British Journal of Nutrition

cambridge.org/bjn

Serum insulin-like growth factor 1 in young children with moderate acute malnutrition: secondary analysis of a randomised trial in Burkina Faso

Thora W. Helt[1], Bernardette Cichon[2], Christian Fabiansen[2], Ann-Sophie Iuel-Brockdorff[2], Charles W. Yaméogo[2,3], Christian Ritz[4], André Briend[2,5], Kim F. Michaelsen[2], Suzanne Filteau[6], Henrik Friis[2], Vibeke B. Christensen[1,7] and Benedikte Grenov[2]

[1]Médecins Sans Frontières, Copenhagen, Denmark; [2]Department of Nutrition, Exercise and Sports, University of Copenhagen, Copenhagen, Denmark; [3]Département Biomédical et Santé Publique, Institut de Recherche en Sciences de la Santé, Ouagadougou, Burkina Faso; [4]The National Institute of Public Health, University of Southern Denmark, Copenhagen, Denmark; [5]Tampere Center for Child, Adolescent and Maternal Health Research, Faculty of Medicine and Health Technology, Tampere University and Tampere University Hospital, Tampere, Finland; [6]Faculty of Epidemiology and Population Health, London School of Hygiene and Tropical Medicine, London, UK and [7]Department of Pediatrics and Adolescent Health, Rigshospitalet, Copenhagen, Denmark

Research Article

Cite this article: Helt TW, Cichon B, Fabiansen C, Iuel-Brockdorff A-S, Yaméogo CW, Ritz C, Briend A, Michaelsen KF, Filteau S, Friis H, Christensen VB, and Grenov B (2025). Serum insulin-like growth factor 1 in young children with moderate acute malnutrition: secondary analysis of a randomised trial in Burkina Faso. *British Journal of Nutrition*, page 1 of 10. doi: 10.1017/S0007114525000212

Received: 25 October 2024
Revised: 10 December 2024
Accepted: 27 January 2025

Keywords:
Insulin-like growth factor-1; Moderate acute malnutrition; Lipid-based nutrient supplement; Inflammation; Low-income country

Abbreviations:
CSB, corn soy blend; IGF, insulin-like growth factor; LAZ, length-for-age *z*-score; LNS, lipid-based nutrient supplement; MAM, moderate acute malnutrition; MUAC, mid-upper arm circumference; sIGF-1, serum insulin-like growth factor 1; WLZ, weight-for-length *z*-score

Corresponding author:
Benedikte Grenov; Email: bgr@nexs.ku.dk

Abstract

Insulin-like growth factor 1 (IGF-1) is an important growth factor in childhood. We aimed to investigate the impact of food supplements for the treatment of moderate acute malnutrition (MAM) on serum IGF-1 (sIGF-1). Secondary analysis of a randomised $2 \times 2 \times 3$ factorial nutrition trial was performed. Children aged 6–23 months with MAM received 2093 kJ/d as lipid-based nutrient supplement (LNS) or corn soy blend (CSB), containing either dehulled soya or soya isolate and different quantities of dried skimmed milk (0 %, 20 % or 50 % of total protein) for 12 weeks. The trial was double-blind with regard to soya and milk but not to matrix (LNS *v.* CSB). sIGF-1 was measured at inclusion and after 12 weeks of supplementation. Of 1609 children enrolled, 1455 (90 %) had sIGF-1 measured at both time points. During supplementation, sIGF-1 increased 6·7 (95 % CI 6·1, 7·3) ng/ml compared with an expected age-dependent decrease of 0·3 (95 % CI 0·2, 0·4) ng/ml. Children who received LNS *v.* CSB had a lower increase in sIGF-1 (−8 %, 95 % CI − 12, −3). The effect of LNS was partly attenuated when sIGF-1 was corrected for inflammation. Children who received soya isolate compared with dehulled soya had a higher increase in sIGF-1 (6 %, 95 % CI 1, 12). Milk content did not affect sIGF-1. Overall, sIGF-1 increased during supplementation. The lower increase with LNS *v.* CSB was only partly explained by increased inflammation with LNS and needs further investigation. Isolate *v.* dehulled soya led to a higher increase which may be due to antinutrients in dehulled soya.

Moderate acute malnutrition (MAM), defined as moderate wasting or low mid-upper arm circumference (MUAC), is estimated to affect 31 million children below 5 years globally[1]. MAM is associated with increased morbidity and mortality, mainly due to infectious diseases[2]. A new guideline recommends that children with MAM should be considered for supplementary foods if they fulfil certain individual or social risk criteria or live in a high-risk context. Furthermore, lipid-based nutrient supplement (LNS) is the preferred type of food supplement compared with corn soy blend (CSB) or other fortified blended foods[3]; however, the certainty of evidence for the recommendation of food supplement type is low. Several studies have evaluated the effects of the supplement matrix or different protein sources on recovery from MAM and growth. Reviews and meta-analyses have often found superior recovery among children treated with LNS *v.* fortified blended food[4–7]. Some reviews found higher gain in weight, weight-for-height *z*-score or MUAC[5–8], but not height[8] when children with MAM were treated with LNS compared with CSB. However, when LNS was compared with fortified blended food with milk and/or improved micronutrients, there were no or marginal differences in anthropometric outcomes of children with MAM[5,8].

Few studies evaluated the physiological effects of food supplements on growth factors. Insulin-like growth factor 1 (IGF-1) is produced in the liver and is an important endocrine growth factor in young children[9]. Both malnutrition[10,11] and inflammation[12,13] are associated with reduced synthesis of IGF-1, possibly via down-regulation of the growth hormone-IGF-1 axis[10–13]. As the reduction in serum IGF-1 (sIGF-1) in response to starvation

or illness takes place within days[13–15], short-term effects of nutrition on growth may be easier to detect by measuring sIGF-1 than linear growth. Linear growth changes slowly and is difficult to measure accurately in young children as they tend to move during assessments. We have previously shown that both stunting and wasting as well as systemic inflammation were associated with remarkably lower sIGF-1 among 6–23-month-old Burkinabe children[16]. In the same children, we aimed to assess the effect of the food matrix, soya protein quality and milk protein content on changes in sIGF-1, and we assessed for effect modifiers of these effects.

