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Cost-effectiveness of decentralising acute malnutrition treatment with a standard or simplified treatment protocol: an economic evaluation in the region of Gao, Mali

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Abstract

Background Acute malnutrition treatment coverage remains low worldwide, causing significant morbidity and mortality. Decentralisation of treatment to Community Health Worker (CHW) sites has shown to be an effective strategy to improve access and increase coverage, but evidence on the cost and cost-effectiveness of this approach as well the use of simplified treatment protocols in conflict settings is lacking. The objective of this study was to determine cost per child treated as well as the cost-effectiveness of the hybrid model of treatment delivery (where treatment is provided at both health facilities and CHW sites) using either a standard protocol (Intervention 1) or simplified protocol (Intervention 2) compared to standard treatment at health facilities only (Control) in the conflict affected region of Gao in Northern Mali.

Methods This economic evaluation was part of a three-arm cluster randomized controlled trial which enrolled 2038 children with moderate and severe acute malnutrition. Outcomes assessed were cost per child treated as well as average and incremental cost-effectiveness ratios for cost per child cured and disability adjusted life year (DALY) averted. A within study trial horizon, from March 2020 to July 2021, was used. Cost data were collected from accountancy records and through key informant interviews using a societal perspective. Treatment admission and outcome data were obtained from the main trial.

Results In the base case scenario the cost per child treated was 272 US$, 179 US$ and 210US$ in the Control, Intervention 1 and 2 groups, respectively. Cost per child cured was 356 US$ in the Control, 219 US$ in the Intervention 1 and 226 US$ Intervention 2 groups. Ready-to-use therapeutic foods (RUTF) costs among SAM children treated with a simplified protocol were 5.7 US$ less per child. The average cost per DALY averted was 173.1 US$ in the Control compared to 60.3 US$ in the Intervention 1 and 53 US$ in the Intervention 2.

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Conclusion This study shows that involving CHWs in acute malnutrition treatment reduces the cost per child treated and is a cost-effective strategy, due to lower treatment costs and greater coverage in the decentralised model. Switching to a simplified protocol in a conflict setting can lead to cost savings particularly in terms of RUTF, and should be considered where weight-based admission, monitoring or dosage is not possible or RUTF stocks are running low.

Trial registration The study protocol was registered under reference ISRCTN-60,973,756 on the 15th of October 2020.

Keywords Acute malnutrition, Wasting, Simplified protocol, RUTF, RUSF, Community health workers, Cost-effectiveness, Economic evaluation

Background

Acute malnutrition, or wasting and nutritional oedema, continues to cause significant morbidity and mortality worldwide [1, 2]. While effective treatment exists, global coverage remains low, and current financial constraints and supply shortages further threaten access to treatment [3], while climate change, conflict, rising food and fuel prices may increase demand for treatment.

Treatment for severe acute malnutrition (SAM), defined as a weight-for-height z-score (WHZ) <-3 of the WHO growth standards and/or a mid-upper arm circumference (MUAC) < 115 mm and/or nutritional oedema, relies on ready-to-use therapeutic food (RUTF) along with a course of oral antibiotics. Children with moderate acute malnutrition (MAM), defined as a WHZ between − 3 and − 2 and/or a MUAC between 115 mm and 125 mm, should, in high risk contexts, also be considered for specially formulated foods with a preference for RUTFs or ready-to-use supplementary foods (RUSFs) over Fortified blended foods [4].

Over the last decade, adaptations to acute malnutrition treatment service delivery models and protocols have been developed and tested with the objective to increase access and treatment coverage for the over 45 million children suffering from this condition at any point in time [1]. Adaptations include the simplification of treatment protocols as well as the decentralisation of treatment from outpatient treatment centres to community health worker (CHWs) sites thereby reducing travel distances, time and costs for caregivers [5].

Following positive results of the involvement of CHWs in the treatment of acute malnutrition on treatment outcomes, coverage and cost-effectiveness [6–13], the new 2023 edition of the World Health Organisation guideline for the prevention and treatment of wasting and nutritional oedema (acute malnutrition) stated that the identification and management of wasting can be carried out by CHWs providing that adequate training and supervision is provided [4].

In Mali, where an estimated 435,000 children under the age of five, representing 10.6% of the population in this age group, are affected by acute malnutrition at any one time, the treatment of SAM is already recognised as an important part of the services provided by CHWs [1, 14]. Studies in southern Mali have demonstrated the effectiveness and cost-effectiveness of this approach both at small [6, 10] and large scale [7, 15]. However, to our knowledge, there is no evidence on the cost and cost-effectiveness of CHW-led treatment of acute malnutrition in the conflict affected North of the country.

Yet, bringing treatment closer to the patients is even more important in conflict settings where there is a greater risk associated with travel to health facilities. In addition to difficulties for patients travelling to treatment sites, security and access issues may also lead to more frequent stock outs of RUTFs as well as shortages of other equipment and materials needed for treatment. The current WHO guidelines recommend a weight-based dosage of 100-130 kcal/kg/day for children with MAM and 150–185 kcal/kg/day of RUTF for children SAM either until recovery or until the child reaches criteria for MAM [4]. The administration of such a weight-based dosage may present difficulties where equipment, such as weighing scales or batteries, are missing or where health workers may not have the literacy skills required to conduct dosage calculations. Security issues may also hinder supportive supervision of CHWs and other health staff.

The simplified treatment protocol, as first tested in the ComPAS study [16], addresses some of these challenges. It uses MUAC only for admission and discharge as well as a fixed dosage of 2 sachets of RUTF for children with SAM and 1 sachet for children with moderate acute malnutrition (MAM) [16, 17], thereby making dosage calculations unnecessary. Studies have found that using a fixed dosage protocol of 2 sachets per day or reducing the quantity of RUTFs towards the end of treatment results in non-inferior recovery rates. However, reducing the dosage may lead to a lower linear growth [18] and a lower rate of weight gain [19, 20]. But it is unclear whether a lower rate of weight gain should be considered a worse outcome [20, 21]. While the fixed dosage is currently not recommended by the WHO, the discussion on the ideal dosage of RUTF continues [22, 23] and the WHO guideline supports further research on both the CHW-lead

treatment as well as different dosage protocols, in terms of effectiveness, cost and cost-effectiveness [4]. Using alternative dosage protocols has also shown to reduce the number of RUTF sachets needed for treatment. This in turn has an impact on cost: the estimated RUTF cost per SAM child falls between $24 and $67 depending on length of stay and dosage used [16–19, 24–26]. Where RUTF stockouts and funding gaps are encountered adapting dosage protocols may therefore, at least temporarily, be a useful strategy to consider.

In light of the low coverage of acute malnutrition services, resource and financial constraints, frequent and expected RUTF stockouts, and the lack of evidence on the feasibility and benefits of these approaches in conflict settings, Action Against Hunger coordinated a study in the conflict affected region of Gao, Mali comparing facility-based care with the national protocol (Control arm), to a hybrid model where treatment is provided at health centres and associated CHW sites according to either the standard protocol (Intervention 1) or simplified treatment protocol (Intervention 2) [27]. The study showed that making treatment available at CHW sites in addition to health centres had a positive impact on treatment coverage and cure rates [27].

