was calculated from reported data (mean z-score and standard deviation) using an equation and probit regression in Stata software as recommended by WHO.

Table 3. Malnutrition prevalence (WHZ, HAZ & WAZ % <-2 z-scores) and population summary statistics (mean z-scores) using WHO 2006 standard (cont.)

Author	Reference population [†]	Wasting (Weight-for-height z-scores)		Stunting (Height-for age z-scores)		Underweight (Weight-for-age z-scores)	
		Mean WHZ-scores [‡]	Prevalence % <-2 z [§]	Mean HAZ-scores	Prevalence % <-2 z	Mean WAZ-scores	Prevalence % <-2 z
Pameh (2002)	Converted from NCHS 1977	Total:	Total: (by equation)	Total:	Total: (by equation)	Total:	Total: (by equation)
		Cases=-0.64	Cases=25%	Cases=-1.47	Cases=54%	Cases=-1.6	Cases=35%
		Controls=-0.62	Controls=25%	Controls=-0.66	Controls=35%	Controls=-0.92	Controls=21%
		Gastro:	Gastro:	Gastro:	Gastro:	Gastro:	Gastro:
		Cases=-0.92	Cases=27%	Cases=-1.00	Cases=40%	Cases=-1.39	Cases=30%
		Controls=-1.38	Controls=44%	Controls=-0.56	Controls=40%	Controls=-1.53	Controls=35%
		No-gastro:	No gastro:	No-gastro:	No gastro:	No-gastro:	No gastro:
Cases=-0.5	Cases=24%	Cases=-1.70	Cases=61%	Cases=-1.7	Cases=37%		
		Controls=-0.22	Controls=14%	Controls=-0.70	Controls=35%	Controls=-0.62	Controls=16%
Genton (1997)	Converted from NCHS 1977						41%
Han (1995)	Converted from NCHS 1977						Cases=55% Controls=32%
Sapak (1991)	Converted from HARVARD						50%

[†]To standardize prevalence data to the WHO 2006 standard, prevalence (%) of malnutrition from studies using the NCHS and Harvard references was multiplied according to the following WHO algorithm: weight-for-height prevalence x 1.18, height-for-age prevalence x 1.4, weight -for-age prevalence x 0.87. Prevalence data using the CDC 2000 reference generally underestimate stunting at all ages compared to the WHO 2006 reference. No conversion algorithm was applied to the CDC 2000 data.

[‡]The mean z-score describes the nutritional status of the study population directly against the reference population, instead of a subset of individuals below a set cut-off.

[§]Prevalence-based data are reported using a cut-off value, where malnutrition is defined as the percentage of the study population <-2 z-scores against the mean of the reference population or <80% of the median of the reference for wasting and underweight and <90% of the median for stunting

^{||}Where stunting prevalence is reported at 100%, it is due to the application of the WHO algorithm (x 1.4) converting NCHS reference data to the WHO standard, resulting in a value over 100%. (95% CI)

^{§§}SD - Standard Deviation

^{|||}Prevalence was calculated from reported data (mean z-score and standard deviation) using an equation and probit regression in Stata software as recommended by WHO.

Table 4. Malnutrition prevalence (WHZ, HAZ & WAZ % < -2 z-score)

