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ORIGINAL COMMUNICATION

Water and sanitation associated with improved child growth

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Objective: To examine the relation between household water and sanitation, and the risk of stunting and reversal of stunting in Khartoum and Crezira regions Sudan.
Design: Prospective cohort study.
Setting: A total of 25 483 children aged 6–72 months from rural Sudan enrolled in an 18-month field trial in 1988 to study the effect of vitamin A supplementation on child health and survival.
Results: The mean height-for-age z-scores at baseline and the end of study were −1.66 and −1.55, respectively, for the group with water and sanitation facilities, and −2.03 and −1.94 for the group without water and sanitation, after adjustment for age, region, gender, mother's literacy, intervention group (vitamin A *vs* placebo), family wealth, breastfeeding and cleanliness. Among children of normal height-for-age at baseline, the risk of stunting (<−2 height-for-age z-score) was lowest in the group that came from homes that had both water and sanitation compared to children from homes without these facilities (multivariate RR = 0.79, 95% CI 0.69–0.90). Among children stunted at baseline, those coming from homes with water and sanitation had a 17% greater chance of reversing stunting than those coming from homes without either facility (adjusted RR = 1.17, 95% CI 0.99–1.38). We did not detect a synergistic association between access to water and sanitation.
Conclusions: Water and sanitation are independently associated with improved growth of children.
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Introduction

Malnutrition contributes to 15.9% of the total global burden of disease, and water, sanitation and hygiene to 6.8% (Murray & Lopez, 1997). The prevalence of stunting among African children aged 6–72 months has been estimated to be 37% (Ngare & Muttunga, 1999). Stunting in children is associated with increased risk of morbidity (el Samani *et al*, 1988; Kossmann *et al*, 2000), mortality (Bhutta *et al*, 1997; Fawzi *et al*, 1997a; Yoon *et al*, 1997) and cognitive impairment (Berkman *et al*, 2002). Poor water and sanitation has been associated with increased risk of infections in children (Daniels *et al*, 1990; Huttly *et al*, 1990; Mertens *et al*, 1990) and increased malnutrition (Adair & Guilkey, 1997); improved water and sanitation was related to lower risk of malnutrition (Huttly *et al*, 1990; Daniels *et al*, 1991; Ricci & Becker, 1996). In sub-Saharan Africa, the burden of disease attributable to malnutrition is 32.7% and to poor water and sanitation 10.1% (Murray & Lopez, 1997); improved access to safe water and sanitation facilities may therefore have enormous potential to reduce the burden of disease in this region.

Previous studies examining the association between water and sanitation and nutritional status are limited because they have utilized cross-sectional (Kikafunda *et al*, 1998; Abidoye & Ihebuzor, 2001) or case–control (Mertens *et al*, 1990; Daniels *et al*, 1991) designs; although there were a few prospective studies (Magnani *et al*, 1993; Ricci & Becker, 1996; Rivera & Ruel, 1997; Liu *et al*, 1998), only one evaluated the interaction of water and sanitation on growth

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(Esrey *et al*, 1992). Moreover, studies of the interaction of water and sanitation on other health outcomes, including diarrhea and mortality, have had varying results depending upon the environmental characteristics of the place in which they were conducted or educational status of the mothers (Esrey *et al*, 1992; VanDerslice & Briscoe, 1995). The joint effect of water and sanitation may be of interest to policy makers deciding on allocation of scarce resources or setting priorities in health planning. To the scientist it may help in assessing the health outcomes of water and sanitation more accurately. We therefore conducted this study to assess the joint impact of water and sanitation on stunting in a large prospective cohort of children in Sudan.

Methods

Study subjects

Our sample consisted of 25 483 children aged 6–72 months enrolled in a randomized, placebo-controlled field trial that began in June 1988 to study the effect of vitamin A supplementation on mortality, conducted in five areas of Khartoum and Gezira regions in Sudan (Abu Delieg, Rifi Genoub, Jaeli, Rifi Shamal, Gezira). Every household in these regions was surveyed and eligible, consenting children were randomly assigned to blinded intervention and placebo groups. The groups were balanced at baseline and vitamin A supplements were not associated with mortality at the end of the study. Details of the study have been published elsewhere (Herrera *et al*, 1992; Fawzi *et al*, 1994). Anthropometric measurements were taken at four occasions and were 86% complete. Children with overt signs of vitamin A deficiency were excluded from the study. At baseline, information was collected on region, demographics of the household, water supply, sanitation, maternal and paternal education, and household possessions. Height, weight and child dietary vitamin A intake were measured at baseline and updated at each subsequent visit. Interviewers assessed dietary intake by asking the mothers what their children ate on the previous day. This was an observational study in which we followed up children enrolled in the clinical trial for 18 months based on the presence or absence of water and sanitation in the household at the time of the baseline examination.

