Public Health Nutrition: 24(18), 5995–6006 doi:10.1017/S1368980021003980

Persistence of anaemia among Samoan preschool age children: a longitudinal study

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Submitted 19 February 2021: Final revision received 27 July 2021: Accepted 10 September 2021: First published online 15 September 2021

Abstract

Objective: To characterise the prevalence and persistence of anaemia among Samoan children over a 2–3-year period.

Design: Data were from two consecutive waves (2015 and 2017–2018) of the Ola Tuputupua'e 'Growing up' study. Anaemia (Hb < 11·0 or 11·5 g/dl for 2–4 and ≥ 5 years old, respectively) was considered 'transient' when it occurred at only one wave or 'persistent' if it was present at two consecutive waves. Child, maternal and household correlates of anaemia were examined using log-binomial and modified Poisson regressions.

Setting: Eleven Samoan villages.

Participants: Mother–child pairs (*n* 257) recruited in 2015 and reassessed in 2017–2018.

Results: Anaemia prevalence was 33·9 % in 2015 and 28·0 % in 2017–2018; 35·6 % of cases identified in 2015 were persistent. Risk of anaemia at only one wave was lower among children who were older in 2015 (age 4 *v.* 2 years, adjusted relative risk (aRR) = 0·54, (95 % CI 0·35, 0·84), $P = 0·007$), had older mothers (≥ 40 *v.* 18–29 years, aRR = 0·61, (95 % CI 0·39, 0·95), $P = 0·029$) and had higher daily sodium intake (for every 100 mg/d, aRR = 0·97, (95 % CI 0·95, 0·99), $P = 0·003$) than children with no anaemia. Children whose anaemia persisted were more likely to have had a mother with anaemia (aRR = 2·13, (95 % CI 1·17, 3·89), $P = 0·013$) and had higher daily dietary iron intake (for every 10 mg/d, aRR = 4·69, (95 % CI 1·33, 16·49), $P = 0·016$) than those with no anaemia.

Conclusions: Alongside broadly targeted prevention efforts, which are warranted given the moderate-high anaemia prevalence observed, specific attention should be paid to children with risk factors for persistent anaemia. Routine screening of children whose mothers have anaemia should be encouraged.

Keywords
Anaemia
Preschool-age children
Longitudinal study
Samoa

Anaemia is a condition in which the number of red blood cells or the Hb concentration is lower than normal (Hb < 11 g/dl for children under 5 years of age)[1]. Children under 5 years of age are one of the most vulnerable population groups[2], and the global prevalence of anaemia as estimated by WHO in 2016 was 41·7 % (95 % CI 38·1, 45·9) in this age group[3,4]. From a biological perspective, an imbalance between erythrocyte production and loss leads to anaemia[4]. Potential causes include micronutrient deficiencies, inflammation due to chronic and/or infectious diseases, genetic Hb disorders, low socioeconomic position and poor/lack of sanitation[4,5]. Analyses from the multinational Biomarkers Reflecting Inflammation and Nutritional Determinants of Anaemia (BRINDA) project reported that low socioeconomic position, underweight, stunting and wasting were associated with preschool children anaemia in over 50 % of surveys[5].

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Pacific Island small states and countries face an increasing burden of anaemia. A 2017 review of data collected between 1986 and 2015 in Pacific Island jurisdictions found that anaemia was a moderate public health problem among children under 5 (prevalence 20·0 %–39·9 %) in 10 jurisdictions; in another 7, anaemia was a severe problem (prevalence > 40·0 %)[1,6]. Samoa was one of the nations where anaemia prevalence was classified as severe, with a prevalence estimated at 44·1 % in 2014[6,7]. As a rapidly developing lower-middle income nation, Samoa faces significant challenges of infectious disease (dengue, chikungunya and typhoid), food and water insecurity and continued nutritional transition[8–11]. In addition, there is a high prevalence of overweight/obesity in Samoa[12], which is now recognised as an additional/independent risk factor for anaemia[7]. Among a cohort of preschool age Samoan children, the prevalence of overweight/obesity was 16·1 % in 2015[13] and increased in 2017[14]. Despite the individual and environmental characteristics that may promote vulnerability to anaemia and the existing moderate prevalence of anaemia among children in this setting, the burden of anaemia has not been well characterised.

During growth and development, the onset and duration of anaemia may be influenced by a combination of child, maternal and household characteristics. Previous studies in other settings have shown that anaemia may resolve quickly for some children, yet for others it may persist for a longer duration[15–17] leading to poor short- and long-term outcomes, including affected cognitive ability, poor school performance, lower educational attainment and reduced work capacity[17–21]. Child, maternal and household characteristics may vary among those with transient *v.* chronic anaemia and these conditions may also require unique preventative interventions/treatment with differing degrees of intensity. The cross-sectional nature of the existing literature in Samoa and the Pacific more broadly makes it difficult to examine the persistence of anaemia and its correlates. To inform appropriate and effective interventions aimed at reducing anaemia in Samoa and similar settings, it is important to understand its prevalence by age, whether – and for how long – anaemia persists in childhood, and to identify its major determinants.

The current study uses data from the *Ola Tuputupua'e* ('Growing Up') observational cohort study in Samoa[14] to characterise the prevalence of anaemia in preschool age children, examine the persistence of childhood anaemia across two consecutive data collection waves (in 2015 and 2017–2018) and explore risk factors related to having anaemia at either one or two data collection waves.