Subjects and methods

Study design and participants

This study was based on secondary analysis of a randomised $2 \times 2 \times 3$ factorial trial assessing the effects of food supplements with two different food matrices (LNS *v.* CSB), two soya qualities (isolate *v.* dehulled) and three levels of milk protein (0 %, 20 %, 50 % of the total protein content) on body composition and linear growth among children with MAM[17]. The study took place at five sites in the Province du Passoré, Northern Region, Burkina Faso. Children were screened for MAM either by community health workers using MUAC tapes or by designated screening teams using both MUAC and weight-for-length *z*-score (WLZ). Children could also be referred from a health centre or be taken to a site based on the caregiver's initiative. The final eligibility assessment was carried out by study staff at the sites. Children aged 6–23 months who lived in the catchment area and were confirmed to have MAM (MUAC $\geq$ 115 mm and $<$ 125 mm and/or WLZ ≥ -3 and < -2) were enrolled. Children were excluded if they were already in a nutritional programme; were treated for severe acute malnutrition or hospitalised within the past 2 months; had an illness requiring hospitalisation; had haemoglobin $<$ 50 g/l; suspected allergy to milk, peanuts, CSB or LNS or had a severe disability. Only one child per household was included. This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Ethics Committee for Health Research in Burkina Faso (2012-8-059). In addition, consultative approval was obtained from the Danish National Committee on Biomedical Research Ethics (1208204). Information leaflets and informed consent forms were translated into the local language, Mooré, and caregivers gave verbal and written consent (signature or fingerprint) prior to enrolment. The original trial was registered in the ISRCTN registry (ISRCTN42569496).

Intervention, randomisation and blinding

Children received 2093 kJ/d (500 kcal/d) of one of twelve food supplements for 12 weeks. The food matrix was either CSB (120 g/d) or LNS (92 g/d), soya quality was dehulled or isolated and 0 %, 20 %, or 50 % of the total protein was from dried skimmed milk. The contents of protein and fat were 15·9–16·8 g/d and 11·4–11·7 g/d in CSB and 12·5–13·5 g/d and 31·4–32·1 g/d in LNS[17]. The compositions complied with the WHO technical note on food supplements for the management of MAM[18]. LNS was ready to use whereas CSB had to be cooked into porridge before intake. The supplements were manufactured by GC Rieber Compact A/S (Søfteland, Norway).

Individual, stratified block randomisation was used. Block sizes were 12 or 24, and stratification was done by site. Investigators, outcome assessors and other staff were blinded with respect to the matrix, soya quality and milk content; however, participants were only blinded to soya quality and milk content but not a matrix. Further information about randomisation, allocation concealment and blinding are described elsewhere[17]

Data collection

At baseline, trained study nurses collected data on socio-demographic information, breastfeeding status and 2-week medical history and carried out a physical examination.

Anthropometric assessments were taken by trained staff and measured at baseline and week 12. Weight, length and MUAC were measured in duplicate to the nearest 100 g, 1 mm and 1 mm using an electronic scale with a double weighing function (Seca 881 1021659, Hamburg, Germany), a wooden height board and a standard measuring tape, respectively. Knee–heel length was measured five times with a digital caliper (Mitutoyo, Germany) which we mounted with knee and heel caps cast in hard plastic. The mean values were used.

Venous blood samples were collected at baseline and 12 weeks. On-site, a drop of blood was used for diagnosis of malaria (rapid diagnostic test, Bioline Malaria Ag Pf, Abbott, California), and the remaining blood was collected in a serum vacutainer tube (Becton Dickinson #368 492) and transported to the trial laboratory in a cooler box at 2–8°C. After centrifugation at 700 g for 5 min (EBA 20S Hettich, Tuttlingen, Germany), serum samples were stored at −20°C until shipment on dry ice for further analysis. Serum C-reactive protein and α-1-acid glycoprotein were analysed at VitminLab, Wilstaedt, Germany using sandwich enzyme-linked immune sorbent assay with intra- and interassay coefficients of variation between 5 and 14 %[19,20]. IGF-1 was analysed on Immulite 2000 Analyzer (Siemens Healthcare, Erlangen, Germany) at University of Copenhagen (Denmark). Values below 25 ng/ml were not shown automatically but were calculated using algorithms provided by the manufacturer. The intra-assay coefficient of variation was 20 % when sIGF-1 was 10 ng/ml and 6 % when sIGF-1 was 25 ng/ml. All samples were measured in duplicate, and the mean was used.

Statistics

Data were double-entered in EpiData 3·1 (Epidata Association, Odense, Denmark). STATA 12 or 17 was used for all statistical analyses. Baseline characteristics were summarised as mean (SD) for normally distributed variables, median (interquartile range) for non-normally distributed variables and frequency % (*n*) for categorical variables. Distribution was assessed by visual inspection of histograms and normal probability plots. Mean change in sIGF-1 during the intervention was assessed by paired *t* test with 95 % CI.

Linear mixed models were used to assess the effects of the interventions on sIGF-1. Data on sIGF-1 were log-transformed. Model reductions were carried out using likelihood ratio tests. A model containing the three-way interactions, corresponding to the $2 \times 2 \times 3$ factorial design, was compared with a model containing only the main effects of the factors. If there were no interactions in the factorial layout, the main effects of food matrix (LNS *v.* CSB), soya quality (soya isolate *v.* dehulled soya) and content of milk protein (0 % *v.* 20 % or 0 % *v.* 50 %) were extracted from the models. The models included sex, age, season (month of inclusion), baseline MUAC, WLZ, length-for-age *z*-score (LAZ) and sIGF-1 as fixed effects and site as random effect. Further adjustment for inflammation was done using C-reactive protein $>$ 5 or

AGP > 1 mg/l. Effects were presented as estimated means with 95% CIs. We further assessed if sex, age, breastfeeding, inclusion criteria (MUAC only, weight-for-height *z*-score only, or MUAC and weight-for-height *z*-score), fever, malaria and elevated C-reactive protein (> 2 mg/l) and AGP (> 1·2 g/l) modified the effect of the interventions (food matrix, soya quality and milk protein content) on sIGF-1 using the linear mixed model with adjustment for sex, age, season, baseline MUAC, WLZ, LAZ and sIGF-1 as fixed effects and site as a random effect. Model assumptions were assessed by visual inspection of residual and normal probability plots.