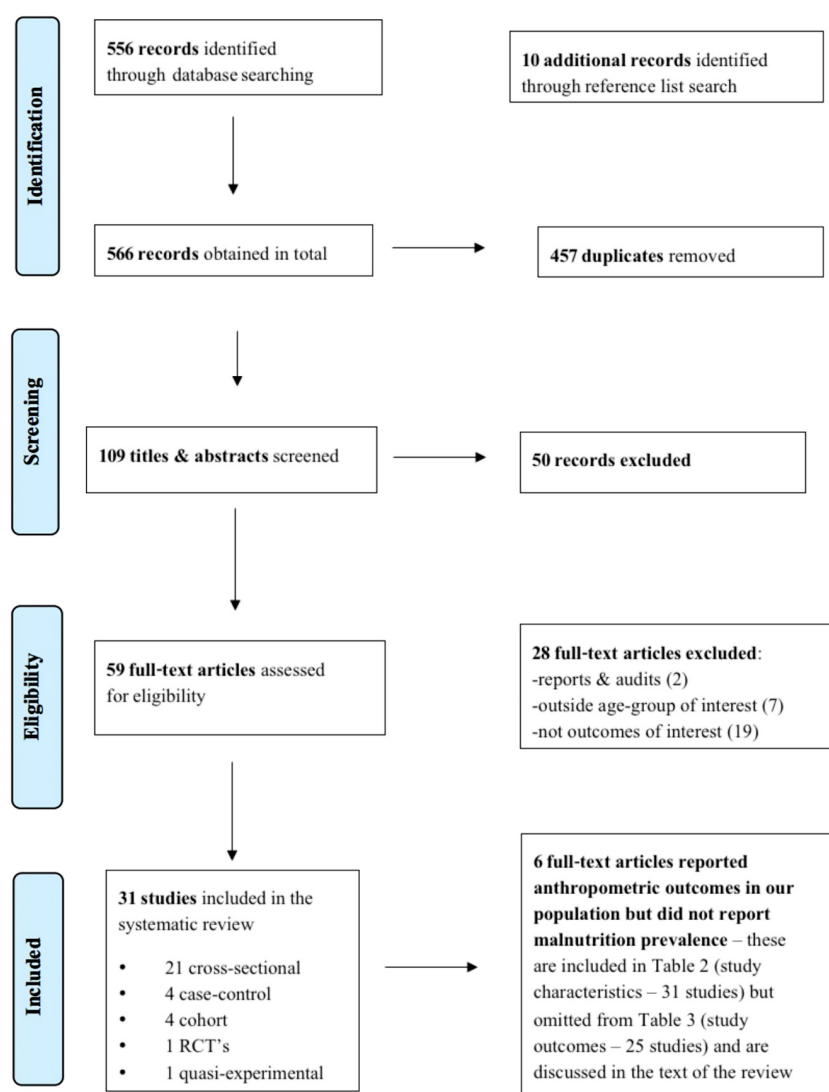
Index	Severity of undernutrition by prevalence ranges (%)			
	Low	Medium	High	Very high
Wasting (weight-for-height)	<5	5-9	10-14	≥15
Stunting (height-for-age)	<20	20-29	30-39	≥40
Underweight (weight-for-age)	<10	10-19	20-29	≥30

mary of study outcomes in Table 3. The articles reported on 21 cross-sectional surveys (including one audit of medical records), four case-control studies, four cohort studies, one randomised controlled trial and one quasi-experimental study. Of the 31 studies, ten were carried out in the administrative region of Papua, ten in Mamose, five in the Highlands, one in the Islands and five were nation-wide samples. (Figure 2) Twenty-two generated data from representative community-based samples, while eight reported data from ill children presenting to a

health facility. One study enrolled participants from both a health facility (cases) and a community setting (controls).¹⁵ Two articles were scored as being of high quality, 13 moderate and 16 as weak. (Table 2) Total population prevalence was reported in 15 studies and presented in graphs, according to anthropometric index. (Figures 3a, 3b & 3c) Results from all 31 studies, including those reporting total population prevalence and data disaggregated by age, gender, study design or population of origin, were presented in Table 3.

Characteristics of the studies

Of the 31 studies included in this review, six articles reported undernutrition prevalence using the percent (%) of median measurement scale and the Harvard population reference. Nineteen studies reported undernutrition by z-scores, (13 by prevalence < -2z and 6 by mean z-scores) of which five used the WHO 2006 child growth standard, one used the CDC 2000 reference and 13 used the NCHS 1977 reference (three of which also used an internally constructed PNG reference).²¹⁻²³ The remaining 6 studies reported nutritional outcomes using different cut-offs, measurement scales or without sufficient data (standard