Methods

Study population

We used data from the first two waves of the *Ola Tuputupua'e* study, an ongoing longitudinal observational study of growth, development and health among Samoan children that was established in 2015. Mother–child dyads (*n* 319) were enrolled between June and August 2015 on the island of Upolu, Samoa (where ~78 % of the Samoan population are resident[22]). Recruitment of the cohort and their demographic characteristics have been described elsewhere[13]. Briefly, convenience sampling took place in a total of ten study villages from urban (Apia Urban Area), peri-urban (Northwest Upolu) and rural (Rest of Upolu) census regions. Eligible children were 2–4 years old and had four Samoan grandparents based on maternal report (reporting four Samoan grandparents has been shown to be a reliable proxy for Samoan ancestry)[23]. Eligible mothers were not pregnant (self-report), had no severe physical or cognitive impairment and were willing and able to complete study procedures. Mother–child dyads were re-contacted and asked to complete a follow-up assessment in either 2017 or 2018; the majority (*n* 279, 87·5 %) of participants were successfully re-contacted. For this analysis, we excluded 15 children (4·7 %) without data on Hb levels either in 2015 and/or in 2017–2018. Another seven mother–child dyads were excluded because, during the second assessment, children were determined to be outside of the original recruitment age range (their date of birth had been misreported/recorded during the first (baseline) assessment). Our final analysis sample therefore included *n* 257 mother–child pairs. We observed no meaningful differences in characteristics (maternal age, years of education, marital status and household total annual income) between the children who were included compared to excluded from the sample (data are not shown).

Physical and biochemical measurements

Research procedures were the same at baseline in 2015 and follow-up in 2017–2018. All measurements were collected with both mother and child in light island clothing. Standing height was measured using a portable stadiometer to the nearest 0·1 cm (Pfister Imports, NY, USA), and weight using a Tanita HD 351 digital weight scale to the nearest 0·1 kg (Tanita Corporation of America, IL, USA). Measurements were taken in duplicate and averaged for use in analysis. Maternal BMI was used to classify participants as either having overweight/obesity (≥ 26 kg/m^2) or not (< 26 kg/m^2) based on Polynesian-specific thresholds[24]. To determine the prevalence of stunting and overweight/obesity at baseline (2–4 years old), we first calculated *Z*-scores for height-for-age, BMI-for-age using WHO (2006) growth standards[25]. We then created binary variables to represent stunting (< −2 SD *Z*-scores for height-for-age) and overweight/obesity (> +2 SD BMI-for-age)[13].

The AimStrip Hb test system (Germaine Laboratories Inc., TX, USA) was used to assess capillary blood Hb levels. Child anaemia was determined to be present if measured Hb was less than 11·0 g/dl for children aged between 2–4 years old and less than 11·5 g/dl for children between

https://doi.org/10.1017/S1368980021003980 Published online by Cambridge University Press

5–7 years old[1]. Maternal anaemia was defined as Hb level less than 12·0 g/dl[1]. Children were considered to have 'resolved' anaemia if they had anaemia in 2015 but not 2017–2018, 'emergent' anaemia if they did not have anaemia in 2015 but did in 2017–2018 and 'persistent' anaemia if their anaemia was present at two consecutive waves (2015 and 2017–2018). Since there were no differences in participant characteristics between the 'resolved' and 'emergent' groups (data are not shown), we combined them for the purpose of analysis and labelled the group as having 'transient' anaemia.

Questionnaire data

At both data collection waves, Samoan research assistants administered a questionnaire to mothers to collect information about community, household, maternal and child characteristics. In this analysis, we utilised questionnaire data collected at baseline and focused specifically on characteristics that had been associated with anaemia in prior studies[4,13]. Participant-reported 'community spirit' was measured using a 5-point Likert scale[12], and classified as weak (0–1), average (2) and strong (3–4). Household characteristics were summarised using the same methods as have been previously reported for this cohort[13]. Annual income was classified as less than or equal to/greater than 10 000 Western Samoan Tala. An asset score – a useful measure of family socioeconomic resources in modernising societies – was calculated for each household based on ownership of 18 consumer durables[13,26]. Scores were classified into four categories according to approximate quartiles: 0–2 for low (*n* 46), 3–4 for medium (*n* 56), 5–7 for high (*n* 70) and 8–18 for very high (*n* 54). We also recorded drinking water sources (pipe into the house, pipe on the house lot, public tap and rainwater) and toilet type (flush, portable or water seal and pit) as measures of sanitation.

Maternal characteristics included age, highest attained education level (high school graduate or not), marital status (married/cohabiting or not) and alcohol consumption (ever consumed alcohol compared to never). Mothers also reported the child's age, sex, birth order, breastfeeding history (ever *v.* never breastfed), health history (diagnoses/illnesses in the prior 3 weeks), average sleep duration (hours) and dietary intake using 104-item Food Frequency Questionnaire with a 30-d reference period[13,26]. Using data on reported illnesses, we created an 'infection' variable, which we used to describe children with symptoms indicative of infection (fever, rash, flu, cough and breathing problems) in the past 3 weeks. Macro- and micro-nutrient intake were estimated using methods previously described for this cohort[13]. We measured the frequency of intake for *n* 104 foods using seven response options (never/less than once in a month to more than six times per day). Daily total energy intake and nutrient intake were calculated by multiplying the daily consumption frequency of each kind of food by the nutrient content of a fixed, standard portion size. The nutrient content of Food Frequency Questionnaire items was estimated according to the US Department of Agriculture Food Composition Tables[27] and the FAO Pacific Island Food Composition Tables[28]. Total energy intake-adjusted micronutrient intake values[29] for vitamin A, vitamin E, vitamin C, sodium, iron, calcium and potassium were used in our analyses.

Statistical methods

We first described the prevalence of anaemia outcomes in 2015 and 2017–2018 and assessed for differences in the sample prevalence of anaemia in 2015 and 2017–2018 by using a McNemar's χ^2 test. We then examined the distribution of individual, maternal and household characteristics in the total sample and by sex among Samoan children at age 2–4 years old in 2015. We presented the baseline characteristics of the children at age 2–4 years as numbers and percentages for categorical variables and as medians accompanied by the lower (Q1) and upper (Q3) quartile for nonparametric continuous variables. χ^2 tests or Fisher's exact tests for categorical variables and exact Wilcoxon two-sample tests for continuous variables were used to assess differences by child sex. The Monte Carlo estimations of exact *P*-values were presented when there was not enough memory available to compute exact *P*-values based on the Wilcoxon two-sample.

Then, we fitted log-binomial models to examine the unadjusted associations between various characteristics and two health outcomes: (1) children with transient anaemia; and (2) children with persistent anaemia. For both anaemia outcomes, the reference group was children with no anaemia at two consecutive data collection waves. In line with the longitudinal nature of our analysis, all of the predictors were measured in 2015. Variables significant at an α of 0·10 were selected into full multivariable models for further analyses.