Measurements

Weight was measured correct to the nearest 100 g on a Salter scale, height (or recumbent length for children <85 cm) was measured correct to the nearest 1 mm with a locally made anthropometer. Height-for-age and weight-for-height z-scores were calculated using the Centers for Disease Control Anthropometric Software package (Dean *et al*, 1994). We examined the association between household water and sanitation and the reversal of stunting and incidence of stunting. For the reversal of stunting analyses, we examined data from children who were stunted (< −2 height-for-age z-score) at the start of the study, and were not wasted (weight-for-height z-score ≥ −2). If a child was not stunted at the end of the study, we classified that child as having reversal of stunting. For incidence of stunting analyses, we started with children not stunted at baseline (≥ −2 height-for-age z-score) and not wasted (weight-for-height z-score ≥ −2). If at the end of the study the child was stunted, this was classified as incident stunting.

The exposures of interest (water and sanitation) were grouped into a four-level variable water and sanitation (both private latrine and inside water supply), only water (no private latrine but inside water supply), only sanitation (private latrine but no inside water supply), and no water and no sanitation (neither private latrine nor inside water supply). The last group was used as the reference group for comparisons. We adjusted for subjective assessment of family wealth by the interviewer in four categories (rich, middle, poor and very poor), and cleanliness of the child on a 3-point ordinal scale (1 = very clean and tidy, 2 = moderately clean and tidy and 3 = unclean and untidy), age of the child in three categories (≥36+ months, ≥12 but less than 36 months, and less than 12 months), region (five categories); breastfeeding, intervention group (vitamin A or placebo), sex and mother's literacy (mother literate or not) were dichotomous variables.

Dietary data were collected for vitamin A containing foods using a 24-h recall questionnaire that contained 30 commonly consumed foods. We did not have information on total energy intake, but caloric intake calculated from these foods was not related to child growth in this population (Fawzi *et al*, 1997b). We evaluated green leafy vegetable and dairy intake by averaging the number of servings consumed from the available 24-h dietary recalls obtained at the first three visits, and by treating intake at each visit as an independent observation. Mean beta-carotene was estimated from the foods reported in the 24-h dietary recalls and nutrient composition tables; the mean beta-carotene intake calculated from the three dietary questionnaires was used.

Statistical methods

We first compared the distribution of demographic, household, maternal and nutritional status of the children by levels of water and sanitation of the household. Only one child per household was included in this sample. We used separate analysis of variance models for the baseline height-for-age z-score and end of study height-for-age z-score, and water and sanitation as the explanatory variables. We calculated adjusted means controlling for age, family wealth, and cleanliness of the child, region, mother's literacy, assignment to intervention or placebo group, and breastfeeding in categories mentioned above. We repeated this analysis with the difference between height-for-age z-score at the end of the study and the z-score at baseline.

We used logistic regression to model the probability of reversal of stunting and incidence of stunting with water and sanitation as the exposure of interest, adjusting for all the variables in the model from the analysis of variance. We further adjusted for mean intake of green leafy vegetables and carotenoids one at a time to assess possible confounding because the intake of these foods may have varied by socioeconomic status. We reran the models within strata of child's age, mother's literacy, region, wealth, and sex, and tested for interaction by the likelihood ratio test comparing models with main effects and those with the main effects and the interaction terms. We tested whether there was a synergistic association of water and sanitation by including presence or absence of water, sanitation and the product of water and sanitation in the model. The exposure variable was classified into four levels for ease of interpretation. The formal test of interaction was done by introducing the multiplicative term described above. The multiplicative term evaluates if the combined association of water and sanitation is different from the individual associations.

Results

Out of 25 483 children aged 6–72 months, 9808 (39%) were stunted at baseline, 12 542 (49%) were not stunted and 3135 (12%) either had missing measurements or were stunted and wasted. Of those who were stunted, 7791 (79%) were not stunted after 18 months (reversal of stunting). Among the 12 542 children who were not stunted at baseline, 2626 (21%) became stunted at the end of the study (incidence of stunting).