**Figure 1.** Flow diagram of the study selection process.

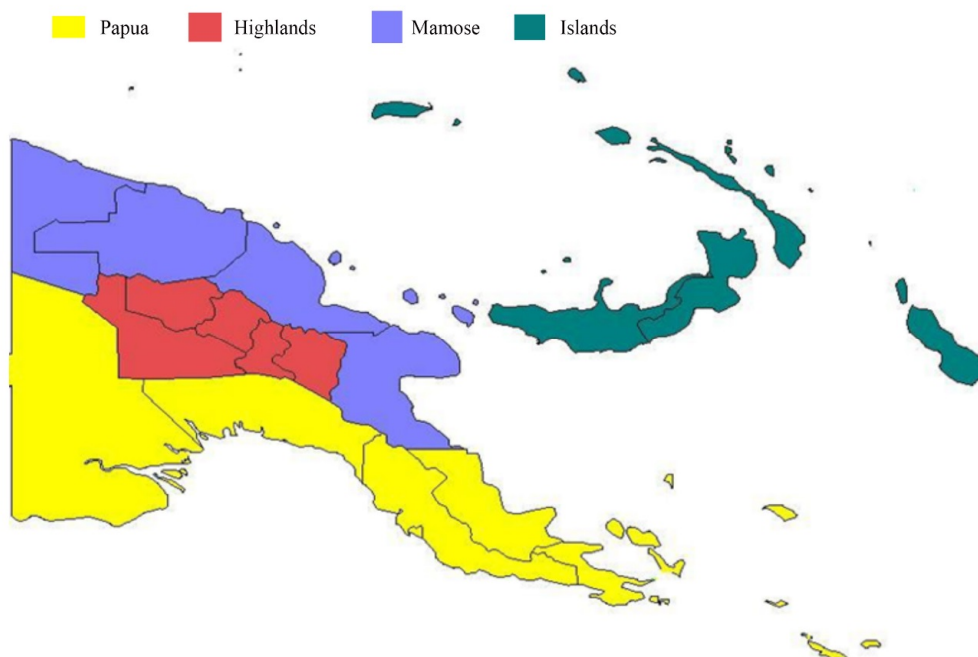


Figure 2. Map of Papua New Guinea by government administrative regions.

deviation) to calculate prevalence and so were excluded from the results.

Nineteen studies reported undernutrition prevalence by wasting, nineteen by stunting and twenty by underweight. Fifteen of the studies reported undernutrition by all three indices. Two studies reported wasting prevalence by MUAC according to our definition ($\% < 12.5$ cm).^{21,25} The prevalence of undernutrition among children can be classified as very high, high, medium or low, according to WHO recommended thresholds.¹ (Table 4)

Wasting

The overall prevalence of acute undernutrition among children was reported in 11 studies. In community-based samples ($n=10$ studies), it ranged from 1% to 39%, with a median of 11% using WHZ. High or very high prevalence was reported in Papua (14% to 39%)²⁶⁻²⁸ and Mamose (18% to 25%),^{24,29} medium to high prevalence in the Highlands (8% to 14%)^{21,29} and low to medium in the PNG-wide studies, (4%-7%)^{25,30,31} and low in one study from the Islands (2%). (Figure 3a) Eleven studies did not report overall prevalence of acute child undernutrition, but instead reported data disaggregated by age, population characteristics, or study participant characteristics (cases vs controls or interventions vs placebo). Wasting was reported consistently to be higher in children under the age of 24 months compared to older children.^{22-24,32} King et al (2002) reported disaggregated age data in 3-month intervals and showed higher prevalence of wasting in children after 6 months of age (range 29-55%) compared to younger infants (range 11-13%). One study reported wasting prevalence from a hospital-based sample, and was very high at 76%.³³

Wasting prevalence by mid-upper-arm-circumference (MUAC) was reported in five studies according to our definition ($\% < 12.5$ cm), but only two reported prevalence by both MUAC ($\% < 12.5$ cm), and by weight-for-

height ($\% < -2$ z-scores (WHZ)). (Figure 3a) Wasting prevalence by both measures correlated well in one study from Highlands (prevalence by MUAC was 8.1% compared to 8.3% using WHZ), and another from a PNG-wide study (prevalence by MUAC of 6.3% and 7.0% using WHZ).