As we did not have an unsupplemented reference group, baseline values were analysed in relation to age and sex to estimate the typical changes in sIGF-1 over a period equivalent to the length of the intervention. This 'calculated reference' was used for descriptive purposes only and not for the linear mixed models. Specifically, changes in sIGF-1 during 12 weeks were estimated using linear regression of baseline IGF-1 with age as a fractional polynomial. Separate regressions were prepared for boys and girls, and the selection of the best model was based on the Akaike information criterion. We did not impute missing data in any analyses. *P*-values below 0·05 were considered significant.

Results

As previously reported[17], we enrolled 1609 children with MAM from September 2013 to August 2014. The randomisation resulted in baseline equivalence (Table 1). Of 1609 enrolled children, 1548 (96·2 %) were followed up for 12 weeks (Figure 1). During the intervention, 102 (6·9 %) children developed SAM, four children died and no child developed an allergic reaction to the supplements. The proportion of these adverse events was similar between treatment groups, and none were attributed to the food supplements. Children lost to follow-up had similar baseline characteristics as those followed up (online Supplementary Table 1). However, children without data on sIGF-1 were generally younger with lower weight and height, but not lower LAZ or weight-for-height *z*-score, and were more likely to have fever and inflammation (online Supplementary Table 2).

At baseline, the median (inter quartile range [IQR]) age was 11·3 (8·2–16·0) months, 45·4 % (730) were boys and the mean (SD) LAZ was −1·7 (1·1). Median (IQR) levels of the inflammatory markers C-reactive protein and AGP were 2·3 (0·8–9·4) mg/l and 1·22 (0·88–1·64) g/l, and 40% (*n* 644) had a positive malaria test. sIGF-1 was available on 1549 (96%) of the 1609 children at baseline and 1509 out of 1548 (97%) at week 12 (Figure 1) and 1455 (90%) had sIGF-1 data at both time points.

Median (IQR) sIGF-1 was 12·0 (8·2–18·2) ng/ml at baseline and 18·4 (12·3–26·9) ng/ml at endline. The mean (SD) increase in sIGF-1 during the 12-week supplementation was 6·7 ng/ml (95 % CI 6·1, 7·3).

There were no three- or two-way interactions between the experimental factors with respect to effects on sIGF-1 ($P = 0·66$); hence, the main effects could be assessed (Table 2). LNS (*v.* CSB) resulted in an 8 % (95 % CI: 3, 12) lower change in sIGF-1, and soya isolate (*v.* dehulled soya) resulted in a 6 % (95 % CI: 1, 12) higher change in sIGF-1. There was no effect of either 50 % or 20 % (*v.* 0 %) milk protein ($P \geq 0·43$) on sIGF-1. After adjustment for inflammation, the effect size of the difference between soya isolate *v.* dehulled soya was maintained (5 %, 95 % CI: −0·0008, 10), but the effect size of LNS *v.* CSB was reduced (-4 %, 95 % CI: −9, 4).

Table 1. Baseline characteristics of 1609 children age 6–23 months with moderate acute malnutrition (Median values and interquartile ranges; mean values and standard deviations)

	Matrix				Soya quality				Milk protein content					
	CSB, *n* 800		LNS, *n* 809		Dehulled, *n* 800		Isolate, *n* 809		0 %, *n* 541		20 %, *n* 528		50 %, *n* 540	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Characteristics														
Sociodemographics														
Age (months)														
Median	11·1		11·5		11·2		11·4		11·1		11·4		11·1	
IQR	8·2–15·5		8·3–16·4		8·4–16·0		8·0–16·0		8·1–16·2		8·4–16·2		7·9–15·6	
Sex, male (%)	45		46		47		44		45		46		45	
Anthropometry														
Weight (kg)	6·9	0·9	6·9	0·9	6·9	0·9	6·9	0·9	6·9	0·9	6·9	0·9	6·9	0·9
Length (cm)	70·3	5·2	70·5	5·4	70·4	5·2	70·4	5·4	70·5	5·6	70·6	5·2	70·2	5·2
Length-for-age (*Z*-score)	−1·6	1·1	−1·7	1·1	−1·7	1·1	−1·7	1·1	−1·7	1·1	−1·7	1·1	−1·7	1·2
Weight-for-age (*Z*-score)	−2·5	0·6	−2·6	0·7	−2·5	0·6	−2·5	0·7	−2·5	0·7	−2·5	0·6	−2·5	0·7

(*Continued*)

Table 1. (*Continued*)

	Matrix				Soya quality				Milk protein content					
	CSB, *n* 800		LNS, *n* 809		Dehulled, *n* 800		Isolate, *n* 809		0 %, *n* 541		20 %, *n* 528		50 %, *n* 540	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weight-for-length (*Z*-score)	–2·2	0·5	–2·2	0·5	–2·2	0·5	–2·2	0·5	–2·2	0·5	–2·2	0·5	–2·2	0·5
MUAC (mm)	123	4	123	4	123	4	123	4	122	4	123	4	123	4
Knee-heel length, *n* 1608 (mm)	192	18	192	18	192	18	192	18	192	19	193	18	192	17
Inclusion criteria														
WLZ and MUAC (%)	51		50		51		49		51		52		47	
WLZ only (%)	21		21		21		21		21		21		21	
MUAC only (%)	28		30		28		30		29		27		22	
Morbidity and inflammation														
Ill in the last 2 weeks*, *n* 1597 (%)	77		77		78		76		76		80		75	
Diarrhoea* (%)	19		21		21		18		21		20		19	
Cough*, *n* 1606 (%)	29		30		30		29		27		32		30	
Fever, ≥ 37·5 †, *n* 1607 (%)	19		16		16		19		18		16		19	
Malaria rapid test, positive, *n* 1601 (%)	41		40		41		40		40		40		41	
CRP, *n* 1564 (mg/l)														
Median	2·2		2·6		2·6		2·2		2·2		3·0		2·1	
IQR	0·7–9·4		0·8–9·3		0·8–10·3		0·7–8·9		0·7– 10·0		0·9–11·1		0·7–7·7	
AGP, *n* 1564 (g/l)														
Median	1·23		1·21		1·23		1·21		1·19		1·27		1·21	
IQR	0·87–1·66		0·89–1·63		0·88–1·69		0·87–1·62		0·84–1·62		0·95–1·68		0·86–1·64	
Breastfeeding, *n* 1607 (%)	94		95		95		95		95		93		95	
IGF-1, *n* 1549 (ng/ml)														
Median	12·1		12·0		12·4		11·9		12·1		11·6		12·7	
IQR	8·4–18·5		8·0–18·1		8·2–17·4		8·2–18·9		8·0–18·1		8·2–17·2		8·5–19·1	