The proportions of children in the different water and sanitation groups were similar with respect to age and sex (Table 1). In our sample, children from households with water and sanitation were more likely living in the region Rifi Shamal and children from households without water and sanitation were more likely living in Abu Delieg. Mothers from households without water and sanitation facilities were less likely to be able to read as compared with

Table 1 Characteristics of children by water and sanitation levels

	Water, latrine N=*7499*	*Water, no latrine* N=*3209*	*No water, latrine* N=*2685*	*No water, no latrine* N=*12 090*
Age of children				
<1 y (%)	5	7	6	7
1–3 y (%)	21	22	21	25
3+y (%)	74	71	74	69
Male (%)	51	49	50	51
Region				
Abu Delieg	2	2	31	22
Rifi Genoub	12	14	30	24
Jaeli	24	6	14	5
Rifi Shamal	31	5	14	7
Gezira	31	74	12	42
Intervention group (%)	50	52	51	48
Prevalence of stunting (%)				
<1 y	20	15	26	25
1–3 y	45	43	51	55
3+y	38	40	44	50
Height-for-age z-score (median)	−1.61	−1.68	−1.84	−1.99
Weight-for-height z-score (median)	−0.94	−1.01	−1.06	−1.13
Weight-for-age z-score (median)	−1.74	−1.84	−1.97	−2.09
Mother could read %	55	25	32	10
Interviewer's impression of child (%)				
Very clean	38	19	26	9
Moderately clean	56	58	61	51
Unclean	6	22	14	40
Interviewe impression of household (%)				
Rich	19	7	13	3
Middle income	64	61	55	36
Poor	16	28	28	43
Very poor	1	4	4	18

households having these facilities. In the interviewers' perception, households with water and sanitation were more wealthy and the children living there cleaner as compared to households without these facilities (Table 1).

On average, all children had improved growth over time (Table 2). The mean adjusted height-for-age z-scores for baseline and the end of study were −1.66 *vs* −1.55 for the group with water and sanitation facilities, and −2.03 *vs* −1.94 for the group without water and sanitation. Overall, children coming from homes with both water and sanitation facilities had higher height-for-age z-scores at the end of the study than other children after adjustment for confounders ($P<0.001$ for the contrast of water and sanitation *vs* water only, and $P<0.001$ for the contrast of sanitation only). Those coming from homes with only water or only sanitation facilities had similar average z-scores, while those coming from homes without either of these facilities had the lowest average z-scores (Table 2). The interaction between water and sanitation was not significant (P-value$=0.51$). The results were similar in models with and without baseline height-for-age z-score in the model. Similar trends were seen in children who were stunted at baseline and those who were not stunted at baseline (Table 2). In the multivariate model with the difference in z-score as the outcome, children coming from homes with water and sanitation had on average gained 0.20 height-for-age z-scores as compared to 0.15 for the group without water and sanitation (P-value<0.01). There was no significant difference between average z-scores for children coming from homes with both water and sanitation and those with water only (contrast$=0.19$, $P=0.73$) and sanitation only (contrast$=0.17$, $P=0.14$).

In all, 79% of the children stunted at baseline had height-for-age z-scores >2 at the end of the study period and were found to reverse stunting by the end of the study. Stunted children coming from homes with water and sanitation were twice as likely to reverse stunting as compared to those coming from homes without water and sanitation facilities (RR$=2.20$, 95% CI 1.93–2.49); after adjustment for potential confounders, this association was attenuated and borderline significant (RR$=1.17$, 95% CI 0.99–1.38) (Table 3). In the multivariate analyses, children coming from homes with water but no sanitation, and those coming from homes with no water but sanitation, had approximately a 20% higher chance, respectively, of reversing stunting compared to children coming from homes lacking both facilities after adjusting for potential confounders. The multivariate contrasts of risks of reversing stunting were not significant when comparing children coming from homes with both water and sanitation *vs* homes with water but no sanitation (P-value$=0.56$) or sanitation and no water (P-value$=0.88$). The relation did not change substantially when we adjusted for average intake of carotenoids or green leafy vegetables. There was no synergistic effect of having access to both water and sanitation and the risk of reversal of stunting.