Stunting

Ten community-based studies reported prevalence of chronic undernutrition ranging from 10% to 91% with a median of 51%. Very high prevalence according to the WHO classification (Table 4) was reported in the only study reporting stunting from the Highlands, at 91%.²¹ Three studies from Mamose reported high to very high prevalence 34%,²⁴ 56%³⁴ and 54%,²⁹ three PNG-wide studies reported medium to very high prevalence of 32%³¹, 42%³⁰ and 71%,³⁵ and three from Papua showed a range from low to very high prevalence with values of 10%,²⁶ 20%²⁸ and 77%.²⁷ Total population stunting was generally higher in males^{34,36} and as children grew older.³⁴ One study reported total stunting prevalence from a hospital-based population, which was 92%.³³

Underweight

In the twelve studies which reported overall prevalence of underweight, seven were from community-based study samples and prevalence ranged from 14% to 59% with a median of 32%. (Figure 3c) Three studies from Papua reported high to very high prevalence of underweight at 26%,²⁶ 58%²⁷ and 59%²⁸ and three PNG-wide studies reported medium to very high prevalence ranging from 18%,³⁰ 33%³¹ and 38%.³⁵ The only community-based study reporting overall prevalence of underweight from Mamose reported medium prevalence of 14%.³⁴ Miyoshi (2015) reported low prevalence from 2 separate community-based populations in the same study, one from Papua (2%) and another from Mamose (9%).³⁷ Five studies

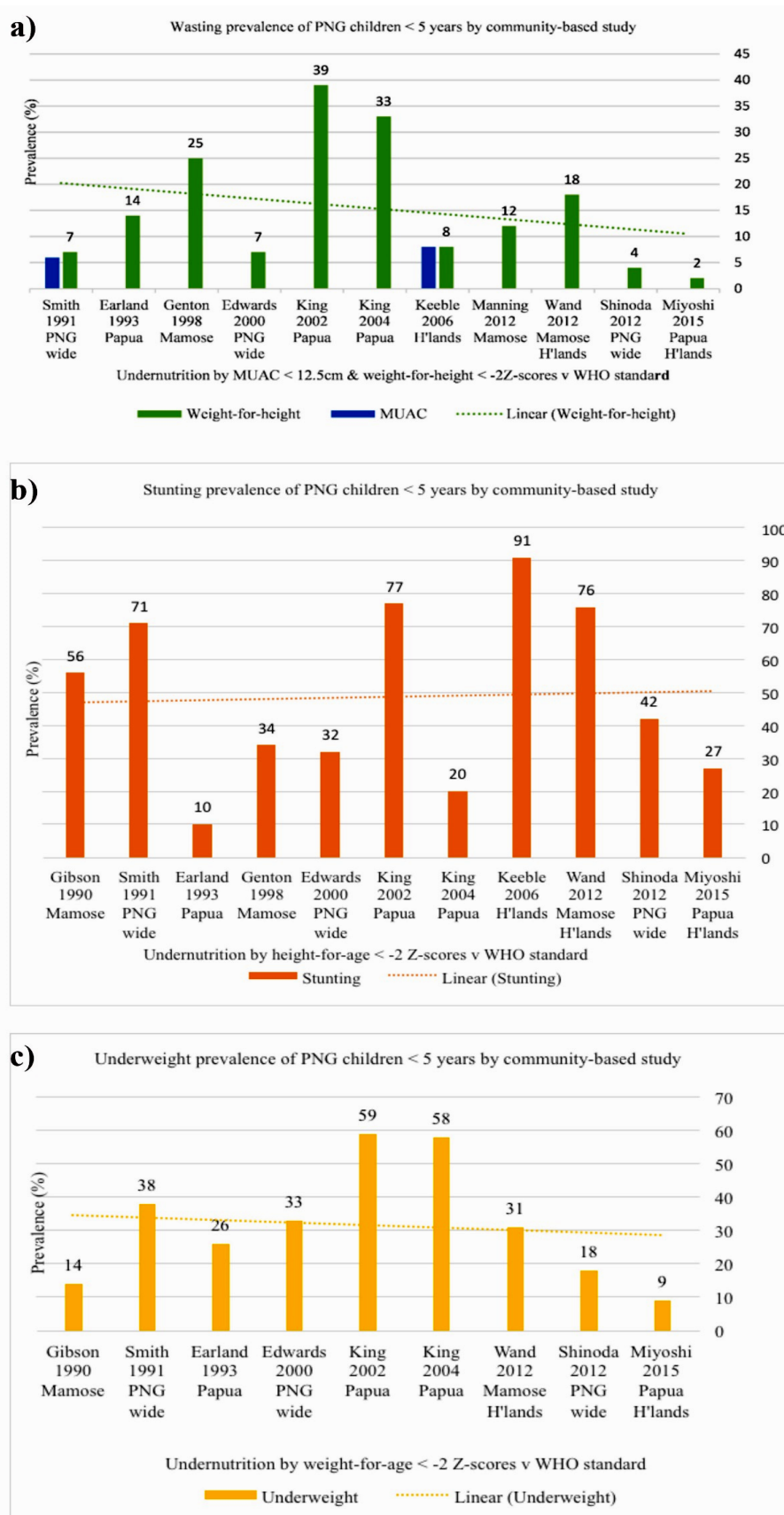


Figure 3. Prevalence of (a) wasting, (b) stunting and (c) underweight of children by study.