This article details the economic evaluation conducted alongside the aforementioned study. The objective was to assess the cost and cost-effectiveness of the three different models of treatment in the conflict affected region of Gao. Evidence on the cost of care and cost-effectiveness of different treatment approaches in addition to treatment outcomes is critical for informing resource allocation decisions and is relevant and timely in the context of Mali, where funding shortfalls and RUTF stockouts are anticipated in 2024 and 2025 [3].

Methods

Study context

This economic evaluation of acute malnutrition treatment was carried out within the framework of an operational research project entitled "Severe acute malnutrition treatment delivered by community health workers in emergency settings of Mali (iCCM + Project)", from here-on referred to as the parent study, coordinated by Action Against Hunger from March 2020 to June 2021 in the Gao health district, in the north of Mali. This part of Mali has been affected by a complex humanitarian crisis over the past decade involving armed conflict and extreme climatic conditions [28].

Gao has the highest prevalence of acute malnutrition in the country, with a rate of 16.1% (95% CI: 13.0;19.7) for Global Acute Malnutrition (GAM) and 3.3% for SAM (95% CI: 2.2;4.9) [29]. The research project was conducted with support from the Nutrition Department of the Ministry of Public Health and Hygiene, the local non-governmental organisation Association d'Aide à Gao (AAG) and the Institut National de Santé Publique (INSP). Treatment supplies including RUTF, RUSF and medicines were donated by UNICEF and WFP. The study was approved by the Ethics Committee of the INSP of the Government of Mali (decision nº 35/2029/CE-EX-INRSP) as well as the Ethics Committee of the Hospital Clínico San Carlos which is linked to the Complutense University of Madrid, Spain (favorable report C.I. 19/363-R-X-BC). The study protocol was registered under reference ISRCTN-60,973,756 on the 15th of October 2020.

Parent study methods and interventions

The parent study was a three-arm cluster randomised trial, with a control and two intervention arms. In the control arm, the treatment for acute malnutrition was provided according to the standard community-based management of acute malnutrition (CMAM) protocol at six health centres. In the two intervention arms, treatment was provided at three health centres and 10 CHW sites. The latter were located at least 30 km away from the referral health centres. In the Intervention 1 arm, treatment was provided according to the country's standard acute malnutrition treatment protocol and in the Intervention 2 arm, treatment was provided according to a simplified acute malnutrition treatment protocol. The simplified protocol differs from the standard protocol in terms of the admission criteria as well as dosage and type of RUF as described in Table 1. Children aged 6–59 months with moderate or uncomplicated severe acute malnutrition were eligible to participate in the study. Patients with medical complications or those who failed the appetite test were not eligible for inclusion and were referred to inpatient care. The primary outcome of the parent study was the recovery rate from acute malnutrition in the three study arms, determined as per the discharge criteria set out in Table 1. Secondary outcomes inlcuded defaulting, non-response, referral to inpatient facility and death. The unit of randomisation, were the health centres and randomisation was done on a 2:1:1 basis, meaning that for each 2 health centres assigned to the control was assigned to each intervention group. A full set of data was available for 2038 children with acute malnutrition (including both MAM and SAM), 549 in the control arm, 800 in Intervention group 1 and 689 in Intervention group 2. Baseline characteristics in terms of age and anthropometry of the study participants are shown in Table 2. Participants in the control area had better quality housing and access to electricity and food compared to the two intervention arms, but there was no difference in access to safe water [27]. At endline, SAM treatment coverage was higher in the interventions compared to the Control, but there was no significant

Table 1 Description of the intervention in the three study arms[1]

	Control Group (CMAM)	Intervention Group 1 (iCCM with standard protocol)	Intervention Group 2 (iCCM with simplified protocol)
Treatment providers	Nurses at health centres	Nurses at health centers + CHWs at villages	Nurses at health centers + CHWs at villages
Treatment Protocol	Standard CMAM protocol	Standard CMAM protocol	Simplified treatment protocol
Follow-up frequency	Weekly	Weekly	Weekly
Admission criteria	*SAM*: Oedema (+) or WHZ < -3 or MUAC < 115 mm *MAM*: WHZ ≥-3 to < -2 or MUAC ≥ 115 to < 125 mm	*SAM*: Oedema (+) or WHZ < -3 or MUAC < 115 mm *MAM*: WHZ ≥-3 to < -2 z-score or MUAC ≥ 115 to < 125 mm	*SAM*: Oedema (+) or MUAC < 115 mm *MAM*: MUAC ≥ 115 to < 125 mm
Discharge criteria	No oedema and WHZ ≥ 1.5 or MUAC ≥ 125 mm for two consecutive follow-up visits	No oedema and WHZ ≥ 1.5 or MUAC ≥ 125 mm for two consecutive follow-ups visits	No oedema and MUAC ≥ 125 mm for two consecutive follow-up visits
Product and dosage	*SAM*: 170 kcal/kg/day of RUTF *MAM*: 1 sachet/day of RUSF (≈ 537 Kcal/day)	*SAM*: 170 kcal/kg/day of RUTF *MAM*: 1 sachet/day of RUSF (≈ 537 Kcal/day)	*SAM*: 2 sachets/day of RUTF (1000 kcal/day) *MAM*: 1 sachet/day of RUTF (= 500 Kcal/day)

[1] Abbreviations: CMAM, Community based management of acute malnutrition; iCCM, integrated community case management; CHW, Community Health Worker; SAM, Severe acute malnutrition; WHZ, Weight-for-height z-score; MUAC, mid-upper-arm circumference; MAM, moderate acute malnutrition

difference between the two intervention areas (Table 2) [27]. Overall, recovery was significantly higher in the two intervention groups than in the control (Table 2). Coverage surveys were conducted according to the Simplified Lot Quality Assurance Sampling Evaluation of Access and Coverage (SLEAC) methodology before the start of the study in March 2020 and towards the end of the study in May 2021 [30]. Further details on the methods of the parent study, socio-economic characteristics of participants and results have previously been published [27].

Design of the economic evaluation

This economic evaluation was conducted from a societal perspective, and therefore included the costs of the patients and their families as well as all project partners to treat both MAM and SAM. As indicated above, project partners included the CHWs, Community health centres, referral health centre at district level, Regional Health Directorate, Department of Nutrition of the Ministry of Public Health and Hygiene, Action Against Hunger, AAG, UNICEF, WFP and the communities. Outcomes of the economic evaluation were cost per child treated, cost per child cured and cost per death and Daly averted. Both average and incremental cost-effectiveness ratios are presented. We used a within-trial time horizon, spanning over a 17 months period from March 2020 to July 2021. This timeframe began with the training of the health centre technical directors (DTCs) and community health workers in March, through to the enrolment of patients from June 2020 – June 2021, until the discharge of the last patients in July 2021.