The incidence of stunting was lowest in the group that came from homes that had both water and sanitation compared to children from homes without these facilities (RR$=0.50$, 95% CI 0.45–0.55) (Table 3); after adjustment for potential confounders, the reduction in risk was attenuated but still significant (RR$=0.79$, 95% CI 0.69–0.90) (Table 3). The multivariate contrasts of risks of incidence of stunting were not significant when comparing children coming from homes with both water and sanitation *vs* homes with water

Table 2 Mean height-for-age z-scores by groups of water and sanitation

	Water, latrine	*Water, no latrine*	*No water, latrine*	*No water, no latrine*
All children	*N*=7499	*N*=3209	*N*=2685	*N*=12 090
Baseline[a]	−1.66	−1.92	−1.80	−2.03
End of study[b]	−1.36	−1.69	−1.64	−1.95
End of study[a]	−1.55	−1.79	−1.74	−1.94
End of study[c]	−1.66	−1.73	−1.73	−1.80
Stunted at baseline	*N*=2623	*N*=1113	*N*=1037	*N*=5034
Baseline[a]	−3.08	−3.20	−3.12	−3.22
End of study[b]	−2.37	−2.66	−2.55	−2.82
End of study[a]	−2.38	−2.53	−2.47	−2.63
End of study[c]	−2.50	−2.56	−2.55	−2.65
Not stunted at baseline	*N*=4182	*N*=1736	*N*=1298	*N*=5326
Baseline[a]	−0.68	−0.78	−0.73	−0.79
End of study[b]	−0.66	−1.00	−0.80	−1.03
End of study[a]	−0.73	−0.87	−0.84	−0.93
End of study[c]	−0.85	−0.92	−0.93	−0.99

[a]Adjusted for age (<1 y, 1–3 years, 3+y), region, sex, mother's literacy (mother can read *vs* cannot), intervention group (vitamin A *vs* placebo), interviewers' perception of wealth (rich, middle, poor and very poor), cleanliness (ordinal variable) and breast-feeding status.
[b]Unadjusted.
[c]Additional adjustment for z-score at baseline.

Table 3 Associations between water and sanitation groups and reversal and incidence of stunting from multiple logistic regression analysis

	Unadjusted	*Multivariate adjusted*[a]
	RR (95% CI)	*RR (95% CI)*
Reversal of stunting		
Water and sanitation	2.20 (1.93–2.49)	1.17 (0.99–1.38)
Water, no sanitation	1.21 (1.12–1.32)	1.23 (1.13–1.34)
No water, sanitation	1.32 (1.24–1.41)	1.15 (1.08–1.24)
No water, no sanitation	1.00	1.00
Incidence of stunting		
Water and sanitation	0.50 (0.45–0.55)	0.79 (0.69–0.90)
Water, no sanitation	0.79 (0.73–0.84)	0.79 (0.74–0.85)
No water, sanitation	0.78 (0.74–0.82)	0.86 (0.81–0.91)
No water, no sanitation	1.00	1.00

[a]Adjusted for age (<1 y, 1–3 y, 3+y), region, sex, mother's literacy (mother can read *vs* cannot), intervention group (vitamin A *vs* placebo), interviewers' perception of wealth (rich, middle, poor and very poor), cleanliness (ordinal variable) and breast-feeding status.

but no sanitation (*P*-value = 0.89) or sanitation and no water (*P*-value = 0.18). The relation did not change substantially when we adjusted for average intake of carotenoids or green leafy vegetables. There was no evidence of interaction between water and sanitation and age, mother's literacy, region, wealth or sex (data not shown).

Discussion

On average, all children had had improved growth over 18 months of the study period but the largest average net gain in height-for-age z-score was in children coming from homes that had both water and sanitation. Stunted children were approximately 17% more likely to recover from stunting over that period if they came from homes that had water and sanitation facilities as compared to children whose homes did not have these facilities after adjusting for age, sex, region, breastfeeding at baseline, vitamin A intake, socio-economic status and mother's literacy. The incidence of stunting was 21% lower among children from homes with both water and sanitation as compared to those lacking these facilities.