Abbreviations: MUAC = Mid-upper arm circumference, CRP = C-reactive protein, AGP = α_1-acid glycoprotein, IGF-1 = Insulin-like growth factor 1.
Values are presented as median (IQR), mean (SD) or %.
*Based on maternal recall and physical examination, †Based on physical examination.

Table 2. The effect of matrix, soya quality and milk content of food supplements on serum insulin-like growth factor-1 (sIGF-1) among children with moderate acute malnutrition (Median values and interquartile ranges; mean, ratios and 95 % CI)

		Baseline, ng/ml		12 weeks, ng/ml		Change, ng/ml		Difference in change*		
		n 1549		*n* 1509		*n* 1455		*n* 1455		
Type of supplement		Median	IQR	Median	IQR	Mean	95 % CI	Ratio	95 % CI	*P*
Food matrix	CSB	12·1	8·3–18·5	19·1	12·4–29·9	7·3	6·7, 8·5			
	LNS	12·0	8·0–18·1	17·5	12·1–25·1	5·8	4·9, 6·8	−8 %	−12, −3	0·003
Soya quality	Dehulled	12·4	8·2–17·4	17·1	12·0–26·4	6·5	5·5, 7·4			
	Isolate	11·9	8·2–18·9	19·3	12·7–27·6	7·0	6·1, 7·9	+6 %	1, 12	0·026
Milk protein content	0 %	12·1	8·0–18·1	18·2	12·6–26·7	6·3	5·3, 7·3			
	20 %	11·6	8·2–17·2	18·5	11·6–26·5	7·2	6·2, 8·3	−0·003 %	−7, 6	0·93
	50 %	12·7	8·5–19·1	18·8	12·7–27·4	6·6	5·4, 7·9	+3 %	−4, 9	0·43

Abbreviations: CSB, corn soy blend; LNS, lipid-based nutrient supplement; SD, Standard deviation. *sIGF-1 data were log-transformed. Results are therefore presented as the ratio of change based on linear mixed models adjusted for sex, age, season, baseline MUAC, WLZ, LAZ and sIGF-1 as fixed effects and site as random effect.

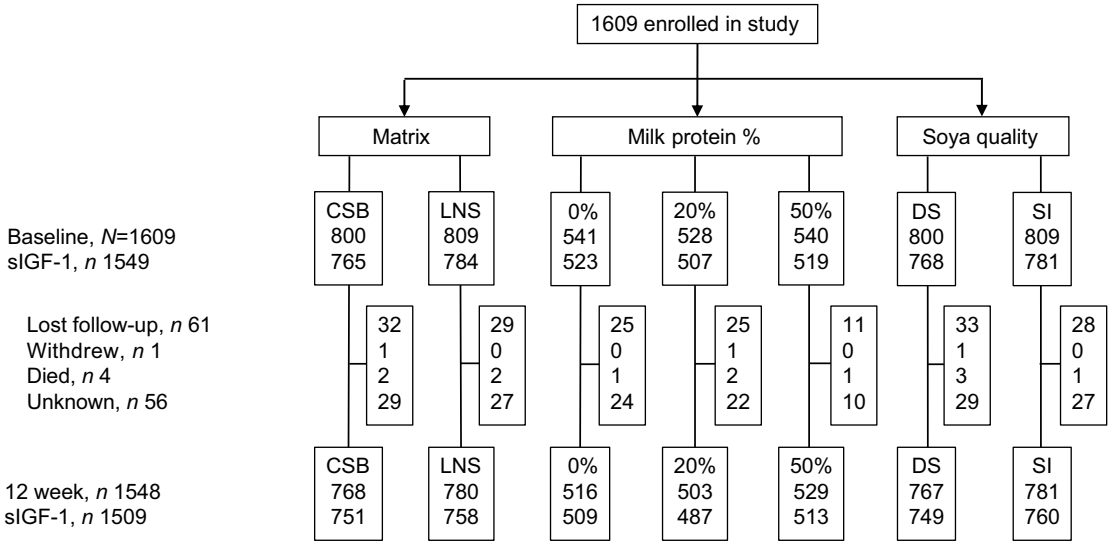

Figure 1. Flow chart showing the total number of children and the number of children with serum insulin-like growth factor-1 (sIGF-1) data available at baseline and at week 12. CSB corn soy blend, DS dehulled soya, LNS lipid-based nutrient supplement, SI soya isolate.

We assessed effect modification by sex, age, LAZ, WLZ, inclusion criteria for MAM (MUAC only, WLZ only or WLZ and MUAC), malaria, fever and elevated serum C-reactive protein and α-1-acid glycoprotein (Table 3). For LNS (*v.* CSB), there were no interactions between the matrix and any of the potential effect modifiers. For soya isolate (*v.* dehulled), there was an interaction by age (age ≥ 16 months, $P = 0{\cdot}026$), reflecting that the positive effect of soya isolates on change in IGF-1 was larger in children above (17 %, 95 % CI 6, 30) than below 16 months (2 %, 95 % CI: −4, 9). As for 20 % milk protein content, we found a trend for interaction with wasting (WLZ < −2, $P = 0{\cdot}050$) and fever (≥ 37·5 , $P = 0{\cdot}046$) with tendencies to larger increases in sIGF-1 for children with WLZ > −2 and fever. There were no interactions between 50 % milk protein and any of the potential effect modifiers.