reported data from hospital-based population samples, all of which were of very high prevalence. Two were from Papua, with prevalence of 80%,³⁸ and 100%,³³ two were from Mamose, with prevalence of 41%³⁹ and 50%,⁴⁰ and one was from the Highlands, with prevalence of 39%.⁴¹

Five studies reported age-disaggregated data for underweight instead of overall community prevalence. Prevalence was reported to either increase^{27,34,41} or decrease^{22,23} with age, in line with the influence of weight and age on undernutrition measured by all three indices.

Synthesis of findings from studies in our review

Nutrition

The quality of nutrients in the diet is the major problem for nutrition in PNG, rather than the quantity of dietary intake, which may explain the high prevalence of stunting nation-wide.²³ Eighty per cent of total dietary intake comes from root crops rich in fibre and moisture, but low in energy, so bulkiness can prevent ingestion of sufficient volume for energy, protein or other nutrients.²³ Increased stunting prevalence in males^{34,37} was considered to be due to low protein and zinc intake, and possibly due to increased male requirements for zinc.^{23,34} Reduced weight gain was associated with children eating traditional staples such as sago and taro (parts of Mamose, Islands and Papua diet) whilst eating yams was associated with increased stunting, (Sepik Provinces in Mamose) possibly due to seasonal shortages, as they are harvested only once a year. Children consuming high protein and energy dense foods were more likely to have good growth in length (parts of Papua and Islands), whilst those consuming legumes and tinned fish were heavier, and those eating coconut (lowland and coastal regions) were taller and heavier.²³

Socioeconomic status

Poor child nutritional outcomes were associated with low parental socioeconomic status,³³ or when the age of the primary carer was either older or younger than parental norms,²⁷ if parents used tobacco or alcohol³³ or if the child was adopted.⁴² Better child nutritional outcomes were associated with better educated mothers^{15,22,27,28,33} or parents³³ and the father's employment.^{22,33} This may be related to improved cash availability or greater health awareness leading to better hygiene, improved health-seeking behaviour during illness, or more effective disposal of stools.²⁷ While there is no clear stratification of income in most PNG communities, the nutrient quality of diets is related to the ability to purchase foods, disposable income, education level, housing conditions, use of health services and risk of illness, all of which can affect child growth.⁴³ All improvements in socioeconomic status increased growth outcomes, except commercial palm oil production.²³

Infection

Nutritional status and infection have a reciprocal relationship, but it is not always clear if undernutrition is a cause or an effect of infection. Child undernutrition was associated with incomplete vaccination and poor water and sanitation.³³ Child undernutrition, falciparum malaria and parvovirus infection were all associated with an increase in anaemia.¹⁵ Conversely, Manning (2012) reported that vivax malaria was protective of anaemia.¹⁵ This seeming contradiction may be explained by the rapid acquisition of immunity to plasmodium vivax in the presence of falciparum co-infection or that the predilection of vivax malaria for red blood cells (especially reticulocytes), which are absent, or present in low numbers in severe anaemias, prevents vivax from developing in severely anaemic children.¹⁵ Stunting and underweight (but not wasting) were associated with an increase in incidence of acute respiratory infections (rate ratio=2), especially in children under

six months old.³⁵ Stunting (but not wasting) was reported to be protective against falciparum malaria, but not other forms of malaria, and most likely due to protein deficiency augmenting the host immune response via the increased production of cytokines.²⁴ Higher prevalence of wasting was associated with an increased incidence of fever, diarrhoea and malaria.³⁷ Underweight was a significant risk factor for persistent diarrhoea (odds ratio=2.7),⁴⁴ increased resistance to amodiaquine for falciparum malaria⁴⁰ and a decreased humoral immune response in a hospitalised cohort with pneumonia.⁴¹