While the log-binomial models were preferred to estimate the adjusted relative risk of anaemia outcomes, the models did not converge after adjusting for several characteristics and estimates could not be obtained. As the proposed alternative method[30], we proceeded with modified Poisson regression analyses to identify independent individual, maternal and household characteristics of the child anaemia outcomes. Two regression models were built to compare: (1) children with transient anaemia and children with no anaemia; and (2) children with persistent anaemia and children with no anaemia. For each model, we used a backward elimination strategy to determine the most parsimonious model. Characteristics reaching a two-sided α of 0·10 were retained in the final multivariable models, given the limited sample size. In addition, child age, sex, maternal education and census region of village residence were included in the final adjusted model to minimise potential confounding and selection bias. Finally, we conducted sensitivity analyses where the transient anaemia

https://doi.org/10.1017/S1368980021003980 Published online by Cambridge University Press

group was subdivided into those with 'resolved' and 'emergent anaemia'. When relevant, point estimates and 95 % CIs were presented. Analyses were performed using RStudio (RStudio, Inc.) and SAS version 9.4 (SAS Institute Inc.).

Results

Prevalence of anaemia among Samoan children

Among the 257 children in the study sample, 129 (50·2 %) did not have anaemia in 2015 and 2017/2018 (no anaemia), 56 (21·8 %) had anaemia in 2015 that had resolved by 2017/2018; 41 (16·0 %) had emergent anaemia (new cases in 2017–2018 that were not present in 2015; 97 (37·5 %) total children were considered to have transient anaemia) and 31 (12·1 %) had persistent anaemia (anaemia at two consecutive data collection waves). Of the 87 children who had anaemia in 2015, only 35·6 % of them still had anaemia 2 years later. While the prevalence of child anaemia decreased from 33·9 % in 2015 to 28·0 % in 2017–2018, the difference was likely due to chance (McNemar's $\chi^2 = 2{\cdot}02$, $P = 0{\cdot}155$).

Baseline characteristics of enrolled children and mothers

The characteristics of the enrolled child–mother pairs by sex in 2015 are presented in Table 1. The median age of the children was 38·9 (Q1–Q3 30·7–49·0) months in 2015, while the median age of enrolled mothers was 33·1 (Q1–Q3 25·6–40·9) years. A greater proportion of female children had a mother with overweight/obesity, compared to males. Since only one child used iron syrup in the past 3 weeks in 2015, we did not include this variable in further analyses. For other demographic characteristics reported in Table 1, we did not observe any other differences by child sex and additional analyses were completed with the sexes combined.

Unadjusted associations between various characteristics and child anaemia outcomes

The outcomes of unadjusted associations between the participant characteristics and transient anaemia are presented in Table 2. When comparing children with transient anaemia to those with no anaemia, we observed associations with child age, having ever been breastfed, stunting, symptoms of infection and daily dietary intakes of sodium and calcium. Children were less likely to have transient anaemia if they were older in 2015 (for age as a continuous variable, unadjusted relative risk (uRR) = 0·80; (95 % CI 0·67, 0·95), $P = 0{\cdot}013$). Children who had ever been breastfed had a lower risk of transient anaemia compared to children who had never been breastfed (uRR = 0·71; (95 % CI 0·53, 0·95), $P = 0{\cdot}023$). Risk of transient anaemia among children with stunting was approximately 1·5 times the risk among children without stunting (uRR = 1·52; (95 % CI 1·12, 2·07), $P = 0{\cdot}008$). Children with maternal-reported symptoms of infection had nearly 1·5 times greater risk of having transient anaemia compared to children with no reported infection symptoms (uRR = 1·45; (95 % CI 0·98, 2·16), $P = 0{\cdot}062$). Children with higher total sodium intake (100 mg/d) were slightly less likely to develop transient anaemia; (uRR = 0·96; (95 % CI 0·94, 0·99), $P = 0{\cdot}004$) while children with higher total calcium intake (100 mg/d) were more likely to have transient anaemia (uRR = 1·07; (95 % CI 1·01, 1·12), $P = 0{\cdot}012$). Dietary iron intake per day was similar between children with transient anaemia and those with no anaemia.

Maternal age and anaemia in 2015 were associated with transient anaemia in children. Older mothers were less likely to have a child with transient anaemia (as a continuous variable, uRR = 0·98; (95 % CI 0·97, 1·00), $P = 0{\cdot}026$), with the lowest risk among children with mothers over 40 years (uRR = 0·61; (95 % CI 0·38, 0·96), $P = 0{\cdot}033$). Greater risk of transient anaemia was observed among children with mothers who had anaemia in 2015 compared to those whose mothers did not have anaemia (uRR = 1·32; (95 % CI 0·97, 1·82), $P = 0{\cdot}082$).

Unadjusted associations between participant characteristics and persistent anaemia are presented in Table 3. There was evidence of associations between child stunting, daily intake of dietary iron, census region of residence, maternal anaemia and maternal history of alcohol consumption. Children who were stunted were more likely to have persistent anaemia compared to children without stunting (uRR = 1·88; (95 % CI 0·95, 3·72), $P = 0{\cdot}070$). Dietary iron intake was significantly associated with persistent anaemia, with higher iron intake (10 mg/d) increasing risk (uRR = 3·94; (95 % CI 0·99, 15·67), $P = 0{\cdot}052$). Children resident in Northwest Upolu were less likely to have persistent anaemia compared to children in Rest of Upolu (uRR = 0·47; (95 % CI 0·20, 1·10), $P = 0{\cdot}081$). Children had a higher risk of persistent anaemia if they had a mother with anaemia compared to those who had mothers with no anaemia (uRR = 2·40; (95 % CI 1·30, 4·43), $P = 0{\cdot}005$), while the risk was marginally lower if a child's mother reported drinking any alcohol within the past year in 2015 compared to those with a mother who did not (uRR = 0·38; (95 % CI 0·12, 1·19), $P = 0{\cdot}096$).