The increase in sIGF-1 by matrix, soya quality and age was further explored in Figure 2. For matrix (panel A), the increase in sIGF-1 was lowest in the youngest children and then plateaued starting around 9 months of age. The same pattern was seen for children given CSB and LNS but was higher for those given CSB across all ages. As there was no unsupplemented control group, a reference curve was calculated based on baseline data. As seen, the change in sIGF-1 in this reference was negative in the youngest children, and then increased and plateaued around 0. For soya quality (panel B), the interaction between age and soya quality is seen as no difference between those given soya isolate and dehulled soya among children below 16 months, whereas among children above 16 months soya isolate was associated with a greater increase in sIGF-1 that seemed to increase with age.

Discussion

Serum IGF-1 increased 6·7 ng/ml among children receiving food supplements for 12 weeks. For ethical reasons, the trial did not have

Table 3. Effect modifiers of change in sIGF-1 during intervention (12 weeks) in children age 6–23 months with moderate acute malnutrition (Percentages and 95 % CI)

		Matrix			Soya quality			Milk protein					
		LNS *v.* CSB			Isolate *v.* dehulled			20 % *v.* 0 %			50 % *v.* 0 %		
	n	P^{int}	%	95 % CI	P^{int}	%	95 % CI	P^{int}	%	95 % CI	P^{int}	%	95 % CI
Sex		0·54			0·51			0·22			0·84		
Boys	659		−6	−13, 2		4	−4, 13		4	−5, 15		2	−7, 12
Girls	787		−9	−15, 2		8	0·01, 16		−4	−12, 5		3	−5, 13
Age (months)		0·83			0·026			0·16			0·32		
6–15	1075		−7	−13, −1		2	−4, 9		3	−5, 11		1	−6, 9
16–24	371		−8	−18, 2		17	6, 30		−8	−19, 5		9	−4, 23
Breastfeeding		0·83			0·058			0·69			0·74		
Not breastfeeding	76		−10	−28, 14		32	5, 66		−6	−29, 25		−2	−27, 31
Breastfeeding	1368		−7	−12, −2		5	−1, 11		0·00	−6, −7		3	−4, 10
Length-for-age Z		0·70			0·26			0·28			0·97		
≥ −3	1300		−7	−12, −2		5	−1, 11		−0·00	−7, 7		1	−5, 9
< −3	146		−11	−24, 6		16	−2, 37					14	−7, 40
Weight-for-length Z		0·096			0·67			0·050			0·38		
≥ −2	424		−14	−22, −5		8	−2, 19		−10	−21, 2		−2	−13, 10
< −2	1022		−5	−11, −1		5	−1, 12		4	−4, 12		4	−3, 13
Inclusion criteria		0·13			0·87			0·37*			0·37*		
WLZ and MUAC	722		−8	−14, −0·00		5	−3, 13		2	−6, 12		5	−4, 15
WLZ only	302		1	−10, 13		6	−5, 13		7	−7, 24		5	−9, 20
MUAC only	422		−14	−22, −5		8	−2, 20		−10	−21, 1		−3	−13, 10
Fever (≥ 37·5)		0·36			0·66			0·046			0·53		
No	1197		−8	−13, −3		5	−1, 11		−3	−9, 4		2	−5, 9
Yes	248		−2	−14, 11		9	−4, 23		16	−1, 36		7	−8, 25
Malaria (Rapid test)		0·73			0·39			0·74			0·41		
Negative	856		−8	−14, −2		8	1, 16		1	−7, 10		1	−8, 9
Positive	584		−6	−14, −2		3	−5, 12		−1	−11, 9		6	−4, 17

https://doi.org/10.1017/S0007114525000212 Published online by Cambridge University Press

Table 3. (*Continued*)

CRP (mg/l)		0·20			0·89		0·89*			0·89*		
≤ 2	672	−8	−15, −1	5	−3, 13		−3	−11, 7	2	−7, 11		
> 2 and ≤ 5	255	2	−10, 16	10	−3, 24		4	−11, 21	4	−11, 21		
> 5 and ≤ 10	169	−5	−19, 11	9	−6, 27		−8	−24, 12	6	−13, 28		
> 10	348	−14	−23, −5	4	−7, 16		4	−8, 18	4	−9, 19		
AGP g/l		0·073		0·49		0·94			0·47			
≤ 1·2	696	−12	−18, −5	4	−3, 13		−0·01	−9, 9	−0·00	−9, 9		
> 1·2	748	−3	−10, 4	8	1, 16		−1	−9, 8	5	−4, 15		

Abbreviations: CRP = C-reactive protein, AGP = α_1-acid glycoprotein, IGF-1 = Insulin-like growth factor 1, P^{int}, *P*-value of interaction.
sIGF-1 data were log-transformed. Results were back-transformed and presented as the relative change based on linear mixed models adjusted for sex, age, season, baseline MUAC, WLZ, LAZ and sIGF-1 as fixed effects and site as random effects.
*P-value of interaction for 0 % *v.* 20 % *v.* 50 % is combined due to more than two subgroups.

an unsupplemented reference. However, by using baseline data, we estimated that sIGF-1 would have declined in the youngest and barely changed in the remaining children. This pattern among the 'calculated reference' is expected[21]; however, the increase in sIGF-1 in the supplemented children is quite remarkable as the baseline level was only 12·7 ng/ml, around half of better-nourished children from the same country[21] and much lower than children from a high-income country[22]. Both increased energy and protein intake may have contributed to the overall increase in sIGF-1 in the supplemented children[11].

We found a greater increase in sIGF-1 in children receiving CSB than in LNS. This may be due to a higher protein content of CSB *v.* LNS supplements: 15·9–16·8 g/d with CSB and 12·5–13·5 g/d with LNS. Protein intake has been associated with an increase in sIGF-1 in both young infants[23] and older children[24], but the source of protein may have a differential effect on sIGF-1[25]. However, the actual difference in protein intake is difficult to estimate as more children had leftovers and higher amounts of leftovers when given CSB compared with LNS, as measured in a subsample of children from the current trial[26]. The difference between CSB and LNS with regards to change in sIGF-1 was not reflected in more linear or ponderal growth among children receiving CSB[17]. After adjustment for inflammation, the difference between CSB and LNS was attenuated but remained significant. This may be due to an inflammatory effect of LNS. We have previously reported that LNS intake was associated with an increase in inflammation, perhaps due to higher content of linoleic acid or better iron status with LNS[27]. Inflammation is known to decrease the production of IGF-1[12,13,16].