Programme data collection

Data on the number of admissions, quantities of RUTF or RUSF sachets consumed, length of stay, and treatment outcome was collected from the parent study database and disaggregated by MAM and SAM [27]. Study supervisors collected treatment outcome data directly from patient record books at treatment sites using the Kobo Toolbox application, while socio economic data was collected through direct interviews with a sample of 676 randomly selected caregivers at the treatment sites. Due to security challenges, the teams were not able to visit the sites with the intended frequency which was once a month. During the first 5 months, 5 supervision visits were made to each of the sites. In the following 7 months, it was only possible to do 3 visits, meaning that a total of 8 of the planned 12 visits were made to each site. In the outcome database, 116, 102 and 34 children in the Control, Intervention 1 and Intervention 2 groups were discharged as cured despite anthropometric measurements still being in the malnourished range (Table 2). These children were classified as "early discharges". Due to limited access to the sites and communities for data collection these errors could not be verified or corrected.

Cost data collection

Cost data was collected using an activities and ingredients approach and inlcuded both financial and economic costs. An overview of activities and ingredients are shown in Table 3. Costs were compiled from Action Against Hunger's accountancy records obtained in February 2022, and interviews with key informants and carers of children admitted for treatment. Information on quantity of RUTF and RUSF provided to each child was

Table 2 Programme data in the three study groups

	Control Group (CMAM, *n* = 549)	Intervention Group 1 (iCCM with standard protocol, *n* = 800)	Intervention Group 2 (iCCM with simplified protocol, *n* = 689)
Population size of the catchment area	89,855	44,942	53,427
Treatment coverage in May 2021, % (95% CI)	MAM: 16.1% (11.7- 20.5%) SAM: 18.9% (11.6 – 26.2%)	MAM: 23.4% (19 – 27.9%) SAM: 38.5% (31.1- 45.8%)	MAM: 25.9% (17.9 – 33.8%) SAM: 48.8% (33.5 – 64.1%)
Treatment sites	6 Health Centres	3 Health centres and 10 CHW sites	3 Health centres and 10 CHW sites
Baseline characteristics of study participants			
Sex, % girls (n)	56.6 (311)	52.4 (419)	50.8 (350)
Age months, Median (IQR)	14.0 (10.0; 20.0)	12.0 (9.0; 20.0)	12.0 (9.0–18.0)
Nutritional status at admission			
MUAC in mm, median [IQR]	116.0 [111.0;120.0]	115.0 [111.0 ;120.0]	114.0 [110.0 ;120.0]
Weight at admission			
WHZ, mean (SD)	-2.9 (1.8)	-2.8 (1.1)	-3.5 (1.3)
SAM[1], % (n)	67.6 (371)	58.9 (471)	52.8 (364)
Treatment site			
CHW site, % (n)	0 (0)	72.4 (579)	81.3 (560)
Health centre, % (n)	100 (549)	27.6 (221)	18.7 (129)
Treatment outcome			
Cured, % (n)[2]	76.3 (419)	81.8 (654)	92.9 (640)
Defaulted, % (n)	3.6 (20)	2.9 (23)	0.4 (3)
Early discharges, % (n)[3]	18.6 (102)	14.5 (116)	4.9 (34)
Died, % (n)	0 (0)	0.1 (1)	0 (0)
Length of stay, median number of days [IQR]	42.0 [35.0–50.0]	42.0 [32.3–69.0]	43.0 [30.0–69.0]
RUTF sachets, median [IQR]	120.0 [100.0–140.0]	95.0 [75.0–120.0]	SAM children: 76.5 [70.0–91.0] MAM children: 35.0 [28.0–42.0]
RUSF sachets, median [IQR]	47.5 [32.0–56.0]	35.0 [28.0–42.0]	N/A

[1] As per criteria in the respective study locations, i.e. case definition based on both MUAC and Weight-for-height in the Control and Intervention 1 groups and MUAC only in Intervention 2. [2]Recovery rates were significantly different between groups. The risk differences for the comparison of the intervention 1 compared to control, Intervention 2 compared to control, and intervention 2 compared to intervention 1 were 0.10 [0.04–0.15], 0.21 [0.16–0.26] and 0.12 [0.09–0.15], respectively. Risk differences in recovery rates between pairs of protocols were estimated using random effects logistic models, adjusting for clusters as random effects. The models were also adjsuted for sex, age and anthropometry at admission [24]. [3]Early discharges refer to children that were discharged as cured by health workers but whose anthropometric measurements did not meet the criteria for being cured

extracted from the study database. Only country-level costs were included. Research costs were excluded where possible, however we acknowledge that completely disentangling research costs from programming costs in an operational research project is challenging. A total of 41 key informant individual or group interviews were conducted in July 2021. Key informants included all 20 CHWs, two community health volunteers (CHVs), 2–3 staff from all 12 health centres involved in the study, as well as 5 Action Against Hunger staff, 1 person from AAG, UNICEF, WFP and the MoH.

UNICEF and WFP were contacted to determine the price of RUFs as well as transport costs of these supplies to district level. Interviews at health centre or CHW site level, enabled data gathering on the number of staff involved in the treatment of malnutrition, time spent on malnutrition activities, health worker salaries, supervision structures and any additional or shadow costs that are not captured in accountancy data, such as economic costs of space used for treatment and storage of supplies, or transport costs for RUF from the district level to the health centres and from health centres to CHW sites. In order to remove research related costs, the interviewers examined whether costs and time mentioned was linked to the research component of this study or would occur as part of a normal programme. As part of a socio-economic survey, carers of enrolled children were interviewed to determine their costs to access treatment. Due to security related access constraints, study staff were not able to visit the sites as frequently as planned and therefore out of the 2110 children enrolled, only 676 caregivers or 32% responded to the survey. To determine family costs, expenses related to treatment (accommodation, food and transport costs) were added to time lost in wages. Time lost in wages was calculated by multiplying the median hourly wage reported by the child's primary

Table 3 Activity and ingredient costs included in the economic analysis

Activity	Ingredients	Source
1. Training costs	• Perdiems for participants and trainers • Transport costs for participants and trainers • Training materials • Room rental	• Action Against Hunger accountancy
2. Coordination, supervision and support	• Staff salaries • Perdiems • Transport costs • Office costs (rental, upkeep, materials, capital costs) • District-level supervision	• Action against Hunger accountancy • Key informant interviews with MoH, Health Centres and CHWs, AAG staff
3. Case finding	• Mass screening campaign	• Action Against Hunger accountancy
4. Direct treatment costs		
4.1 Health Centre	• Health centre staff time • Health centre rental and upkeep (electricity costs and cleaning materials) • Nutrition treatment materials and equipment (heightboards, MUAC tapes, weighing scales, registers, table, chairs) • RUTF/RUSF, medicines (malaria rapid tests, amoxicillin, albendazole, vitamin A) and associated transport costs	• Key informant interviews with 2–3 staff at each of 12 participating health centres (staff time, space, equipment and upkeep, RUTF transport from district to HC and CHW sites) • Key informant interviews with staff from the local NGOs and with UNICEF/WFP for RUTF/RUSF and medicines cost and transport to district level.
4.2 CHW	• CHW time • CHW rental and upkeep (electricity costs and cleaning materials) • Nutrition treatment materials and equipment (heightboards, MUAC tapes, weighing scales, registers, table, chairs) • RUTF/RUSF, medicines (malaria rapid tests, amoxicillin, albendazole, vitamin A) and associated transport costs	• Key informant interviews with all 10 participating CHWs for time, space and upkeep costs. • Key informant interviews with Health Centres and CHWs for transport costs of supplies from health centre to CHW site. • key informant interviews with AAG, Action against Hunger, UNICEF, WFP for equipment.
5. Family costs	• Transport costs • Food/accommodation costs • Time in lost wages	• Individual interviews with 676 caregivers

caregiver by the time spent at the health centre and commuting.