Adjusted associations between various characteristics and child anaemia outcomes

Comparing children with transient anaemia to children with no anaemia, we found that child age, sodium intake and maternal age remained significantly associated with transient anaemia in children after adjusting for other variables (Table 4). Children who were older at baseline (aged 48–59 months in 2015) were less likely to have transient anaemia than children aged between 24 and 35 months (aRR = 0·54; (95 % CI 0·35, 0·84), $P = 0{\cdot}007$). Children with higher daily sodium intakes (100 mg/d) were less likely to

https://doi.org/10.1017/S1368980021003980 Published online by Cambridge University Press

Table 1 Individual, maternal and household characteristics of children in the sample by sex; Samoan island of Upolu, June–August 2015

Characteristics	Total (*n* 257)		Male (*n* 130)		Female (*n* 127)		
	n or mean/ median	%* or SD/ Q1–Q3	*n* or mean/ median	%* or SD/ Q1–Q3	*n* or mean/ median	%* or SD/ Q1–Q3	*P* value†
Individual							
Anaemia condition							
No anaemia	129	50·2	63	48·5	66	52·0	0·549
Resolved anaemia	56	21·8	27	20·8	29	22·8	
Emergent anaemia	41	16·0	25	19·2	16	12·6	
Persistent anaemia	31	12·1	15	11·5	16	12·6	
Region							
Apia urban area	74	28·8	31	23·9	43	33·9	0·117
Northwest Upolu	88	34·2	44	33·9	44	34·7	
Rest of Upolu	95	37·0	55	42·3	40	31·5	
Age group (months)‡							
Continuous variable	3·2	2·6–4·1	3·4	2·6–4·1	3·2	2·4–4·0	0·112
24–35	104	40·5	49	37·7	55	43·3	0·539
36–47	83	32·3	42	32·3	41	32·3	
48–59	70	27·2	39	30·0	31	24·4	
First child	62	24·1	37	28·5	25	19·7	0·100
Ever breastfed	174	67·7	83	63·9	91	71·7	0·181
Overweight/obesity							
None	215	83·7	107	82·3	108	85·0	0·190
Overweight	38	14·8	19	14·6	19	15·0	
Obese	4	1·6	4	3·1	0	0·0	
Stunting	50	19·5	31	23·9	19	15·0	0·072
Illness in the past 3 weeks	24	9·3	12	9·2	12	9·5	0·952
Infection symptoms§	23	9·0	11	8·5	12	9·5	0·782
Deworming medication use in the past 3 weeks‖	48	18·8	19	14·7	29	23·0	0·091
Night-time sleep (h)‡,‖	9·0	9·0–10·0	9·0	9·0–10·0	9·0	9·0–10·0	0·701
Given any iron syrup in the past 3 weeks	1	0·4	1	0·8	0	0·0	1·000
Given any vitamin or mineral drops in the past 3 weeks	4	1·6	3	2·3	1	0·8	0·622
TEI-adjusted nutrient intake¶							
Vitamin A intake (mg/d)‡	741·2	433·0–1150·6	745·6	409·8–1123·6	741·0	441·9–1225·6	0·571
Vitamin E intake (mg/d)‡	11·5	10·1–13·3	11·4	9·7–13·4	11·6	10·4–13·3	0·215
Vitamin C intake (mg/d)‡	237·2	191·6–291·3	236·7	191·8–294·8	237·3	189·6–287·9	0·959
Sodium intake (100 mg/d)‡	31·1	27·5–34·8	30·6	27·1–34·7	31·6	28·0–35·0	0·169
Iron intake (mg/d)‡	16·3	15·0–18·0	16·1	15·0–18·0	16·4	15·1–18·0	0·473
Calcium intake (100 mg/d)‡	7·4	6·4–8·3	7·4	6·6–8·3	7·3	6·3–8·3	0·471
Potassium intake (mg/d)‡	4579·9	4082·1–5116·1	4557·2	3933·7–5153·3	4597·7	4221·4–5081·9	0·226
Maternal							
Age (years)‡							
Continuous variable	33·1	25·6–40·9	33·0	25·6–42·0	33·1	25·3–40·4	0·936
18–29	103	40·1	51	39·2	52	40·9	0·903
30–39	84	32·7	42	32·3	42	33·1	
> =40	70	27·2	37	28·5	33	26·0	
High school graduated	152	59·1	71	54·6	81	63·8	0·135
Married or cohabitating	197	76·7	96	73·9	101	79·5	0·282
Overweight/obese	224	87·2	107	82·3	117	92·1	0·019
Anaemia	64	24·9	36	27·7	28	22·1	0·295
Alcohol drink within the past 12 months	56	21·8	34	26·2	22	17·3	0·086
Household							
Annual income less than $ 10 000 tala‖	204	79·7	104	80·0	100	79·4	0·900
Asset score							
Quartile 1 (mean = 1·3, SD = 0·8)	54	21·0	23	17·7	31	24·4	0·541
Quartile 2 (mean = 3·5, SD = 0·5)	61	23·7	34	26·2	27	21·3	
Quartile 3 (mean = 5·9, SD = 0·8)	80	31·1	42	32·3	38	29·9	
Quartile 4 (mean = 10·3, SD = 2·8)	62	24·1	31	23·9	31	24·4	
Community spirit‖							
Weak	6	2·3	2	1·5	4	3·2	0·731

https://doi.org/10.1017/S1368980021003980 Published online by Cambridge University Press

Table 1 *Continued*

Characteristics	Total (*n* 257)		Male (*n* 130)		Female (*n* 127)		*P* value†
	n or mean/ median	%* or SD/ Q1–Q3	*n* or mean/ median	%* or SD/ Q1–Q3	*n* or mean/ median	%* or SD/ Q1–Q3	
Average	121	47·3	61	46·9	60	47·6	
Strong	129	50·4	67	51·5	62	49·2	
Type of household drinking water‖							
Pipe into the house	81	31·6	39	30·2	42	33·1	0·932
Pipe on the house lot	149	58·2	76	58·9	73	57·5	
Public tap	23	9·0	12	9·3	11	8·7	
Rain water	3	1·2	2	1·6	1	0·8	
Type of household toilet‖							
Flush	245	95·7	124	95·4	121	96·0	0·799
Pit	11	4·3	6	4·6	5	4·0	