Soya isolate resulted in a higher increase in sIGF-1 than dehulled soya. This effect was modified by age; only children above 16 months had a higher increase in sIGF-1 when given soya isolate *v.* dehulled soya. Soyabeans contain insoluble fibres and antinutritional factors including trypsin inhibitors and phytate that negatively affect the digestibility of protein and the bioavailability of amino acids[28]. In dehulled soya, fibres of the hull have been removed. However, in soya isolate, trypsin inhibitors have also been inactivated to a large extent, and thereby protein digestibility has been improved[28]. This may have resulted in higher production of sIGF-1 and maybe more in older children as they consumed a higher proportion of their supplements[26]. In addition, the protein requirements may have been covered better by home diet and food supplements among the older children. Children with wasting all have high requirements for protein quality and quantity[29], but the overall requirements for protein in terms of g/kg/day decrease between 6 and 23 months[30]. The higher increase in sIGF-1 was not manifested in higher linear or ponderal growth. This may be because linear growth is also determined by other factors than endocrine production of IGF-1 or because there may be a delay in linear growth response after an increase in IGF-1.

There was no effect of the content of milk protein on sIGF-1 in this trial where milk was mainly replaced with soya protein. This is in line with an RCT among 1–5-year-old Ugandan children with stunting[31]. The trial found no difference in the increase in sIGF-1 between children receiving LNS with milk protein isolate *v.* LNS with soya protein isolate. The Ugandan trial had an unsupplemented control group and found an increase in sIGF-1 in supplemented *v.* unsupplemented children similar to the difference observed between supplemented children and a calculated reference in the current trial. In both trials, there was also no effect of milk protein on anthropometric outcomes. The effect of

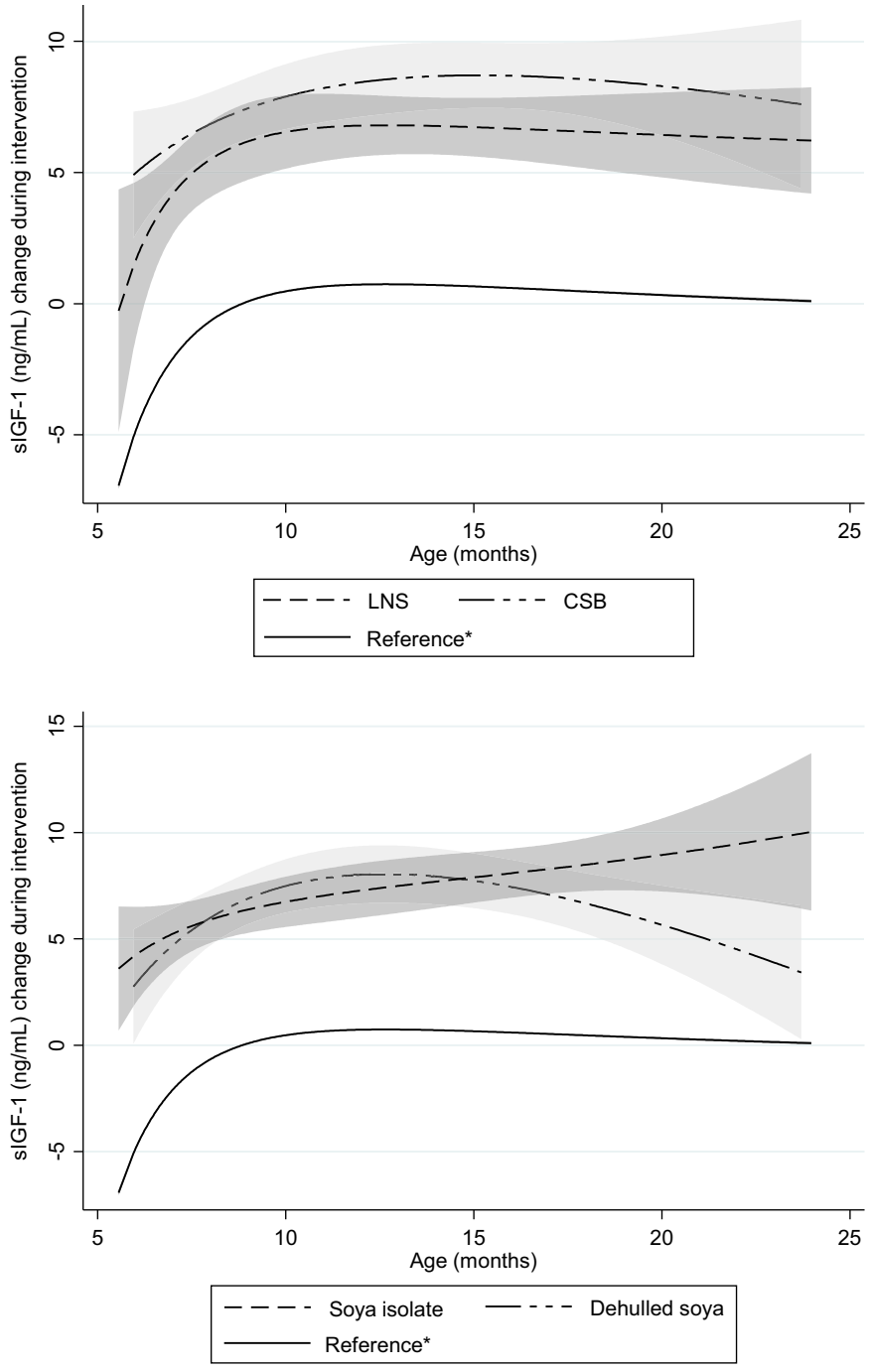

Figure 2. Change in serum insulin-like growth factor-1 (sIGF-1) by age among 1455 children with moderate acute malnutrition during 12 weeks supplementation. Panel A: Supplementation with lipid-based nutrient supplement (LNS) *v.* corn soy blend (CSB). Panel B: Supplement containing soya isolate *v.* dehulled soya. *As we did not have an unsupplemented reference group, we estimated changes in sIGF-1 during 12 weeks using linear regression of baseline IGF-1 with age as a fractional polynomial.

different protein sources was also analysed among 5-month-old formula-fed infants receiving either dairy or meat-based complementary food until 12 months of age ([32]). No difference was found between groups regarding sIGF-1. However, infants receiving meat-based complementary food increased by 0·33 in LAZ whereas infants receiving dairy-based complementary foods decreased by 0·30 in LAZ and increased by 0·76 in WLZ. Some[25,33–35], but not all[36] trials among young school children from high- or low-income settings have found different increases in sIGF-1 depending on the source of protein, typically with a higher increase in sIGF-1 after intake of milk protein. The age of the children, the total amount of milk protein supplied, the comparator and the overall composition of the diet may contribute to these differences.