Cost data management

Costs from all data sources were inputted into an Excel spreadsheet and organised by costs centres (see Table 3). All costs are expressed in 2021 US Dollars. Costs expressed in other currencies were converted to US Dollars using average yearly exchange rates, more specifically this was 565 CFA Francs to the US Dollar and 1.19 Euro to the US Dollar [31]. Costs were adjusted for inflation and capital cost depreciation. The Consumer Price Index was used to adjust for inflation [32]. Capital costs were defined as any item that can be used for more than one year and costs more than 100 USD and were adjusted to only reflect the cost of the time the item was used. A useful life of 5 years was assumed for computers, printers and other IT supplies [33]. Discounting was not applied due to the short timeframe of the study (17 months). Salary costs for iNGO staff were calculated based on accountancy data and adjusted with data on time use collected during key informant interviews. Salary costs for AAG staff were based on both iNGO accountancy records, which included supervisor salaries, and from interviews with the partner staff to include administrative costs. Health centre and CHW space costs, maintenance and salary costs as obtained during key informants interviews with health centres, CHWs and the MoH at district level, were adjusted to reflect the percentage of time spent on malnutrition treatment. Total RUF costs were calculated by multiplying the median number of sachets (Table 2) by cost per sachet (0.3 US$ for RUTF and 0.36 for RUSF). Support, coordination, supervision and mass screening costs were allocated evenly between the three study arms, as they represented institutional costs for the running of the project. Training costs were separated by the two types of trainings provided, i.e. trainings for the technical directors of the health centres and CHWs. Training costs for technical directors of the health centres were split 50% for the control arm and 25% for each intervention arm according to the number of health centres in each arm. CHW training costs were split 50% between the two intervention arms, given the same number of CHW were trained in each intervention arm and that CHW were not present in the control area.

Analysis

The cost per child treated and cured was calculated by dividing the total costs in each study arm by the number of children fully treated and cured, respectively. The incremental cost-effectiveness ratios (ICER) for the incremental cost for additional child recovered as well as incremental cost per additional DALY averted were calculated as follows: $ICER = \frac{Cost_{Intervenion} - Cost_{Control}}{Effects_{Intervention} - Effects_{Control}}$

Here the cost refers to the total cost of the intervention and the effects refer to either the difference in the number of recovered children or the difference in Daly's averted. ICERs were calculated only for the modelled scenario (**see below**), as this was believed to be more meaningful. Uncertainty was incorporated into ICERs as described below.

The number of Disability Adjusted Life Years (DALYs) averted was calculated as the sum of Years Lived with Disability (YLD) averted and Years of Life Lost (YLL) averted. In order to calculate YLD averted for each study arm, the difference in duration of a treated and untreated SAM or MAM episode was multiplied by the disability weight and the number of children cured. We assumed that the duration of an untreated SAM episode was six months, with 3.5 and 7.5 as the minimum and maximum values [34] and that the duration of an untreated MAM episode was 101 days (95%CI: 71; 196) [35]. The duration of treated episodes for both MAM and SAM was obtained from the program data (Table 2). The disability weight for severe wasting was taken from the 2019 Global Burden of Disease Study, which is 0.128 (0.082–0.183) [36]. The disability weight for severe wasting was used rather than that of severe wasting and kwashiorkor, because the number of kwashiorkor cases was very low ($n = 2$). The 2019 Global Burden of Disease Study does not mention a disability weight for moderate wasting. For moderate wasting, the low uncertainty limit of the disability weight for severe wasting was used as previously suggested [37].

YLL averted was calculated by the number of lives saved by the intervention multiplied by the average life expectancy in Mali. The number of lives saved by the intervention, in turn, was estimated by multiplying the expected mortality in that population by the number of cases cured, where the expected mortality was the difference in case fatality rate in an untreated cohort of SAM and MAM and the expected under-five mortality rate [34, 38]. Discounting and age weighting was not used in the DALY calculations [34, 39]. DALYs averted and the uncertainty margins were calculated in Excel. The method used for calculating the uncertainty around the point estimate is described in the following section.

To visualise the incremental costs and effectiveness of the study arms and uncertainty intervals, cost-effectiveness planes are presented in Supplementary Fig. 1. These were generated using the ggplot2 package in R [40]. Costs per DALY averted were compared to two cost-effectiveness thresholds: First, the midpoint of the purchasing power parity adjusted country specific cost-effectiveness

threshold range for Mali of 38 US$ to 844 US$ [41], which is 441 US$, and second, a fixed cost-effectiveness threshold of 100 US$ per DALY averted, which is commonly used to designate interventions as highly cost-effective [34].

Accounting for uncertainty

To account for uncertainty around the cost estimate and to calculate confidence intervals around cost and cost-effectiveness estimates, an approach based on triangular fuzzy numbers and fuzzy arithmetic was used [34]. This is similar to using a sampling-based approach to uncertainty but relies on triangular distributions rather than probability distributions, such as binomial or gamma distributions frequently used in Markov models. It requires specifying a minimum, maximum and most likely value. In the case of cost data, the most likely value is the base case cost estimate, and the minimum and maximum values are the base case +/- an uncertainty margin defined by the researchers based on a best guess. The uncertainty margins for different cost categories are shown in Supplementary Table 1. For the cure rates, the cured proportion +/- 2 standard errors was used. For other variables such as the disability weights or LOS either the mean and 95%CI, or 2.5th, 50th and 97.5th percentiles were used [34]. Upper and lower values for each cost category were generated in excel and a fuzzy arithmetic calculator was used for operations between fuzzy triangular number [42].

Modelled scenario sensitivity analysis

In the base case analysis, due to the nature of the RCT and the need to reach the required sample size, the catchment area in the control and the number of health centres were double compared to the intervention arms. Furthermore, the number of children treated do not necessarily reflect coverage. In order to meaningfully determine the incremental costs of decentralising the treatment by adding affiliated CHW sites to health centres and capturing the impact of decentralisation on coverage, we modelled a scenario with an equal number of health centres and adjusted the number of children treated to reflect differences in coverage according to the coverage surveys. In this scenario we used the number of children enrolled in the intervention 1 and adjusted the number of children proportionally to this number according to the coverage in the control. Given that the coverage surveys did not indicate a significant difference in coverage between the two interventions arms, we used the same number of children treated in both intervention arms. This is different from the base case where the number of children in intervention 2 is lower than intervention 1. Recovery rates from the parent study were applied to the modelled number of enrolled children to determine the number of children cured. Number of RUTF sachets, transport costs, and treatment time by health centre staff in the control and intervention 2 were adjusted to reflect the different numbers of children. In addition, in control arm, training and space costs were reduced due to the lower number of health centres. No changes were made in the intervention 1. This study was conducted according to the declaration of Helsinki and reported in accordance with the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) guideline (see Supplementary Table 2) [43].