Q1, lower quartile; Q3, upper quartile; TEI, total energy intake.
*Percentages may not sum to 100 % due to missing data.
†*P* values for Wilcoxon two-sample test (for not normally distributed continuous variables) or χ^2 test (for categorical variables) to detect differences by sex.
‡Labelled variables are not normally distributed. Median with Q1–Q3 are expressed.
§Infection symptoms included fever, rash, flu, cough and breathing problems.
‖Missing values for the labelled variables: deworming medication use in the past 3 weeks (*n* 2), night-time sleep (*n* 4), annual income less than $ 10 000 tala (*n* 1), community spirit (*n* 1), type of household drinking water (*n* 1), type of household toilet (*n* 1).
¶Boundaries of TEI-adjusted nutrient intake: vitamin A = 450 mg/d; vitamin E = 6 mg/d; vitamin C = 30 mg/d; sodium = 2000 mg/d; iron = 12·6 mg/d; calcium = 600 mg/d; potassium = 3510 mg/d.

develop transient anaemia than children following the WHO sodium intake recommendation (aRR = 0·97; (95 % CI 0·95, 0·99), *P* = 0·003). Mothers aged over 40 years were also less likely to have children with transient anaemia compared with mothers aged between 18 and 30 years (aRR = 0·61; (95 % CI 0·39, 0·95), *P* = 0·029). Similar findings, with the same statistically significant risk factors, were observed when the transient anaemia group were subdivided based on whether anaemia was 'resolved' (2015 only) or 'emergent' (2017–2018 only) (online Supplementary Table 1).

Comparing children with persistent anaemia to children with no anaemia, only maternal anaemia and child daily iron intake in 2015 were associated with persistent anaemia in multivariable analyses (Table 4). Children whose mothers had anaemia had twice the risk of having persistent anaemia compared to children with mothers who did not have anaemia (aRR = 2·13; (95 % CI 1·17, 3·89), *P* = 0·013). Children with higher daily intake of iron had a higher risk of having persistent anaemia compared to children with no anaemia. For every 10 mg increase in dietary iron intake per day, the risk of having anaemia in both 2015 and 2017–2018 increased by 468·8 % (aRR = 4·69; (95 % CI 1·33, 16·49), *P* = 0·016).

Discussion

While the prevalence of childhood anaemia in the Pacific has been well documented[6,7], our study is the first to use longitudinal data from a child cohort to examine the persistence of anaemia during childhood. At each data collection wave, approximately one-third of children had capillary Hb levels indicative of anaemia, but in most cases anaemia was transient and more cases resolved than emerged during the 3 year time frame of the study. Although any population prevalence of anaemia is problematic in terms of consequences for health and development, a relative minority of children in our sample (12·1 %) exhibited persistent anaemia over the study period. Differences in the baseline characteristics associated with transient and persistent anaemia between the ages of 2 and 7 years old suggest that targeting of intervention approaches should take into account the presence of these two 'types' of anaemia in childhood.

In our 3-year study of Samoan children, we observed a moderate-high prevalence of anaemia during two consecutive waves of data collection. The observed prevalence of anaemia in Samoan preschool children was 34·0 % in 2015, and 27·7 % in 2017/2018, which meets WHO criteria for a moderate public health issue (20–40 %) and is similar to many other countries and territories in the region[6]. Our estimates, while not directly comparable, are lower than those reported by the most recent Samoa Demographic and Health Survey (44·1 %)[7], which may be explained by differences in sampling strategy (the Demographic and Health Survey employs a nationally representative approach, whereas we employed convenience sampling) and study timing (the Demographic and Health Survey was conducted a year prior to the start of our study).

In our analyses, there was strong evidence of associations between child age, daily sodium intake, maternal age and transient anaemia. Among our sample, children who were older than 48 months in 2015 were less likely to have transient anaemia compared to children less than 36 months old. Other studies conducted among preschool children in developing countries such as Kenya, the Philippines and Haiti have also reported that children aged older than 24 months were significantly less likely to have anaemia compared with children aged less than 24 months[31–33]. This is likely due to iron intake requirements per kilogram of body weight being

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Table 2 Unadjusted associations between sample characteristics by anaemia (transient anaemia *v.* no anaemia); Samoan island of Upolu, June–August 2015