Environment

Children living in higher constant rainfall areas were more stunted^{22,43} but higher seasonal variation of rainfall was associated with wasting but not growth faltering, especially in the wet season.^{37,43} Variations in undernutrition by altitude and rainfall are likely attributable to differences in diet, especially low fat and protein, which can cause stunting.⁴³ Children from higher altitudes were shorter and heavier than average, and highland fringe communities were even shorter.^{23,43} Those living in areas of steep terrain (regardless of altitude) were more commonly stunted, maybe due to increased energy expenditure, the reduced access to cash crops and health services.²³ Highland communities had a higher incidence of acute respiratory infection, most likely due to the customary use of internal fires within the traditional round houses built in the cooler climate of the Highlands region.^{23,35} Children in urban settings were more susceptible to poverty, infection, and wasting. Children in rural areas were more susceptible to seasonal variation, stunting and underweight and the prevalence of undernutrition among them increased with the distance from the health centre.²⁸ Those groups who relocated to urban settlements from rural areas demonstrated better nutritional status if they had previously been living by subsistence agriculture rather than by hunting and gathering.^{45,46} Overcrowded living conditions, especially in traditional houses, was associated with a greater prevalence of helminth infection and poor nutritional outcomes.^{22,28,33} Living in a household with running water³³ or a tin roof²⁸ were both protective of undernutrition, regardless of location. Smith et al found large differences in linear growth among 29 populations according to the environmental zones in which they lived and which were accounted for by differences in the fat and protein content of the village diets. Importantly, little correlation was found between genetic differences in ancestral populations, as tracked by HLA-gene frequencies, and the variations in the linear growth of children.⁴³

DISCUSSION

Undernutrition is associated with a cycle of poverty and disease, each of which may contribute to the presence and permanence of the others.¹ In children, this may be due to a range of factors related to poor maternal nutrition in pregnancy,^{5,6} poor food quality, insufficient intake and/or repeated infectious diseases. Stunting has been shown to be associated with increased levels of morbidity, mortality and decreased mental development and work capacity.¹ Moderate wasting (z-score <-2 and ≥-3) more than dou-

bles the odds ratio of child mortality, and severe wasting (z-score <-3 and/or bilateral oedema) increases the odds by over nine-fold.² Similar studies using MUAC as a diagnostic criterion showed that the risk of dying is increased below 11.5 cm.

This review collated available data on the nutritional status of disparate communities of PNG children reported by anthropometric indices and standardized the reporting method according to current WHO-recommended protocols. The inclusion criteria selected studies reporting the prevalence of protein-energy undernutrition using cut-offs including moderate and severe values only (z-score <-2) and did not report data on mild undernutrition (z-score <-1 to >-2), or children of normal or overweight (z-score >2) or undernutrition by micronutrient deficiency in PNG.¹⁰

The selected studies were conducted throughout the years from 1990 to 2015, with the majority published between 15 and 25 years ago, and so some data may now be outdated. Over those same years it is worth noting that the PNG population has grown on average at approximately 2.25% per annum, which may have impacted significantly on food security.⁴⁷

The PNG National Nutrition Survey (NNS) from 2005 found that 43.9% of PNG children from 6-59 months of age were stunted (very high prevalence), 4.5% were wasted (low prevalence) and 18.1% underweight (medium prevalence) with major regional differences.¹⁰ The prevalence of stunting of almost 44% compares with 34% in Solomon Islands (1989), 40% in Indonesia (2007) and 58% in Timor-Leste (2009).

Unlike the PNG NNS, this review has reported a range of undernutrition prevalence for each index, as a meta-analysis of pooled data was impractical from such a heterogeneous group of 31 studies, which varied greatly in quality, sample sizes, selection, assessment and reporting methods. For this reason, data for total population prevalence of wasting, stunting and underweight were presented separately, other than including a median value along with the range of values for each index. These data were also presented in graphs. (Figures 3a, 3b & 3c) Data from all studies were presented in Table 3, including both pooled total population prevalence and disaggregated prevalence data.