Results

Total programme costs

In the base case scenario, the estimated total cost of the intervention across the three study arms, encompassing both treatment of moderate and severe acute malnutrition, was 437,267.2 US$ (95%CI: 288,138.2 US$; 484,420 US$). The costs in the three study areas were similar, ranging from 142,944 US$ in the Intervention 1 to 149,285 US$ in the Control area (Table 4). The costs per cost centre are shown in Table 4 and the proportion of costs attributed to each cost centre in the three study arms are shown in Fig. 1. A more detailed breakdown of costs is shown in Supplementary Table 1.

Across all study arms, coordination costs (encompassing support, supervision and office costs) constitute the predominant proportion of costs, ranging from 42 to 44% (Fig. 1). Health centre and CHW site costs (including staff costs, rental, upkeep and materials) account for the second largest share of expenditures ranging from 28%, to 33% and 36% in the Intervention 1, Intervention 2 and Control arms, respectively. RUF and associated transport costs range from 11 to 15% (Fig. 1). Overall, direct treatment costs, including health centre and CHW site costs, RUF costs and medicine costs accounted for approximately 43% in the two intervention arms and 50% in the control arm. Family costs accounted for less than 1% of costs in all three study arms. This was due to a low overall time investment for participation in treatment programme, which ranged from seven hours in the Intervention 1 and eight hours in the control to 14 h in the Intervention 2 group, as well as a low estimated hourly wage of 58 Franc CFA. The total time used for treatment was low because of the proximity to the sites, whereby 82%, 88% and 90% lived within 45 min of the treatment location in the Intervention 2, Control and Intervention 1 areas, respectively. The median number of visits was 7 visits across all groups.

Cost per child treated, cost per child cured and DALY averted

While the overall costs in the three study areas was similar, the cost per child treated, in the observed base case

Table 4 Intervention costs (US$) by cost centre in the observed base case scenario in the three study arms in Gao, Mali

Activity	Ingredients	Control Group (CMAM) (*n* = 549)		Intervention Group 1 (iCCM with standard protocol) (*n* = 800)		Intervention Group 2 (iCCM with simplified protocol) (*n* = 689)	
		Total cost, US$ (95% CI)	Cost per child, US$ (95% CI)	Total cost, US$ (95% CI)	Cost per child, US$ (95% CI)	Total cost, US$ (95% CI)	Cost per child, US$ (95% CI)
1. Training	Staff, room rental, per diems, transport and training materials	2784.6 (2784.6; 2784.6)	5.1 (5.1; 5.1)	8496.2 (8496.2; 8496.2)	10.6 (10.6; 10.6)	8496.2 (8496.2; 8496.2)	12.3 (12.3; 12.3)
2. Coordination, support, supervision	Staff, office costs, per diems, transport, meetings	61535.5 (54589.5; 68481.5)	112.1 (99.4; 124.7)	61535.5 (54589.5;68481.5)	76.9 (68.2; 85.6)	61535.5 (54589.5;68481.5)	87.8 (77.7; 97.9)
3. Case finding	Mass screening and community health volunteer time	1019.6 (1019.6; 1019.6)	1.9 (1.9; 1.9)	1019.6 (1019.6; 1019.6)	1.3 (1.3; 1.3)	1019.6 (1019.6; 1019.6)	1.5 (1.5; 1.5)
4. Monitoring and Evaluation	Coverage surveys	8767.2 (8767.2; 8767.2)	16 (16; 16)	8767.2 (8767.2; 8767.2)	11 (11; 11)	8767.2 (8767.2; 8767.2)	12.7 (12.7; 12.7)
5. Direct treatment costs	Community health worker (CHW) time	Not applicable	Not applicable	3876.4 (3274.5; 4478.3)	4.8 (4.1; 5.6)	2768.8 (2338.9; 3198.8)	4 (3.4; 4.6)
	CHW site costs (rental, upkeep, materials and transport)	Not applicable	Not applicable	13622.9 (11507.6;15738.3)	17 (14.4;19.7)	13298.4 (11240.1; 15372.4)	19.3 (16.3; 22.3)
	Health centre staff time	27709.6 (23406.9; 32012.3)	50.5 (42.6; 58.3)	9434.7 (7969.7; 10899.7)	11.8 (10; 13.6)	8829 (7458.1; 10200)	12.8 (10.8; 14.8)
	Health centre site costs (rental, upkeep and materials)	26144.5 (22084.8; 30204.2)	47.6 (40.2; 55)	11737.6 (9915; 13560.2)	14.7 (12.4; 17)	22007.1 (18589.9; 25424.3)	31.9 (27; 36.9)
	RUTF/RUSF costs	15490.9 (14288.2; 16693.6)	28.2 (26; 30.4)	17568.9 (16204.9;18932.9)	22 (20.3; 23.7)	12394.2 (11660.6; 13127.4)	17.0 (15.9; 19.1)
	Medicines	790.9 (729.5; 852.3)	1.4 (1.3;1.6)	1516.6 (1398.9; 1634.4)	1.9 (1.7;2)	695.8 (641.8; 749.8)	1 (0.9; 1.1)
	RUTF/RUSF transport and storage	3925.6 (3316.1; 4535.2)	7.2 (6; 8.3)	4128 (3487; 4768.9)	5.2 (4.4; 6)	3549.1 (2998; 4100.2)	5.2 (4.4; 6)
	Sensitization	664.3 (664.3; 664.3)	1.2 (1.2; 1.2)	664.3 (664.3; 664.3)	0.8 (0.8;0.8)	664.3 (664.3; 664.3)	1 (1;1)
6. Family costs		452.4 (382.2; 522.7)	0.8 (0.7; 1)	576.9 (487.3; 666.5)	0.7 (0.6; 0.8)	1012.4 (855.2; 1169.6)	1.5 (1.2; 1.7)
Total costs		149,285.1 (132,032.8; 166,537.4)	271.9 (240.5; 303.3)	142.944.6 (195.772.8; 244,918.5)	178.7 (159.7; 197.6)	145,037.6 (129,083.9; 160,991.4)	210.1 (187.3; 233.7)