	Transient anaemia *v.* no anaemia (*n* 226)		
Characteristics	RR	95 % CI	*P* value*
Individual			
Region			
Rest of Upolu	1·00	Ref.	–
Apia urban area	0·96	0·65, 1·42	0·830
Northwest Upolu	1·11	0·78, 1·57	0·560
Age group (months)			
Continuous variable	0·80	0·67, 0·96	0·013
24–35	1·00	Ref.	–
36–47	0·97	0·71, 1·33	0·857
48–59	0·53	0·34, 0·84	0·007
Sex			
Male	1·00	Ref.	–
Female	0·90	0·66, 1·21	0·479
First child	0·94	0·66, 1·35	0·750
Ever breast-fed	0·71	0·53, 0·95	0·023
Overweight/obesity			
None	1·00	Ref.	–
Overweight	0·97	0·62, 1·51	0·875
Obese	0·58	0·11, 3·17	0·525
Stunting	1·52	1·12, 2·07	0·008
Illness in the past 3 weeks	1·38	0·92, 2·07	0·120
Infection symptoms†	1·45	0·98, 2·16	0·062
Deworming medication use in the past 3 weeks‡	1·10	0·76, 1·60	0·610
Night-time sleep (h)‡	0·99	0·89, 1·10	0·841
Given any vitamin or mineral drops in the past 3 weeks	0·77	0·16, 3·86	0·755
TEI-adjusted nutrient intake§			
Vitamin A intake (mg/d)	1·00	1·00, 1·00	0·461
Vitamin E intake (mg/d)	0·96	0·90, 1·02	0·151
Vitamin C intake (mg/d)	1·00	1·00, 1·00	0·914
Sodium intake (100 mg/d)	0·96	0·94, 0·99	0·004
Iron intake (10 mg/d)	1·10	0·52, 2·31	0·804
Calcium intake (100 mg/d)‖	1·07	1·01, 1·12	0·012
Potassium intake (mg/d)	1·00	1·00, 1·00	0·772
Maternal			
Age (years)			
Continuous variable	0·98	0·97, 1·00	0·026
18–29	1·00	Ref.	–
30–39	1·07	0·78, 1·47	0·668
> =40	0·61	0·38, 0·96	0·033
High school graduated	0·87	0·64, 1·17	0·351
Married or cohabitating	0·82	0·59, 1·13	0·221
Overweight/obese	0·91	0·60, 1·40	0·681
Anaemia	1·32	0·97, 1·82	0·082
Alcohol drink within the past 12 months	0·90	0·62, 1·31	0·587
Household			
Annual income less than $ 10 000 tala‡	1·21	0·80, 1·82	0·365
Asset score			
Quartile 1 (mean = 1·3, SD = 0·8)	1·00	Ref.	–
Quartile 2 (mean = 3·5, SD = 0·5)	1·03	0·71, 1·49	0·888
Quartile 3 (mean = 5·9, SD = 0·8)	1·26	0·91, 1·74	0·163
Quartile 4 (mean = 10·2, SD = 2·7)	1·03	0·71, 1·49	0·879
Community spirit‡,¶			
Not strong	1·00	Ref.	–
Strong	1·02	0·75, 1·37	0·910
Type of household drinking water‡			
Pipe into the house	1·00	Ref.	–
Pipe on the house lot	1·23	0·87, 1·75	0·238
Public tap	0·88	0·45, 1·72	0·702
Rain water	0·88	0·17, 4·46	0·874
Type of household toilet‡			
Flush	1·00	Ref.	–
Pit	0·93	0·43, 2·01	0·843

RR, relative risk; Ref., reference category; TEI, total energy intake.
*Based on log-binomial regression models.
†Infection symptoms included fever, rash, flu, cough and breathing problems.
‡Missing values for the labelled variables: deworming medication use in the past 3 weeks (*n* 2), night-time sleep (*n* 4), annual income less than $ 10 000 tala (*n* 1), community spirit (*n* 1), type of household drinking water (*n* 1), type of household toilet (*n* 1).
§Boundaries of TEI-adjusted nutrient intake: vitamin A = 450 mg/d; vitamin E = 6 mg/d; vitamin C = 30 mg/d; sodium = 2000 mg/d; iron = 12·6 mg/d; calcium = 600 mg/d; potassium = 3510 mg/d.
‖Conducted with the modified Poisson regression model since the log-binomial model did not converge.
¶Due to the small sample size of the weak group, community spirit was classified as strong (Likert scale 3–4) and not strong (Likert scale 0–2).
**Given any iron syrup in the past 3 weeks was deleted from unadjusted models because of the small sample size of children having this behaviour.

https://doi.org/10.1017/S1368980021003980 Published online by Cambridge University Press

Table 3 Unadjusted associations between sample characteristics by anaemia (persistent anaemia *v.* no anaemia); Samoan island of Upolu, June – August 2015

	Persistent anaemia *v.* no anaemia (*n* 160)		
Characteristics	RR	95 % CI	*P* value*
Individual			
Region			
Rest of Upolu	1·00	Ref.	–
Apia urban area	0·73	0·35, 1·50	0·388
Northwest Upolu	0·47	0·20, 1·10	0·081
Age group (months)			
Continuous variable	0·86	0·60, 1·23	0·414
24–35	1·00	Ref.	–
36–47	1·28	0·65, 2·55	0·478
48–59	0·55	0·22, 1·36	0·192
Sex			
Male	1·00	Ref.	–
Female	1·02	0·54, 1·91	0·964
First child	0·75	0·33, 1·68	0·478
Ever breastfed	0·80	0·41, 1·55	0·505
Overweight/obesity	1·38	0·66, 2·87	0·397
Stunting	1·88	0·95, 3·72	0·070
Illness in the past 3 weeks	1·32	0·47, 3·72	0·598
Infection symptoms†	1·45	0·52, 4·03	0·475
Deworming medication use in the past 3 week‡	1·31	0·62, 2·74	0·477
Night-time sleep (h)‡	0·97	0·79, 1·19	0·749
Given any vitamin or mineral drops in the past 3 weeks	1·74	0·34, 8·92	0·504
TEI-adjusted nutrient intake§			
Vitamin A intake (mg/d)	1·00	1·00, 1·00	0·622
Vitamin E intake (mg/d)	1·01	0·90, 1·13	0·926
Vitamin C intake (mg/d)	1·00	1·00, 1·01	0·544
Sodium intake (100 mg/d)	1·00	0·95, 1·05	0·962
Iron intake (10 mg/d)	3·94	0·99, 15·67	0·052
Calcium intake (100 mg/d)	1·13	0·98, 1·31	0·099
Potassium intake (mg/d)	1·00	1·00, 1·00	0·795
Maternal			
Age (years)			
Continuous variable	0·99	0·95, 1·02	0·379
18–29	1·00	Ref.	–
30–39	0·82	0·37, 1·80	0·616
> =40	0·89	0·42, 1·85	0·746
High school graduated	0·69	0·37, 1·30	0·253
Married or cohabitating	0·78	0·38, 1·58	0·483
Overweight/obese	0·74	0·32, 1·71	0·485
Anaemia	2·40	1·30, 4·43	0·005
Alcohol drink within the past 12 months	0·38	0·12, 1·19	0·096
Household			
Annual income less than $ 10 000 tala‡	1·18	0·52, 2·64	0·694
Asset score			
Quartile 1 (mean = 1·3, SD = 0·8)	1·00	Ref.	–
Quartile 2 (mean = 3·5, SD = 0·5)	1·14	0·90, 1·46	0·278
Quartile 3 (mean = 5·8, SD = 0·8)	1·10	0·87, 1·39	0·447
Quartile 4 (mean = 10·9, SD = 3·1)	1·05	0·80, 1·36	0·742
Community spirit‡,‖			
Not strong	1·00	Ref.	–
Strong	0·83	0·44, 1·57	0·575
Type of household drinking water			
Pipe into the house	1·00	Ref.	–
Pipe on the house lot	1·17	0·59, 2·32	0·661
Public tap or rain water	0·60	0·15, 2·49	0·481
Type of household toilet‡			
Flush	1·00	Ref.	–
Pit	0·72	0·12, 4·57	0·731