The wide variation in the estimated prevalence and the regional differences of undernutrition raises important questions about the different characteristics and health of the populations under study, the accuracy of anthropometric measurement and analysis, and the environment or the season in which the survey was conducted. PNG has very diverse local environmental conditions, living circumstances, cultural practices and traditional and staple diets, nationally and even within administrative regions. These factors and seasonal variations are known to influence agricultural growing conditions, dietary habits and rates of infectious diseases, all of which may explain the wide variety of undernutrition prevalence seen in the review. Single cross-sectional surveys of nutritional status are not sufficient to identify trends over time. There was no clear trend in prevalence by any anthropometric index (Figures 3a, 3b & 3c) in those years (and during which, the PNG population increased significantly) and from this

review it is difficult to say whether the nutritional situation in PNG is changing.

Chronic undernutrition is clearly widespread throughout the country and most studies reported from communities with very high prevalence, according to the WHO classification. The wide range of prevalence estimates (10%-91%) and the very high prevalences of 71%,²⁵ 77%²⁷ and 91%²¹ are notable and much higher than the PNG national prevalence of 44%. They have been raised by a factor of 1.4 during the WHO recommended conversion process.¹⁴ From those studies reporting data disaggregated by age, rapid growth faltering occurs across PNG between 4-6 months of age, with limited catch-up growth. The high prevalences defy simple explanation and have significant repercussions for child physical and mental development, work capacity and community productivity. No significant correlation has been shown between genetic differences in PNG populations and differences in length,⁴³ in line with global data from WHO that children the world over have much the same growth potential, at least to the age of seven years.¹ Rather, maternal nutrition during pregnancy, environmental factors and consequent physiological adaptation play a far greater role in stunting than genetic variants. Gibson concluded that stunting in a group of Sepik children was related to chronic deficits in energy and protein as a result of a diet of mainly tubers, and was exacerbated in older male children by suboptimal zinc intake.³⁴ Similarly, Mueller concluded that differences in diet and, to a lesser extent, the physical environment were the main determining factors in growth differences among populations, especially altitude, relief and rainfall patterns due to their effects on local subsistence agriculture.²² These, in turn were associated with variations in socioeconomic status.²³ The positive effects of increased socioeconomic status on improved linear growth were confirmed by Shack, who observed that the children of agriculturalists who had moved to a plantation settlement grew more in proportion to the income spent on protein and rice, relative to children from the same society of origin raised in their rural community in poorer socioeconomic and dietary circumstances.^{45,46}

Acute undernutrition or wasting prevalence was very high in studies from Papua and Mamose, especially among children aged 6-36 months, and was more common in the wet season⁴⁵ and at lower altitudes,²⁵ with some variability. The clear trend was for wasting to be higher in children from 6 months of age,^{24,27,28} at a time when growth faltering begins, and coincides with the addition of complementary food and water to breastfeeding.^{22,23,27,43,48} It is also when worm infestation is highest,²⁸ suggesting that gastrointestinal infection, and water, sanitation and hygiene (WASH) practices are contributing factors to acute undernutrition during the important transition in child feeding. MUAC has been used as a proxy for weight-for-height measurement to assess wasting, especially in emergencies, famines or refugee crises.⁴⁹ It has been shown to have operational advantages, as it is a simple measure, taken independent of age, gender and height, and it is a better predictor of child mortality than weight-for height and so is very useful for identifying population-level undernutrition. However, MUAC has

been shown to be prone to measurement error in the field and to correlate poorly with weight-for-height in identifying wasting in individual children.^{25,31,49,50} This variability in correlation was not reflected in this review, as the prevalence of wasting correlated well in two studies when using MUAC and weight-for-height measures.^{21,35}

Underweight was of high or very high prevalence in five of the seven community-based studies, especially in Papua, and in all of the hospital-based study populations. The unusually high prevalence of underweight (as well as wasting and stunting) in two studies by King and Taylor^{27,28} are notable and suggest high rates of chronic or recurrent infection as well as poor quality of nutrition intake over a long period and are similar to the results from a 1995 survey of the same district by Saweri.⁵¹ It was found to be a significant contributor to antimalarial drug resistance,⁴⁰ decreased humoral response to pneumonia⁴¹ and a clear risk factor for persistent diarrhoea⁴⁴ and child mortality.³⁸

The quality of the studies varied, with only two scoring a high rating and the remainder as moderate or weak. Sampling methods were not always clearly explained and sample sizes ranged from small in local surveys (n=21) to large in the nation-wide studies (n=26,290) bringing into question the representation of the study population and the accuracy and comparability of the prevalence estimates. Anthropometric measurement techniques and the extent of training and calibration of instruments is sometimes unclear, introducing potential measurement bias as another explanation for wide-ranging prevalence results.