Since this was a prospective study it reduced the possibility of recall bias, and since follow-up was high selection bias was not likely (Rothman, 1998). Random error in measuring height and weight would probably attenuate any underlying association, but because these variables are measured with little error, it is unlikely that measurement error would substantially affect the results. We adjusted for a number of potential confounders and still found the associations to be significant; however, it is possible that residual confounding could affect the results. We did not have information on total calories that are associated with growth and could be associated with the exposure, but caloric intake calculated from 30 commonly eaten foods rich in vitamin A was not associated with growth in this population (Fawzi *et al*, 1997b). Adjustment for green leafy vegetables and dairy products did not substantially alter the results. The large sample size ensured that there was adequate power to detect small differences in associations and evaluate interactions. Moreover, this study fulfills the criteria of temporality and biological plausibility to assess causality in epidemiological studies (Rothman, 1998). We analyzed height-for-age z-score as a continuous variable, used the difference of end of study and baseline z-scores, and categorized the z-scores for the stunting and reversal of stunting analyses and the results were consistent demonstrating that the results were robust. The categorical results yield odds ratios which may be easier to interpret for some as opposed to differences in mean z-scores.

Our results are consistent with findings from other studies examining this question. Daniels *et al* (1991) found among children less than 5 y old in rural Lesotho that those whose homes had latrines had on average 0.27, 95% CI 0.12–0.42 higher height-for-age z-scores than children coming from homes without latrines, after adjusting for age, sex, water availability, hygiene habits and other socioeconomic variables. Magnani *et al* (1993) found the presence of water and sanitation facilities positively associated with height-for-age z-scores among children 1–5 y old from low socioeconomic groups in urban and rural Philippines after adjustment for potential confounders. In the same population, Ricci and Becker (1996) found inverse associations with water and sanitation facilities and risk of stunting in a prospective study after adjustment for potential confounders among children over 6 months of age. Abidoye and Sikabofori found similar associations between water and sanitation and stunting in preschool children in Nigeria (Abidoye & Ihebuzor, 2001).

Sedgh *et al* (2000) evaluated factors associated with reversal of stunting in our study population. They reported a 20% lower chance of stunted children recovering (RR = 0.80, 95% CI 0.69–0.92) if they came from homes without water in the house compared to those having water in the house, after multivariate adjustment (Sedgh *et al*, 2000). In the multivariate model, vitamin A supplementation had no effect on reversal of stunting but the chances of reversal of stunting were higher with higher intake of dietary vitamin A, for females compared to males, if the child was breastfed as compared to not, and if the mother was literate as compared to not (Sedgh *et al*, 2000). The results of the present study explore the effect of water and sanitation on child growth in more detail. Specifically, the evaluation of the joint effect of water and sanitation on child growth complements the findings of the study done by Sedgh *et al*. (2000).

Esrey *et al* (1992) reported a synergistic effect of water and sanitation among infants in Lesotho in a prospective study.

Infants coming from homes with latrines and those households that increased water use in the wet season had significantly better growth than children coming from homes with no latrine or those children coming from homes with latrines but where water use was not increased in the wet season. Water and sanitation is associated with improved child health in communities where the risk of diarrhea is high, and complementary factors that reduce risk of diarrhea (like increased water use in conjunction with the presence of sanitation facilities) are present (Esrey *et al*, 1992). For these reasons, the interaction of water and sanitation on child health is complex. It has been shown in the Philippines that environmental sanitation played a larger role in the reduction of diarrhea than the presence of a latrine in the home (VanDerslice & Briscoe, 1995). Latrines and water were associated with lower risk of mortality of infants of illiterate but not literate mothers in Malaysia (Esrey & Habicht, 1988).

We found that children coming from homes with both water and sanitation had better growth after adjusting for confounders than those coming from home with either water or sanitation or neither. However, we did not find a synergistic effect of water and sanitation on growth in this population. It is possible that in this population the condition of the external environmental or hygiene practices modified the association.

In this study, we assessed the growth at the start and end of the study. A limitation of this approach is that we would expect to observe regression to the mean. That is, we would expect some stunted children to become not stunted and not stunted children to become stunted at the end of the study just because they had extreme values to start with. While this is inevitable, and we did observe it in our data, the comparison of exposure groups is less likely to be influenced by regression to the mean phenomenon.

Water and sanitation are independently associated with improved growth of children in poor communities, but we did not find any evidence of a synergistic effect of these factors on child growth. Programs to improve water and sanitation in developing countries are likely to improve child health. Introducing either water or sanitation to a community lacking both facilities will improve child growth.

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