RR, relative risk; Ref., reference category; TEI, total energy intake.
*Based on log-binomial regression models.
†Infection symptoms included fever, rash, flu, cough and breathing problems.
‡Missing values for the labelled variables: deworming medication use in the past 3 weeks (*n* 1), night-time sleep (*n* 3), annual income less than $ 10 000 tala (*n* 1), community spirit (*n* 1), type of household toilet (*n* 1).
§Boundaries of TEI-adjusted nutrient intake: vitamin A = 450 mg/d; vitamin E = 6 mg/d; vitamin C = 30 mg/d; sodium = 2000 mg/d; iron = 12·6 mg/d; calcium = 600 mg/d; potassium = 3510 mg/d.
‖Due to the small sample size of the weak group, community spirit was classified as strong (Likert scale 3–4) and not strong (Likert scale 0–2).
¶Given any iron syrup in the past 3 weeks was deleted from unadjusted models because of the small sample size of children having this behaviour.

https://doi.org/10.1017/S1368980021003980 Published online by Cambridge University Press

Table 4 Multivariable regression models of sample characteristics associated with child anaemia; Samoan island of Upolu, June – August 2015

	Transient anaemia *v.* no anaemia (*n* 226)			Persistent anaemia *v.* no anaemia (*n* 160)		
Characteristics	Adjusted RR	95 % CI	*P* value*	Adjusted RR	95 % CI	*P* value*
Region						
Rest of Upolu	1·00	Ref.	–	1·00	Ref.	–
Apia urban area	1·05	0·71, 1·54	0·822	0·87	0·44, 1·73	0·691
Northwest Upolu	1·15	0·82, 1·61	0·415	0·52	0·23, 1·16	0·108
Child age (months)						
24–35	1·00	Ref.	–	1·00	Ref.	–
36–47	1·04	0·76, 1·43	0·798	1·36	0·69, 2·66	0·371
48–59	0·54	0·35, 0·84	0·007	0·57	0·24, 1·34	0·197
Female child	0·91	0·68, 1·22	0·530	1·09	0·59, 2·01	0·778
Mother high school graduated	0·90	0·67, 1·22	0·511	0·69	0·38, 1·25	0·219
Total sodium intake (100 mg/d)	0·97	0·95, 0·99	0·003	–	–	–
Total iron intake (10 mg/d)	–	–	–	4·69	1·33, 16·49	0·016
Maternal age						
18–29	1·00	Ref.	–	–	–	–
30–39	1·03	0·76, 1·40	0·855	–	–	–
> =40	0·61	0·39, 0·95	0·029	–	–	–
Maternal anaemia	–	–	–	2·13	1·17, 3·89	0·013

RR, relative risk; Ref., reference category.
*Conducted with the modified Poisson regression model since the log-binomial model did not converge.

higher in younger than in older children[33]. During breastfeeding (usually between birth and 2 years of age), children must meet their iron needs from breast milk. After weaning, however, children tend to participate in the family meals and receive more diverse nutrient intake[33]. Similar developmental behaviours related to food consumption may explain our observations, although we did not ask explicitly about the type of transitional, complementary foods being consumed by the cohort or their iron content or examine how dietary patterns varied by age at the baseline assessment.

Counter-intuitively, we found that higher daily sodium intake among children at the time of the baseline assessment was associated with reduced risk of transient anaemia, although the relative risk was suggestive of only a weak association[34]. One possible reason for the observed association may be a positive correlation between child sodium and iron intake (Spearman correlation test, $P < 0{\cdot}001$, rho $= 0{\cdot}224$). In Samoa, commonly consumed processed or canned foods that contribute significantly to children's dietary iron intake may also have relatively high levels of sodium (for example, corned beef or fortified breakfast cereals). Previous studies have shown that table salt (sodium chloride) is commonly fortified with iron[35], and iron-fortified foods have been found to be effective in increasing Hb levels in children in several clinical trials[36,37]. However, since most of the children in our sample exceeded the WHO recommendations for sodium intake recommendations[38], we advocate for future interventions to focus on iron supplementation without increasing sodium intake. Finally, we also found that children with transient anaemia were more likely to have mothers under 40 than over 40 years old. Reported associations between maternal age and childhood anaemia are not consistent across previous studies from developing countries[39–41] and this finding warrants further investigation.

Daily child iron intake and maternal anaemia condition were the only two baseline characteristics associated with persistent anaemia. The association between child total iron intake and anaemia was inverse, such that greater reported iron intake was associated with increased risk of anaemia. While counterintuitive, this may be because children were diagnosed with anaemia in 2015 during their initial study encounter. At that time, they were given referrals to the medical system for further examination as well as literature from the Samoan Ministry of Health suggesting foods with high iron intake. If mothers followed clinicians' advice and increased the availability of foods with bioavailable iron (without the child reversing their anaemia) or if participants had received an anaemia diagnosis from a clinician prior to the 2017–2018 study encounter, reverse causality may explain these findings. Children with persistent anaemia may also have had higher physiological demand for iron and may have displayed preferences for foods rich in iron.

Several previous studies in developing countries also reported that maternal anaemia was an important risk factor associated with childhood anaemia[40,42]. A shared common living environment may contribute to this association[40,42], as children are exposed to the same physical, socioeconomic and dietary patterns as their mothers. Another explanation posited by prior studies is that maternal anaemia may be associated with poor birth outcomes including low birth weight or preterm birth[42], both of which increase the probability of developing anaemia in childhood. Since we were unable to assess birth outcomes for these children, future analyses would benefit from additional information on birth weight and other perinatal

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outcomes. Routine screening of women – during well-woman visits or prenatal care – may be an effective strategy for identifying children who may require additional monitoring and focused prevention efforts.