The standardization process recommended by WHO changed the prevalence estimates, (raising wasting and stunting prevalence and lowering underweight) when converting estimated prevalence from studies using the NCHS 1977 reference population to the WHO 2006 standard, though the method of conversion has been described as valid and reliable.¹⁴ Stunting in particular was affected during the conversion process, as the reported prevalence was raised by a factor of 1.4 by applying the algorithm recommended by WHO. (Wasting prevalence was raised by a factor of 1.18 and underweight lowered by 0.87). After application of the algorithms, some values of stunting and underweight exceeded expected prevalence against the global standard. As the algorithms were designed using a 95% confidence interval, this is in line with the expectation that up to 5% of the values would fall outside the normal range. The algorithms were calculated for an age range from 0-60 months, but can equally apply to smaller age ranges, as in some of the studies included in the review (e.g. 2-6 months, 3-36 months, 6-60 months etc) WHO estimates are very close to observed values for these age ranges.¹⁴ For the six studies reporting nutritional status by mean z-scores, the prevalence was estimated by applying a conversion via probit regression in Stata, though this did not influence the prevalence estimate and has been tested and validated by WHO.⁵²

The reporting of total population prevalence of undernutrition provides a convenient means of comparison for nutritional status of all children under 5 years, but it does not provide trajectory data as children grow, unless age-disaggregated data are also presented. This also limits identification of the possible causes of undernutrition, as

age is an important determinant for feeding practices. The lack of accurate universal vital registration data (births and deaths) in PNG reduces the accuracy of estimates of total population nutritional status (stunting and underweight) that rely on age.

The influence of maternal under-nutrition, though not specifically addressed in this review, is an important consideration for the short-term health and nutritional status of children and long-term maternal and neonatal outcomes with intergenerational consequences for both.⁶ The provision of Child Support Grants (CSG's) is one method of addressing this issue, some commencing in pregnancy, and continuing throughout the life of the child. They can vary from cash payments only, or cash plus vouchers to supplement additional costs incurred during pregnancy and birth. Evidence from these programs varies but has been shown to be most successful when cash only is used, using simple enrolment procedures and integrated within existing social grant and health systems. The benefits have been shown to be both short-term, in providing poverty relief, as well as reducing intergenerational effects of poverty.⁵³

Conclusions, implications for current practice and future research

This review reported the prevalence of child undernutrition which varied widely in different studies and by PNG region. The higher prevalence of child undernutrition in PNG compared to the global average requires area-specific assessment to determine the local values, causes and contributing factors.^{29,37} Given the importance of nutritional status to the health and development of individuals, populations and the nation, there is an urgent need to increase monitoring, surveillance and evaluation of the nutritional and health status of PNG children and to implement programmes to address the underlying causes of their poor nutritional status.

Nutritional assessment using multiple anthropometric indices, and reported by z-scores, disaggregated by age, and using WHO cut-offs against the international standard, allows uniformity in data and meaningful comparison of different populations to design appropriate local interventions. Multiple cross-sectional measures would add valuable growth trend data to identify children and populations at risk and provide opportunity for timely interventions. Firstly, nutrition-specific interventions will address the immediate causes of child undernutrition. In areas reporting high wasting, interventions will likely involve improved child access to adequate foods, effective feeding, care-giving and parenting practices and the prevention and treatment of infectious diseases. Where stunting prevalence is high but wasting is low, interventions to improve long-term food security, dietary quality including greater energy and protein and socioeconomic inequality are important. Secondly, nutrition-sensitive interventions to address the underlying causes of child undernutrition will require adequate food security, access to effective health services and a safe, hygienic environment, including consideration to implement a system of Child Support Grants beginning in pregnancy and continuing throughout childhood. Thirdly, to address the basic societal causes of child undernutrition, interventions may

involve strategies to decrease poverty, improve governance, enhance government policy and improve community illiteracy around nutrition, especially for women.

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