The main limitation of the study was a high (20 %) intra-assay coefficient of variation when sIGF-1 was low (10 ng/ml). The large sample size was considered a strength.

During the supplementation period, an increase in sIGF-1 was observed which far exceeds levels in a calculated reference group. While the increase in LNS was lower than in the CSB group, the difference was modest and partly explained by increased inflammation with LNS. This finding needs further investigation. Soya isolate compared with dehulled soya led to a higher increase in sIGF-1 which may be due to a higher level of antinutrients in dehulled soya. Although sIGF-1 cannot predict growth alone, it may be a more sensitive marker of growth than anthropometric measurements in nutrition trials among young children.

Supplementary material. For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114525000212

Acknowledgements. The study was funded by the Danish International Development Agency (KFM, 09-097 LIFE); Médecins Sans Frontières (Denmark, Norway); Arvid Nilsson's Foundation; The World Food Program, which was part of a donation to the World Food Program from the American people through the support of the USA Agency for International Development's Office of Food for Peace; the Alliance for International Medical Action; the European Union's humanitarian aid funds, in partnership with Action Contre la Faim and a private donation from Merete and Mogens Brix Christensen. The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.

H. F. has received research grants from Arla Food for Health Centre. H. F. and B. G. have received research grants from the Danish Dairy Research Foundation. K. F. M. received funds from Arla Foods Amba and finally H. F., K. F. M., B. G., S. F. and A. B. have had research collaboration with Nutriset, a producer of LNS. Other authors declare no financial relationships with any organisations that might have had an interest in the submitted work in the previous five years and declare no other relationships or activities that could appear to have influenced the submitted work.

H. F., K. F. M., S. F., A. B., V. B. C.: designed the Treatfood trial. C. W. Y., C. F., B. C. and A-S. I-B: conducted the research. T. W. H., C. R.: analysed data. B. G.: wrote the manuscript and had primary responsibility for final content. T. W. H., H. F., K. F.M., V. B. C.: contributed to data analysis. All authors: read and approved the final manuscript.