The greatest limitation of this work is the fact that we could not account for duration of anaemia among the children who only had anaemia at one wave of data collection in the study. We did not ask mothers about whether their children had been previously diagnosed with the condition when we saw them first in 2015 (a lack of widespread testing suggests though, that if anaemia had been present, parents may not have been aware). We also do not know for how long the newly emerging cases persisted. For these reasons, the term 'transient' anaemia should be considered only within the context of this 3-year study. Further follow-up of the cohort is ongoing and additional assessments will continue to help us understand the nature of anaemia in this setting. Similarly, we cannot be sure that the 'resolved' and 'emergent' cases were the same; while we combined the groups based on a lack of significant differences in participant characteristics, the causes of anaemia may have been different. Another significant limitation of our study was that we could not capture the contribution of infection or parasitic disease – either acute or chronic – to anaemia risk. While we asked mothers about their child's medical history, recent illnesses and any hospital visits in last 3 weeks and used this information to create an 'infection' proxy variable, this measure was imperfect, and no association was observed with anaemia risk. Several studies indicate that diseases causing blood loss, haemolysis, erythropoiesis, pathological disorders like malabsorption, inflammation and some genetic disorders are associated with anaemia[4,43], but these were unable to be assessed. We also recognise the limitation of convenience sampling, which was the most cost-effective, feasible approach at the time the cohort was established (initially intended as a cross-sectional pilot study) and the resulting inability to generalise our findings to other settings. Knowledge that the study was health-focused may have led to greater willingness to participate among mothers educated about health or with concerns about their child's health. The analyses may be prone to selection bias given that a greater proportion of children resided in the rural Rest of Upolu region in the analytic sample compared to those that were excluded from the sample. Additionally, since child daily nutrient intake was estimated based on Food Frequency Questionnaires, we must acknowledge common weaknesses of the tool related to maternal recall memory, misreporting or restriction of estimates to only those items listed in the instrument[44].

A notable strength, and the unique contribution of our study, is the use of data from an ongoing cohort study to characterise the different presentations of anaemia among Samoan children. While the consequences of chronic anaemia are well understood, we know relatively less about the potential long-term impact of transient anaemia on child health and studies focused on this topic are limited. Further research is needed in Samoa to understand whether there are later adverse health outcomes associated with having anaemia for a short period of time, particularly if it occurs during critical periods of growth and development. In Samoa, there are currently no ongoing programmatic attempts to reduce the prevalence of anaemia, although anaemia is often a focus of nutritional outreach efforts by the Samoan Ministry of Health. If the risks associated with transient anaemia were to be minimal, future government efforts to identify, prevent and treat anaemia could perhaps be focused more explicitly on those with risk factors for chronic anaemia. Future studies should aim to further elucidate the determinants of chronic anaemia in Samoan children, with the goal of implementing prevention, early detection and treatment measures. We are currently conducting an additional follow-up of the cohort where we will examine health, well-being and cognitive function as well as being able to report on the continuing dynamic nature of anaemia in the study sample.

Conclusion

There was a moderate-high prevalence of anaemia observed among participants in the ongoing *Ola Tuputupua'e* study. Of all children with anaemia in 2015, only 35·6 % of cases persisted 2–3 years later, indicating that many cases are likely 'transient' or will resolve over time. Risk factors for transient *v.* persistent anaemia were different, indicating that national policy for prevention and treatment, which should be encouraged given the prevalence estimates, may need to take a more targeted approach to those with risk factors for persistent anaemia as well as employing more general national strategies. Further studies to understand the nature of anaemia and the adverse health outcomes associated with anaemia (both transient and persistent) are also needed.

Acknowledgements

Acknowledgements: The authors would like to express our sincere appreciation to the participants in the *Ola Tuputupua'e* cohort as well as to the Samoa Ministry of Health, Samoa Bureau of Statistics and Ministry of Women, Community and Social Development for their support of this work. We would also like to thank our research assistants, particularly Vaimoana Lupematisila and Folla Unasa, without whom the recruitment and retention of this cohort would have been impossible. *Financial support:* This work was supported by China Scholarship Council (B.W.); Yale School of Public Health (Faculty Funding, N.L.H., David Dull Internship Fund, C.C.C., Jan A.J. Stolwijk Fellowship Fund, Yale Downs International

https://doi.org/10.1017/S1368980021003980 Published online by Cambridge University Press

Health Student Travel Fellowship, Thomas C. Barry Travel Fellowship); National Institutes of Health Minority and Health Disparities International Research Training Program; U.S. Fulbright Graduate Student Research Fellowship (C.C.C.); Brown University School of Public Health (International Health Institute, Framework in Global Health Summer Research Scholarships and Nora Kahn Piore Award, C.C.C.); Brown University Population Studies and Training Center which receives funding from the NIH, for training (C.C.C., T32 HD007338) and general support (C.C.C., P2C HD041020); Ruth L. Kirschstein National Research Service Award Individual Predoctoral Fellowship NIH (C.C.C., 1F31HL147414-01); the Fogarty Global Health Equity Scholar Program (C.C.C., FIC D43TW010540); and Infrastructural support was provided by NIH (PI: McGarvey, grant HL093093). The funders had no role in the design, analysis or writing of this article. *Conflict of interest:* There are no conflicts of interest. *Authorship:* B.W., C.C.C. and N.L.H. conceived the study, and B.W. wrote the initial draft of the manuscript. C.C.C. collected study data with the support of R.L.D., C.S-U., T.N., M.S.R., N.L.H., B.W., C.C.C., A.C.R. and N.L.H. analyzed and interpreted the data. All authors read and approved the final manuscript. *Ethics of human subject participation:* This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Yale and Brown University Institutional Review Boards and Health Research Committee of the Samoan Ministry of Health (IRB # 2000020519 and IAA #18-41 959). Written informed consent was obtained from all parents and assent from children in 2015 and 2017–2018.

Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980021003980

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https://doi.org/10.1017/S1368980021003980 Published online by Cambridge University Press