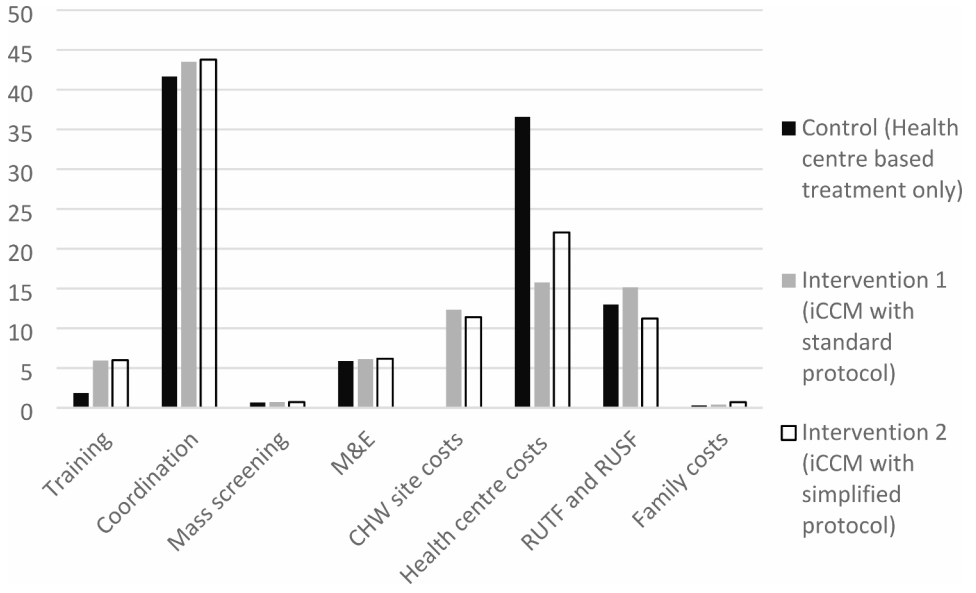

Fig. 1 Cost centres as a percentage of total costs in the three study arms, Gao, Mali

Table 5 Cost and cost-effectiveness outcomes in the three study arms (observed base case scenario)

	Control Group (Standard CMAM, *n* = 549)	Intervention Group 1 (iCCM with standard protocol, *n* = 800)	Intervention Group 2 (iCCM with simplified protocol, *n* = 689)
Total intervention cost, US $ (95%CI)	149,285.1 (132,032.8; 166,537.4)	142,944.6 (127,781.4; 158107.8)	145,037.6 (129,083.9; 160,991.4)
Cost per child treated, US $ (95%CI)	271.9 (240.5, 303.3)	178.7 (159.7; 197.6)	210.5 (187.3; 233.7)
Direct treatment cost per child only, US $ (95%CI)	138 (119.3; 156.6)	79.5 (69.3; 89.6)	94.6 (82.2; 107.4)
Cost per child cured, US $ (95%CI)	356.3 (315.1; 397.5)	218.6 (195.4; 241.8)	226.01 (201.7; 251.5)
Cost per Daly averted, US $ (95% CI)	173.1 (104.56; 528.66)	60.32 (41.82; 127.13)	52.8 (37.8; 95.3)
Cost per Death averted, US $ (95% CI)	10,835.8 (6,492.8; 30,537.4)	3,759.3 (2606; 7285.6)	3,273.7 (2355.8; 5570.3)

scenario, was significantly higher in the control arm at 272 US$ (95% CI: 240.5 US$; 303.3 US$) compared to 179 US$ Intervention 1 (95%CI: 244.7 US$; 306.1 US$) and 210US$ (95%CI: 187.3 US$; 233.7 US$) in the Intervention 2 areas (Table 5). Although we did not estimate any differences in training, coordination, support and supervision costs between MAM and SAM treatment, the direct treatment costs (including staff time, site and RUF costs) for SAM were generally higher than MAM (Table 6).

Comparison of control with intervention 1

In the comparison of Control with Intervention 1 (same treatment protocols but different treatment locations), the average cost of treatment was 93 US$ (95% CI: 43US$, 144US$) higher in the Control than the Intervention 1 group, or 129US$ (95%CI: 78; 181) higher among MAM children and 88US$ (95%CI: 35; 140) for treatment of SAM. This difference increased to 138US$ (73; 202) in cost per child cured (Table 5and Table 6). Costs per child treated and cured were similar in the modelled and base case scenario (Table 7). The ICER for recovering an additional child from acute malnutrition was 81 US$, ranging from a negative ICER (indicating dominance of the intervention) to 100 US$ in the modelled scenario. The intervention was also determined to be cost-effective when DALY averted were compared to our chosen cost-effectiveness thresholds of 441 US$ and 100 US$ (Tables 7 and 8and Supplemental Fig. 1).

Comparison of control with intervention 2

In the comparison of Control with Intervention 2 (different treatment protocols and different treatment locations), the average cost of treatment was 65.7 US$ (95% CI: 11.5 US$, 120.0 US$) higher in the Control than the Intervention 2 group, or 88.8 US$ (95%CI: 42.4 US$; 135.2 US$) higher among MAM children and 37.8 US$ (95%CI: -29.9 US$; 91.3 US$) for treatment of SAM. This difference increased to 134.3 US$ (95%CI: 68.5 US$; 200.0 US$) in cured children (Table 5). In the modelled

Table 6 Average cost and cost-effectiveness ratios in the three study arms (observed base case scenario) disaggregated into moderate and severe acute malnutrition

	Control		iCCM standard		iCCM simplified	
	MAM (*n* = 178)	**SAM (*n* = 371)**	**MAM (*n* = 329)**	**SAM (*n* = 471)**	**MAM (*n* = 325)**	**SAM (*n* = 364)**
Total cost, US $ (95%CI)	45,246.0 (39,941.6; 50,550.5)	104,039.07 (92,091.22; 115,986.92)	52,094.9 (46,648.8; 57,541.1)	90,849.69 (81,132.59; 100,566.79)	53,755.34 (48,364.4; 59,146.3)	91,282.3 (83,271.7; 104,432.2)
Total cost per child treated, US $ (95%CI)	254.2 (224.4; 284.0)	280.43 (248.2; 312.6)	158.3 (141.8; 174.9)	192.9 (172.3; 213.5)	165.4 (148.8; 182.0)	250.8 (228.8; 286.9)
Direct treatment cost per child treated, US $ (95%CI)	118.4 (101.4; 135.4)	144.6 (125.2; 164.0)	57.9 (50.1; 65.6)	92.4 (80.6; 104.2)	48.1 (41.8; 54.4)	133.5 (110.7; 146.5)
Total cost per child cured, US $ (95%CI)	293.8 (249.1; 345.0)	392.6 (332.4; 462.3)	164.3 (144.8; 184.9)	269.6 (231.0; 313.8)	167.5 (149.3; 186.1)	286.2 (261.0; 327.4)
Direct treatment cost per child cured, US $ (95%CI)	136.8 (117.2; 156.5)	202.5 (175.3; 229.7)	60.0 (52.0; 68.1)	129.1 (112.6; 145.7)	48.7 (42.; 55.0)	152.3 (126.4; 167.2)
Cost per DALY averted, US $ (95%CI)	464.4 (305.4; 2177.2)	136.0 (81.6; 397.7)	168.7 (105.2; 452.4)	44.1 (25.3; 100.5)	160.5 (99.6; 391.0)	37.8 (28.6; 68.1)
Cost per death averted, US $ (95%CI)	29,000.1 (19059.0; 124195.4)	8,515.9 (5067.7; 12298.2)	10,498.8 (6552.5; 25192.6)	2,738.7 (1941.4; 5183.1)	9,980.6 (6230.7; 22393.0)	2,345.5 (1781.3; 3988.1)

scenario the point estimate for the cost per child treated and cured in the intervention 2 are lower than in the base case (Table 7). The ICER shows that recovering an additional child from acute malnutrition cost 49.2 US$, ranging from a negative ICER to 131 US$. The average cost per DALY averted was lower in the Intervention 2 compared to Control. Cost per additional DALY averted was below the chosen cost-effectiveness thresholds (Table 8and Supplemental Fig. 1b).