References

1. The UNICEF/WHO/WB (2021) Joint Child Malnutrition Estimates (JME) Group Released New Data for 2021. https://www.who.int/news/item/06-05-2021-the-unicef-who-wb-joint-child-malnutrition-estimates-group-released-new-data-for-2021 (accessed December 2024).
2. Black RE, Victora CG, Walker SP, *et al.* (2013) Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet* **382**, 427–451.
3. WHO (2023) WHO Guideline on the Prevention and Management of Wasting and Nutritional Oedema (Acute Malnutrition) in Infants and Children under 5 years. https://www.who.int/publications/i/item/9789240082830 (accessed December 2024).
4. Gluning I, Kerac M, Bailey J, *et al.* (2021) The management of moderate acute malnutrition in children aged 6–59 months in low- and middle-income countries: a systematic review and meta-analysis. *Trans R Soc Trop Med Hyg* **115**, 1317–1329.
5. Lazzerini M, Rubert L & Pani P (2013) Specially formulated foods for treating children with moderate acute malnutrition in low- and middle-income countries. *Cochrane Database Syst Rev 2013*, issue 6, CD009584.
6. Lenters LM, Wazny K, Webb P, *et al.* (2013) Treatment of severe and moderate acute malnutrition in low- and middle-income settings: a systematic review, meta-analysis and Delphi process. *BMC Public Health* **13**, S23.
7. Das JK, Salam RA, Saeed M, *et al.* (2020) Effectiveness of interventions for managing acute malnutrition in children under five years of age in low-income and middle-income countries: a systematic review and meta-analysis. *Nutrients* **12**, 116.
8. Cichon B, Das JK, Salam RA, *et al.* (2023) Effectiveness of dietary management for moderate wasting among children > 6 months of age-a systematic review and meta-analysis exploring different types, quantities, and durations. *Nutrients* **15**, 1076.
9. Murray PG & Clayton PE (2013) Endocrine control of growth. *Am J Med Genet C Semin Med Genet* **163C**, 76–85.
10. Fazeli PK & Klibanski A (2014) Determinants of growth hormone resistance in malnutrition. *J Endocrinol* **220**, R57–R65.
11. Hawkes CP & Grimberg A (2015) Insulin-like growth factor-I is a marker for the nutritional state. *Pediatr Endocrinol Rev PER* **13**, 499–511.
12. Maleta K, Fan Y-M, Luoma J, *et al.* (2021) Infections and systemic inflammation are associated with lower plasma concentration of insulin-like growth factor I among Malawian children. *Am J Clin Nutr* **113**, 380–390.
13. Jones AD, Rukobo S, Chasekwa B, *et al.* (2015) Acute illness is associated with suppression of the growth hormone axis in Zimbabwean infants. *Am J Trop Med Hyg* **92**, 463–470.
14. DeBoer MD, Scharf RJ, Leite AM, *et al.* (2017) Systemic inflammation, growth factors, and linear growth in the setting of infection and malnutrition. *Nutr Burbank Los Angel Cty Calif* **33**, 248–253.
15. Grinspoon SK, Baum HB, Peterson S, *et al.* (1995) Effects of rhIGF-I administration on bone turnover during short-term fasting. *J Clin Invest* **96**, 900–906.
16. Kjaer TW, Grenov B, Yaméogo CW, *et al.* (2021) Correlates of serum IGF-1 in young children with moderate acute malnutrition: a cross-sectional study in Burkina Faso. *Am J Clin Nutr* **114**, 965–972.
17. Fabiansen C, Yaméogo CW, Iuel-Brockdorf A-S, *et al.* (2017) Effectiveness of food supplements in increasing fat-free tissue accretion in children with moderate acute malnutrition: a randomised 2 × 2 × 3 factorial trial in Burkina Faso. *PLoS Med* **14**, e1002387.
18. WHO (2012) *Technical Note: Supplementary Foods for the Management of Moderate Acute Malnutrition in Infants and Children 6–59 Months of Age*. Geneva, World Health Organization. https://www.who.int/publications/i/item/9789241504423 (accessed December 2024).
19. Erhardt JG, Estes JE, Pfeiffer CM, *et al.* (2004) Combined measurement of ferritin, soluble transferrin receptor, retinol binding protein, and C-reactive protein by an inexpensive, sensitive, and simple sandwich enzyme-linked immunosorbent assay technique. *J Nutr* **134**, 3127–3132.
20. Fischer CM, Zhang M, Sternberg MR, *et al.* (2022) The VitMin Lab Sandwich-ELISA assays for iron and inflammation markers compared well with clinical analyzer reference-type assays in subsamples of the Nepal National Micronutrient Status Survey. *J Nutr* **152**, 350–359.
21. Kouanda S, Tonglet R, De Coninck V, *et al.* (2008) Reference values of IGF-I in children from birth to 5 years of age, in Burkina Faso, using blood samples on filter paper. *Growth Horm IGF Res J Growth Horm Res Soc Int IGF Res Soc* **18**, 345–352.
22. Ejlerskov KT, Larnkjaer A, Pedersen D, *et al.* (2014) IGF-I at 9 and 36 months of age — relations with body composition and diet at 3 years — the SKOT cohort. *Growth Horm IGF Res J Growth Horm Res Soc Int IGF Res Soc* **24**, 239–244.
23. Socha P, Grote V, Gruszfeld D, *et al.* (2011) Milk protein intake, the metabolic-endocrine response, and growth in infancy: data from a randomized clinical trial. *Am J Clin Nutr* **94**, 1776S–1784S.
24. Hoppe C, Udam TR, Lauritzen L, *et al.* (2004) Animal protein intake, serum insulin-like growth factor I, and growth in healthy 2·5-year-old Danish children. *Am J Clin Nutr* **80**, 447–452.
25. Hoppe C, Mølgaard C, Juul A, *et al.* (2004) High intakes of skimmed milk, but not meat, increase serum IGF-I and IGFBP-3 in eight-year-old boys. *Eur J Clin Nutr* **58**, 1211–1216.
26. Iuel-Brockdorf A-S, Draebel TA, Ritz C, *et al.* (2016) Evaluation of the acceptability of improved supplementary foods for the treatment of moderate acute malnutrition in Burkina Faso using a mixed method approach. *Appetite* **99**, 34–45.
27. Cichon B, Fabiansen C, Iuel-Brockdorf A-S, *et al.* (2018) Impact of food supplements on hemoglobin, iron status, and inflammation in children with moderate acute malnutrition: a 2 × 2 × 3 factorial randomized trial in Burkina Faso. *Am J Clin Nutr* **107**, 278–286.
28. Sarwar Gilani G, Wu Xiao C & Cockell KA (2012) Impact of antinutritional factors in food proteins on the digestibility of protein and the bioavailability of amino acids and on protein quality. *Br J Nutr* **108**, S315–332.
29. FAO (2018) Protein Quality Assessment in Follow-Up Formula for Young Children and Ready to Use Therapeutic Foods. Rome. 50 pp. Licence: CC BY-NC-SA 3.0 IGO. https://openknowledge.fao.org/items/7a8264f0-bbc2–4924-b2ef-6db1001e82cc (accessed December 2024).
30. WHO (2007) Joint FAO/WHO/UNU Expert Consultation on Protein and Amino Acid Requirements in Human Nutrition (2002: Geneva, Switzerland), Food and Agriculture Organization of the United Nations, World Health Organization & United Nations University. (2007). Protein and Amino Acid Requirements in Human Nutrition: Report of a Joint FAO/WHO/UNU Expert Consultation. World Health Organization.

https://apps.who.int/iris/handle/10665/43411. WHO Technical Report Series 935. https://iris.who.int/bitstream/handle/10665/43411/WHO_TRS_935_eng.pdf (accessed December 2024).
31. Pesu H, Mutumba R, Mbabazi J, *et al.* (2021) The role of milk protein and whey permeate in lipid-based nutrient supplements on the growth and development of stunted children in Uganda: a randomized trial protocol (MAGNUS). Curr Dev Nutr 5, nzab067.
32. Tang M, Hendricks AE & Krebs NF (2018) A meat- or dairy-based complementary diet leads to distinct growth patterns in formula-fed infants: a randomized controlled trial. *Am J Clin Nutr* **107**, 734–742.
33. Grenov B, Larnkjær A, Lee R, *et al.* (2020) Circulating insulin-like growth factor-1 is positively associated with growth and cognition in 6–9 year-old schoolchildren from Ghana. *J Nutr* **150**, 1405–1412.
34. Hoppe C, Mølgaard C, Dalum C, *et al.* (2009) Differential effects of casein *v.* whey on fasting plasma levels of insulin, IGF-1 and IGF-1/IGFBP-3: results from a randomized 7-day supplementation study in prepubertal boys. *Eur J Clin Nutr* **63**, 1076–1083.
35. Thorisdottir B, Gunnarsdottir I, Palsson GI, *et al.* (2014) Animal protein intake at 12 months is associated with growth factors at the age of six. *Acta Paediatr Oslo Nor 1992* **103**, 512–517.
36. Grenov B, Larnkjær A, Ritz C, *et al.* (2021) The effect of milk and rapeseed protein on growth factors in 7–8 year-old healthy children - a randomized controlled trial. *Growth Horm IGF Res J Growth Horm Res Soc Int IGF Res Soc* **60–61**, 101418.