Comparison of intervention 2 vs. intervention 1

In the comparison of Intervention 1 to Intervention 2 (same treatment providers but different protocols) there was little difference in cost per child treated, cost per child cured, cost per DALY averted or cost per death averted in the observed base case scenario. However, RUTF costs among SAM children were 5.7 US$ (1.7 US$; 9.7 US$) less per child, which reflects a difference in 19 sachets at 0.3US$ per sachet. The difference in the average cost of RUFs for MAM treatment between the 2 groups was small: The median number of sachets in both groups was 35 and the price per sachet was similar at 0.3US$ for RUTF compared to 0.36 US$ for RUSF, which equates to a difference of 2US$.

Discussion

In this economic evaluation we investigated the cost and cost-effectiveness of three different models of acute malnutrition treatment, namely health facility-based treatment with the national treatment protocol and treatment at both health facilities and CHW sites with either the national or simplified treatment protocol.

While overall costs across study arms were similar, the costs per child treated and cured were significantly lower in the intervention arms than in the control: In the base case analysis treatment cost of acute malnutrition ranged from 272 US$ in the Control to 210 US$ in the Intervention 2 and 179 US$ in the Intervention 1, while cost per child cured ranged from 356 US$ in the Control to 226 US$ in the Intervention 2 and 219 US$ in the Intervention 1. The results of our study fall within the cost per child treated and cured estimates previously reported in the literature, ranging from US$ 56 to US$ 805 and US$114 to US$1041, respectively [10, 16, 44–55]. In terms of DALYs averted, the treatment cost 172 US$, 60 US$ and 52 US$ in the Control, Intervention 1 and Intervention 2, respectively. Costs per DALY averted were significantly higher in MAM than SAM children, with costs per DALY averted ranging from 161 US$ to 464US$ in MAM Children and 38US$ to 136 US$ in SAM children. Similar results in costs per DALY averted have been found previous studies in Mali and Kenya which found a cost per DALY averted of 347 US$ [56] and 397 US$ [13] for MAM treatment. A study in Bangladesh estimated

Table 7 Results in modelled scenario sensitivity analysis

	Control Group (CMAM)	Intervention Group 1 (iCCM Standard)	Intervention Group 2 (iCCM Simplified)
Treatment coverage in May 2021, % (95% CI)	MAM: 16.1% (11.7- 20.5%) SAM: 18.9% (11.6 – 26.2%)	MAM: 23.4% (19 – 27.9%) SAM: 38.5% (31.1- 45.8%)	MAM: 23.4% (19 – 27.9%) SAM: 38.5% (31.1- 45.8%)
Treatment sites	3 Health Centres	3 Health centres and 10 CHW sites	3 Health centres and 10 CHW sites
Total intervention cost, US $ (95%CI)	118,301.0 (105308.5; 131293.4)	142,944.6 (127,781.4; 158,107.8)	137,565.3 (123,074.8;152,294.7)
Number of children treated	463	800	800
Number of children cured	353	654	743
Cost per child treated, US $ (95%CI)	255.5 (227.4; 283.6)	178.7 (159.7;197.6)	172 (153.8; 190.4)
Cost per child cured, US $ (95%CI)	335.1 (287.2; 388.2)	218.6 (195.4; 241.8)	185.1 (165.6;204.9)
Cost per Daly averted, US $ (95% CI)	216.6 (132.4; 705.4)	60.6 (42.1; 126.7)	39.8 (28.2; 82.7)
Cost per Death averted, US $ (95% CI)	13,482.5 (8,165.9; 40,715.9)	3,759.3 (2,606; 7,285.6)	2,471.0 (1,756.9; 4,810.7)

Table 8 Incremental cost-effectiveness ratios in the modelled scenario

	Intervention 1 vs. Control	Intervention 2 vs. Control	Intervention 2 vs. Intervention 1
Cost per child cured			
Incremental costs (95% CI), USD	24,367.9 (-3,744.9; 52,480.8)	19,214.5 (-8,361.6; 46,790.6)	-5,259.8 (-35,033.0; 24,513.4)
Incremental effects (95% CI), number of children cured	301 (270; 332)	390 (364; 416)	89 (61; 17)
Incremental cost-effectiveness ratio (ICER) (95%CI)	81 (-15.8[1]; 199.7)	49.2 (-23.9[1]; 130.6)	-59.1[1] (-656.6[1]; 467.0)
Cost per DALY averted			
Incremental effects, DALYs (95%CI)	1,812.7 (337.8; 3,125.5)	2,911 (1,002.6; 4,550.6)	1098.3 (-1,303.6; 3,393.5)
ICER (95%CI)	13.4 (-678.8[1]; 100.6)	6.6 (-21.9[1]; 95.0)	-4.8[1] (-13.3[1]; 16.9)

[1]The ICER is negative due to lower costs in intervention at greater effects, indicating dominance of the intervention

the cost of community treatment of SAM treatment to be 26 US$ per DALY averted [51], while a 2009 study in Zambia found that CMAM cost 53 US$ per DALY averted [48].

A total of 42-44% of costs were coordination, supervision and support costs, 9–15% were RUF costs and 28-36% were other direct treatment costs. Previous studies using comparable costing approaches found similar proportions around the main cost categories [10, 16, 24, 51, 52, 57]. More specifically, a study in southern Mali found that RUTF costs accounted for 7% in the intervention arm where treatment was also provided by CHWs compared to 13% in the control arm while supervision, monitoring and support costs made up about two thirds of total costs [10]. Costing studies have consistently shown a high proportion of costs being coordination and support costs, this is largely due to supervision costs (staff, transport and fuel costs) which is crucial to ensuring good outcomes for malnourished children. Nevertheless, it could be explored whether efficiencies could be made by integrating coordination and supervision better into existing systems, less involvement of iNGOs or reducing intensity of supervision as staff become more experienced.

Our findings revealed several important insights into the cost-effectiveness of the different treatment approaches. First, treating children at health centres and CHW sites was cheaper and more cost-effective than treating children at health facilities alone. The expansion of treatment to CHW sites was considered a cost-effective strategy in comparison to the Control as well as the selected cost-effectiveness thresholds of 441 US$ and 100USD$. This was the case whether children were treated with a standard or simplified protocol. It should be noted however that the comparison of Intervention 2 with the Control is more challenging than the comparison of Intervention 1 with the Control, because the admission and discharge criteria in the simplified protocol differ. While in the Control and Intervention 1 arm, children could be admitted either on WHZ or MUAC and discharged once they reach either a MUAC or WHZ above the cut-off, in the Intervention 2 arm children were admitted and discharged by MUAC only. However, both a higher WHZ at admission in the two standard protocol groups and the fact that in these groups children could be discharged as cured by whichever criteria they reached first, did not translate into higher recovery rates or shorter lengths of stay.

Second, the impact of the decentralised treatment model on cost and cost-effectiveness is closely linked to its impact on coverage. In the comparison of Intervention 1 to the Control for example, the lower cost per child

treated, was due to both the cheaper treatment costs at CHW site, and the greater number of children treated in the Intervention 1 arm. When the number of children in the control arm was increased to match the number of children in the Intervention 1 the difference in costs between the two groups was reduced (results not shown). Our results are in line with a similar study conducted in the south of Mali in 2018 which found that cost per child treated and cost per child cured were 198 US$ and 242 US$ lower, respectively, in the decentralised treatment model compared to treatment at health facilities only [10].

Third, cost-savings can be made by switching to a reduced dosage protocol. Our study went one step further than the previous study in southern Mali, exploring not only the impact of moving from a facility-based to a hybrid approach of health facility and CHW-based treatment, but also what the impact of switching to a simplified protocol would be in areas where the standard protocol cannot be implemented due to missing equipment, RUTF stockouts or where health workers did not have the literacy skills required for dosage calculations. While there was little to no difference in the cost per child treated in the modelled scenario and cured overall between Intervention 1 and 2, the cost of RUF was 5 US$ per child lower. In line with these findings, a costing study in Niger comparing treatment with a simplified and standard protocol revealed cost-savings linked to RUF costs of about 5.4US$ overall, and about 10US$ in SAM children [24]. Studies in Burkina Faso, Kenya and South Sudan have also demonstrated reductions in RUTF costs while not negatively impacting effectiveness [16, 25].

Apart from the difference in RUTF costs between Intervention 1 and 2, there was little difference between these two groups. Given that the number of children treated in the Intervention 1 was significantly higher than the Intervention 2 arm, but coverage surveys revealed no difference in coverage between the two approaches, we conducted a modelled sensitivity analysis where the number of children between these two arms was equal. In this analysis the point estimate of the cost per child treated and cured was slightly reduced due the higher number of children. It is worth noting that the lower recovery rates in the two standard protocol arms compared to the Intervention 2, were partly because of a significantly higher number of discharge errors which accounted for 19%, 15% and 5% of discharges in the Control, Intervention 1 and Intervention 2, respectively (Table 2). It is possible that this indicates a greater difficulty in implementing a protocol with two criteria as well as a need for better training and supervision where the more complex standard protocol is used. The importance of adequate training and supervision for CHWs was also highlighted in the recently published guideline [4].

Limitations

This study had a number of limitations. First, due to security issues, the study staff encountered challenges accessing the study sites and did not reach the intended sample size for SAM children, furthermore only 32% of study participants responded to the socio-economic survey from which the data for family costs was drawn. These therefore have to be considered with caution. It is also unclear whether the data collected reflects all children enrolled at the sites or if some cases were missed. This means that the cost per child treated and cured may be slightly overestimated. Secondly, the cost of RUF was based on the number of sachets provided to the patients and does not include losses or wastage. Third, we had to rely on various assumptions and apply shadow prices where accountancy data was unavailable which may lead to imprecision in the cost estimates. Finally, the comparison between the Intervention 1 and Intervention 2 arms is challenging because, while the treatment locations are the same, the admission and discharge criteria in the protocol differ in addition to the different dosage. When interpreting these results, it is important to consider that this is a programmatic analysis meaning that differences in cure rates are due to a combination of factors, such as dosage, discharge criteria and difficulties in application of the standard protocol arms as evidenced by the higher amount of discharge errors. However, this study adds to the limited evidence base on cost and cost-effectiveness of CMAM programming and to our knowledge it is one of very few studies that have costed the decentralised approach to treatment provided at CHW or health post level in combination with a simplified protocol dosage protocol in a conflict setting. While the new treatment guideline does not support a MUAC only or a fixed dosage approach, WHO and UNICEF acknowledge that in exceptional circumstances as part of acute emergencies deviations or simplifications from the standard may be needed on a temporary basis and UNICEF recognises that more research on some of the simplifications is needed [58]. Finally, it is difficult to disentangle research and programming costs, so costs in these analyses may be higher than they would be in routine programming.

Further research

Since the study was conceived, the new WHO guidelines for the treatment of acute malnutrition have been published. Further research should investigate the implications of the new guideline on treatment cost. This new guideline for the first time acknowledges the importance that adequately trained and supervised CHWs play in the treatment of acute malnutrition but differs from the national protocol in Mali in terms of admission criteria, discharge criteria and RUF dosage. While the current Mali national protocol indicates that children must only

reach one criterion, the new WHO guidelines state that children should recover based on both criteria, which may increase length of stay but could also reduce relapse.

Future research could explore other approaches to reduce treatment costs without sacrificing effectiveness for example by targeting some of the biggest cost contributors including coordination and support costs, as well as how training and supervision can be improved to reduce the amount of discharge errors where the standard protocol is being used. The implications of discharge errors on relapse and related cost are also worth investigating.

Conclusion

This study shows that involving CHWs in acute malnutrition treatment reduces cost and is a cost-effective strategy, due in part to its impact on treatment coverage, but that training and supervision are needed particularly where the more complex standard protocol is used. Switching to a simplified protocol in an emergency context can lead to cost savings particularly in terms of RUTF costs for children with severe wasting, less discharge errors and should be considered where weight-based admission, monitoring or dosage is not possible or RUTF stocks are running low. More research is needed on the implications of the recently published 2023 WHO guidelines on cost and cost-effectiveness of treatment and the adequate level of training and supervision for CHWs.

Abbreviations

CHWs	Community health worker
iNGO	International non-governmental organisation
MAM	Moderate acute malnutrition
RUTF	Ready-to-use therapeutic food
RUSF	Ready-to-use supplementary food
SAM	Severe acute malnutrition
WHO	World health organisation

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-21411-5.

Supplementary Material 1

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Author contributions

Pilar Charle, Noemi Lopez-Ejeda and Bernardette Cichon conceived the work and oversaw the data collection. Cornelia Aton supported cost data collection. Bernardette Cichon analysed the costing data and wrote the first draft of the article. Noemí López-Ejeda, Salimata Samake, Abdias Ogobara Dougnon, Mahamadou N'tji Samake, Aliou Bagayoko, Magloire Bunkembo, Alexandra Rutishauser-Perera and Pilar Charle-Cuellar reviewed and shaped the article and supported the interpretation. All authors approved the final version of the article.

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Data availability

As some of the financial data is of a sensitive nature and consent was obtained only to share data as aggregate and not individual level, the full data set cannot be shared. Further information can be obtained from the corresponding author upon request.

Declarations

Ethics approval and consent to participate

The studies involving humans were approved by Ethics Committee of the Institut National de Santé Publique (INSP), the reference agency of the Ministry of Health of the government of Mali (decision n° 35/2029/CE-EX-INRSP), and the Ethics Committee of the Hospital Clínico San Carlos, reference organism for human studies of the Complutense University of Madrid, Spain (favorable report C.I. 19/363-R-X-BC). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Prior to key informant interviews, participants were provided with information about the study verbally and in writing. Consent for participation was obtained from key informants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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